EVALUATION OF A NUMBER OF RESTORATION TECHNOLOGIES IN TWO DEGRADED AREAS IN THE MPUMALANGA PROVINCE, SOUTH AFRICA.

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Abstract

This study was conducted to evaluate different scientific techniques to restore degraded rangelands. It involves field-descriptive, field-analytical and laboratory-analytical assessments. The work took place in a degraded savanna (lowveld) ecosystem, at two sites characterised by duplex soils. The two sites are Mthethomusha Game Reserve (MGR) of Mpumalanga Parks Board and Sabi Sand Game Reserve, a private game reserve (SSPGR). The site at Mthethomusha game reserve is a fenced denuded area around a buffalo boma (in South Africa, a protective enclosure for domestic and game animals for research purposes is referred to as a boma). The Sabi Sand private game reserve site represents an open, heavily degraded, flat rangeland. This site was water logged during the month of February, three months after the trials. Both study sites fall within the duplex ecological unit. Duplex soils refer to soils with relatively permeable topsoil that abruptly overlay a very slowly permeable diagnostic horizon that is not a hardpan. The duplex soils at the SSPGR and MGR study sites are classified under the Estcourt form. Soil samples were taken from both sites to analyse their physical and chemical properties.

The effects of different restoration techniques at these two degraded areas were examined and compared. The aim was to establish the appropriate restoration techniques suitable for the two sites and to recommend the techniques to land owners with similar ecological problems. Different restoration treatments, which included the combination of organic matter treatments, brush packing, ripping, over-sowing, and lime application, were implemented. At both restoration sites, all the sub-plots, with the exception of the control plots, were ripped by rip-plough. The same mixture of *Chloris gayana, Cenchrus ciliaris, Digitaria eriantha* and *Panicum maximum* was used in the over-sowing treatment at both sites. The establishment of the seedlings, vegetative and reproductive growth forms from the grass mixture of all the treatments were compared to each other. Sites restored at MGR were compared to sites at SSPGR. The restoration sites were monitored for a period of two seasons between the years 1999/2000 and 2000/ 2001. The surveys that were carried out in this study are: frequency (through the use of a wheel point), density, population dynamics, importance value (through the use of a quadrat) and soil analysis. Frequency and density tables and graphs were

constructed from data collected at both sites through the use of the Microsoft Excel program and statistical analysis. Principal Component analysis (PCA), Canonical Correspondence analysis (CCA) and Redundancy analysis (RDA) ordinations with the CANOCO program were used to identify positive and negative correlation and to quantify data and deductions made from tables and graphs. They were also used to compare species and environmental by habitat data as well as species and experimental treatment data.

Results from the field analytical assessments of soil samples from both sites and the different experimental treatments are discussed. The results from the soil analysis indicated that the soil at MGR is highly sandy with a high calcium concentration. It has a lower sodium content than at SSPGR, but is deficient in phosphorus. The analysis results also indicated a high sandy soil with high calcium concentration at SSPGR. However, the analytical values of calcium, sodium and magnesium at this site were relatively high especially the concentration of sodium and magnesium which gave the soil the characteristics of a saline soil. During the first survey in 1999/2000 the frequency and density of *C. gayana, P. maximum* and *C. ciliaris* were higher at Mthethomusha game reserve, the fenced site than at Sabi Sand private game reserve, the open site, where the game animals roam freely. Rip plough cultivation at both sites stimulated the germination and establishment of most species in the soil seed bank as compared to the control plots. For a quicker establishment of seedlings from the soil seed bank as well as sown-in species, ripping is recommended as a treatment in restoration of degraded duplex soil types. It was also observed that *C. gayana* and *C. ciliaris* responded rapidly in sub-plots with the rip-organic-seed application and controlled grazing as compared to rip-seed application, with or without grazing. This is due to the good influence of organic material in the soil which include: improvement of soil structure, reduction of soil erosion, regulating effect on soil temperature, reduction of plasticity, cohesion, and stickiness of clay soils and helping the soil to store more moisture. It therefore seems that if degraded sites are restored with the addition of organic materials after rip plough application, rapid results could be achieved in improving the state of the area. Among the sown-in species in the seed mixture, *C. gayana* was outstanding in its rapid response to both rip plough cultivation and organic treatment by spreading with its stoloniferous growth form to cover the soil surface. Through this growth pattern, its stems (stolons) and leaves interact with water flow at the ground surface, resulting in higher interception storage and higher volume of water for infiltration. It also provides greater soil surface roughness and obstacles for the flow of air and water, reducing their velocity. This stoloniferous nature makes *C. gayana* a suitable pioneer species, which is therefore highly recommended for inclusion in restoration projects. From this study it was also noted that all the other sown-in species established well at MGR (the fenced site). The seedlings *of C. ciliaris*, however, do not withstand grazing and water logged areas. At the SSPGR study site, which is also sandy, *C. ciliaris* seldom developed to the vegetative growth stage. At MGR, *C. ciliaris* was a co-dominant species with *C. gayana* in most of the sown-in treatment plots.

At the SSPGR, where the game animals grazed freely at the study site, *C. ciliaris* was absent in most of the treated plots. The few seedlings recorded during the second survey were in the plots treated with brush. This absence could be attributed to the fact that it is a palatable species that is heavily grazed by game animals when not protected. Rainfall could have been another contributing factor to the absence of *C. ciliaris* at SSPGR. During the first season there was a higher rainfall at both sites, which caused SSPGR to be waterlogged. *Cenchrus ciliaris*, which is adapted to dry, well-drained sandy soils could not establish in the waterlogged situation at SSPGR. It is recommended that *C. ciliaris* should not be used in restoration projects in waterlogged areas. The numbers of seedlings recorded for the rest of the sown-in species at SSPGR were lower compared to the numbers at MGR. It is therefore recommended that, for a better species establishment, species richness and sustainability, restoration sites in game reserves and communally managed rangelands with over-sowing treatments should either be fenced or protected with brush packing. It was further observed from the results of the current study that the rip plough cultivation stimulated the establishment of the seedlings of the sown-in species as well as seedlings from the soil seed bank. Rip plough cultivation is therefore a suitable technique that can be included in restoration projects on degraded duplex soil types.

From the results of these assessments, rangelands with a duplex soil type of the above soil conditions can be restored through the application of appropriate techniques as tested in this study.

Opsomming

Hierdie studie is uitgevoer om die verskillende tegnieke vir die restorasie van gedegradeerde weiding te evalueer. Dit behels beskrywende veld-, analitiese veld- en analitiese laboratoriumbepalings. Die werk is op twee terreine, gekarakteriseer deur dupleksgronde, in 'n gedegradeerde savanna- (laeveld) ekosisteem gedoen. Die twee terreine is die Mthethomusha Wildtuin (MGR) van die Mpumalanga Parkeraad en die Sabi Sand Wildtuin, 'n privaatwildtuin (SSPGR). Die terrein in die Mthethomusha Wildtuin is 'n omheinde, uitgetrapte gebied om 'n buffelboma (in South Africa word 'n beskermende kamp vir plaas- en wilde diere vir navorsingsdoeleindes 'n boma genoem). Die Sabi Sand privaatwildtuinterrein verteenwoordig 'n oop, gedegradeerde, plat weiveld. Hierdie terrein was sterk versuip gedurende Februarie, drie maande na die proewe. Beide studieterreine lê binne die dupleks ekologiese eenheid. Dupleksgronde verwys na gronde met relatief deurlaatbare bogrond wat skielik oorgaan in 'n baie stadig deurlaatbare diagnostiese horison wat nie 'n dorrebank is nie. Die dupleksgronde by die SSPGR en MGR studieterreine word onder die Estcourtvorm geklassifiseer. Grondmonsters is by beide terreine getrek ten einde hul chemiese en fisiese eienskappe te analiseer.

Die effek van verskillende restorasietegnieke op die twee terreine is ondersoek en vergelyk. Die doel was om die gepaste restorasietegnieke vir die twee terreine te bepaal en om die tegnieke aan grondeienaars met soortgelyke ekologiese probleme aan te beveel. Verskillende restorasietegnieke, wat die kombinasie van organiese materiaalbehandelings, die pak van takke, skeurploeg, insaai en kalktoediening insluit, is geïmplementeer. Op beide terreine is al die subpersele, met die uitsondering van die kontrolepersele, geploeg met 'n skeurploeg. Dieselfde mengsel van *Chloris gayana*, *Cenchrus ciliaris*, *Digitaria eriantha* en *Panicum maximum* is gebruik vir die insaaibehandeling op beide terreine. Die vestiging van saailinge en die vegetatiewe en reproduktiewe groeivorms van die grasmengsel van al die behandelings is met mekaar vergelyk. Die terreine wat in die MGR gerestoreer is, is met die in die SSPGR vergelyk. Die restorasieterreine is vir 'n tydperk van twee seisoene tussen die jare 1999/2000 en 2000/2001 gemonitor. Die opnames wat in die studie uitgevoer is, is: frekwensie (met behulp van 'n wielpunt), digtheid, populasiedinamika, belangrikheidswaarde (met behulp van

'n kwadrant) en grondanalise. Frekwensie- en digtheidstabelle en - grafieke is, deur gebruik te maak van die Microsoft Excel program en statistiese analise, saamgestel uit data wat vanaf beide terreine versamel is. Hoofkomponentanalise (PCA) en die sogenaamde Canonical Correspondence analysis (CCA) en Redundancy analysis (RDA) ordinering met die CANOCO program is gebruik om positiewe en negatiewe korrelasies te identifiseer en om data en afleidings uit tabelle en grafieke te kwantifiseer. Dit is ook gebruik om spesie- en omgewings-/habitatsdata, sowel as spesie- en eksperimentele behandelingsdata te vergelyk.

Resultate van die analitiese veldbepalings van grondmonsters vanaf beide terreine en van die verskillende eksperimentele behandelings word bespreek. Die resultate van die grondanalises dui daarop dat die grond by MGR baie sandering is met 'n hoë konsentrasie kalsium. Dit het 'n laer kaliuminhoud as by SSPGR, maar 'n tekort aan fosfor. Die analiseresultate vir SSPGR dui ook op 'n baie sanderige grond met hoë kalsiumkonsentrasie. Die kalium- en magnesiumkonsentrasies was op hierdie terrein besonder hoog wat aan die grond die eienskappe van 'n soutgrond verleen. Met die eerste opname was die frekwensie en digtheid van *C. gayana*, *P. maxicum* en *C. ciliaris* hoër by Mthethomusha Wildtuin, die omheinde terrein, maar laer by Sabi Sand privaatwildtuin, die oop terrein waar wild vryelik kon beweeg. Skeurploegbewerking het op beide terreine die ontkieming en vestiging van die meeste spesies in die grondsaadbank gestimuleer. Skeurploeg word aanbeveel as 'n behandeling in die restorasie van gedegradeerde dupleksgrondtipes vir vinniger vestiging van saailinge vanuit die grondsaadbank, sowel as van ingesaaide spesies. Daar is ook waargeneem dat *C. gayana* en *C. ciliaris* vinniger reageer in subpersele met skeurploeg-organies-insaai en gekontroleerde weiding in vergelyking met skeurploeg-insaai, met of sonder weiding. Dit is as gevolg van die positiewe invloed van organiese materiaal in die grond, wat die grondstruktuur verbeter, erosie laat afneem, 'n regulerende effek op grondtemperatuur het, plastisiteit, kohesie en kleweringheid van kleigronde laat afneem en die grond help om meer vog te stoor. Dit wil dus voorkom of, indien gedegradeerde persele gerestoreer word met die toediening van organiese materiaal na die skeurploegbehandeling, vinnige resultate vir die verbetering van die gebied se toestand verkry kan word. Uit die ingesaaide saadmengsel het *C. gayana* uitstekend gereageer op beide die skeurploeg- en organiese behandeling deur met sy stolongroei te sprei en die grondoppervlak te bedek. Deur hierdie groeivorm reageer die stingels (stolons) en blare met die watervloei aan die oppervlak, wat 'n hoër opvangsberging en 'n groter volume water vir infiltrasie tot gevolg het. Dit verskaf ook meer grofheid aan die grondoppervlak en dus hindernisse vir die vloei van lug en water wat hul snelheid verminder. Dit is hierdie stolongroeivorm wat *C. gayana* 'n geskikte pionierspesie maak. Hierdie spesie word dus sterk aanbeveel vir insluiting in restorasieprojekte. In hierdie studie is ook waargeneem dat al die ander ingesaaide spesies goed gevestig het op die MGR se omheinde perseel. Die saailinge van *C. ciliaris* weerstaan egter nie weiding en versuiping nie. Op die SSPGR-studieperseel, wat ook sanderig is soos by MGR, was *C. ciliaris* saam met *C. gayana* 'n ko-dominante spesie op die meeste van die ingesaaide behandelingspersele.

In die SSPGR, waar die wild vryelik die studieperseel kon bewei, was *C. ciliaris* afwesig op die meeste van die behandelde persele. Die paar saailinge wat waargeneem is met die tweede opname was op persele waar takke gepak is. Hierdie afwesigheid kan daaraan toegeskryf word dat dit 'n smaaklike spesie is wat intensief deur wild bewei word wanneer dit nie beskerm word nie. Reënval kon ook 'n bydraende faktor gewees het tot die afwesigheid van *C. ciliaris* by SSPGR. Gedurende die eerste seisoen was daar 'n hoër reënval by beide terreine wat versuiping in SSPGR tot gevolg gehad het. *Cenchrus ciliaris*, wat aangepas is vir droë, goedgedreineerde sandgronde kon nie vestig in die versuipte toestande in die SSPGR nie. Daar word aanbeveel dat *C. ciliaris* nie in restorasieprojekte in versuipte gebiede gebruik word nie. Die aantal saailinge van die res van die ingesaaide spesies wat by SSPGR waargeneem is was laer in vergelyking met die aantal by MGR. Daar word dus aanbeveel dat restorasiepersele in wildtuine en gemeenskapsbestuurde weidings waar insaaibehandelings toegepas word omhein word of deur gepakte takke beskerm word ten einde beter spesievestiging, spesierykheid en volhoubaarheid te bereik. Daar is verder uit die resultate van die huidige studie waargeneem dat skeurploegbewerking die vestiging van saailinge van die ingesaaide spesies, asook saailinge uit die grondsaadbank gestimuleer het. Skeurploegbewerking is dus 'n gepaste tegniek wat in restorasieprojekte op gedegradeerde dupleksgrondtipes ingesluit kan word.

Vanuit die resultate van hierdie bepalings kan weidings met 'n dupleksgrondtipe onder die bogenoemde grondtoestande gerestoreer word deur die toepassing van gepaste tegnieke soos in hierdie studie getoets is.

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CHAPTER 1

INTRODUCTION

1.1 Background.

Land is one of the most precious resources, which is linked to mankind's survival. Terrestrial organisms, including mankind, are so much linked to the resources provided by the different pieces of land we occupy that the destruction of these pieces of land threatens our very existence. Land is needed to provide soil for our crops to grow in and to allow natural terrestrial ecosystems to thrive and secure genetic resource for the future. The utilization of land by mankind has led to the modifications of all areas of the earth (Harris *et al.*, 1996).

A common feature of both developed and underdeveloped areas all over the world is the presence of ecosystems that have been degraded to such an extent that many of the structural functional properties that characterize a healthy environment have been lost. How to control the rate at which our terrestrial ecosystems are being degraded has become a dilemma for governments of different countries and all agricultural communities of the world (Brady & Weil, 1996).

In Sub-Saharan Africa (SSA), the predominant farming systems are based on shifting cultivation practices. Farmers fell and burn the fallow vegetation, cultivate the cleared land (usually for 1 to 3 years), and then abandon the site (from 4 to 20 years) to forest or bush cover (Sanchez, 1976). This traditional agricultural production system, which is known to be stable and biologically efficient, operates efficiently only when there is sufficient land to allow a fallow period long enough to restore soil productivity (Kang *et al.*, 1989).

In recent years, however, rapid demographic and economic changes have caused expansion of the cultivated areas into marginal soil types and fallow periods are being reduced, resulting in systematic degradation of major land areas and declining yields (Ehui & Hertel, 1992; Kang *et al.*, 1989; Matlon & Spencer, 1984). In addition, most soils of humid tropical Africa are sandy, highly weathered, low in organic-matter content, and susceptible to soil erosion and compaction (El-Ashry & Ram, 1987; Lal, 1987). Thus, the challenge faced by decision makers in many nations in SSA, arid and semi-arid regions of Southern Africa is how to feed an increasing population without irreparably damaging the natural resource base on which agricultural production depends (Ehui *et al.*, 1990; Ehui & Hertel, 1989).

Clearly, new technologies being developed must not only enhance food production but also maintain ecological stability and preserve the natural resource base; they must be both ecologically viable and sustainable (BIFAD, 1988). For that reason, the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) has recommended that international centers should plan and conduct their research within a sustainability perspective (CGIAR, 1989a,b). However, practical and quantifiable methods for measuring the sustainability and economic viability of agricultural systems still need to be developed (CGIAR, 1991). Several researches have examined the concept of sustainability, either as applied to agricultural systems, or in a manner that can be applied to them (Barbier *et al.*, 1990; Ciriacy-Wantrup, 1968; Denny & Fuss, 1983; Dumanski, 1987; Lynam & Herdt, 1989). There is general agreement at present that within agricultural development, projects should be accepted, not on the basis of the net present value, but on whether the resulting environmental benefits compensate for environmental damage caused elsewhere. However, this requires measurement of the associated environmental effect of each project so that compensatory benefits can be defined (Ehui & Spencer, 1994).

1.1.1.Degradation

Degradation results from the combination of processes which lead to the land under consideration being no longer fit for wide range of uses from natural systems to building sites. The causes of land degradation are many, which include the abuse of the environment through ignorance; climatic variability; injudicious management practices; political, industrial and historical issues (Harris *et al.*, 1996; Rogers, 1996; Squires, 1994). Degradation is not restricted to land alone but it also occurs in surface water resources, groundwater resources, soil and vegetation (Hoffman, *et al.*,1999).
There are different terms used by different authors to describe the

problems of degradation. The following terms are used by Harris *et al.*, (1996) to describe problems related to degradation:

Contaminated Land: This term refers to a piece of land that contains substances (e.g. chemical pollution), when present in sufficient concentrations, are likely to cause harm directly or indirectly to humans, the environment or other targets such as construction materials.

Disturbance: It is any event which causes a sudden change in the nutrient status of the system. This event may be either in a destructive or an enriching way. Either activity may lead to changes in the size of the standing crop and its species composition.

Stress: This term is used to describe any environmental factor that prevents the accumulation of additional biomass.

Degradation: This is the combination of processes which lead to the land under consideration being no longer fit for a wide range of uses from natural system to building sites. There may be uses to which such land may be put, but whenever a self-sustaining system is the end-point, then remedial action will be required.

Derelict land: This is land so damaged by industrial or other development such that it is incapable of beneficial use without treatment.

The recognition of continuing degradation of natural resources particularly in South Africa and the world in general, has become a major priority that requires careful evaluation and innovative thinking in respect of policy reform, scientific endeavour, education and technology transfer (Arbuthout, 1995). The ability to assess and monitor the condition or conservation status of the vegetation of a particular area and to interpret the assessment ecologically has now become a prerequisite for range land planning and sound management decision (Bosch & Gauch, 1991). The problem of degradation is of global concern and if not properly controlled, can result in one or more of the following:

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

3 Reduction in biodiversity (coupled with the loss of genetic variation) of an area (Tilman, *et al.*, 1996).
4. Wind and water erosion (Dregne, 1995).
5. Decrease in the palatability of the field composition (Walker,1988) which in turn leads to the loss in animal production, and
6. Unstable conditions for seedling establishment and survival (Dean, *et al.*, 1995).

Degradation of semi-arid grassland as well as savanna, is mainly characterized by changes in the ratio between palatable (sweet), and unpalatable (sour) species due to grazing mismanagement. The largest palatable component occurs in the composition with light to moderate grazing conditions, while overgrazing leads to an increase in unpalatable species (Bosch, 1989). Overgrazing is the repeated utilization of the grass plant until the reserve nutrients in the root are exhausted. The plant's root system becomes weak; it struggles to absorb water effectively and dies off (Van Oudtshoorn, 1999). According to Van Oudtshoorn (1999) and Bosch (1989), most palatable grasses are usually the first to be overgrazed with the less palatable ones being impacted at a later stage. The pattern can continue until it is virtually only the annual and particularly unpalatable grasses that remain. The areas that are first to be overgrazed are usually the low lying parts in the terrain. Such areas, where the soil is most fertile, are also very susceptible to bare patch formation due to repeated grazing without allowing the veld to rest. Such overgrazed veld is not only prone to erosion but is also most sensitive to drought.

The problem of overgrazing, leading to erosion and degradation is a widespread phenomenon in semiarid regions of Africa. According to Christiansson *et al.* (1991) parts of Tanzania most severely affected by environmental degradation are the semiarid areas and dry regions where about 20% of the human population and the majority of livestock are found. The authors believe that land degradation in Tanzania and Africa in general is being viewed to be following simple rules, which are connected to precipitation, slope gradient, soils, or to a few roughly-defined socioeconomic systems. The authors further stated that, considering the distribution of land degradation in semiarid regions in Africa, few of these generalizations hold true. In an area with homogeneous physical conditions, ethnic groups with only slightly differing land use systems may have a very different impact on the environment; one devastating the productive base while the other causes only marginal damage (Christiansson *et al.*,1991). When planning restoration programs in sub-Saharan Africa, there should be the awareness, that advanced tertiary research management degree programs from developed countries are often not applicable to African conditions (Kellner, 2000). Most of the inhabitants of the semiarid regions in Africa are agropastoralists who depend on agriculture for subsistence but maintain herds of cattle and small stock for security, capital and social purposes (Christiansson *et al.*,1991). The livestock carrying capacity of these semi-arid areas is low and are always greatly overstocked, leading to overgrazing and erosion which, in turn speed up the process of land degradation (Kikula, 1986; Viljoen, *et al.*, 1993).

In southern Africa, degradation of the semi-arid grassland is a multifaceted problem involving the erosion and the degradation of soil, and a changing composition and basal cover of pasture species. In these areas, farmers tend to overstock their lands with grazers. This practice has become a major cause of conversion of basal cover from palatable and ecologically stable types of vegetation to an unpalatable, unstable pioneer type of vegetation. It has become a situation that has a negative influence on the acceptable stocking rate and on the physical and chemical characteristics of the soil (Bosch, 1989: Kellner and Bosch, 1992; Mott *et al.* 1979). Bare patches form in cleared. neglected and degraded areas and especially in duplex soils which lead to changes in the surface, such as the formation of soil seal scalds, and uneven micro-topographical surfaces and pore density (Fraser *et al.* 1987). These physical characteristics, as well as the chemistry of surface and subsurface soil in different states of degradation, have a direct influence on seedling establishment, root penetration, water-use efficiency, and nutrient levels (Mott *et al.*, 1979).

According to Friedel (1990), a shift in the species composition over a time is a result of degradation, a situation that leads to the crossing of the threshold. In all cases, crossing a threshold means the vegetation occupies a new domain and will not revert to its former state without considerable intervention (Bosch & Kellner, 1991). Friedel (1990) further stated that there are two thresholds, which are readily recognized in arid and semi-arid rangelands. The first threshold is the change from grass to woody vegetation, which arises when the grass layer is grazed beyond its capacity to recover quickly. Fire suppression enhances the survival of the woody plant seedlings. This kind of change has occurred in western New South Wales, Australia, where open eucalypt woodlands have become infested with inedible shrubs to the detriment of grazing sheep (Harrington *et al.,* 1984). The second threshold is reached when soil erosion outstrips replenishment and both the physical and chemical properties of soil are effectively altered irreversibly, an example of such situation is when the sandy, nutrient-rich A horizon is stripped from an impoverished medium or fine-textured B horizon. Rainfall is lost in runoff and the environment becomes too xeric for the establishment of either grass or woody plants (Friedel, 1990).

Land degradation in South Africa is a serious problem in the Northern Province and parts of Mpumalanga but it is particularly worse in the territories which were occupied by the former Homelands. According to the Provincial Fact Sheet on Land Degradation (Hoffman, *et al.*, 1999), soils in Mpumalanga are relatively susceptible to erosion. Sheet erosion is a problem in croplands, especially in the communally managed areas. Grazing lands and forestry are affected by gully erosion. All these factors contribute to the deterioration and degradation of the natural ecosystem.

The main cause of degradation in the communal areas, according to Viljoen *et al.*, (1993), is the tribal life style of the numerous rural communities. The denudation around villages is ascribed to a number of factors which include: (1) the collection of wood used to make fire for cooking food and as building materials, (2) the communal system of livestock grazing practiced by the inhabitants. Field investigation of the badly denuded areas revealed varying degrees of both sheet and gully (donga) erosion. The livestock carrying capacity of the area is low and the area is greatly overstocked, leading to overgrazing and erosion. Dwindling firewood and water supplies are characteristic features of the area (Viljoen *et al.*, 1993). These processes which contribute to the degradation are significant in duplex soils. Large areas of Mpumalanga province are characterized by these duplex soil types.

One of the main objectives of pasture research in South Africa is to improve the productivity of the non-arable part of the country. In the tall grassveld of Natal, attention has been focused on the highly erosive duplex soils which cover some 30 to 40% of the landscape in a representative area near Escourt (Dept. Agricultural Technical Services, 1972). These soils cannot be safely ploughed; the main factor limiting production on them is infertility, especially with regard to nitrogen status (I'ons, 1973). The realization of the devastating conditions of rangelands in the rural areas has led to the government's latest approach that most research has to be focused and redirected to the small-scale farmer and communally managed areas. These areas are mostly underdeveloped and characterized by a high poverty ratio. With the shift in priority towards subsistence farming, communally managed areas and the needs of the previous disadvantaged communities, great care must be taken in order not to disregard all previous research, which were mostly directed at the commercial farmer as irrelevant and inapplicable (Smit, 1998) since a large percentage of existing research is applicable to all farming systems.

1.1.2 Degradation in game reserves.

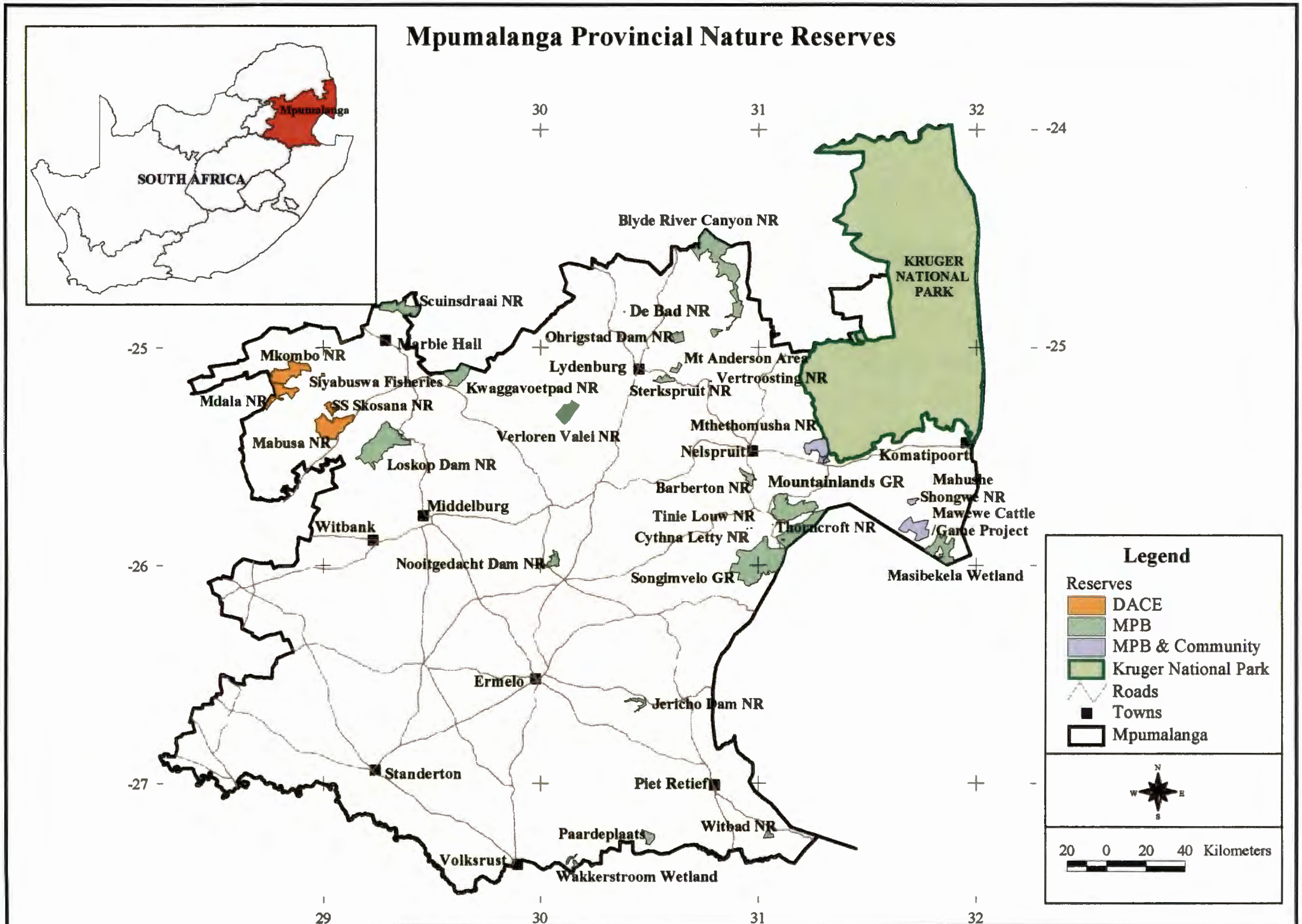
Tourism is internationally accepted as one of the world's fastest growing industries. South Africa has emerged as a highly attractive tourist destination. The National parks, for example the Kruger National Park, Provincial Parks and the Private Game reserves, are among South Africa's biggest tourist attractions. They are the home to a large number and variety of amphibians, reptiles, birds and mammal species including the Big Five (lion, leopard, buffalo, rhino and elephant). Included in the South African tourist attractions are the protected areas. The aim of the protected areas is to conserve living and genetic resources that are essential for sustainable developments. The protected areas include scientific research areas and National Parks (such as the Kruger National Park), Wilderness areas such as the Mthethomusha game reserve (MGR), Provincial managed Parks and equivalent reserves[1].

The two study areas for the current study are located at two game reserves in Mpumalanga Province. One at MGR, a reserve managed jointly by the community and the Mpumalanga Parks Board. The second one is located at Sabi Sand, a privately owned game reserve. Both reserves share common borders with the Kruger National Park (see Fig. 1.1).

[1] South Africa Yearbook, Sixth edition. 1999. Government Communication and Information System, Private Bag X745, Pretoria 0001. Tel: (012) 314-2911 Fax: (012) 323-3831.

Mpumalanga Province is noted for the numerous natural reserves as indicated in Figure 1.1. Some of the reserves are managed by Mpumalanga Parks Board (MPB) such as the Thorncroft nature reserve, others are managed jointly by MPB and the community as found in Mthethomusha game reserve(MGR) and the Mawewe Cattle/Game Project. There are those categorized under National Parks Boards, as in Kruger National Park (KNP), Private Game Reserves such as the Sabi Sand Game reserve and Protected areas under the Department of Agriculture Conservation and Environment (DACE). The management and the research strategies of the game reserves, especially in KNP are designed to take cognisance of the complex dynamic nature of ecosystems (Pienaar, 1983). Ecosystem may be defined as identifiable ecological entities resulting from the interactions and interdependencies within and between biotic communities and their abiotic environment. In exercising management options, KNP and its neighbouring game reserves, the SSPGR and MGR accepted a guiding principle based on management by "minimum intervention" (Joubert, 1983). In the application of this principle an ecosystem-oriented approach has been taken, in which the perpetuation of diversity and species richness has played a decisive role, and in which the dynamic functional aspect of ecosystems (i.e. the interactions and interdependencies of the components) are acknowledged. Management by "minimum intervention", therefore implies the restoration of disrupted natural processes by simulating the natural state of affairs (Joubert, 1986).

Figure 1.1: The map of Mpumalanga Province in South Africa showing the locations of the numerous nature reserves and the authorities managing them (supplied by the Mpumalanga Parks Board).



Mpumalanga Provincial Nature Reserves
Mpumalanga
SOUTH AFRICA
KRUGER NATIONAL PARK
Blyde River Canyon NR
Scuinsdraai NR
De Bad NR
Ohrigstad Dam NR
Marble Hall
Mkombo NR
Lydenburg
Mt Anderson Area
Siyabuswa Fisheries
Kwaggavoetpad NR
Sterkspruit NR
Vertroosting NR
Mdala NR
SS Skosana NR
Mthethomusha NR
Mabusa NR
Verloren Valei NR
Nelspruit
Komatipoort
Loskop Dam NR
Barberton NR
Mountainlands GR
Mahushe Shongwe NR
Middelburg
Tinie Louw NR
Mawewe Cattle /Game Project
Witbank
Cythna Letty NR
Thorncroft NR
Nooitgedacht Dam NR
Songimvelo GR
Masibekela Wetland
Ermelo
Jericho Dam NR
Standerton
Piet Retief
Witbad NR
Paardeplaats
Volksrust
Wakkerstroom Wetland
Legend
Reserves
DACE
MPB
MPB & Community
Kruger National Park
Roads
Towns
Mpumalanga
N
W
E
S
20 0 20 40 Kilometers
29
30
31
32
-24
-25
-26
-27

In spite of the stated objective of managing KNP and the surrounding game reserves in such a way that the natural attributes and dynamic properties are preserved intact, several inevitable developments which constitute a threat to the natural pristinity have been imposed on these areas. A major complicating factor is the fact that the KNP, MGR and Sabi Sand game reserve are situated almost in the center of the large Lowveld ecosystem, and are on the receiving end of a number of adverse influences such as mining and coal-fired power stations that cause chemical pollution, heavy metals and other toxic substances that pollute the rivers which service the park. The perennial river which forms an integral part of the KNP, MGR and the surrounding private game reserves. all flow from west to east. To the west of the KNP major developments have taken place, including urbanisation, agricultural. forestry and industrial developments, as well as large scale exploitation of mineral deposits by means of open cast and underground mining. Increased demands have been placed on the renewable natural resources, and have inevitably led to a degradation in quality and quantity of water in the perennial rivers. Increased siltation of the rivers, the introduction of alien plant encroachers that threaten certain habitats, and, more recently, increased air pollution and the possibility of 'acid' rain are also common problems in most game reserves. These are problems which could increase soil degradation. The increase in agricultural activity, and the resultant danger of transmitting contagious diseases between wild animals and livestock eventually led to the fencing of the boundaries of the Kruger National Park (Joubert, 1986), and other game reserves in Mpumalanga Province as well as others in different parts of the country. These artificial barriers inevitably curtailed the natural migration and dispersion patterns of various large mammal species. The boundaries also created a situation that leads to overgrazing as the animals are then concentrated on water holes and palatable grass within the boundaries. The constant trampling of the grass in the same area and the increase in overgrazing have also led to bare patches and denudation which are precursors to soil erosion. This was the situation at the SSPGR study site in the current study. Tourists from European and other countries visiting our Parks want to see the game animals in their natural habitat. To keep South Africa in general and Mpumalanga in particular, in the forefront of the highly competitive Tourism Industry, degraded areas in game reserves and protected areas need to be scientifically restored and an awareness and education programmes be established. This can be done through education at restoration demonstration sites.

1.2 Objectives of the study.

The objectives of this study are:

1. To evaluate a number of restoration technologies and strategies in the restoration of degraded duplex soil types.
2. To evaluate four different grass species that can be used in oversowing treatments and the restoration of degraded, duplex soils.
3. To use the plots as demonstration sites for raising awareness to local communities, range managers, farmers and researchers.

A literature study was carried out to get an in depth understanding of principles of restoration ecology and technologies.

1.2.1 Restoration ecology.

There are theories that when rangeland has degraded and deteriorated past a certain threshold value, it can no longer recover to a climax or an optimal condition with normal management practices (Bosch & Kellner, 1991; Friedel, 1988; Kellner & Bosch, 1992). This is due to the fact that, a number of physical soil factors (Bosch, 1989; Snyman *et al.,* 1985) have resulted in the formation of open bare patches in natural pasture and have monopolized hundreds of hectares on some farms. Because the natural recovery of vegetation on these bare patches is a long process, rangeland improvement programs have been implemented by farmers and researchers to improve the productivity of the rangeland (Pretorius, 1991; Coetsee, 1992).

Different sources use different terms for rangeland improvement. Harris *et al.* (1996), described some of the terms as follows:

<u>Reclamation:</u> a process by which previously unusable land is returned to a state whereby some use may be made of it. This is the first stage of restoration and includes land gained from submerged coastal lands, desert or wetland areas.

<u>Rehabilitation</u>: applies to areas which formerly had no plant growth

at all, but with careful fertilisation and landscaping may be used to grow a limited amount of plant species.

Restoration: the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems. The process whereby an area is returned to its original state prior to degradation of any sort, i.e. back to a fully functioning sustaining ecosystem. Exotic species can be considered for restoration purposes in some circumstances (Harris, *et al.*,1996 Rogers, 1996).

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

According to The Society for Ecological Restoration[2] (1991), "Ecological restoration is the process of assisting the recovery and management of ecological integrity." In a stricter ecological sense, land restoration can be referred to as a process by which an area is returned to its original state prior to degradation of any sort, in other words, back to a fully functioning self-sustaining ecosystem (Harris *et al.*1996). In his contribution to the recovery and the practice of restoration in Australia, McDonald (2000) stated that. finding ways to resonate with natural processes is often the key to restoration. The extensive disturbance of much of the world's vegetation which has already taken place can be used as huge experiments which provide information on its resilience and response to various levels of disturbance (Hobbs & Hopkins, 1990).

Land restoration and reclamation on degraded rangelands is becoming an increasingly topic for scientists, land managers and land users, especially in arid and semi-arid regions. With the ever increasing human population and the demand for food and water, the pressure on land and other natural resources has never been greater. Potentially arable land resources cannot meet the needs of projected increases in human and animal population. Therefore, not only should the desired high net output in production be achieved

[2] The Society for Ecological Restoration, 1955 W.Grant Road # 150, Tucson, AZ 85745, USA, Tel.(520)622 5485(0), (520)622 5491 (f), info@ser.org

with a minimum of soil degradation but the soil quality and its productive capacity must also be restored and improved by preventing soil erosion, the promotion of high biological activity of soil *fauna*, the improvement of soil organic matter content, and replacement of the nutrients harvested in crops and animals through the application of chemical fertilizers and organic amendments supported by effective nutrient recycling mechanisms (Lal & Stewart, 1992). The conservation of existing ecosystem is simply not enough to ensure the future of living populations. It is therefore clear that degraded systems will not recover by natural successional processes in arid and semi-arid systems within a short period of time to a potential that can be used for crop and livestock production. This is a fact which emphasizes the necessity for restoration (Kellner, 2000).

1.3 Restoration technologies.

There are several restoration technologies applied to the restoration of range lands by different ecologists which are mostly site specific (Harker, 1993). Van der Merwe (1997) grouped a number of restoration techniques used in degraded rangelands into **organic, biological** and **mechanical** approaches. In the current study, five techniques are employed which include soil disturbance (Tainton, 1981), application of organic material, over sowing, application of lime and brush packing.

In the **organic** approach, organic materials such as brush packing, straw packing and the placement of organic blocks or well decomposed farm manure on soil can be used. For centuries the use of farm manure has been synonymous with a successful and stable agriculture. Not only does manure supply organic matter and plant nutrients to the soil, but it is associated with animal agriculture and with forage crops, both of which protect and conserve the soil (Brady & Weil, 1996). According to Allison (1973), soil organic matter is a key component of any ecosystem and variation in its abundance and nature may have profound effects on soil processes. Brady & Weil (1996) also stated that, organic matter has great influence on soil physical as well as chemical properties. It improves the soil structure, reduces soil erosion, has a regulating effect on

soil temperature and helps the soil to store more moisture (FAO)[3]. Humus tends to give surface horizons dark brown to black colour. It encourages the stability of granulation and aggregate. Plasticity, cohesion, and stickiness of clay soils are reduced making these soils easier for root penetration and water infiltration. Humus has a high cation exchange capacity (CEC) and like clay, humus colloids hold nutrient cations (potassium, calcium, magnesium) in an easily exchangeable form (Brady & Weil, 1996; Allison, 1973). Organic - rich soil is a soil that contains at least 20% organic matter (by weight) if the clay content is low and at least 30% if the clay content is as high as 60%. Soil organic matter is derived from manure (I'ons, 1973).
Brush packing is a treatment where branches of trees and shrubs or hay are packed on bare patches. This practice is effective in protecting bare patches against wind erosion and sun. It also protects the new seedlings against grazing and the elements of nature (Van Oudtshoorn, 1999). The stems and the leaves used in brush packing interact with water flow at the ground surface, resulting in higher interception storage and higher volume of water for infiltration. The covering of the ground surface through brush packing also helps to absorb the impact of traffic by both humans and animals and prevent damage to the soil in wet conditions through trampling (Harris *et al.* 1996).

Biological approaches include different sowing methods used in restoration practices (Tainton, 1981). Over sowing: (re-seeding; re-vegetation) is an attempt to restore any part of the structure and or function of an ecosystem or to restore the site to its former land use. For example restoration of grass cover to decrease soil erosion or seed and transplant wild-land shrubs and trees to promote wildlife. It is typically applied to large areas after considering practical, ecological, economic, and social constraint and demand. A common example is the seeding of perennial grasses into degraded rangelands to decrease soil erosion and increase forage production for wildlife and livestock (Jordan, *et al.* 1987).

Range conditions that require re-seeding of palatable grass species, include overgrazed pastures dominated by annual species with bare and denuded patches, or characterised by unpalatable grass

[3] Food and Agriculture Organization of the United Nations. Land and Water Development Series, No.8. Rome, Italy.

species that signifies poor range condition status (Brown, 1994). Over-sowing methods that can be used in restoration practices include broadcasting and row application (Cairns, 1995; Lochner, 1987). With broadcast application, the seeds are distributed by hand or a specific implement over the entire surface of the study area while with row application, the seeds are sown in strips by hand along the furrows after cultivation. In comparison to row application, broadcast application leads to a higher cost per hectare (R/ha) since some of the seeds can land at undesirable places and prevent their germination. Even though row applications of the same seed mixture as used in broadcast application, would be less expensive (Van der Merwe, 1997), it has its own disadvantage. With row application, the entire populations of undesirable species are not always removed therefore exposing the untreated areas to re-invasion by undesirable plants (Call & Roundy, 1991). It is very important that any restoration activity or application should be followed with sound management practices in order to encourage the dominance of the sown-in grass species (O'Connor, 1985).

Under the **mechanical** approach, a variety of implements, each with a specific cultivation function, can be used to cultivate the soil (Van der Merwe, 1997). Most farmers use the rip (subsoiler) plough cultivation method for restoration treatment. Ripping (subsoiler) is the loosening of the topsoil especially where compaction has occurred. It helps to slow down runoff water and increase infiltration. Using a tractor or a grader with a ripper attached, is used to break the hard upper soil surface and allow better soil infiltration. Different types of implements are used in different soil types, but the main factors affecting the choice of cultivation equipment are the type of tilth required, soil type and the rate at which the tilth has to be produced. (Davis *et al.*, 1986; Van der Merwe, 1997). In southern Africa, most farmers in the rural areas, due to the high cost of tractors attach one or two tine rippers to oxen, which are driven across the target area to loosen the soil.

1.3.1 Soil amelioration.

Reclamation of soil means treatment to correct a severe excess salinity, sodicity or alkalinity. Saline soils are soils that contain large amounts of soluble salts, appreciably more soluble than calcium sulphate. Most commonly, these are salts of sodium (Na), calcium (Ca), and magnesium (Mg), with chloride, sulphate, and bicarbonate. Sodic soils on the other hand contain Na as a significant proportion of their total exchangeable cations (Brady & Weil, 1996; Van Rensburg, 1999).

According to Adam (1988) and Tyurin *et al.* (1967), saline and sodic soils can be described as **solonetz** soils. Solonetz belongs to the family of salt affected soils in spite of the fact that in some solonetzes, particularly in their upper horizons, salt concentration is at present low or very low, they developed under the dominant influence of electrolytes which determine their morphology, physical, chemical and biological properties as well as their fertility (Adam, 1988). Duplex soils as found in the two study areas are characteristic of the solonetz soil type complex. Tyurin *et al.*, (1967) explains that a typical solonetz soil have marked characteristics: 1) an upper layer, thin foliated, gray, sometimes humidified, often structureless; 2) below the upper layer is a very compact, dark, columnar, sometimes cloddy layer, reaching a thickness of 20-30 cm or more; when moist, this layer swells and is water-impermeable; 3) still lower, the soil becomes less compact and either calcium carbonate and salt, or gypsum appear. The second of these layers (the solonetz layer) has very unfavorable agronomic properties: in addition to negative physical characteristics, the layer is often highly alkaline, and harmful to cultivated plants (Tyurin *et al.*, 1967).

Sodium is toxic to certain plants, especially if calcium concentrations are low but the overriding effects of high Na are on the soil's physical properties. Sodic soils readily lose their structure, becoming impermeable, unless the salt concentration in the solution is kept high (Van Rensburg, 1999). As stated above, reclamation of soil means treatment to correct a severe excess in salinity, sodicity or alkalinity. It is the drastic fix needed if things are bad. "Control" is the preventive practices and management needed to keep problems from developing, recurring, or worsening. Reclamation and control depend on the same principles and use similar processes and practices. For the reclamation of both saline-sodic and sodic soils, attention must first be given to reducing the level of exchangeable Na^+ ions and then to the problem of excess soluble salts (Brady & Weil, 1996).

Exchangeable sodium cannot be leached unless something is done to displace it into solution and to keep soil flocculated. Both objectives are achieved by maintaining a sufficient concentration of other cation in solution. In practice, the critical cation is calcium. It is abundant, and being divalent and little hydrated, it replaces Na readily and flocculates clay at a low total salt concentration (Van Rensburg, 1999). **Gypsum** ($CaSO_4 \cdot 2H_2O$) is soluble enough to maintain Ca at a useful concentration. Removing Na^+ ion from the exchange complex is most effectively accomplished by replacing them with either the Ca^{2+} or the H^+ ion. Providing Ca^{2+} in the form of gypsum is the most practical way to bring about this exchange (Brady & Weil, 1996; Van Rensburg, 1999). The alkalinity (nitrates), acidity (ammonium) and the amount of organic material, all affect soil pH. Lime or gypsum can be applied to restore the pH of the specific soil type.

Duplex soils refer to soils with relatively permeable topsoil abruptly overlying a very slowly permeable diagnostic horizon which is not a hardpan (Macvicar, 1991). An Estcourt soil form falls under the duplex ecological unit as found in both study sites, MGR and SSPGR. The ameliorative effect on the soil structure can be enhanced when cereal stubble is incorporated with gypsum or lime (Baldock & Oades, 1990).

There are two forms of agricultural lime:

- Calcitic lime is a finely ground limestone which consists mainly of calcium carbonate ($CaCo_3$).
- Dolomitic lime is also a finely ground limestone, but it is a mixture of calcium carbonate and magnesium carbonate ($MgCo_3$) (FAO)[3].

Lime has physical, chemical and biological effect on soil. **Physically** lime has a flocculating effect which improves the granulation of soil and makes it more friable. This improves aeration and drainage of especially clay soils. **Biologically** lime increases the activity of soil microbes due to the pH changes. Organic matter content of the soil increases as the rate of decomposition also increases (Brady & Weil 1996; Kuun *et. al.*, 1993).

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[3] Food and Agriculture Organization of the United Nations. Land and Water Development Series, No.8. Rome, Italy.

1.4 Use of vegetation in restoration (e.g. Oversowing).

In land reclamation and restoration, an efficient nutrient cycling is always required and the role of vegetation in this has to be understood. In the reclamation of open-cast mined land or a bare degraded rangeland, with aforestation and with agriculture, a pioneer crop of a short growth duration is established as part of a program of soil improvement before the final crop or vegetation is established. Pioneer crops also can aid the accumulation and cycling of nutrients by providing organic matter, improved soil structure and nitrogen but the effectiveness of any vegetation in fulfilling the role of nutrient accumulation and cycling is dependent on the ability of the species to survive and grow under the conditions on site (Harris *et al.* 1996). Despite their ecological importance, pioneer crops can have a long term negative influence on the results of restoration projects. For example in some situations they maintain the system in an alternative stable state, not allowing natural succession to take place because of their highly competitive nature.

Harris *et al.* (1996), grouped the importance of vegetation in restoration under **hydrological** and **mechanical**. The following are beneficial effects under hydrological. Foliage intercepts rainfall causing:

- Absorptive and evaporative losses, reducing rainfall available for infiltration.
- Reduction in kinetic energy of raindrops and thus erosivity.

Stems and leaves interact with flow at the ground surface, resulting in:

- Higher interception storage and higher volume of water for infiltration.
- Greater roughness on the flow of air and water, reducing its velocity.

Roots permeate the soil leading to:

- Extraction of moisture which is lost to the atmosphere in transpiration, lowering pore-water pressure and increasing soil strength.

The beneficial effects under mechanical are grouped as follows:
Roots bind soil particles and permeate the soil, resulting in:

- Restraint of soil movement reducing erodibility.
- Increase in strength through a matrix of tensile fibres.

- Network of surface fibres create a tensile mat effect restraining underlying strata.

Roots penetrate deep strata giving:

- Anchorage into firm strata, bonding soil mantle to stable subsoil or bedrock.
- Support to upslope soil cover through buttressing and arching.

Stems and leaves cover the ground surface so that:

- Impact of traffic is absorbed, thus protecting soil surface from damage.
- Foliage is flattened in high velocity flows, covering the soil surface and providing protection against erosive flows.

Harris *et al.* (1996), further stated that the properties of vegetation are seasonal in nature and vary in vegetation type and plant species and age.

1.4.1 Seeding rate in oversowing treatments

There are two types of oversowing that can be used in restoration: the **broadcast sowing** and the **row sowing.** Broadcast sowing means the seed is spread evenly over a given area. This is done by using a cyclone seeder or by hand. In row sowing, sharp-pointed hoes or forks or a mechanical implement are used to make shallow furrows which are spaced 30-50cm apart and seeds are sown in these furrows either by hand or planter. Rows of grass seedlings will emerge and trap silt to help stabilize the area (Kellner *et al.*, 2000).

Broadcast mix applications have the highest cost per hectare (R/ha); while row applications of the same mixture would be less expensive (Van der Merwe, 1997). As previously mentioned, with row application, the entire population of undesirable species are not always removed and the treated area can be exposed to re-invasion by undesirable plants (Roundy & Call, 1988) and subsequent competition (Fair,1986), unless the oversown species are of higher competitive nature.

With respect to seed propagation, depending on the seed type and morphology, approximately 3 kg/ha more seed (species with unchaffy seeds) is required for broadcast application than in the case of row application (Van der Merwe, 1997). Broadcast application of chaffy (grass seeds with glumes and appendages greater than 4mm, ISTA[4]) grass seeds are approximately double that of row applications (Advance Seed[5], 1997).

Seeds used in restoration projects can be collected locally by the restoration experts themselves or purchased from commercial vendors. Collecting the seeds locally by oneself is relatively cheaper but buying from a reputable supplier of locally derived seeds has several advantages. The right quantity of seed needed for a project is delivered at the right time and therefore cutting down cost due to time saved. The purchased seed is less bulky because it has less chaff and other non-seed material. Seed from suppliers normally comes with information such as pure live seed and the number of seed per kilogram as well as guaranteed germination rates (usually between 20-30% for grass species as stipulated by the Plant Improvement Act No. 174, 1995). This type of information is always important to enable one decide on the amount of seed needed for a specific project (Lochner, 1987; Billett, 1988).

Commercial seed used for restoration projects can either be ordinary (uncoated) or enhanced (coated) seed. Three different types of **enhancement** can be distinguished, namely: (1) pre-sowing hydration treatments (priming); (2) coating (encapsulating) technologies and (3) seed conditioning. Pre-sowing hydration treatments include non-controlled water uptake system (method in which water is freely available and not restricted by the environment) and controlled systems (methods that regulate moisture content preventing the completion of germination). Two techniques are used for controlled water uptake, namely priming with solution or solid particulate systems or by controlled hydration with water (Taylor, *et al.* 1998).

1.4.2 Laboratory seed germination test and analysis.

For the purpose of this study, a seed is defined as a result from the fertilisation and maturation of an ovule. It consists of the embryo, which develops into the seedling during germination, a nutritive tissue, and a protective coat, the testa (Fahn, 1990; Bold *et al.*,

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[4] International Seed Testing Association, Secretariat, P.O Box 412,8046 Zurich CH-Switzerland, Tel +41 1 377 60 00, Fax +41 1 377 60 01, e-mail istache@iprolink.ch

[5] Advanced Seed, P.O. Box 414, Krugersdrop, 1710, South Africa, +27 11 762 5261

1987). Weier *et al.*, (1982), described a seed simply as the matured ovule without the accessory parts.

1.4.3 The necessity for seed germination test.

The main objective for seed germination test is to determine the maximum germination capacity of the seed and to provide results that can be used to evaluate the performance of seeds used in a restoration project. Normally seed germination tests are not done under field conditions because the results obtained cannot be repeated with certainty due to varying environmental conditions. Reliable laboratory methods have been designed in which the external environmental conditions are controlled to give the most regular, rapid and complete germination records for the majority of samples of a particular species. Germination of seed in a laboratory test is the emergence and development of seedling to a stage where its essential structures indicate its ability to develop further into a satisfactory plant under favourable conditions in the field. All seeds require moisture, temperature (ranging from 10°C to 30°C), and adequate oxygen supply (Seed Control Directorate of Genetic Resources, 1999). Some seeds have specific light requirements for germination, e.g. *Poa sp.* The role of light in seed germination is however very complicated. Most grass will germinate irrespective of the presence of light or not (Roberts, 1986), but the presence of light prevents the etiolation of the seedling and promotes the formation of chlorophyll.

1.4.4 Seed purity

Frequently, however, in the laboratory the unit tested and commonly termed the "seed" also contains remains of other parts of the flower. When seed samples (which always come in sealed bags) are brought to the laboratory for germination test and analysis, the purity of the seeds are first determined. The term "pure seed" of a particular seed sample is the percentage of seeds that actually corresponds with the identification label on the seed bag (ISTA)[4]. Generally, it is not possible to completely remove all impurities during the cleaning process. Therefore, standards have been set to determine the composition of the seed. The main aim of a purity

[4] International Seed Testing Association, Secretariat, P.O Box 412,8046 Zurich CH-Switzerland, Tel +41 1 377 60 00, Fax +41 1 377 60 01, e-mail istache@iprolink.ch

analysis is to determine firstly, the percentage composition of the sample being tested. Secondly the composition of the entire seed and thirdly the identity of the various species of the seeds and inert particles constituting the sample (Seed Control Directorate of Genetic Resources, 1999). There are a number of definitions for seed purity but for this study, only the analytical purity and species purity will be considered.

Analytical purity is the percentage of the material in the intact seed bag with the species named on the label. It is estimated by a small sample (approximately a tenth of the mass according to the Seed Control Directorate of Genetic Resources, 1999) from the bag. In grass seeds (caryopsis), the most common impurities are empty florets. According to Thompson & Grime (1979), species purity is determined from a larger sample (8 x 100 seeds according to the Seed Control Directorate of Genetic Resources, 1999) and is expressed as the mass of the seeds or particles of other species relative to the mass of all the seeds examined. Seed purity is therefore an indicator of the percentage of seed present for germination, be it viable or not.

Among the so-called impure seeds, seeds of other species as well as stalks, sand granules and florets are present. When impure seeds are sown, it results in a pasture that consists of other plant species as well as the preferred plant species of a lowered density than the anticipated density. A viable seed is a living seed (Bewley & Black, 1983) capable of developing and surviving independently (Cowie, 1989) and is influenced by the temperature, the moisture content of the soil and oxygen pressure (Roberts, 1986). Germination starts with the rapid imbibition of water by the seed, usually through the micropyle, resulting in a dramatic increase in the mass of the seed. The swelling of embryonic tissues ruptures the seed coat, thereby allowing the growing plumose and radicle to emerge. Apart from water, the other requirements are correct illumination, suitable temperature and presence of oxygen (Roberts, 1986). The first indication that the processes of germination have begun is generally the swelling of the radicle (Weier, *et al.* 1982). Bewley & Black, (1983) view the processes of germination as when a viable seed is wetted, it takes up water which triggers the process of respiration, protein synthesis and other metabolic activities. After a certain period of time the embryo emerges from the seed, generally the radicle appears first in other words the seed has germinated.

Species purity is determined from a larger sample (8x100 seeds according to the seed control directorate of genetic resources, 1999) and expresses as the weight of seeds or particles of species related to the weight of all the seeds examined (Thomson & Grime, 1979). Seed purity is an indicator of the percentage of seeds present for germination, weather viable or not. In an impure seed, seeds of other species as well as stalks, sand granules and empty florets are present. Sowing an impure seed would result in a pasture consisting of other plant species and of preferred plant species at a lower than anticipated density. One manner in which to lower the initial cost of restoration is to determine the least amount of seeds necessary for a treatment.

1.4.5 Soil seed bank.

The viable seeds and fruits present in or on the soil are referred to as the seed pool or seed bank (Barbour, *et al.*, 1987; Grime, 1979; Thompson & Grime, 1979). Some of these seeds germinate to become seedlings. The environment acts as sieve, as some seedlings become established and other seeds remain in the seed pool. Near the end of the growing season, new seeds are produced and another seed pool is available for the next generation. The length of time that seeds survive in the seed pool is related to growth form and environment (Barbour, *et al.*, 1987). According to Barbour *et al.*, (1987), out of the seed bank the next generation of a species is born and the species is propagated.

The behaviour and fate of the seed fraction of a population are often of importance to its overall dynamics, and large number of seeds may accumulate in the soil seed bank. The seed bank therefore serves as an important reservoir of genetic variation and may increase the population numbers if the recruits from it to the active population do not belong to few numerically dominant genotypes (Silvertown & Lovett-Doust, 1993). A striking feature of the seed bank is the general discordance between the species contained in the soil and the associated vegetation. Chippindale & Milton (1934) showed that the presence of viable seeds of species of former successional stages or plant communities can reflect an earlier stage in vegetation succession history. Moore (1983) also indicated that the loss of vegetative stage in a plant's life history, even if absent for several decades, does not necessarily show that the species is not present as dormant seed. This phenomenon can be applied in nature conservation to recreate former or endangered plant communities (Bakker, 1989). When the establishment of seedlings from a seed bank corresponds with the standing vegetation, the following deductions can be made:

1) The species might have developed from a **transient** seed bank, being a seed pool represented by species that will either die or germinate within a year. They have little impact on the population, beside their numbers and position in safe sites. They usually originate from annuals growing in predictable habitats where successful reproduction is essentially a sure thing.

2) The species might have developed from a **persistent** seed bank, which is a seed pool that accumulates seeds over a longer period of time. Annual species in very harsh conditions tend to have extremely long periods as viable seeds. Persistent seed pools are characteristic of ephemeral plants and perennial herbs or shrubs occurring in unpredictable environments. Typically, seeds of the 'biennials' live long enough to survive extended periods when the habitat is unavailable and they have few special requirements for breaking dormancy (Barbour, *et al.* 1987).

1.5 Population dynamics

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

1. Those studies focusing on the successful establishment of new plants as an uncommon event. The establishment event depends on the right combination of available propagules,

current climatic conditions and the presence and/or absence of fire and/or herbivores. Once established, the propagules demonstrate typical cohort survivorship curves. Theoretically, a cohort is all the seedlings that survive from one time of measurement to the next. Mortality may be influenced by plant condition, which in turn may be influenced by available moisture, fire and grazing.

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

Detailed autecological studies of the rangeland species improve management strategies. This enables us to identify the time when management could successfully intervene and influence the dynamics of the sward in the desired direction (Walker, 1980; Theunissen, 1993). As part of a community, every plant in an ecosystem has a specific role to fulfil. Removing or disturbing the plant(s) could cause an imbalance in the systems' productivity and self-sustainability (Barbour, *et al.* 1987; Harris, *et al.* 1996; Rogers, 1996; Richardson, 1997). Studies on the autecology and plant-environment relationships of the species enlightens their full potential as restorative agents and also contributes to the preservation of the species (Archer & Pyke, 1991; Harris, *et al.*, 1996). In determining the sustainability of a grass population, as this study did, the turnover rate between the different life growth stages of a plant species needs consideration (Kellner & Jordaan, 1996).

The scope of population dynamics is extremely broad. Terms describing population dynamics include turnover rate, variation at the tiller and seed levels (O'Connor & Everson, 1998) or the presence or absence of a specific species (persistence of a species). Turnover rate is the change of species or part thereof in a given space for a given period of time, (Hodgson & Illius, 1996; Kellner & Jordaan, 1996; Morgan, 1998). Community dynamics include species richness and can be described as a community having a given stability (Begon, *et al.*, 1990). Population dynamics is concerned with the recruitment and death of plants with density being the accumulated net result of these processes. Pastures are considered stable when the same basic botanical composition is maintained. Unstable pastures will not maintain the same botanical composition and this instability can be desirable or not. For example, introduction of legumes and application of nutrients to nutrient limited soil or the replacement of some unproductive species by more agronomically desirable species may be more desirable to a specific land-user (Jones & Mott, 1980).

The parameters of population dynamics include the different growth stages of species, which are established seedlings, vegetatively matured plants (having more than one tiller emerging from the ground), and reproductive plants (which clearly bear reproductive organs or their remains (Barbour *et al.* 1987). In other species, for example *C. gayana* which are vegetatively reproducing plants forming stolons, each daughter plant is counted as a different established ramet under the heading of seedlings (De Wet, 2001). Seedlings are the visible progeny of a generation of grass and therefore an estimate of the following generation (Fair *et al.*, 1999).

1.6 Format of the dissertation.

The dissertation consists of five chapters:
Chapter 1 is the literature study on degradation and restoration treatments. The study areas of the two restoration sites are described in detail in Chapter 2. Chapter 3 covers the procedure, materials, vegetation sampling and data analysis techniques used. The results and discussions are covered in Chapter 4. Chapter 5 deals with conclusion and recommendation while Chapter 6 ends the dissertation with the list of references.

CHAPTER 2

DESCRIPTION OF THE STUDY AREAS

At the initial stage of the current study, suitable degraded sites that could be used for the establishment of experimental plots for practical investigation and demonstrations for certain restoration technologies were sought for. Two areas in the Mpumalanga Province were chosen for this study, one which was fenced and another site on an open degraded area. A site around a buffalo boma in Mthethomusha Game Reserve of Mpumalanga Parks Board (from this point referred to as MGR) was selected for the fenced site. The grasses around the boma were removed by spraying herbicides on the site. The site the place became bare giving it a characteristic typical of a degraded area in this environment. When it became apparent that the degraded areas around MGR were not suitable to set a restoration site, the boma at the MGR was then chosen to represent the fenced restoration site. The second site at Sabi Sand Private Game Reserve (SSPGR) which is situated at the border between Mpumalanga Province and Northern Province was chosen to represent an open degraded area.

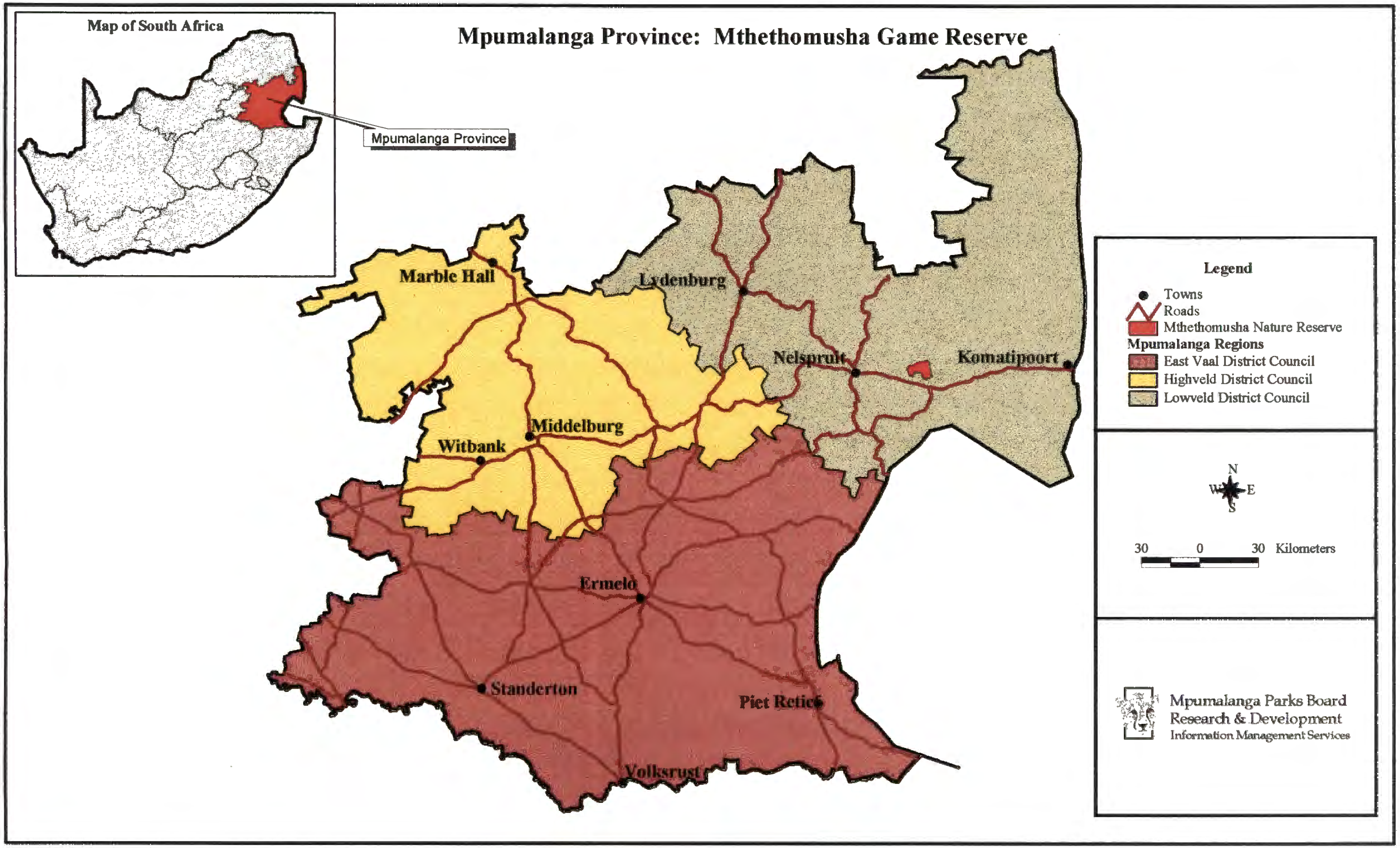
2.1 Mthethomusha Game Reserve (boma)

The MGR is one of the game reserves managed by the Mpumalanga Parks Board and the surrounding rural community. It is in the Luphisi district south of the Kruger National Park (Figs.1.1 & 2.1). This area lies in the Mixed Lowveld Bushveld in the Mpumalanga Province. Geographically, it represents part of the north eastern limits of the well-known Barberton Mountain land. MGR has an area of 7200ha (Coetzee, 1998).

2.1.1 Climate

MGR has an annual summer rainfall that varies from 450 to 600mm and the climate is hot. Temperatures vary between –4°C and 45°C, with an average of 22°C (Van Rooyen & Bredenkamp, 1998). The average monthly rainfall data for the two year period in which the restoration experiment took place at the study site (MGR-Boma), is graphically represented in Fig. 2.2. The rainy season at MGR is generally in the summer months (December to March). In 1999, the rainfall pattern of the first three months was similar but the second quarter of the year was very dry (April to June).

Figure 2.1: The location of the study area, Mthethomusha Game Reserve (MGR)- Boma, in the Mpumalanga Province of South Africa (supplied by the Mpumalanga Parks Board).


Mpumalanga Province: Mthethomusha Game Reserve
Map of South Africa
Mpumalanga Province
Marble Hall
Lydenburg
Nelspruit
Komatipoort
Middelburg
Witbank
Ermelo
Standerton
Piet Retief
Volksrust
Legend
Towns
Roads
Mthethomusha Nature Reserve
Mpumalanga Regions
East Vaal District Council
Highveld District Council
Lowveld District Council
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Mpumalanga Parks Board
Research & Development
Information Management Services

The average rainfall for 1999 was 59.9mm (Fig. 2.2). The rainfall during the year 2000 especially in the first three months were much higher. According to the Weather Bureau (1965), the long term average rainfall, calculated over 46 years, from Skukuza station, which is the nearest station to both study sites, is 574.7mm/a. The rainfall data for January and February in the year 2000 were much higher as compared to the previous years. The total rainfall for the first nine months was 1097mm with an average of 121.9mm as compared to an average of 56.9mm at the same period in 1999 (Fig. 2.2).

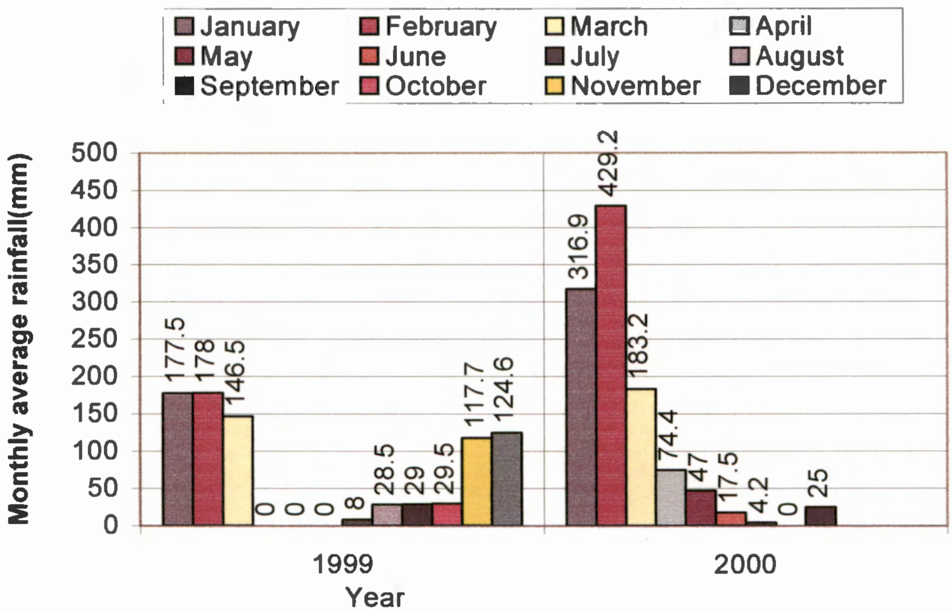


Figure 2.2: The average monthly rainfall at MGR for the two-year study period (1999 to 2001).

2.1.2 Vegetation

MGR is confined to a frost-free area, with frequent fires and general grazing by game. The area lies in the Savanna Biome (bushveld), in the plains at altitudes between 150 and 600 m above sea level It is classified as Lowveld under Acocks veld type 10 (Acocks, 1988; Van Rooyen & Bredenkamp, 1998).

The vegetation of MGR is dense bush on the higher grounds and open tree savanna biome in the bottomland (lower lying areas). *Acacia nilotica*, *A. nigrescens* and *Euclea divinorum* dominate the tree layer at bottomland situations. The grass layer is poorly to moderately developed. Grasses such as *Pogonarthria squarrosa, Panicum maximum*, *Digitaria eriantha* and *Heteropogon contortus,* characterise the surrounding areas of the study site (Acocks, 1988; Van Rooyen & Bredenkamp, 1998).

2.1.3 Soil type

Sandy soil in the uplands and clayey soils with high sodium content in the bottomlands characterize the substrata. The geology is granite and gneiss with low frequency dolerite dyke intrusions (Van Rooyen & Bredenkamp, 1998). The study site falls within the **duplex** ecological unit. Duplex soils refer to soils with relatively permeable topsoil abruptly overlying a very slowly permeable diagnostic horizon which falls under **Estcourt** soil form (Macvicar *et al.*, 1984). A soil form is a specification of the kind and sequence of diagnostic horizons present and, in some cases, also of the general nature of the underlying material. The horizons making up the Estcourt soil form are, the Orthic A horizon, followed by a shallow E horizon which abruptly overlay a Prismacutanic B horizon.

According to Macvicar *et al.*, (1984), the prismacutanic B horizon has an abrupt transition with an overlying E or A horizon. It has a prismatic or columnar structure with occasional primary blocky structure being more pronounced than the secondary prismatic or columnar structure. Macvicar, *et al.* (1984) further stated that the prismacutanic B horizon accommodates the classical concept of the solodized solonetz B in which prismatic or columnar structure has developed under an abrupt transition (See 1.3.1).

2.1.4 Geomorphology

MGR falls under the Malelane land system. Mainly granitoid rocks underlie this land system. In the northern part of the land system, porphritic granite and gneiss of the Nelspruit suite are dominant, while the southern parts are dominated by tonalitic and trondhjemitic banded gneiss and schist (Schutte, 1986). According to Venter (1990), the localized areas, which are dominated by magmatite also occur. In certain areas, the gneiss and migmatite occur in association with schistose and other related metamorphic rocks of the Barberton sequence. At the study site at MGR, the intrusion of dolerite dykes is found at the north-eastern corner of the buffalo boma, on a slope where erosion was more severe. The frequency at which dolerite dykes occur is relatively low in this land system and such dykes are often weathered and eroded into deep narrow valleys, hence their role as a parent material to form soil substances is minimized (Van Rooyen & Bredenkamp, 1998; Venter, 1990).

2. 1.5 Land form

The landform of MGR, which forms part of the Malelane land system, consists mainly of low mountains and hills. The mountains are highly dissected by numerous small first to second order seasonal streams, which are usually characterised by relatively narrow steep-sided valleys, which give the area a rugged appearance (Venter, 1990). The strike directions of mafic dykes often control drainage lines. Wider valleys have been formed by three seasonal drainage channels of the third and fourth order which are Nsikazi, Matjulu and Mlambane. The southern fringes of the land system i.e. the area between the Crocodile River and a relatively narrow belt of moderately undulating land characterises the mountainous land. The highest point in the MGR, Mpakeni Mountain, rises 1034m above sea level and the lowest point is 488m above sea level.

2.1.6 History and management of the site at MGR

In 1998, the Mpumalanga Parks Board (MPB), with the assistance from the State Veterinary Services and from the Kruger National Park (KNP) established a production boma, Entsangeni Buffalo project, where disease free buffalo could be bred. This project is one of the current buffalo projects being carried out in South Africa. It is a multi-million rand project with a 10-year budget estimate of R29,5 million. The animals are kept in a boma that provides good bio-security, lion, and primate proof and the fencing which allows space between facilities and the surrounding area, prevent the transmission of airborne diseases and tick infection (Coetzee, 1998).

The site for the experiment is the five-hectare land surrounding the boma between the electric fence and the wooden fence of the boma. To prevent ticks from moving from the surrounding natural vegetation, through the wooden fence to the buffalo in the boma, the space between the wooden fence and the electric fence was cleared of all vegetation with the exception of a few trees. The grasses were sprayed with the following herbicides: Chopper with Imazapyr as its active ingredient; Mamba and Roundup both with Glyphocide as their active ingredient. The spraying of the herbicides was carried out one year prior to the trial. Since large bare and denuded patches could not be found in this study area, the sprayed area was taken as a simulated area similar to degradation and denuded patches. Lack of vegetation cover and the duplex nature of the soil resulted in severe erosion. This threatened the structure of the boma and the existence of the buffalo breeding project. The whole study site is on a gentle slope and the topsoil was gradually being washed away through erosion due to lack of vegetation cover. The soil of this area being duplex and prone to severe erosion, there was the possibility that if the erosion was not checked, it could affect the very foundation of the boma and bring the entire buffalo project to a stand still. Furrows were made across the slope on the contours by the MGR management, but the area was already bare and erosion could not be stopped (Fig. 2.3). This resulted in a need to find ways to restore the vegetation as quickly as possible. It was for this reason that the site was chosen for the restoration project as a typical example of a degraded duplex soil in this area where bare patches are rampant.

Figure 2.3: The degraded area around the boma at MGR before restoration.

2. 2 Sabi Sand

The SSPGR is an amalgamation of privately managed game reserves located on the western border of Kruger National Park in Mpumalanga Province (Fig. 2.5). The site chosen for the restoration is a flat open heavily degraded rangeland at an area of the reserve called the Rhino Park. It is situated near Dam three of the SSPGR.

2. 2.1 Geographic position

The SSPGR study site (24°46'S, 31°21'E) forms part of the larger Sabi Sand game reserve and this area of the reserve is jointly managed by Inyati and Ulusaba game lodges.

2.2.2 Climatic factors

The rainy season at SSPGR is similar to MGR with the wet months occurring in the summer months, (December to March). The monthly rainfall data at the restoration site is given in Fig. 2.4. The total rainfall for the first 9 months in the year 2000 was 1254mm with an average of 139.3mm as compared to an average of 56.9mm for the same period in 1999 (Fig. 2.4). The only rainfall data available at MGR study site during the time of compiling the results were for nine months. To make the data from SSPGR more comparable to that of MGR, the data for the first nine months were used. The annual summer rainfall of SSPGR as in the MGR, varies from 450 to 600mm. The long term average rainfall is similar to MGR, namely 574.7mm/a. Generally the temperatures for this veld type vary between -4°C and 45°C, with an average of 22°C (Van Rooyen & Bredenkamp, 1998).

2.2.3 Vegetation

The SSPGR falls under the Tropical Bushveld and Savanna biome. It is classified as Lowveld under Acocks veld type 10 (Acocks, 1988). The vegetation is dense bush on the uplands and open tree savanna in the bottomlands. *Acacia nilotica*, *A. nigrescens* and *Euclea divinorum* dominate the tree layer at bottomland situations. The grass layer is poorly to moderately developed. Grasses such as *Pogonarthria squarrosa*, *Panicum maximum*, *Digitaria eriantha* and *Heteropogon contortus* characterise the site. SSPGR is confined to a frost-free area, with frequent fires and general grazing by game

(Acocks, 1988; Van Rooyen & Bredenkamp, 1998).

2.2.4 Soil type

The area is characterised by sandy soil in the uplands and clayey soils with high sodium content in the bottomlands. The geology is granite and gneiss with numerous dolerite dyke intrusions (Van Rooyen & Bredenkamp, 1998). The study site at SSPGR falls within the **duplex** ecological unit (See 2.1.3). The site was a degraded area having a number of bare patches with the soil showing the typical characteristics of the second layer of a solonetz soil (See section 1.3.1). The area is heavily eroded with a shallow E-horizon which was 5cm in depth at some places during field inspection.

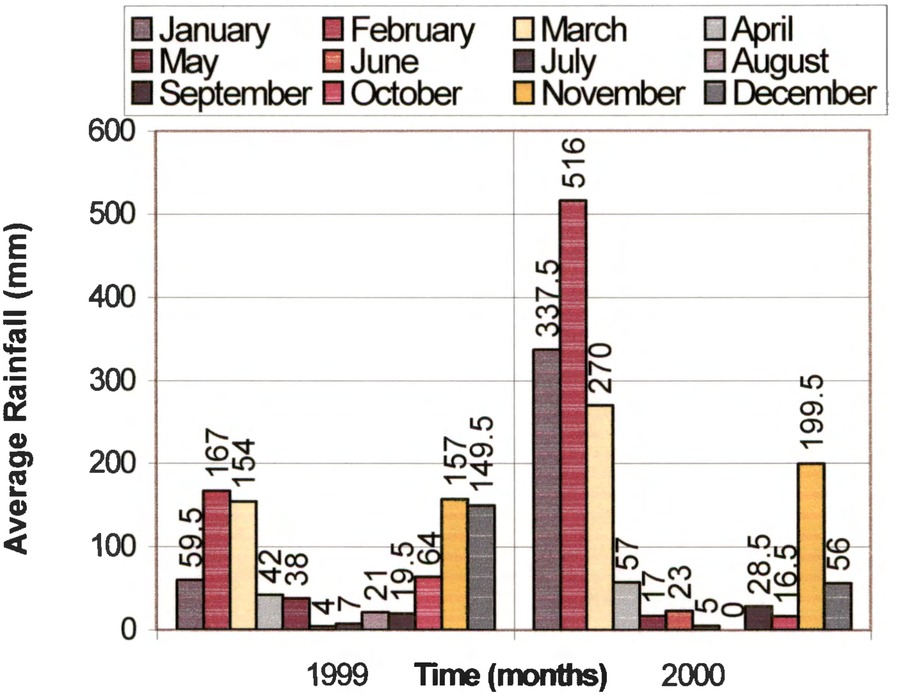
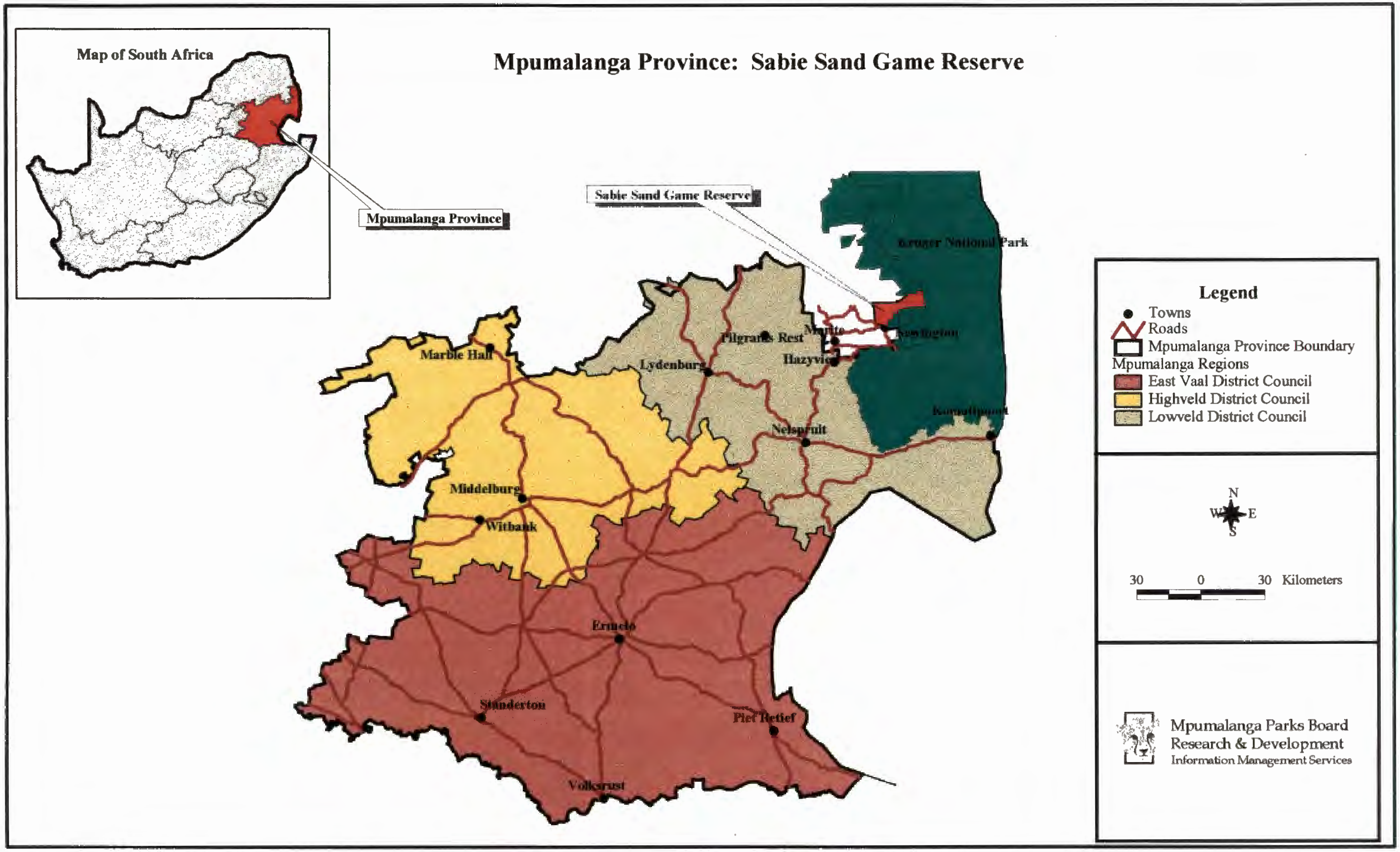


Figure 2.4: The average monthly rainfall for the two year period 1999-2000 at SSPGR.

Figure 2.5: The location of the Sabi Sand private game reserve (SSPGR) study site in the Mpumalanga Province of South Africa (supplied by the Mpumalanga Parks Board).



Mpumalanga Province: Sabie Sand Game Reserve
Map of South Africa
Mpumalanga Province
Sabie Sand Game Reserve
Pilgrims Rest
Lydenburg
Marble Hall
Nelspruit
Middelburg
Witbank
Ermelo
Standerton
Piet Retief
Volksrust
Legend
Towns
Roads
Mpumalanga Province Boundary
Mpumalanga Regions
East Vaal District Council
Highveld District Council
Lowveld District Council
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Mpumalanga Parks Board
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2.2.5 Geomorphology

Sabi Sand falls under the Malelane land system. Mainly granitoid rocks underlie this land system. In the northern part of the land system, porphritic granite and gneiss of the Nelspruit suite are dominant, while the southern parts are dominated by tonalitic and trondhjemitic banded gneiss and schist (Venter, 1990). According to Venter (1990), magmatite which dominated the (localized) local areas also occur. In certain areas, the gneiss and magmatite occur in association with schistose and other related metamorphic rocks of the Barberton sequence. The frequency at which dolerite dykes occur is relatively low in this land system and such dykes are often weathered and eroded into deep narrow valleys, hence their role as a parent material is minimized (Van Rooyen & Bredenkamp, 1998; Venter, 1990).

2.2.6 Land form

The landform of SSPGR consists mainly of low mountain, hills and flat lands. The mountains are highly dissected by numerous small first to second order seasonal streams. These streams which are usually characterised by relatively narrow steep-sided valleys which give the area a rugged appearance (Venter, 1990). The strike directions of mafic dykes often control drainage lines. Wider valleys have been formed by seasonal drainage channels of the third and fourth order streams which include the Sabi River and the Sand River (Venter, 1990)

2.2.7 History and management of the site at Sabi Sand.

The SSPGR is a well-established private game reserve, made up of several managerial game reserves owned by different owners. Each section has its own private lodge with its unique tourist attractions. They include Inyati Lodge, Ulusaba, Exeter, Sparta, Toulon and Lisbon lodges. The area covering the farmlands, which represent the SSPGR, was part of the Transvaal Consolidated Lands. In 1926, the land was offered for sale and the first person to buy the game farm named Sparta was Charles Varty. These private lodges, with their early morning and late afternoon game drive, have become one of the tourists destination in Mpumalanga Province.

The site selected for this study at Sabi Sand is jointly managed by Inyati and Ulusaba lodges. In July 1999 the site was identified and after consultation with the management team of the two lodges, the permission was granted for the restoration project to be carried out.

CHAPTER 3

PROCEDURES

Different restoration techniques, as indicated in 3.1 and 3.2 were applied to the two experimental sites, Mthethomusha game reserve(MGR) and Sabi Sand private game reserve (SSPGR).

3.1 Mthethomusha Game Reserve (boma) study site

3.1.1 Experimental design

The denuded area of MGR within the boma, (between the outer electrified fence and the inner wooden fence) was divided into three major experimental plots. The vegetation in the area surrounding the wooden fence of the boma was removed and the entire area sprayed with herbicides. The area had very little to no vegetation cover (see 2.1.6). The plots A, B and C as indicated in Fig. 3.1, were further divided into five 20m x 20m sub-plots. Each sub-plot had a different treatment which was assigned at random. Iron droppers were used to demarcate each plot with the first dropper of each plot bearing records of treatments and date of treatment (Fig. 3.2).

3.1.2 Treatments

The following treatments were randomly assigned to all the three major plots. Each plot had three replicates (see Table 3.1):

1. Ripping + Organic material + oversowing (ROS)
2. Ripping + Oversowing (RS)
3. Ripping + Brush packing (RB)
4. Ripping + Organic material (RO)
5. Control (no treatment) (C)

3.1.2.1 A rip cultivation method

At the boma in the MGR, the Mpumalanga Parks Board, through the range manager, provided a grader with a ripper attached (Fig. 3.3) It was used to break the hard surfaces along the contours (see section 1.3) in the three major plots except A1, B1 and C4, which were marked for the control (Fig. 3.1). The rip depth was mostly 15cm to 20cm depending on the slope of the contours. Safety tape was used to demarcate the areas of the experimental plots (Fig. 3.2)

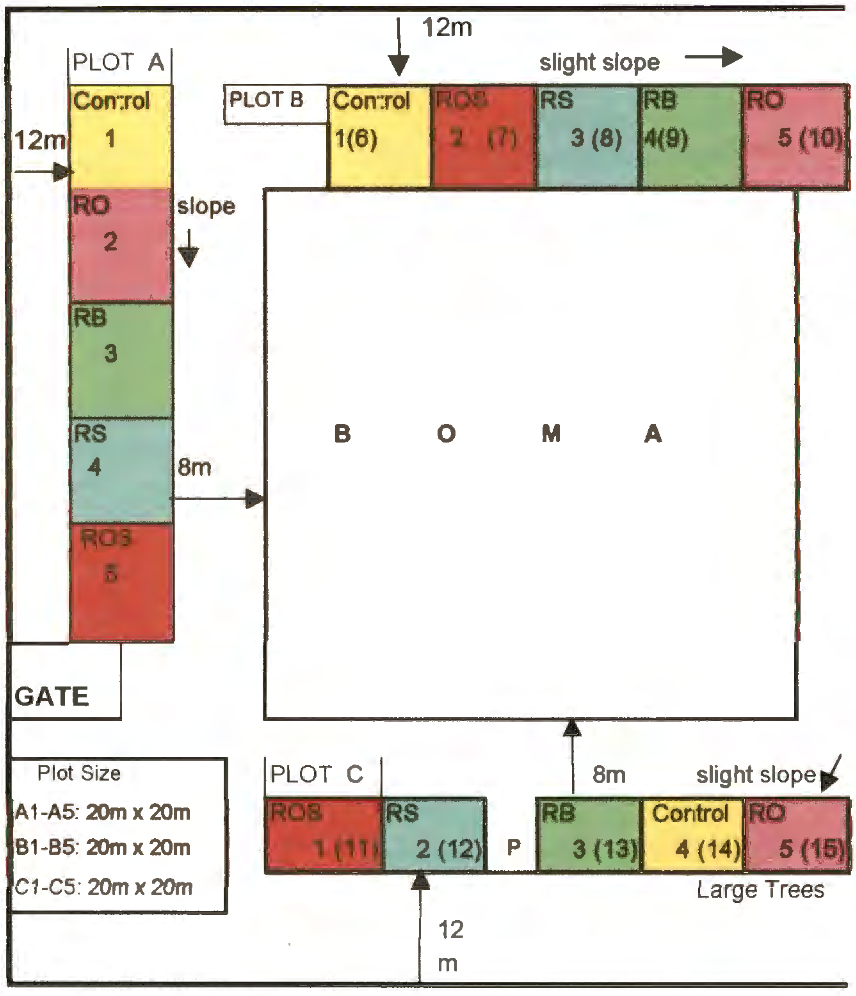

Figure 3.1: Experimental design of the restoration site at the boma in Mthethomusha Game Reserve (MGR). Rip-organic-seed(ROS), rip-seed (RS), rip-brush (RB), rip-organic (RO), power supply (P). The numbering of the sub-plots begins with 1 from Plot A1 and ends with 15 at Plot C5. The numbers in the brackets indicate the actual sub-plot number as shown in Table 3.1.

Figure 3.2: Mthethomusha Game Reserve (MGR)-boma study site showing the ripped area and the demarcated line.

Table 3.1: Experimental treatments with their corresponding sub-plots at Mthethomusha Game Reserve (MGR)-boma. All the sub-plots were ripped except the control plots 1, 6 & 14 (See Figure 3.1 for legend).

	Experimental Plots														
Treatments	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rip-organic-seed					x		x				x				
Rip-seed				x				x				x			
Rip-organic		x								x					x
Rip-brush			x						x				x		
Control	x					x								X	

Figure 3.3. A grader with a ripper attached was used to rip the soil at a depth of 15cm to 20cm along the contours.

3.1.2.2 Organic material treatment

Two experimental plots in each of the major plots A, B and C were treated with buffalo dung. The dung was collected from the boma and heaped outside the wooden fence (Fig. 3.4). From this heap, old manure which was already decomposed was collected for the treatment. A small truck was used to carry two loads of dry buffalo dung which was applied evenly by hand to the surface of a 20m x 20m sub-plot.

Figure 3.4: A heap of buffalo dung outside the buffalo boma at Mthethomusha Game Reserve. The heap at the extreme left is old and decomposed. From that heap, dung was taken for the organic material treatment.

3.1.2.3 Brush packing

The denuded area around the boma (between the outer and inner fence) has very few trees. They have an estimated crown cover of less than 5 per cent of the soil surface of the experimental site. Three replicates of brush packing were included in the experimental set up. Four workers from the local community were employed to cut branches from the reserve about a kilometer away from the study site. The reserve manager provided an armed ranger to protect the workers from wild animals. The brush cutting lasted four days and the woody species which were cut were mostly *Acacia nilotica.* The branches were transported to the study site. The thorny *Acacia* branches were packed half a meter from each other with the twig of the canopy facing the slope. The branches were packed to a height of half a meter (Fig. 3. 5, & Fig. 3.6).

Figure 3.5: These young men from the local community, were trained in the branch cutting and the brush packing.

Figure 3.6: Brush packing treatment at MGR with branches arranged a meter apart.

3.1.3 Oversowing and Grass seed type.

The aims for restoration include the increase in vegetation cover, increase in production for higher grazing capacity and the reduction of the rate of erosion. With these aims in mind, **enhanced seeds** of four different grass species which have been evaluated for restoration practices by the PU for CHE since 1995, were chosen for the current study. The grass species are: *Cenchrus ciliaris, Chloris gayana, Digitaria eriantha,* and *Panicum maximum.* These grass species were used due to the fact that, they are common grass species found in the area and have higher ecological status that will prevent soil erosion and contribute to an increase in vegetation cover. They are also good fodder species with high grazing values, high production and biomass. The mass and quantity of seeds representing each species in the mixture are given in Table 3.3.

Table 3.2: Mass and quantity of seeds in the seed mixture applied to sub-plots in MGR (boma) and SSPGR sites.

Species	Mass of seeds (g)/400m^2	No. of seeds Per 400m^2	Mass of seeds per hectare	No. of seeds per hectare
Chloris gayana	300g	87 977g	7500g	2 199 425
Cenchrus ciliaris	300g	29 880g	7500g	747 000
Digitaria eriantha	300g	142 857g	7500g	3 571 425
Panicum maximum	300g	174 419g	7500g	4 360 475

These grass species were chosen because, their seeds are relatively available in the commercial sector and are already used by land users over a wide range in South Africa. Secondly they are the species that are adapted to the habitat where the current study is taking place. The viability, germination and establishment rate in different soil types and under certain climatic conditions, as well as population dynamic of each species have been tested and evaluated in detail by the Potchefstroom University for Christian High Education (PU for CHE) since 1996. The tests and evaluations were done in a glass house, laboratory trials and at a previous restoration study curried out by the PU for CHE at demonstration sites other than explained here (Kellner, 1998). A short description of each of the species used in the oversowing trials is given below:

Digitaria eriantha (Common Finger Grass) is a very palatable, hardy, widely adapted, indigenous summer grass with a long perennial, tuft-forming growth pattern (Oosthuizen, 1987). It grows in sandy and gravel soil in the more arid parts and in damp soil such as beside vleis in areas with a high rainfall. It often has varieties with long, hairy stolons, which are sometimes established to control soil erosion. Under favourable conditions leaves grow 600-800mm high and stems 1.5m and higher. It mainly grows in undisturbed veld even though it utilises a wide range of other habitat types. *D. eriantha* occurs naturally in southern Africa but it is cultivated as pasture grass in other countries (Van Oudshoorn, 1999).

Panicum maximum (Guinea Grass) is a leafy perennial tufted grass that prefers growing in shade under trees and shrubs. It grows well in damp conditions in fertile soil, often along rivers. Guinea grass is highly palatable, delivers a high leaf production and usually occurs in abundance in good veld. It is also a persistent weed which is exceptionally difficult to eradicate when its tufts have reached maturity (Van Oudshoorn, 1999), a characteristic which makes it suitable for the prevention of soil erosion when used in restoration projects.

Chloris gayana (Rhodes Grass) is a very leafy grass, which spreads by means of stolons. The inflorescence is digitate with loose fingers that typically curl when the spikelets have fallen off (Van Oudshoorn, 1999). It is a pioneer grass that grows well in all types of soils but mostly in loam soil. According to Van Oudshoorn (1999), Rhodes grass is a very good grazing grass and is easy to establish. It is a perfect grass for stabilising disturbed soils and is generally used to stabilize exposed soil in degraded areas.

Cenchrus ciliaris (Foxtail Buffalo Grass) is a perennial tufted grass with a shrub-like growth form. According to Van Oudshoorn (1999), the inflorescence of *C. ciliaris* are a dense purple to straw coloured spike. It grows in all types of soil but mostly in sandy soils in dry warm areas. It is a good grazing grass with a high leaf production and palatability. *C. ciliaris* is a hardy cultivated pasture with a good root system (up to 2m), a characteristic that helps to hold soil particles, especially of duplex soils together and prevent soil erosion.

At the MGR study site, six sub-plots were treated with an oversowing treatment (Fig. 3.1). An equal measurement of **enhanced** seeds (obtained from the seed company, Advance Seed[5]) of four different species, *C. ciliaris, C. gayana,. D. eriantha,* and *P. maximum*, were thoroughly mixed and sown by hand in rows along the furrows made by the ripper at a depth of 1cm to 2cm. They were later covered with a thin soil layer by using a leafy branch (Fig. 3.7). The average amount of seed in each mixture sown into each of the sub-plots is depicted in Table 3.2. The oversowing treatment was carried out at the start of the rainy season in November 1999.

[5] Advanced Seed, P.O. Box 414, Krugersdrop, 1710, South Africa, +27 11 762 5261

Figure 3.7 A leafy-branch is seen here being used to brush a thin soil layer to cover the seeds.

3.2 Sabi Sand Private Game Reserve Study Site.

3.2.1 Experimental design

The restoration site at the SSPGR is a heavily degraded flat land near Dam 3 along a dry river bed (Fig. 3.8). Due to the high grazing pressure near the dam, the area is highly degraded. The site measuring 0.775 hectares was divided into 19 sub-plots. Sub-plots 8-13 measured 15mx15m while sub-plots 1-7 and 14-19 measured 20m x 20m. A road on the southern side of the site, separates sub-plot 1 from the rest of the plots (Fig. 3.8).

3.2.2 Treatments

The following treatments were randomly assigned to all the 19 sub-plots each with, unfortunately, only two replicates, except the lime + organic + seed treatment. All the sub-plots were loosened (ripped) except the control plots (see Table 3.3):

1. Lime + organic + seed + brush (LOSB).
2. Lime + organic + seed (LOS).
3. Organic + seed + brush (OSB).
4. Organic + seed (OS) .
5. Lime + brush (LB).
6. Lime (L).
7. Brush (B).
8. Rip only (R) .
9. Control – no treatment (C).

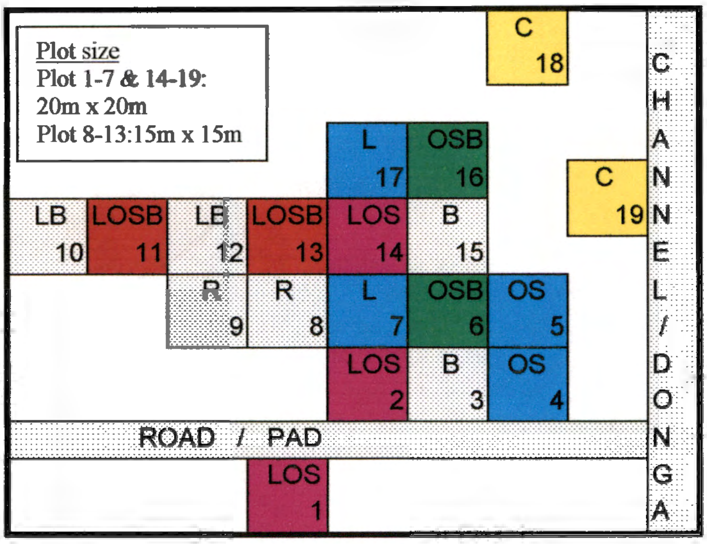

Figure 3.8: Experimental design of SSPGR site (See Table 3.3 for treatment and legend).

Table 3.3: Experimental sub-plots at SSPGR site showing the

Table 3.3: Experimental sub-plots at SSPGR site showing the plot numbers and their corresponding treatments. All the sub-plots were ripped except the control plots (18 &19).

	Experimental Plots (1-19)																		
Treatments	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Lime/Organic/Seed/Brush (LOSB)											x		x						
Lime/Organic/Seed (LOS)	x	x												x					
Organic/Seed /Brush (OSB)						x										x			
Organic/Seed (OS)				x	x														
Lime/Brush (LB)										x		x							
Brush (B)			x												x				
Lime (L)							x										x		
Ripping only (R)								x	x										
Control (C)																		x	x

3.2.2.1 A rip cultivation method

A tractor with a one tine ripper attached, was used to rip all the plots with the exception of plots 18 and 19 which were marked for the control. The rip rows were 20cm deep and 80cm apart. Iron droppers were used to demarcate each treated plot from the other.

3.2.2.2 Organic material treatment

Nine experimental plots at the SSPGR study site were treated with well decomposed buffalo dung. The dung was collected by the rangers from a heap of decomposed rhino dung near the water point around Dam Three for the treatment. At a rate of three tons/ha, the dry rhino dung was applied evenly to the surface of each of the nine treatment plots and were carefully worked into the soil.

3.2.2.3 Brush packing

Six plots treated with brush packing were included in the experimental set up. Four workers from the Ulusaba Game Lodge helped to cut branches which were used for the brush packing. The branch cutting lasted for four days and the species cut were mostly from the woody *Acacia nilotica*. The thorny *Acacia* branches were packed half a meter from each other and piled to a height of half a meter (Fig. 3.6).

3.2.2.4 Lime Application

Soil samples were taken for analysis from the study site prior to experimental set up. From the results of the analysis it was recommended that, due to the chemical properties of the soil (see section 1.3.1 and 2.2.4), application of lime should be included in the experimental set up. Nine treatment plots (Table 3.3) were treated with Dolomitic lime at the rate of 1.5 tons/ha. The application was by hand along the furrows made by the ripper.

3.2.3 Oversowing Treatment

At the SSPGR site the same enhanced seed types, *C. ciliaris, C. gayana, D. eriantha,* and *P. maximum,* used at the MGR study site, were used (see 3.1.3). Nine sub-plots were treated with oversowing treatment (see Table 3.3). An equal measurement of seeds of four species (*C. ciliaris, C. gayana,. D. eriantha,* and *P. maximum*) were thoroughly mixed and sown by hand in rows along the furrows made by the ripper at a depth of 1cm to 2cm. They were later covered with a thin soil layer by using a leafy branch (Fig. 3.7). The average amount of seed in each mixture sown into each of the sub-plots is depicted in Table 3.3. The oversowing treatment was carried out at the start of the rainy season, in December 1999.

3.3 Soil sample (collection and analysis)

At the beginning of the study, soil samples were collected from the different experimental sub-plots, at both study sites. Soil auger was used to take soil samples from the top soil (E-horizon) and the sub-soil (B-horizon). At MGR study site, the depth of the E-horizon in the overgrazed, degraded area was 180mm while the B-horizon was 100mm. In the good veld with no overgrazing. outside the study area, the depth of the E-horizon was 100mm. A depth of 280mm was recorded for the B-horizon and at a certain point 400mm was recorded without getting to the saprolite.

At SSPGR study site the depth of the E-horizon ranged from 50mm to 200mm and the B-horizon never exceeded 200mm. The samples from MGR study site were sent to the Soil Science division of the

Department of Agriculture[6] to be analysed while the samples from Sabi Sand were sent to Eko Rehab[7] at Potchefstroom. The soil samples were analysed to provide information on the chemical properties of the soil (See section 1.3.1 and 2.2.4) and to suggest the soil ameliorants that could be included in the restoration of the sites. It was from the result of the SSPGR study site that the recommendation for the application of lime to be included in the experimental set up was made. Towards the end of the first year of the study, a new set of soil samples from the E-horizon were taken from each treatment plot at both sites. At the MGR study site, three replicates of soil samples were taken from each treatment plot while two replicates were taken at Sabi Sand study site. The samples from both sites were sent to the Agricultural Research Council (ARC)[8] in Pretoria to be analysed. The aim for this analysis was to gather environmental and soil information at each experimental sub-plot which could be used to determine the relationship of species frequency and density distribution in each treatment. The second soil analysis was used to discuss the results of the restoration treatment. Among the properties tested were phosphorus, potassium, calcium, magnesium, and sodium. The pH values as well as the percentage of clay, sand and silt were also analysed. The clay and the silt were analysed through hydrometer method while the sieve method was used for the sand.

3.4 Vegetation monitoring

According to Hoffman, *et al.* (1999), resilience in an ecosystem is directly linked to an increase in species richness because of niche specialisation by different grass species. This resilience provides the ecosystem with the sustainability necessary for long-term utilisation of high quality grass.

In the study, vegetation surveys were carried out over two seasons. The first survey during the 1999/2000 season was carried out in March, four months after the establishment of the experimental plots. In December 2000,the second survey for the 2000/2001 season was also carried out 13 months after the establishment of the experimental plots. A major field problem in ecology is the determination of population distribution, size and change in

[6] Soil Science, Department of Agriculture, P/Bag X804, Potchefstroom 2520
[7] Institute For Ecological Rehabilitation, P.O. Box 19752 Potchefstroom 2520 Fax +27 18 293 2258
[8] Agricultural Research Council (ARC), Institute for Soil, Climate and Water, Pretoria. Tel. 012-3102605

abundance. There are several methods of analyzing vegetation occupying a given site. The literature discussing these methods, the underlying philosophies and the statistical treatments are extensive (Smith, 1990). The major decision here is, which method to choose for a specific study.

In order to understand the interrelationships, functions and distribution of plant communities it is necessary to first measure the plant community in some quantitative way. The data collected can then be used to answer questions relating to the community. Plant communities are made up of a number of different species and the distribution of these species, vary as well. A useful method for describing a plant community in quantitative terms is species diversity (Barbour *et al.*, 1987). This is an expression of the ratio between the number of different species within the community. It is expressed as a single index number and can be a measure of biomass, productivity or the number of individuals. Species diversity gives an indication of the degree of heterogeneity of a community and is related to the environment (Barbour *et al.*, 1987). In this study species richness was determined. According to Kent & Coker (1997), species richness means a count of the number of plants in a quadrat, area or community. Among a number of vegetation sampling techniques that could be suitable for this studies, the wheel point, which is an instrument used in the point method (Tidmarsh & Havenga, 1995), as well as the quadrat method were used. Density and frequency sampling were carried out at both study sites.

3.4.1 Density

Density is the count of the number of individuals of a species per unit area while relative density is the density of one species as a percentage of total plant density (Kent & Coker, 1996; Barbour, *et al.*, 1987). Species density and frequency measures can be used to assess plants distribution pattern. According to Barbour, *et al.*, (1987), a species with a high density but a lower frequency signifies a clumped pattern while a much less abundant species with high frequency signifies a regular pattern. Generally, density and frequency measurement are independent measures unless the plants are distributed randomly (Barbour, *et al.*, 1987).

Density of species in an area can be measured through the use of a quadrat. According to Smith (1990), quadrats may be square, rectangular or circular. Even though circular plots are relatively easy to lay out, rectangular plots appear to give a more accurate sampling of vegetation composition. One of the usefulness of a quadrat is to determine the density and species richness of all the plant species at a given site. When using quadrats in experimental plots they are placed away from the extreme corners and borders of the plots to avoid edge effects.

In the current study, the density of each species at both study sites were determined using a randomly placed quadrat (0.5m x 0.5m) (Barbour, *et al.* 1987) in each sub-plot. Twelve replicate quadrats per sub-plot were monitored. In the quadrat, the density and relative density of the following three plant growth stages were recorded: established seedling, vegetative mature plant (having more than one tiller protruding from the ground), and reproductive plant which clearly bear reproductive organs or its remains. The different growth stages were determined to indicate the sustainability of the sown-in grass species. The growth and death of plants after germination through time and space is one way of measuring the sustainability of a plant population. The presence of all three growth stages, seedling, vegetative and reproductive, was regarded as an indication of a healthy, sustainable population in this study. In the case of *C. gayana,* the vegetative or reproductive plant forming stolons, each daughter plant was also counted as an established seedling. The quadrats were placed away from the extreme corners and borders of the treatment plots to avoid edge effects. The number of all the species rooted in each quadrat was recorded. These data were used to calculate the density and average density of all the species encountered and expressed as plants/m^2. The calculation of density using the data from the quadrat sampling is explained as follows: There were 12 replicates of 0.5m x 0.5m quadrat thrown per sub-plot. The total number of each species counted from the 12 quadrats were divided by 3 in order to obtain the number of species as plants/m^2. Example of the calculation is given below:

$$\text{Density of species y} = \frac{\text{Total no. of sp. y} \times 12 \times 0.5\text{m} \times 0.5\text{m}}{3} = \text{sp. y plants/m}^2 \quad \text{.........3.2}$$

3.4.2 Frequency.

Frequency is defined as the probability or chance of finding a species in a given sample area (Kent & Coker, 1996) while **relative frequency** is the frequency of one species as the percentage of total plant frequency (Barbour, *et al.*, 1987). In this study, relative frequency was used because it allows an accurate comparison of species frequency in the total sampling plot. Frequency is determined by the point method through the use of the point-frequency frame (Smith, 1990), the wheel point, (Tidmarsh & Havenga, 1995) and the descending point method (Brown, 1954). The point frequency frame method involves the use of a point frequency frame to sample basal and canopy cover of grassland vegetation. It is most useful in studies involving changes in the condition of grassland over time (Smith, 1990). According to Smith (1990), though the point-frequency frame method provides a highly accurate measure of foliar cover of grassland vegetation, its application is relatively slow and often misses scattered clumps of herbaceous species in the sampling area. A relatively faster and accurate way of applying the point method is therefore by using the wheel point, (Fig. 3.9). In the point method, both Tidmarsh & Havenga (1995) and Brown, (1954) using the wheel point method and descending point method respectively, agree that the nearest plant at the point where the spike or the point touches the ground within a of 30cm radius is noted.

In each sub-plot at both study sites, the frequency of the grasses was determined by means of the wheel point method with the 100 nearest plants recorded on the rows where seed was sown (Tidmarsh & Havenga, 1995). These surveys were carried out in the treated and non-treated (control) areas.

The relative frequency was calculated using the following formula:

$$\text{Relative frequency} = \frac{\text{Frequency value of species A}}{\text{Total frequency value of all species}} \times 100 \qquad \text{......3.1}$$

Figure 3.9: A wheel point was used to obtain the frequency and species diversity in the sample plots. In the picture is one of the members of the local community who was trained in grass monitoring.

3.5 Data analysis

3.5.1 Ordination Analysis.

As explained by Kent & Coker (1996), ordination means "to set in order" and it attempts to summarise sampling and species data in a simpler, low-dimensional space so that similar entities are close by and dissimilar entities far apart. Ordination results are almost wholly graphical, and are mostly computer plotted graphs. Ordination results show the stands or species plotted against two or more axes, each axis corresponding to a dimension in space. Ordination methods aim to depict gradients along the axis, so-called gradient analysis (Kellner & Cilliers 1998). Different authors, including Ter Braak (1987), view ecosystems as being complex because they consist of several biotic and abiotic components that interact with each other. It is also pointed out by Austin (1977) that, ecosystems are usually complex since they are composed of a three-dimensional matrix. The components of such a matrix are the following:

- Observations/surveys carried out at a number of survey points/sites.
- The surveys may be done at different times and various vegetation and environmental characteristics(s) may be gathered at such a site.

Austin (1977), further states that multivariate analytical techniques can be used very successfully to simplify and summarise this complex data. Ordination techniques are examples of multivariate analytical techniques that can be used successfully in the processing of complex ecosystem data. Gauch (1982) points out that the uses of ordination techniques have a dual purpose, which are:

1. Ordination techniques are used to summarise community patterns by creating low dimensional ordination space where corresponding species and sites are situated together and irreconcilable entities are situated apart.
2. The community patterns are compared to environmental information in order to identify and interpret environmental gradients.

A common problem in community ecology is to discover how a multitude of species respond to external factors such as environmental variables, pollutants and management regime. By using different sampling techniques, data are collected on species composition and the external variables at a number of points in space and time (Ter Braak, 1987). According to Ter Braak (1987), analysing the generally non-linear, non monotone response of a community of species requires one to resort to the data analytic methods of ordination and cluster analysis - "indirect" methods that are generally less powerful than the "direct" statistical method of regression analysis. According to Kellner & Cilliers (1998), both the terms "direct" and "indirect" refer to ordination activities in relation to environmental factors. Direct gradient analysis is an ordination based directly on either individual or a combination of known environmental factors, which have been defined before the ordination analysis procedures. Kellner & Cilliers (1998) further explained that indirect gradient analysis, sometimes referred to as just "ordination" starts with the analysis of community data alone and then only later use environmental data for interpreting the results expressed in the ordination graphs. Ter Braak (1987) points out that, the simplest data processing are direct gradient analysis where the species occurrence is placed on one axis as against the environmental or management variable on the other axis. Recently, regression and ordination have been integrated into techniques of multivariate direct gradient analysis, called **Canonical ordination** or the **Canonical Correspondence Analysis (CCA).** The use of canonical ordination improves the power to detect the specific effects one is interested in. The computer program **CANOCO** is designed to make these techniques available to ecologists studying community responses (Ter Braak, 1987). The main aim of the CCA according to Ter Braak (1988) is to visualise:

- a pattern of community variation and
- the main characteristics of species distribution across the environmental or management variables.

The CANOCO program (Ter Braak, 1987-1992) was used to perform the Principal Component Analysis (**PCA**) and redundancy analysis (**RDA**) ordination techniques on the data. PCA has a wide range of applications both within and outside plant ecology. The usual eigenvalue value and eigenvector are calculated for each axis. The eigenvector is an indication of the factor by which the incidence value of each species is multiplied to determine the plot's value on the PCA axis. By analysing this eigenvector we can establish how each component (e.g. species) explains the variation in the direction of the axis in question. In PCA, only one entity is ordinated at a time. If a plot-species data matrix is used, either plots or species are ordinated. A plot-environmental matrix should be used to ordinate plots so that the contributions of the various environmental factors (or components) to relationships in the plots can be observed. The arch effect is unfortunately strongly evident on the second and subsequent axes and in extreme cases the sequence of the plots near the ends of the axes may be reserved. RDA is a direct ordination technique, based on the principles of the PCA-ordination technique, where the species are constrained by a number of environmental variables.

The PCA and RDA ordination techniques. from the CANOCO computer program (Ter Braak, 1987-1992) were used for data analysis. Because RDA is based on the PCA ordination technique, it is a linear model (Ter Braak, 1984). The PCA and RDA ordination techniques were considered for the analysis of the data set due to the short gradients and the homogeneity of each sample plot.

The quantitative data was statistically analysed using the ANOVA/MANOVA technique in the STATISTICA for windows

(Statsoft, Inc., 1999) computer program. The purpose was to find significant differences between the means of variables by comparing that variable's variances. Results were considered statistically significant if $p < 0.05$ except otherwise indicated.

All the statistical analysis on the total density data from MGR were conducted with STATISTICA for Windows ((Statsoft, Inc., 1999). Data over time series were tested with Friedman's ANOVA, a non-parametric one-way repeated measurement of analysis variance was used to determine the significance of species abundance between the first and second survey periods in the five treatments.

The Kruskal-Wallis one-way ANOVA, based on ranks, rather than means, was used to determine the significance of each species (first and second sampling period) with regard to the five different restoration treatments. Data of the second survey were used to carry out the general MANOVA to determine the significance of the density of the sown-in species as well as the significance between the different treatments.

Statistical data analysis was only carried out on MGR data where three replicates of each treatment were present. At the SSPGR, unfortunately, only two replicates of the treatments were present due to lack of space, so no statistical analysis was done on this data. This is a shortcoming of this study, for, at SSPGR, only tendencies (trends) are discussed especially under the short survey period.

3.5.1.1 Importance Value

When dealing with regions with heterogeneous plant community, classifying the communities on the basis of dominant or co-dominant becomes rather impracticable. For this reason, Curtis & McIntosh (1951) developed a logical approach through the use of importance value (Barbour *et al.* 1987; Smith 1990).
Once importance values have been obtained for species within a stand, stands can be grouped by their leading dominants according to importance value (Smith, 1990). The investigator can then place the groups in a logical order based on the relationships of predominant species. Smith (1990), further stated that, importance value (IV) is the sum of relative density, relative frequency and relative dominance for each species involved. In the current study relative frequency and relative density were used to calculate the importance value. The importance value for each species in the

seeded plots was calculated. This helped to arrange the different seeded plots in a sequence, so that, the amount of each species showed a single peak or increase or decrease monotonically along the series of treatments. Each species was allocated a weight according to the position of the peak (Kent & Coker 1996). The importance value can be calculated with two or three of the following components: relative density, relative frequency and relative dominance. At both study sites the importance values of the species were calculated from the relative density and relative frequency as follows:

1. $$\text{Relative density} = \frac{\text{Number of individuals of species}}{\text{Total number of individuals}} \times 100$$

2. $$\text{Relative frequency} = \frac{\text{Frequencies of a species}}{\text{Frequency of all species}} \times 100$$

3. Importance value of a species = Relative density + relative frequency.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Mthethomusha Game Reserve (MGR)

4.1.1 Frequency

The relative frequencies of the grass species from all the treated plots including the control (no treatment) for the two-year (1999/2000 and 2000/2001) study period are given in Table 4.1 & Fig. 4.1.

Table 4.1 Average relative frequency (%) of all grass species in the restoration treatments for the two year study period (1999 to 2001) at MGR. Rip-organic-seed (ROS); rip-seed (RS); Rip-organic (RO); Rip-Brush (RB); control (C). The four sown-in species are highlighted.

	ROS		RS		RO		RB		C	
Species (%)	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01
Chloris gayana	**34.3**	**35.0**	**25.6**	**30.7**	**0.0**	**0.0**	**3.3**	**5.7**	**0.0**	**0.0**
Cenchrus ciliaris	**20.7**	**23.3**	**8.0**	**13.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Panicum maximum	**19.7**	**22.0**	**18.0**	**20.3**	**9.3**	**9.0**	**10.3**	**5.3**	**1.7**	**0.7**
Digitaria eriantha	**0.0**	**1.0**	**4.7**	**2.7**	**0.0**	**1.0**	**1.7**	**1.0**	**0.7**	**2.7**
Cynodon dactylon	1.0	0.0	1.3	0.3	4.3	4.3	4.0	0.0	7.3	18.0
Chloris virgata	1.0	0.0	6.0	0.0	2.7	0.3	7.3	0.0	4.3	0.3
Eragrostis curvula	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.7	0.0	0.0
Eleusine coracana	0.0	0.0	0.0	0.0	2.7	0.0	6.0	0.0	0.0	0.0
Urochloa mosambicensis	9.3	7.3	5.3	6.7	21.0	12.0	3.3	5.3	11.3	12.0
Pogonathria squarosa	1.0	0.7	2.0	1.0	4.0	1.3	2.7	1.0	1.3	0.0
Eragrostis superba	0.7	1.0	0.7	3.0	2.7	1.7	3.0	3.3	4.0	1.7
Eragrostis trichophora	4.7	3.7	16.0	7.7	10.0	8.3	24.7	17.3	12.7	12.7
Sedges	0.0	0.0	0.0	0.3	0.0	3.7	0.0	5.3	0.0	2.0
Forbs	0.3	3.7	2.0	7.7	16.0	36.0	11.3	37.3	12.0	27.0
Eragrostis rigidior	4.3	1.3	6.7	4.3	17.7	17.7	14.0	16.0	40.0	21.0
Panicum coloratum	0.0	0.0	0.0	0.0	4.7	0.0	0.3	0.0	0.0	0.0
Other grasses	3.0	0.0	3.7	1.7	5.0	3.7	8.0	1.7	4.6	2.0
TOTAL	100	100	100	100	100	100	100	100	100	100

In the rip-organic-seed (ROS) treatment, *C. gayana* was the dominant species (34.3%) followed by *C. ciliaris* and *P. maximum* with 20.7% and 19.7% respectively. *Digitaria eriantha* was not represented in the

ROS treatment during the first survey in March 2000 (Table. 4.1 & Fig. 4.1). Among the species that were not included in the seed mixture sown-in, *U. mosambicensis* had the highest frequency of 9.3%, followed by *E. trichophora* and *E. rigidior*. All the other species encountered during the first survey, with the exception of *Eragrostis curvula, Eleusine coracana, Panicum coloratum* and sedges were represented in the ROS treatment during the first survey (Table 4.1). During the second survey in December 2000, there were increases in relative frequencies of all the sown-in species including *D. eriantha* (Table 4.1 & Fig. 4.1). However, the smallness of the increases, especially with *D. eriantha* could have been as a result of sampling error and may therefore not be considered significant. There was a decrease in frequency recorded in each of the other species with the exception of forbs, *E. curvula* and *E. superba* which recorded increases in their frequencies during the 2000/2001 season (Table 4.1).

A similar trend of species frequencies was recorded for the rip-seed (RS) treatment during the first survey as for the ROS treatment. The sown-in species had the highest frequencies but unlike the ROS treatment, all the four sown-in species were represented in the first survey. All the sown-in species recorded increased in their frequencies with only *D. eriantha* decreasing in the second survey. While *U. mosambicensis* was the dominant species among the species not sown-in in the ROS treatment, *E. trichophora* was the dominant in the RS treatment with a frequency of 16% (first season). The rest of the species decreased in their frequencies but *U. mosambicensis* and forbs recorded increases of 5.3 to 6.7% and 2.0 to 7.7% respectively during the second survey (Table 4.1). This indicates that the seeds of *E. trichophora* and *U. mosambicensis* could have been high in the soil seed bank.

In the rip-organic (RO) treatment, even though there was no sown-in, *P. maximum* was represented with a frequency of 9.3% and 9.0% for the first and second surveys respectively. This is an indication that the seeds of *P. maximum* could also have been present in the soil seed bank or the RO treatment plots were contaminated by seeds from the adjacent seeded plots. The dominant species in RO treatment were *U. mosambicensis (21%), E. rigidior* (17.7%) and forbs (16%). During the second survey, the frequency of forbs doubled while there was a decrease in all the other species.

The rip-brush (RP) treatment had the highest species richness with three sown-in species, (*C. gayana, P. maximum* and *D. eriantha*) being represented during the first survey. The dominant species were *E. trichophora* (24.7%), *E. rigidior* (14.0%) and *P. maximum* (10.3%). This is another indication that these species could have been present in the soil seed bank and were stimulated by rip and organic treatments. During the second survey (2000/2001), there was a decrease in the species richness while other species had lower frequencies recorded. Forbs was outstanding with an increase from 13.3% in the first survey to 37.3% in the second survey.
The control (C), where no treatment took place, had the least number of species encountered in both first and second surveys. The species with frequencies above 10% in the control were forbs 27%, *E. rigidior* (21%) *C. dactylon* (18%) *E. trichophora* (12.7%) and *U. mosambicensis* (12%) (Table 4.2 & Fig. 4.1).

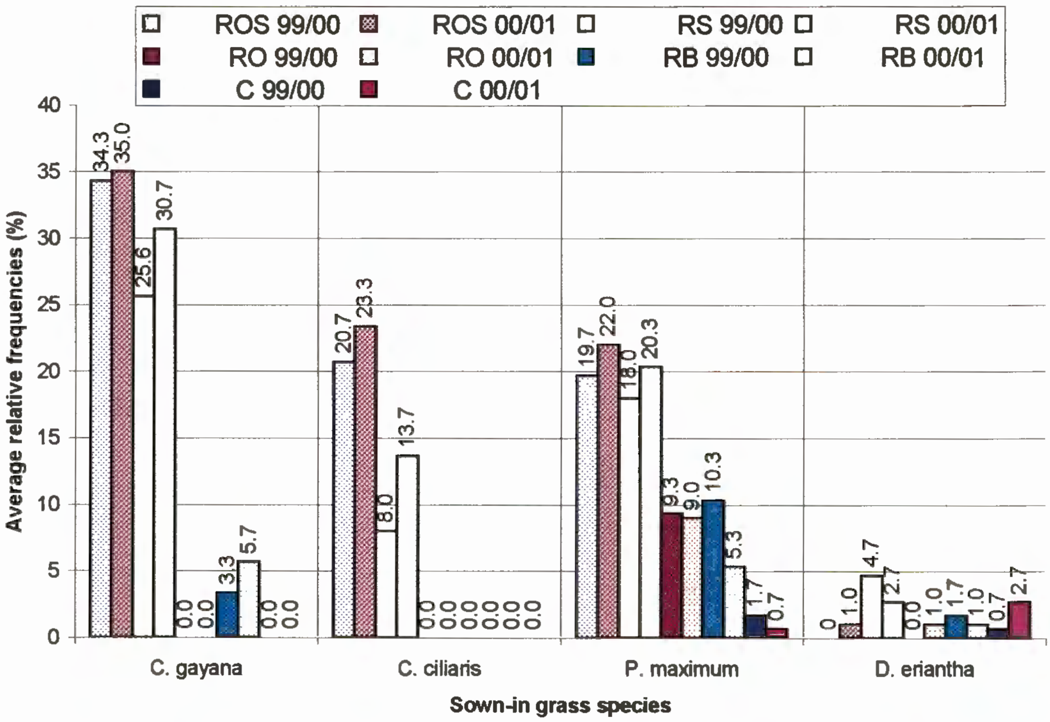

Figure 4.1 The average relative frequency (%) of the four sown-in grass species (*C. gayana, C. ciliaris, P. maximum* and *D. eriantha*) from all treatment plots for the two seasons 1999/2000 and 2000/2001 at MGR.

Most of the species in the soil seed bank responded to the ripping cultivation treatment during the first survey in March 2000 when the area received an above average rainfall (see Fig. 2.2). While the frequencies of these species stayed almost the same in ROS treatment, the frequencies of the pioneer species, *C. dactylon, C. virgata, E. rigidior* and "other grasses" could not be sustained through to the second survey (Fig. 4.1). According to Berendse, (1990), the accumulation of soil organic matter leads to an accelerated increase in nitrogen mineralization during succession. In this study, the increase in nitrogen supply through the application of organic material after loosening the soil through ripping, favoured the fast growing perennial and other grasses, (in this case the *C. gayana*, *P. maximum* and *C. ciliaris*). These grass species can out-compete a great variety of slow-growing species adapted to nutrient-poor soils resulting in a strong decline in plant species richness (Bakker & Berendse, 1999).

The **PCA ordination results** showing the correlation between the species frequency and restoration treatments of the first and second survey at MGR are given in Fig. 4.2 and Fig. 4.3. Both ordination graphs show a clear emergence of different groupings in three separate parts of both diagrams. According to axis 1 in the first survey (Fig. 4.2), *C. gayana*, *C. ciliaris, P. maximum* and *D. eriantha*, are positively correlated to ROS and RS treatments which corresponds with Table 4.1 where these species contributed more than 50% of the total relative frequency in both the first and the second surveys in both seeded treatments. These are all sown-in species that established and probably out–competed the unseeded species. There is a positive correlation between RB and RO treatments with *C. dactylon*, forbs, *E. trichophora* and *C. virgata*. These species are probably originally from the soil seed bank and responded positively to the ripping cultivation. The control and RO treatment are positively associated with *U. mosambicensis* and *P. coloratum* (Fig. 4.2). Both act as pioneer species that developed from the soil seed bank as a result of the higher rainfall received in the first quarter of 2000 (Fig. 2.2).

There are similar groupings of species and their correlation with treatment plots in the second survey as indicated in the first survey. According to the first axis, all the sown-in species with the exception *D. eriantha*, are strongly positively correlated to ROS and RS treatments (Fig. 4.3).

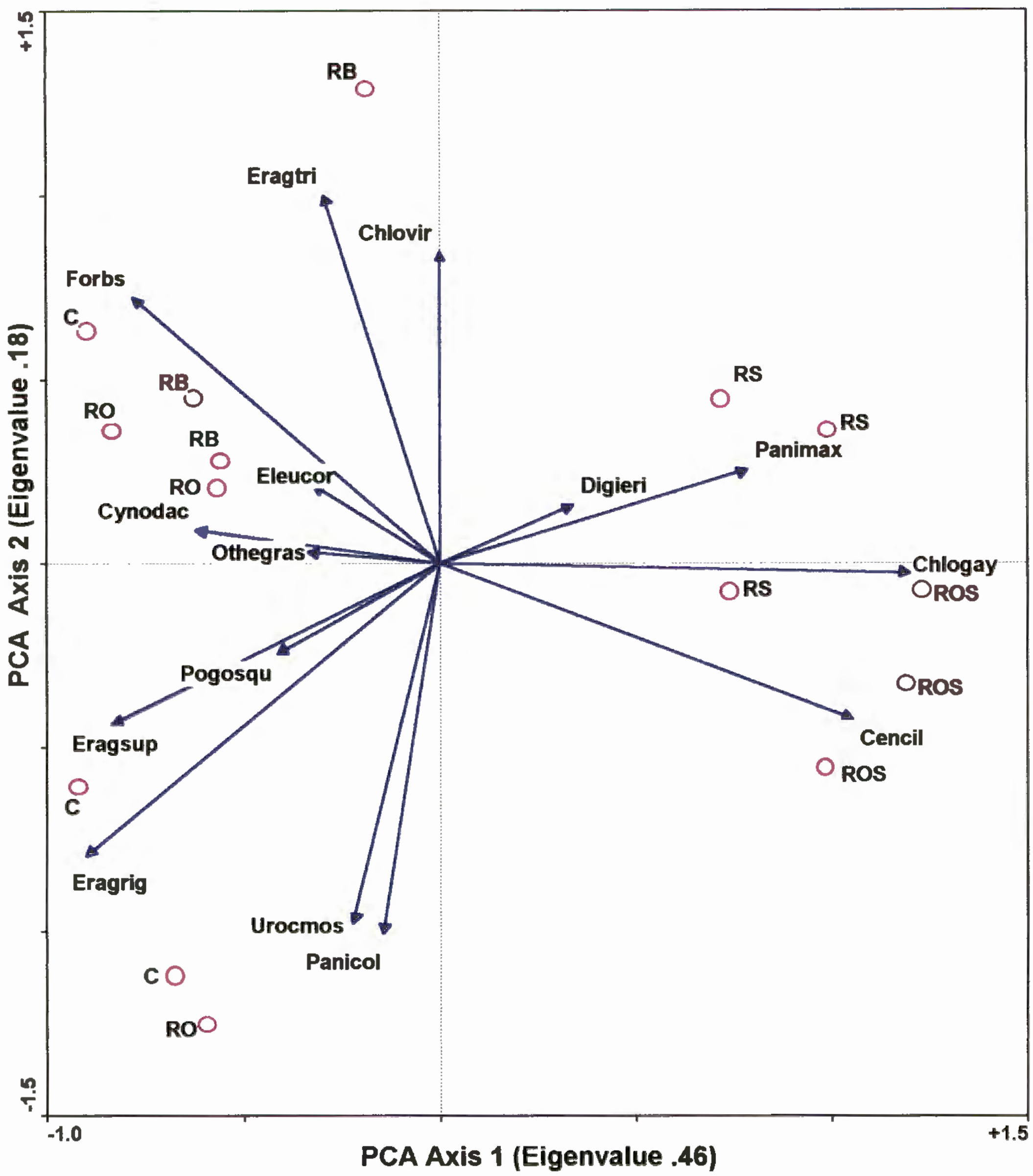

Figure 4.2 Species relative frequency by treatment association for the 15 experimental sub-plots at MGR during the 1999/2000 season. (*Chlogay=C. gayana; Cenccil=C. ciliaris; Digieri=D. eriantha; Panimax= P. maximum; Cynodac=C. dactylon; Eragtri=E. trichophora; Chlovir=C. virgata; Eleucor=E. coracana; Pogosqu=Pogonarthria squarrosa; Eragsup=E. superba; Panicol=P. coloratum; Urocmos=U. mosambicensis; Eragrig=E. rigidior;* Othegras=Other grasses).

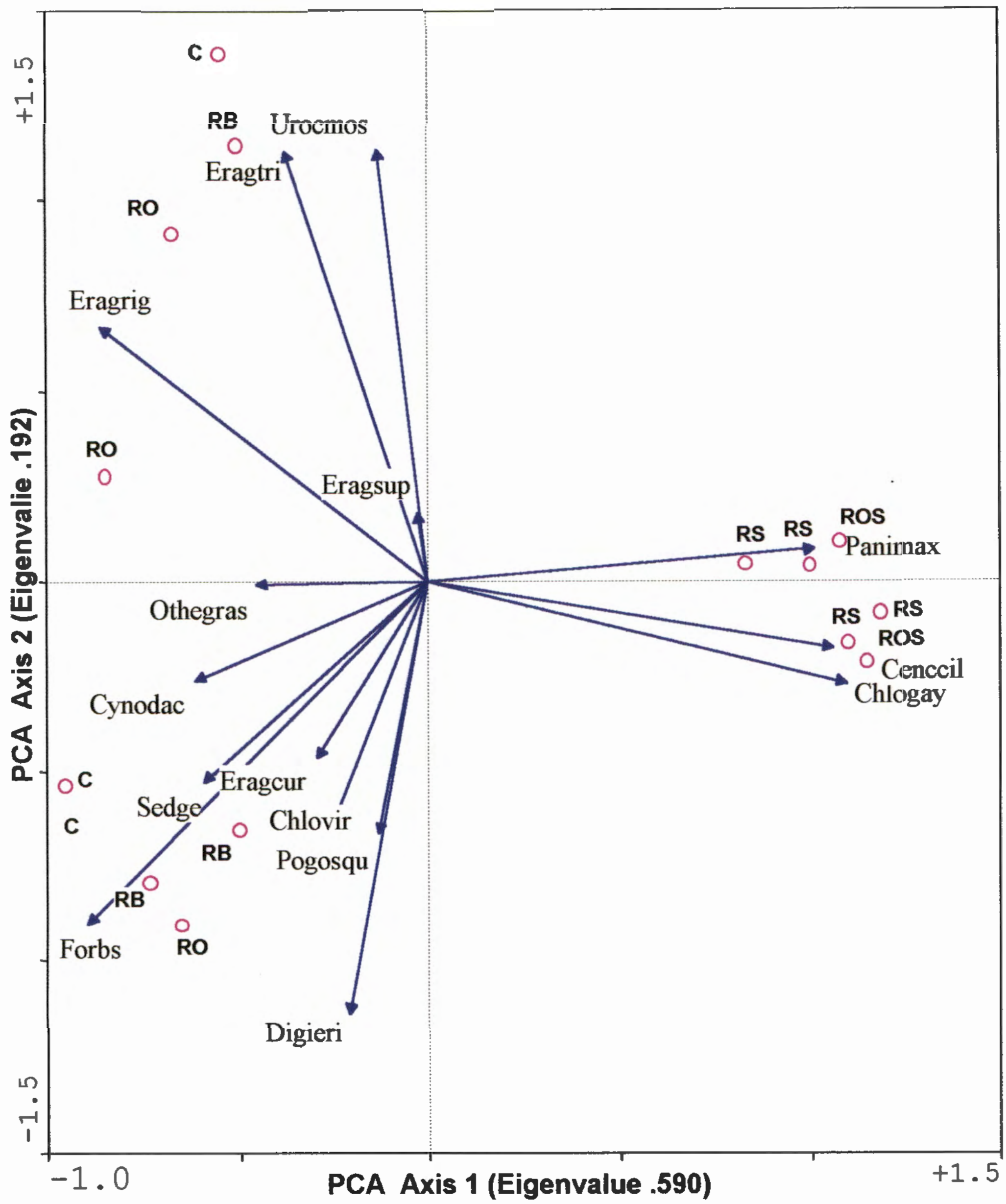

Figure 4.3 Species relative frequency by treatment association for the 15 experimental sub-plots at MGR during 2000/2001 season (*Chlogay=C.gayana; Cenccil=C.ciliaris; Digieri=D.eriantha; Panimax=P.maximum; Cynodac=C.dactylon; Eragtri=E.trichophora; Chlovir=C.virgata; Eragrig=E.rigidior; Pogosqu=Pogonarthria squarrosa; Eragsup=E.superba; Urocmos=U. mosambicensis; Eragcur=E.curvula;* Othegras=Other grasses).

The sown-in species with the exception of *D. eriantha,* recorded an increase in frequency in ROS and RS treatments during the second survey (Table 4.1). The positive correlation of *U. mosambicensis* and

E. trichophora with the control plots became stronger in the second survey as the frequency of *U. mosambicensis* increased. *Cynodon dactylon*, sedges and forbs were also positively correlated to the control plots during the second survey (Table 4.1).

4.1.2 Density

The average absolute density of all the grass species at the MGR study site is given in Table 4.2. The average density of the sown-in species of the rip-organic-seed (ROS) treatment and the rip-seed (RS) treatment showed a great difference with regard to the not sown-in species. The density of *C. gayana* (37.1 plants/m^2) and *C. ciliaris* (17.6 plants/m^2) in the rip-organic-seed treatment during the first year, were 50% higher than in the rip-seed treatment (Table 4.2 & Fig. 4.4). The average density of all the sown-in grass species increased over the two year period in both sown-in treatment plots with *C. gayana* as the dominant species.

Even though *C. gayana* was the dominant species among the seeded plants in the two sown-in treatments at MGR study site, the increase in its total density for the two year period was not significant ($p=0.157$). However it had a significant increase among the five treatments during the first survey ($p=0.0106$) and the second survey ($p=0.0141$). The increase of *C. ciliaris*, from the first year to the second year was not significant ($p< 1.000$). As for *C. gayana*, *C. ciliaris* had a significant increase in the total density among the species of the five treatments during the first survey ($p=0.0194$) as well as the second survey ($p= 0.0095$).

The increase in the total density for *D. eriantha* for the two year period was significant ($p=0.01964$). With regards to the five different restoration treatments, *D. eriantha* had no significant increase during the first year ($p=0.1147$) but quite significant increase in the second year ($p= 0.0141$).

Among the sown-in species, *P. maximum* and *D. eriantha* were the only species that had a significant increase during the two year study period. This confirms the observation made above, that *P. maximum* is the most suitable species for MGR among the sown-in species (see Fig. 4.4). This observation however, depends on the years and the treatments. *Digitaria eriantha* and *P. maximum* were good in the second year while *C. gayana*, and *C. ciliaris* establish better in the first year. *Panicum maximum* had a significant increase for the two year period (p=0.0209). With regards to the five restoration treatments, its increase in density was not significant in the first year (p=0.0719), but it was significant in the second year (p=0.0299).

Apart from the four sown-in species, other species that were not in the seed mixture for the restoration, also had significant increases in their total density for the two year study period. *U. mosambicensis* had a significant increase in the total density. From the Friedman ANOVA test it was found out that the increase of *U. mosambicensis* and forbs over the two seasons were significant; *U. mosambicensis* (p=0.0125), forbs (p=0.0 209). Even though there was an overall significant increase in *U. mosambicensis* for the first and second surveys the Kruskal-Wallis ANOVA shows that it was not significant among the five treatment for both the first year (p=0.892) and the second year (p=0.475). Forbs was significant among the five restoration treatments only for the first survey (p=0.0270) but not for the second survey (p=0.1226). The reduction of the densities of forbs could be attributed to the fact that, most of them were annuals that enjoyed the abundance of water during the floods in 2000 (see Fig. 2.2). During the dry months of the second year, they could not sustain their growth and were overtaken by other species in the treatment plots except the control where a high density was sustained.

The higher frequency and density of *C. gayana* in both sown-in treatments, as compared to the other grass species in the grass mixture used in the current study, is due to the fact that *C. gayana* is stoloniferous and each daughter plant from the mother plant, was counted as a separate rooted individual (Gibbs-Russell, *et, al.*, 1990; Van Oudtshoorn, 1999). This growth nature makes it a rapidly spreading species that establishes easily. There were fewer species encountered in the ROS treatment. *D. eriantha* was not encountered during the first survey as was the case in the frequency but it recorded a significant (p=0.014) higher density (9.1 plants/m^2) in the second survey as well as in the RS treatment (Fig. 4.4). It can therefore be stated that *D. eriantha* establishes well in soils with less organic material.

Table 4.2: The average absolute density (plants/m^2) of all the grass species at MGR study site for the seasons 1999/2000 & 2000/2001.

Treatment	ROS		RS		RO		RB		C	
Species	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01
Chloris gayana	**37.1**	**41.7**	**18.6**	**26.9**	**0.0**	**0.0**	**8.3**	**1.9**	**0.0**	**0.0**
Cenchrus ciliaris	**17.6**	**24.4**	**8.2**	**11.1**	0.1	**0.0**	**2.4**	**0.0**	**0.2**	**0.0**
Panicum maximum	**9.7**	**22.3**	**7.2**	**11.1**	**4.0**	**5.4**	**2.1**	**2.1**	**0.1**	**1.1**
Digitaria eriantha	**0.0**	**9.1**	**1.1**	**16.8**	**1.0**	**1.2**	**0.6**	**0.0**	**0.0**	**0.0**
Cynodon dactylon	0.0	0.0	0.0	**1.1**	0.9	3.4	0.0	4.2	2.3	4.9
Forbs	0.0	4.1	0.0	8.0	15.8	22.9	8.3	30.2	22.2	22.0
Eragrostis rigidior	0.0	0.0	0.9	3.8	10.6	8.4	1.6	5.4	19.0	17.9
Chloris virgata	0.7	0.0	0.3	0.0	0.4	0.0	0.6	0.0	0.0	0.0
Digitaria ternata	0.0	0.0	0.0	0.0	2.2	0.0	5.8	0.0	1.3	0.0
D. aegyptium	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	3.8
Eragrostis trichophora	0.9	0.0	1.3	2.9	1.9	8.8	2.4	8.3	0.3	6.8
U.mosambicensis	0.7	1.4	0.8	1.2	2.2	8.3	1.1	4.6	1.2	9.4
Aristida congesta	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.6	0.0
Sedge	0.2	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	2.2
Eragrostis superba	0.0	0.0	0.1	0.8	0.9	2.4	0.1	1.1	0.7	1.9
Other grasses	0.9	0.0	0.2	0.1	1.7	2.0	1.0	2.1	1.6	3.3

The other grass species encountered in ROS treatment in the first survey had very low densities with most of them reducing to zero in the second survey. They included *E. trichophora* (0.9 to 0) and *C. virgata* (0.7 to 0) which had less than 1 plant/m^2. An important difference between the frequency and density data was that the frequency showed an increase but not in the density. The explanation could be that there were too few quadrats (12 x 0.5m x 0.5m quadrats) per sample. The sown-in species in the RS treatment like in the ROS treatment, increased in density from the first survey to the second season.

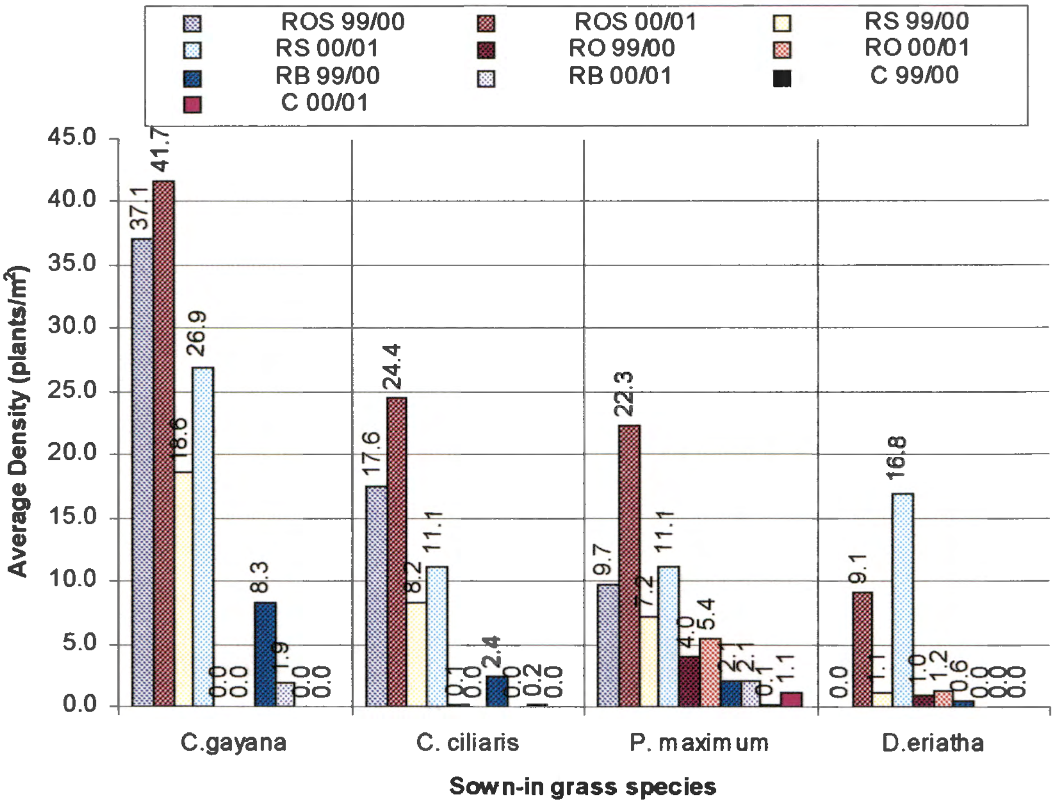

Figure 4.4 Average absolute density (plants/m^2) of the sown-in grass species (*C. gayana, C. ciliaris, P. maximum* and *D. eriantha*) from all the treatment plots at MGR study site for the 1999 to 2001 study period.

There were more diversity of species encountered in the RS treatment than in the ROS treatment. Furthermore, the densities of the other grass species encountered, increased in the second survey instead of decreasing as was the case in the ROS treatment. The reason for the differences could probably be linked to the fact that the density in the RS treatment, (sown-in species) were approximately half of those in the ROS treatment. Secondly, the relatively higher density of the sown in species in the ROS treatment (which also indicated high crown and/or basal cover) negatively affected the establishment of other species that germinated from the soil seed bank after the rip-plough cultivation. They were possibly out-competed by the sown-in species with regard to sun light, water and nutrients. The relatively lower density of the seeded plants in the RS treatment (see Table 4.2) in turn reduced the crown and basal cover allowing the unseeded species a better chance to compete and increase in density in the second survey. Treatments with organic material have shown the best results either with or without seeding in this study. This is found in the non-seeded plots where other grass species flourished and the seeded plots with sown-in species dominating.

Chloris gayana was the only sown-in grass species that was not represented in the RO treatment. The remaining three sown-in species also increased in density in the second survey. The dominant species in RO treatment were forbs with 16 plants/m^2 which increased to 23 plants/m^2 in the second survey. The density of *E. rigidior*, *C. virgata* and *D. ternata* reduced during the second survey but the rest of the species encountered, had an increase in their density. It is quite strange that all the sown-in species were represented in RB treatment with relatively higher densities. *Chloris gayana* and forbs for example were co-dominant species with a density of 8.3 plants/m^2 (Table 4.2). A similar situation occurred in the frequency data with the exception of *C. ciliaris* which was not represented (Table 4.1). A site verification revealed that the RB treatment sub-plot 9 in plot B was directly below RS treatment sub-plot 8 on a slope (see Fig. 3.1) which could have resulted in some of the seeds being washed from the RS treatment plot to the RB treatment plots. This could have resulted in the relatively higher frequency and density of sown-in species in the RB treatment which was not oversown. The species density in the control was similar to that of the RB treatment with forbs and *E. rigidior* being the dominant species. However, fewer sown-in species were encountered in the control plots especially in the second survey. *Panicum maximum* and *D. eriantha* were also represented in the control which indicates their presence in the soil seed bank. There was no or very little contamination from the sown-in plots that could have occurred to the control plots as they are situated at the top of the slope (Fig. 3.1). In general the frequency and density of species in all the treatments followed a similar pattern for the sown-in species (Tables 4.1 & 4.2; Fig. 4.1 & Fig. 4.2). The same trend is true for all the other grass species, not sown-in (see Tables 4.1 & 4.2). *Panicum maximum* is well adapted to the area because it was represented in all the treatment plots as indicated in both the frequency and density data. It is found in the surrounding area and around the study site which also confirms its presence in the soil seed bank. The richness of *P. maximum* in the soil seed bank indicates that it is adapted to duplex soils and can be left out of the seed mixture in future restoration projects at MGR if sufficient topsoil is present. This indicates that soil seed bank studies are important and should be done before oversowing restoration treatments are applied.

According to the PCA ordination of the species density by treatment, 17 principal components were extracted with eigenvalues = 1.0 from the 15 variables which accounted for 94% of the total variance in the first survey and 13 principal components with eigenvalues =1.0 from the 15 variables which also accounted for 96% of the total variance in the second survey. The ordination results, (Fig. 4.5 & Fig. 4.6) show similar trend of three distinct groupings as indicated in the frequency-treatment ordination graphs (Fig. 4.2 & Fig. 4.3). The most significant species according to the length of the arrows (all seeded) in the first group in both surveys is *C. gayana*, followed by *C. ciliaris* and *P. maximum*. There is a positive correlation between *C. gayana* and *C. ciliaris* in both the first and second survey. According to axis one, *C. gayana* and *C. ciliaris* are positively correlated to ROS and RS treatments while *E. rigidior* is strongly positively correlated to RO treatment on axis 2. The same trend was observed for the frequency data for *E. rigidior*. Forbs and *C. dactylon* are positively correlated to RB treatment during the first survey (Fig. 4.5). Stimulating the establishment and growth of *E. rigidior* can be increased in the presence of organic material supplement, if the seed is in the soil seed bank. Increase in forbs establishment and growth from the soil seed bank can also be achieved through rip and maybe brush packing. As for frequency *D. eriantha* becoming more strongly correlated with the seeded treatments in the second season is the proof that *D. eriantha* is a slow starter and only establishes well after the second season (Dannhauser, 1987b; Fair, 1986). If surveys were carried out for longer than two years, it is possible that *D. eriantha* would become dominant as found in the studies by De Wet (2001) who did sampling over five years. The correlation of species density and treatments coincided with the species frequency and treatments. In both ordinations, for the first and the second surveys, there were strong positive correlation between ROS and RS treatments with *C. gayana*, *C. ciliaris* and *P. maximum* (see Fig. 4.2, Fig. 4.3, Fig. 4.5 & Fig. 4.6).

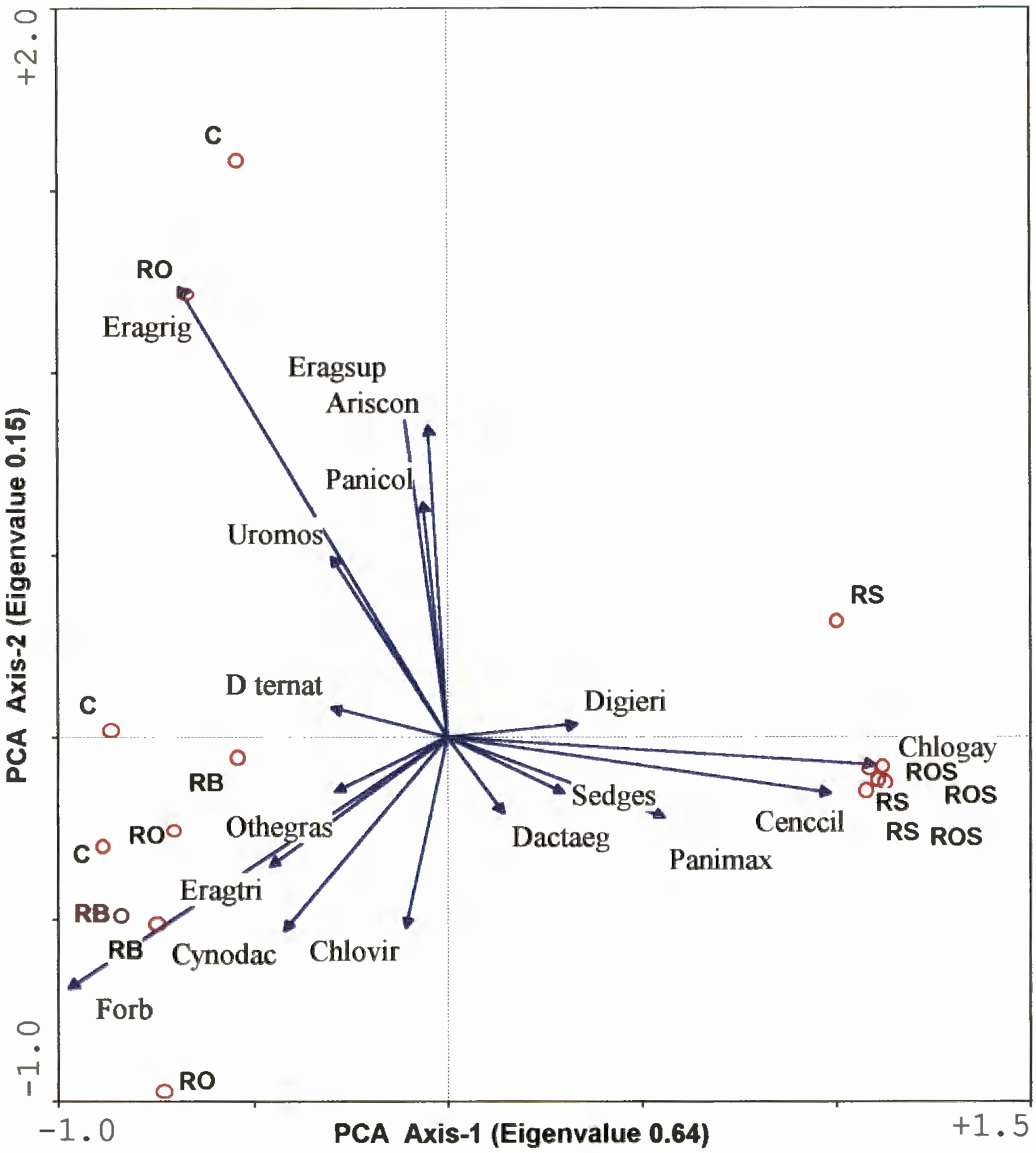

Figure 4.5 Species density by treatment association for the 15 treatment plots at MGR during the first survey, 1999/2000. (*Chlogay= C. gayana; Cenccil= C. ciliaris; Digieri=D.eriantha; Panimax=P.maximum; Cynodac=C. dactylon; Eragtri= E trichophora; Chlovir= C.virgata; Ariscon=Aristida congesta; Eragrig=E.rigdior; Eragsup= E.superba; Panicol= P.coloratum; Urocmos= Urochloa mosambicensis*; Dactaeg=*Dactyloctenium aegyptium; D ternat=D. ternata*; Othegras= Other grasses).

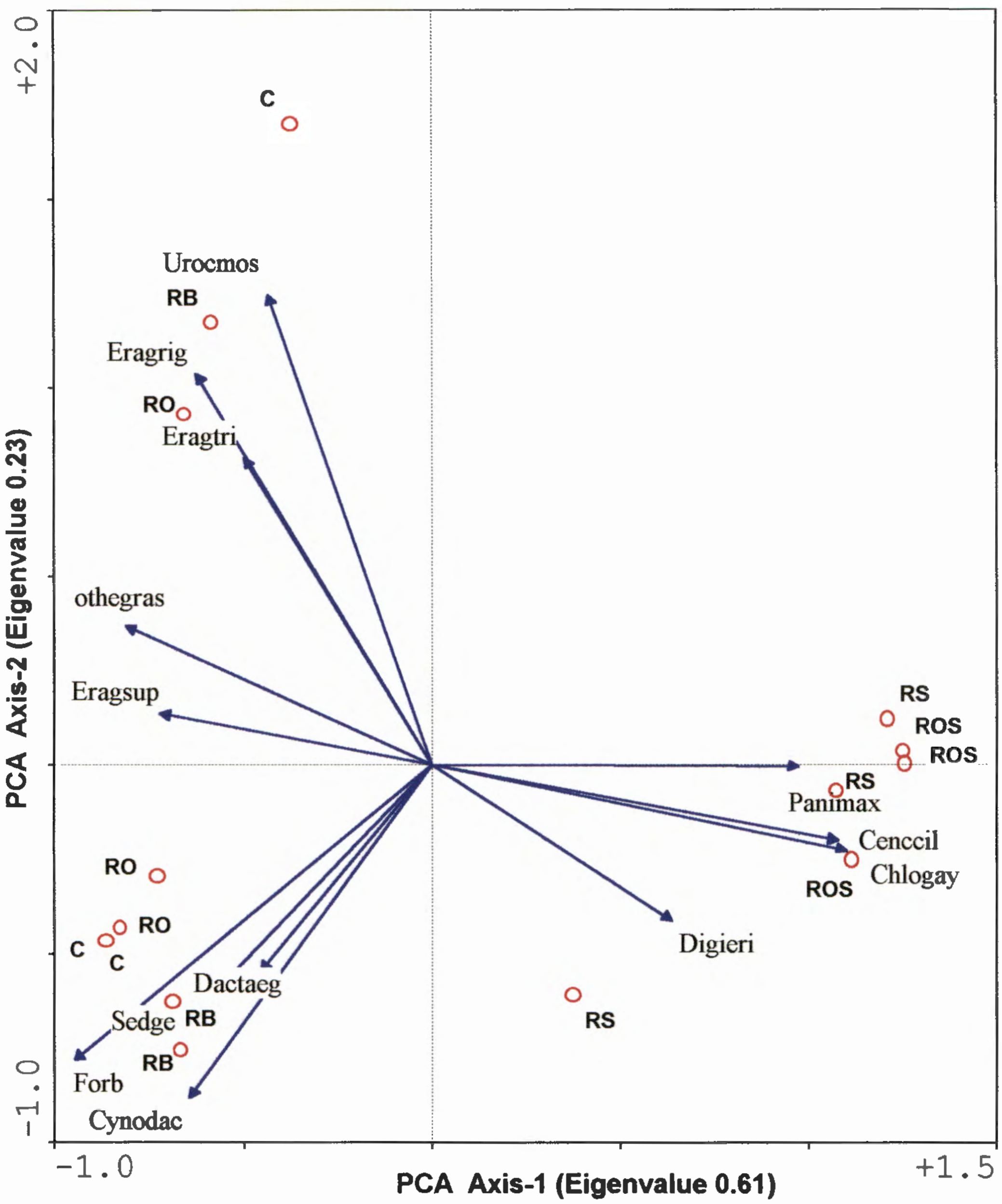

Figure 4.6 Species density by treatment association for the 15 Treatment Plots at MGR during the second survey, 2000/2001 through PCA ordination. The graph is based on Table 4.6. (*Chlogay= C. gayana; Cenccil= C. ciliaris; Digieri= D. eriantha; Panimax= P.maximum; Cynodac= C.dactylon; Eragtri= E. trichophora; Eragrig=E.rigdior; Dactaeg=D. aegyptium; Eragsup= E.superba; Urocmos=U. mosambicensis*; Othegras= Other grasses).

4.1.3 Population dynamics

There are eight important stages that can be recognized in an individual plant or population. These stages can be grouped into three different growth stage categories: **seedling, vegetative** and **reproductive** growth stages. The age distribution of a population can be used as a predictive tool in a community ecology. If a population shows all the three stages without any further changes occurring in the age structure, that population is said to be stable and can replace itself at the site (Barbour *et al*., 1987).

In the current study, the number of individuals in different growth stage categories seedling (SL), vegetative (VG) and reproductive (RP) started to increase in both over-sown treatments (ROS and RS) during the second year as indicated in Tables 4.3 & 4.4; Figs. 4.3 & 4.4; Fig. 4.7 & Fig. 4.8, except for *C. gayana* in the seedlings and reproduction of *P. maximum*.

Table 4.3: The average number of plants representing the seedling, vegetative and reproductive growth stages of the sown-in grass species in the rip-organic-seed (ROS) treatment sub-plots at MGR during 1999/2000 and 2000/2001 seasons.

Rip-organic-seed

	Seedlings		Vegetative		Reproductive	
	1999/2000	2000/2001	1999/2000	2000/2001	1999/2000	2000/2001
C. gayana	59	18	12	45.6	40	60.7
C. ciliaris	1.7	6.3	42	44.3	8.6	12.7
P. maximum	1.7	5	6.3	42.3	21	19.7
D. eriantha	0	9.3	0	18	0	0

Table 4.4: The average number of plants representing the seedling, vegetative and reproductive growth stages of the sown-in grass species in the rip-seed (RS) treatment sub-plots plots at MGR during 1999/2000 and 2000/2001 seasons.

Rip-seed

	Seedling		Vegetative		Reproductive	
	1999/2000	2000/2001	1999/2000	2000/2001	1999/2000	2000/2001
C. gayana	25.3	19	7	30	23.3	31.7
C. ciliaris	2.67	1.7	21	27.3	1	4.3
P. maxiximum	4	8	11.7	14	6	11
D. eriatha	0.67	19.3	2.67	30	0	1

In the rip-organic-seed (ROS) treatment during the two surveys (1999/2000 & 2000/2001), *C. gayana* decreased in seedlings but the decrease was not significant (p=0.654). On the contrary there was a significant increase in the vegetative growth stage (p=0.0339). The increase in the average number of reproductive plants from 40 to 60.7 plants/m^2 for the two year period was however not significant (p=0.4795). From the Kruskal-Wallis ANOVA test, *C. gayana,* among the five treatments was significant in seedlings in both the first survey (p=0.026) and second survey (p=0.037). It was also significant in both vegetative and reproductive growth stages during the first survey (p=0.0353) and the second survey (p=0.0128). *Cenchrus ciliaris* and *P. maximum* increased in all three stages while *D. eriantha* even though it was too short a time to reproduce, increased in the seedling and vegetative stages. All the four sown-in species increased in the vegetative growth stage. *P. maximum* had a significant increase (p=0.0348) from 6.3 plants/m^2 in the first season to 42.3 plants/m^2 in the second season (Fig. 4.7). In the rip-seed (RS) treatment the representation of *C. gayana* in the three growth stages was the same as in ROS treatment. *C. ciliaris* rather decreased in the number of seedling while *P. maximum* had the same number as was in the ROS treatment. *D. eriantha* was better represented in RS treatment, it had the highest number in both seedling and vegetative stages (Fig. 4.8.). The increase of *D. eriantha* for the two year period was not significant (p<0.1024). Among the five treatments the seedlings of *D. eriantha* was also not significant (p=0.1832) during the first season but was significant (p=0.0262) in the second season. Even though the other species recorded increases in their vegetative and reproductive stages, they were not as high as *D. eriantha* which increased from 0.67 to 19.3 in SL, 2.67 to 30 plants/m^2 in VG and 0 to 1 plant/m^2 in RP (Table 4.4). In general, all four species were well adapted to the two over-sown treatments but *D. eriantha* responded quite well in the rip-seed (RS) treatment, *C.gayana* and *C. ciliaris* in rip-organic-seed treatment while *P. maximum* remained constant and did not differ in its response in the two sown-in treatments. The decrease in the seedling growth stage of *C. gayana* is an indication that it is a short-lived perennial, that does not have a life span longer than three years (Dannhrauser, 1987b; De Wet, 2001). From the results in both Tables one can conclude that both treatments had more or less the same results so the addition of organic material did not make such a big difference. However, if one looks at the number of species/m^{2}of ROS and RS treatments, it gives a clear indication that in the ROS treatment the numbers are much higher (in the 40s, 50s and 60s) whereas the other treatment (RS), are in the 20s and 30s (Tables 4.3 & 4.4; Fig. 4.7 & Fig. 4.8), confirming the good effects of the organic treatment on species abundance.

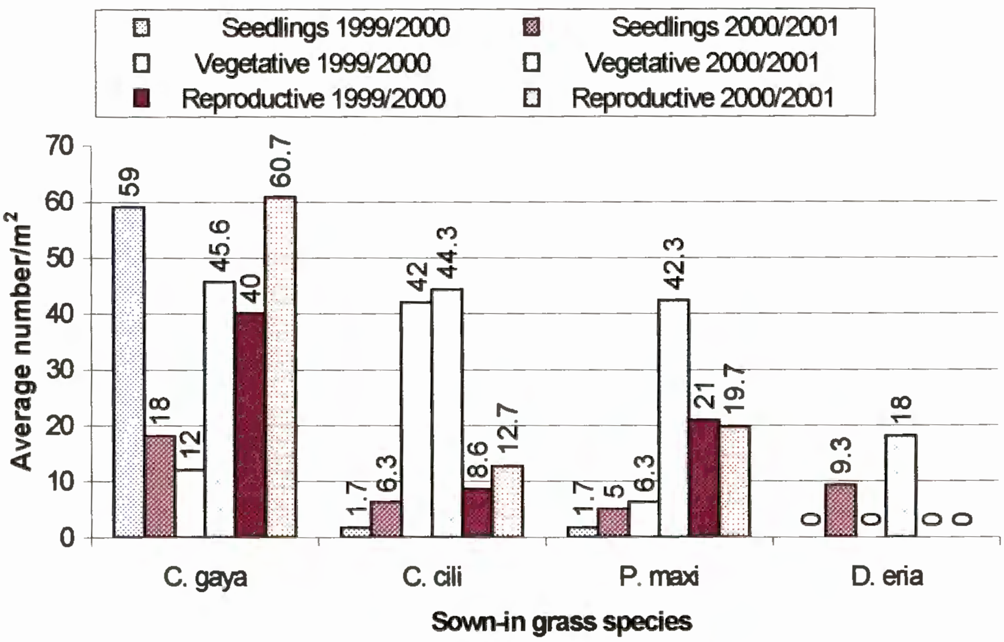

Figure 4.7 The average number of plants representing the seedling, vegetative and reproductive growth stages in the rip-organic-seed (ROS) treatment for the two seasons 1999/2000 and 2000/2001 at MGR.

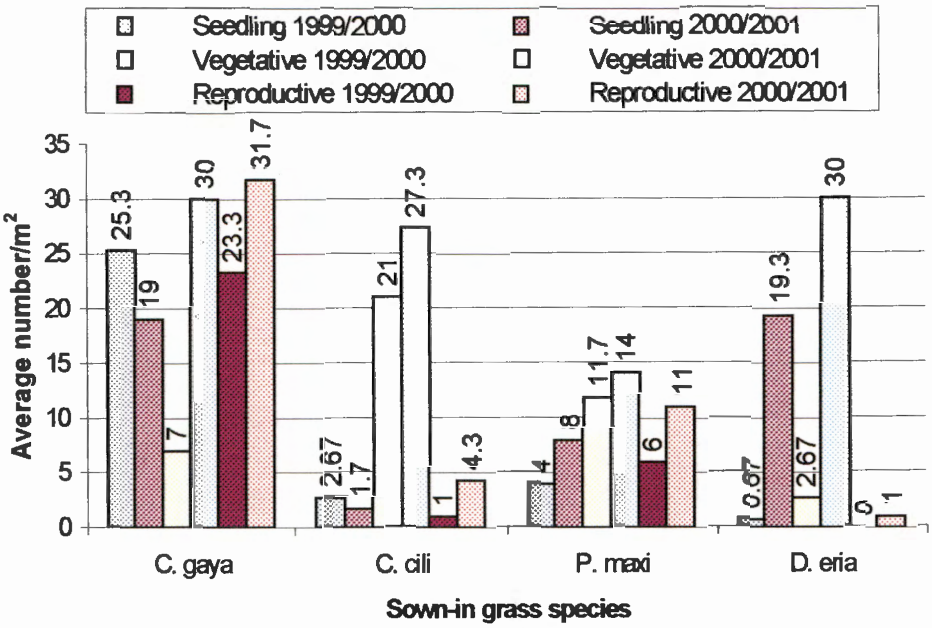

Figure 4.8 The average number of plants representing the seedlings, vegetative and reproductive growth stages of the rip-seed (RS) treatment for the two seasons 1999/2000 and 2000/2001 at MGR.

4.1.4 Soil analysis and treatment plots

The result of the analysis from the different treatments is given in Table 4.5 and graphically represented in Fig. 4.9. Among the soil fractions analysed in the samples from the MGR study site, sand had the highest percentage ranging from 75.5% in the control to 71.7% in the RB treatment. There was a lower concentration of clay in the soil sample which also ranged the 15% in the RB and between 12 to 13% in the other treatments (Table 4.5).

Calcium concentration was the highest among the macro nutrients with 596 mg/kg in the ROS treatment to 488 mg/kg in the RS treatment (Table 4.5 & Fig. 4.9). The high Ca in all the treatments is typical for this type of soil (see 1.3.1). According to Van Rensburg (2001), the analytical values of the environmental variables from MGR (boma) with lower concentrations Na and K, are normal, except the **P** value which is very low with the **Mg** value slightly above average.

Table 4.5 The average result of the analysis of the soil samples taken from the sub-plots of the five experimental treatments at MGR. The macro-nutrients were measured in mg/kg while the soil fractions were measured in percentage (%).

		Average soil environmental conditions (mg/kg)					Soil Fraction (%)		
Treatment	P	K	Ca	Mg	Na	pH	Clay	Sand	Silt
ROS	6.3	209	596	208	23	6.09	13.3	73.3	13.3
RS	3.9	140	584	191	20.3	6.19	12	73.8	14.2
RO	7.1	162	488	156	10.3	6.16	12.6	74.3	13.1
RB	3.1	115	544	208	22	6.04	15	71.7	13
Control	3	207	526	195	20.3	6.24	12	75.5	12.5

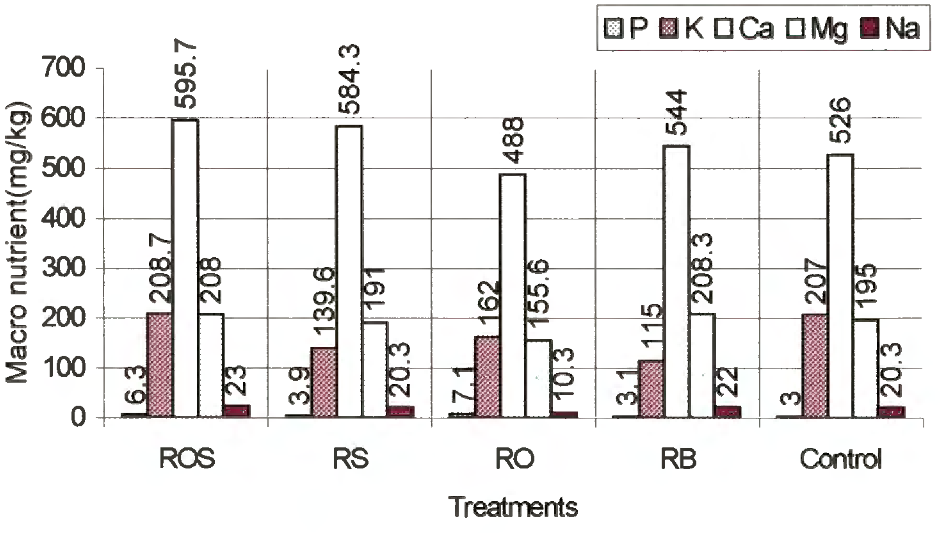

Figure 4.9: The composition of macro nutrients (mg/kg) in the different restoration treatments at MGR. The graph is based on Table 4.5.

From the result of the analysis (Table 4.5) it can be deduced that the soil at MGR study site is very sandy. The sandy nature of the soil has also affected the concentration of phosphorus for it is leaching out due to the sandy nature of the soil leading to its deficiency. It can also be concluded that the problem at the MGR study site is more of a physical one which is its sandy nature. The results shown in Fig.

4.9 & Table 4.5 are similar for all the sample plots. This is a good indication that the soil conditions were the same for all the plots sampled. They were very homogenous and could therefore be very well compared. It also means that the differences in species and population dynamics between the treatments as described previously were not influenced by different soil characteristics.

The soil was homogeneous in all the treatment plots as shown in Fig. 4.9. A PCA ordination was done to see if there is any correlation between the soil texture and the macro-nutrient. From the ordination result (Fig. 4.10), Ca and P are strongly correlated to clay and silt, Mg is correlated to sand and Na is negatively correlated to K.

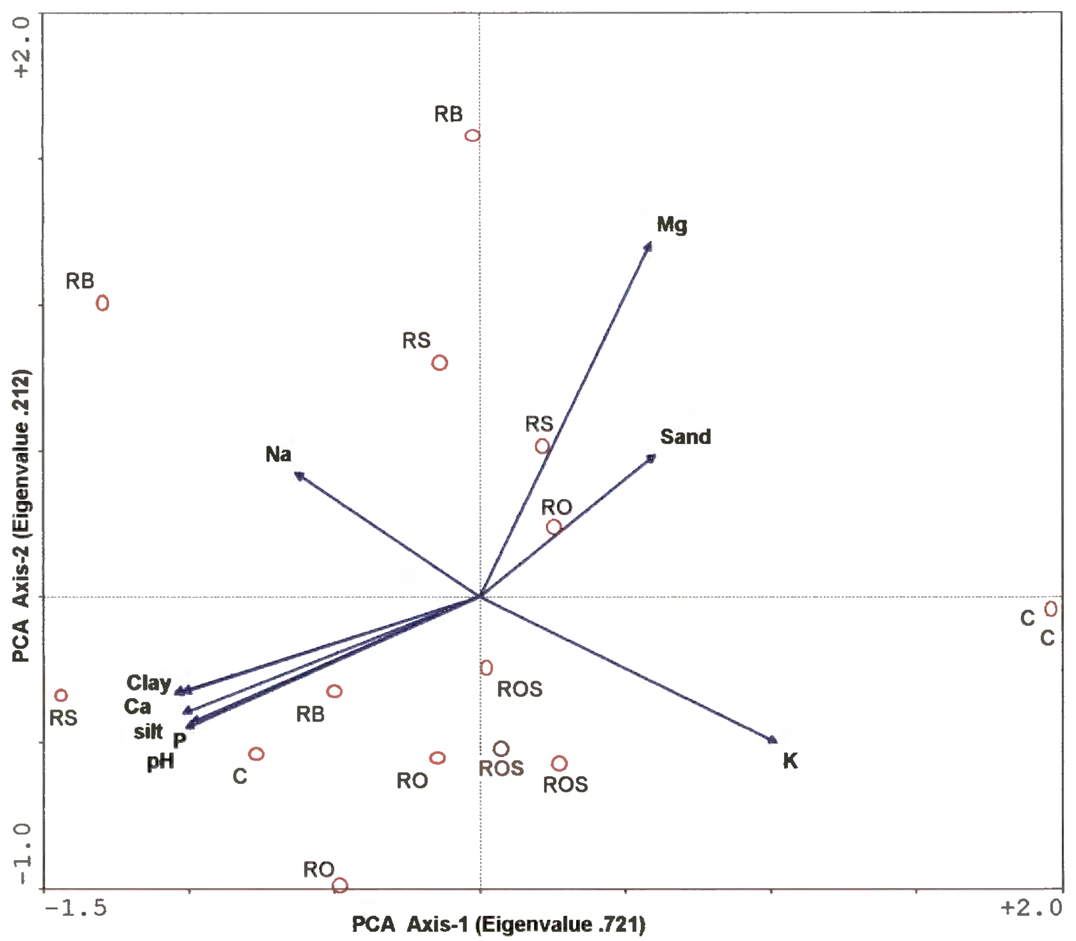

Figure 4.10: PCA ordination graph showing the correlation between soil environment and treatments at MGR.

4.1.5 Environmental/soil variables and species frequency and density at MGR study site.

The correlation between the environmental variables from MGR, were compared with the species frequency and density using a RDA ordination. Only data of the second survey 2000/2001 was used in this analysis. The ordination graphs are presented in Figures 4.11 & 4.12. The trend of grouping of the macro nutrients and their correlation with species frequency and density in the ordination graphs is discussed. According to axis 1 of the frequency-environmental ordination (Fig. 4.11), there is a strong positive correlation between the macro nutrients (Mg, P, K and Na) and the soil fractions clay and silt with all the sown-in species except *D. eriantha*. Clay is strongly negatively correlated to sand, but sand is also associated with *C. virgata, P. squarrosa, E. curvula*, forbs and sedges. *E. rigidior, E. trichophora E. superba, U. mosambicensis* are positively correlated to clay on the second axis. Similar trend of grouping, correlation and association of the macro nutrients and species is recorded in density by environmental ordination (Fig. 4.12), with *D. eriantha* being positively correlated to the macro nutrients and strongly associated with the other sown-in species.

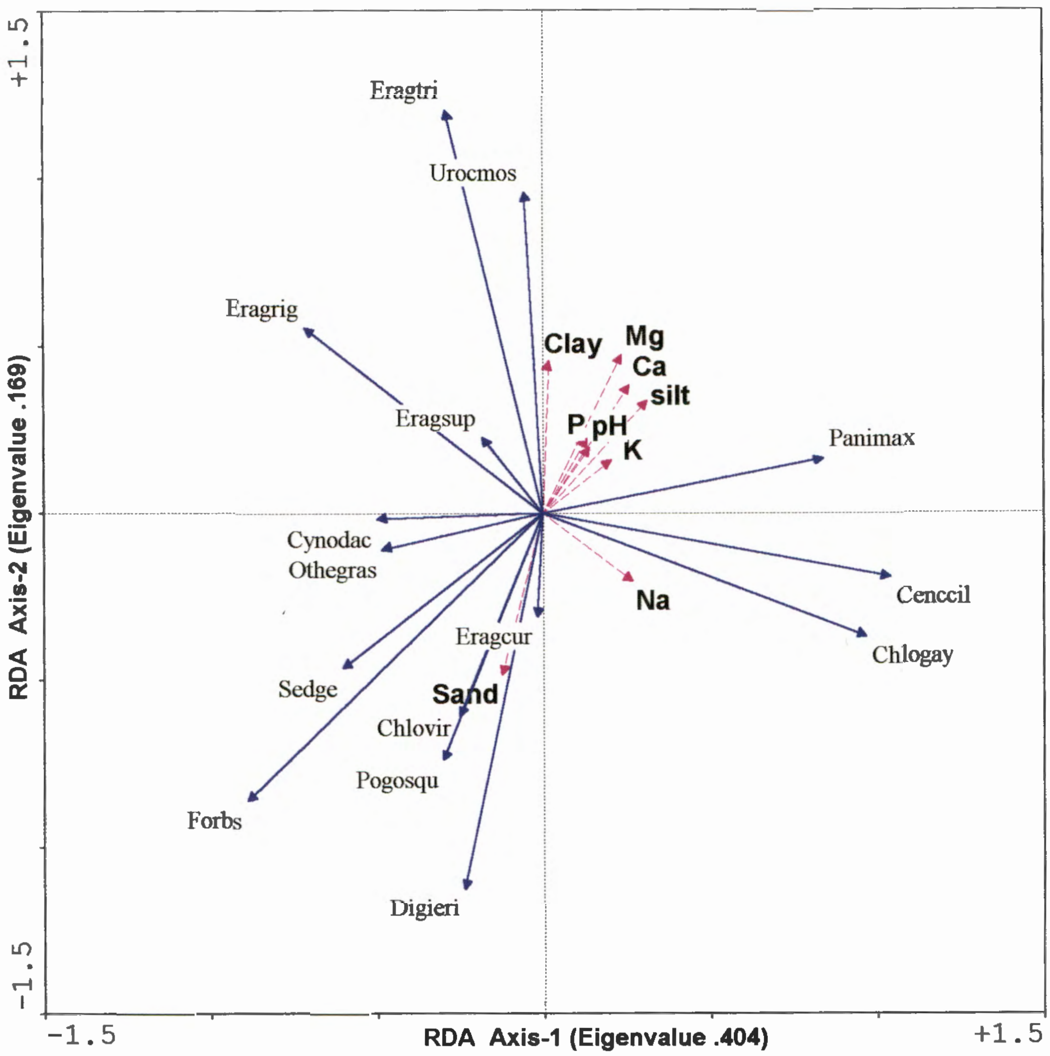

Figure 4.11 : Biplot based on redundancy analysis (RDA) showing correlation between grass species frequency and environmental variables at the MGR during the second survey, December, 2000. (*Chlogay=C. gayana; Cenccil=C. ciliaris; Digieri=D. eriantha; Panimax=P. maximum; Cynodac=C. dactylon; Eragtri= E. trichophora; Chlovir=C. virgata; Eragrig=E.rigidior; Pogosqu=Pogonarthria squarrosa; Eragsup= E. superba; Eragcur=E. curvula; Urocmos=U. mosambicensis*, Othegras= Other grasses).

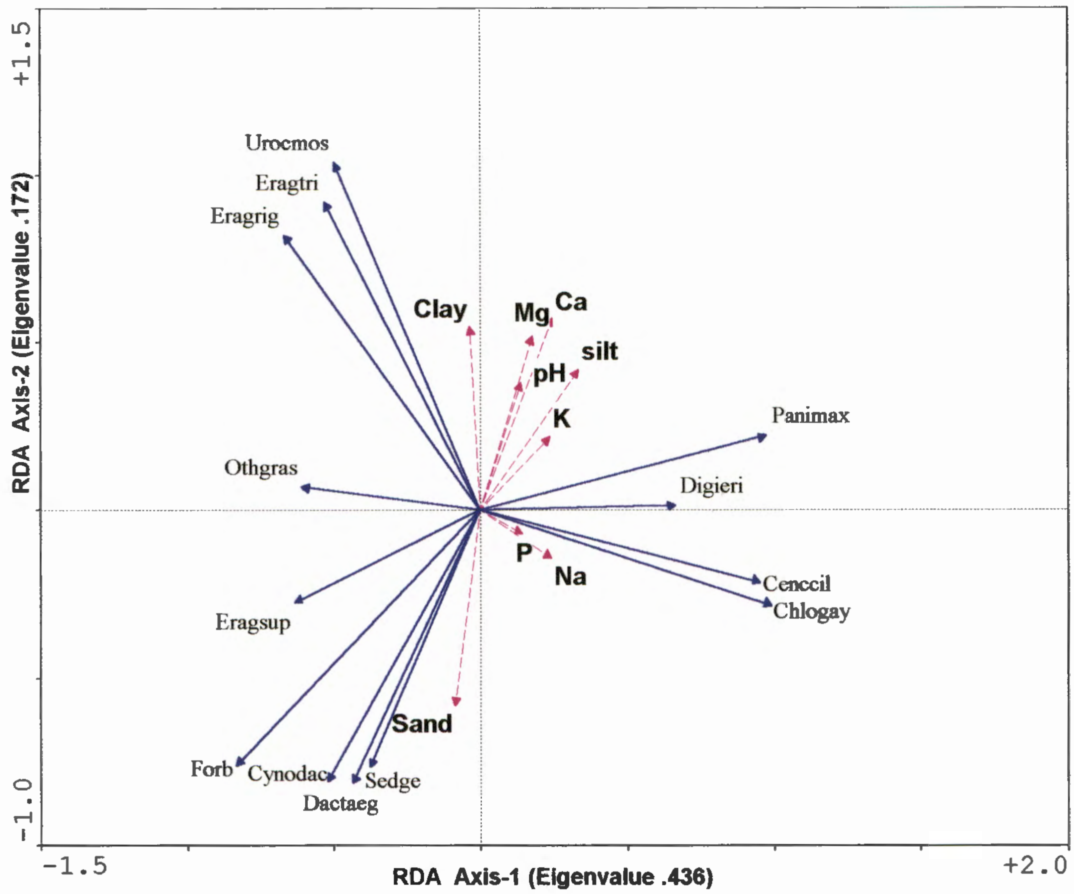

Figure 4.12 Biplot based on redundancy analysis (RDA) showing correlation between grass species density and environmental variables at the MGR during the second survey December, 2000. (*Chlogay=C. gayana; Cenccil=C. ciliaris; Digieri=D. eriantha; Panimax=P. maximum; Cynodac=C. dactylon; Eragtri=E. trichophora; Dactaeg=D. aegyptium; Eragsup=E. superba; Urocmos=U.mosambicensis*; *Eragrig=E.rigidior;* Othegras=Other grasses).

According to Figs.4.11 & 4.12, the frequency and density of certain species are correlated with specific environmental variables. *C. ciliaris* and *C. gayana* are always found in sodium type of soils. *U. mosambicensis*, *E. trichophora* and *E. rigidior* are higher in clay type of soils. Forbs and sedges are distributed in sandy type of soil.

4.1.6 Importance Value.

The importance values (I V) of the sown-in grass species in the current study, as explained in section 3.5.1.1, were calculated from the relative frequency and relative density (see Table 4.6). The importance of calculating the importance value is that certain species could have higher frequency but lower density and *vice versa*. In both rip-organic-seed and rip-seed treatments, the IV of *C.gayana* was ranked first (1) (Table 4.6). This explains that, *C. gayana* is a very good species to have in a seed mixture especially in the short term. It has a high frequency and density which is due to its stoloniferous growth form. *C. ciliaris* was ranked second (2) after *C. gayana* in the rip-organic-seed treatment but with a very low relative frequency in the rip-seed treatment where its importance was ranked third (3). The relative frequency and relative density of *P. maximum* in the rip-seed treatment had little or no difference (Table. 4.6) and was rated Second (2). The similar distribution of *P. maximum* in both ROS and RS signifies that it was randomly distributed in both treatments (Barbour, *et al.*, 1987). In the current study, *C. gayana* and *C. ciliaris* established well in the rip-organic-seed treatment while *C. gayana* and *P. maximum* dominated in the rip-seed treatment. *D. eriantha* is known to have a higher germination percentage in the second year after sowing (Fair, 1986; Dannhauser, 1987b). Even *D. eriantha* had the lowest relative frequency and relative density with fourth (4) IV ranking. In both sown-in treatments this could change if sampling could be carried out for a longer time than two years.

Table 4.6 Importance value (IV) of sown-in grass species with their ranks (IV R) calculated from relative frequency (%) (RF) and relative density (%) (RD) during the first survey at MGR.

	Rip-organic-seed treatment				Rip and Seed Treatment			
SPECIES	RF	RD	IV	IV R	RF	RD	IV	IV R
Chloris gayana	34	54.8	88.8	1	25.7	47.85	73.6	1
Cenchrus ciliaris	21	25.9	46.9	2	8	21.2	29.2	3
Panicum maximum	20	14.3	34.3	3	18	18.6	36.6	2
Digitaria eriantha	0	0	0	4	4.67	2.87	7.5	4

4.1.7 The response of other grass species in all the treatment plots.

The grass species that were in the good veld outside the fenced study site at MGR before the restoration include *E. rigidior*, *E. trichophora* and *U. mosambicensis*. During the first and the second surveys a lot of species were encountered but these four species were well represented in all the sub-plots. *U. mosambicensis* had a relative frequency of 9.3% in the rip-organic-seed sub-plots and 5.3% in rip-seed sub-plots during the first year but as the sown-in species increased in their basal cover, its frequency decreased in the sown-in plots and increased in the other sown-in treatment plots. *Urochloa mosambicensis, E. rigidior* and *E. trichophora* even though appeared in the sown-in sub-plots with relative frequency ranging between 4% and 9%, they could not compete with the sown-in grass species but rather established with higher frequencies in the other treated plots with no sown-in treatments. *E. trichophora* and *E. rigidior* were both prominent in the rip-seed treatment plots. They both demonstrated a trend of reduction in the sown-in plots during the second survey but this trend was also recorded in all the other treatments. (Table. 4.1). Rip-organic treatment plots were dominated by forbs, *U. mosambicensis* and *E. rigidior*. Rip-brush treatment was dominated by forbs, *E. tricophora* and *E. rigidior*. These are pioneer species that took the advantage of the improved soil condition brought about by the rip cultivation and the application of the organic material and the absence of competition from seeded plants. Control plots were dominated by *C. dactylon, E. tricophora* and *U. mosambicensis*. Both *U. mosambicensis and C. dactylon* have very good rooting systems and could have out-competed the other grass species for water after the first survey. Grass species which were encountered but had frequency or density less than 1 (except a sown-in grass species) were all grouped under other grasses. These include *Melinis repens, Aristida congesta, Dactyloctenium giganteum* and *Diheteropogon amplectens*.

4.2 Sabi Sand Private Game Reserve (SSPGR)

4.2.1 Frequency

Out of the nine experimental treatments researched at the SSPGR study site, four had sown-in treatments (see Table 3.2). During the first year lower frequencies of the sown-in grass species were recorded in all the four sown-in treatments. *C. gayana* however, was dominant among the sown-in grass species. The lower frequency recorded in the first year survey could be attributed to the fact that the whole area was under water after the floods (see Fig. 2.4 for the rainfall data) that took place in Mpumalanga during January/February 2000. The study site is a low lying stretch of land with less outlets for run-off water. The site has a poor drainage and because of its flatness, the dry river beds and channels (see Fig. 3.8) fill up rapidly and flood the entire area.

In the lime-organic-seed (**LOS**) treatment, *C. gayana* was the dominant species (10%) among the sown-in species during the first survey followed by *D. eriantha* (6%), *P. maximum* (2%) and *C. ciliaris* (1%). *Dactyloctenium aegyptium* was the dominant species among all the species encountered in the LOS with a frequency of 35%, followed by *Sporobolus nitens* (17%) and *U. mosambicensis* (13%). All the sown-in species with the exception of *C. ciliaris* increased in relative frequency during the second year but most of the species which were not among the sown-in species, decreased in relative frequency especially those with higher relative frequencies like *Dactyloctenium aegyptium* (Table 4.7). Although there were increases in the sown-in species (except *C. ciliaris*), the significance of these increases could not statistically be proved because the data from SSPGR were of two replicates and could not be used for statistical analysis.

In the **LOSB** treatment, there was a 50% increase, from 14% to 28% in *C. gayana*, 6 to 14% in *P. maximum*, 4 to 14% in *D. eriantha* while nothing was recorded for *C. ciliaris* (Table 4.7; Fig.4.16). The water logged nature of the soil did not favour *C. ciliaris* although SSPGR study site also has a high percentage of sand as it is at MGR study site. In the **OSB**, *C. gayana* was still the dominant species among the sown-in species during the first survey but the frequency of *D. eriantha* increased greatly in the second survey and became the overall dominant species with a frequency of 23%. As was in LOSB, all the species which were not among the sown-in species decreased in frequency in the second survey. *C. gayana* and *P. maximum* were the only sown-in species which were represented in **LB**, **B** and **L** treatments. The distribution of the species in LB, B, L, and R followed the same trend. *Dactyloctenium aegyptium* was prominent in all the different treatments and in some instances contributed to more than 50% of the total frequency in some treatments. However it decreased in all the seeded plots which is an indication that, even though ripping had a positive effect, it could not compete with the sown-in species. Other species which were stable in their distribution in all the treatment plots include, *U. mosambicensis, S. nitens* and forbs.

Each treatment at the Sabi Sand private game reserve study site had a brush and a non-brush sub-plot. In general, there was an increase in the species frequency (%) of the sown-in grass species during the second survey (Fig. 4.18), but comparing the relative frequencies of the sown-in grasses from a brush and a non-brush sub-plots of treatments with the same combination, the plots with brush packing had relatively higher relative frequencies than the non-brush treatments. In the organic-seed (**OS**) treatment the relative frequency of *D. eriantha* was 4% in the first year and 8% in the second year but in the organic-seed-brush (OSB) treatment the relative frequency increased from 5% to 23% in the second year (Table 4.7 & Fig. 4.16). The difference between the relative frequencies of the two treatments could be the brush packing effect, that prevented the grazing of the seedlings. This is a good indication that, for a better establishment of species in the restoration of degraded rangelands which are not fenced, brush packing is an appropriate technique that could be used in protecting the seedlings from the grazers and allowing them to develop into vegetative and reproductive stages. *U. mosambicensis* like *D. aegyptium,* was prominent in all the treatment plots. Seeds of the species were either in the soil seed bank or already at the site before the restoration and therefore well adapted to the site.

The application of lime in the current study did not bring about any major change to the treatments with lime application instead, the relative frequencies of some species in plots with lime application were rather lower when compared to the frequencies of species in plots with no lime treatment. For example the frequency of *C. gayana,* in the LOS treatment from the first year to the second year, was 10% to 14%. In the OS treatment, the same combination of treatments with no lime, the relative frequency of the same species, *C. gayana* was16% to 29%. In the LOSB and OSB treatments the same trend occurred with *D. eriantha*, *P. maximum* and *C. ciliaris* (Table 4.7 & Fig. 4.16). It could be that the two year period was too short to see the effect of the lime on the species distribution. On a short term basis, the lime had little or no effect. Another possibility is that the effect of the lime on the soil could have been weakened by the flood and the water logged situation in February 2000 and needed to be re-applied. However the time frame for this study was too short for further investigation along that line.

Table 4.7 Average relative frequency (%) of all plant species from the different treatment plots at SSPGR study site. Lime-organic-seed (LOS), lime-organic-seed-brush (LOSB), organic-seed-brush (OSB), organic-seed (OS), brush-lime (BL), brush (B), lime (L), rip only (R), control(C).

Treatment	LOS		LOSB		OSB		OS		BL		B		L		R		C	
Year **Species (%)**	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01	99 /00	00 /01
C. gayana	**10**	**14**	**14**	**28**	**13**	**21**	**16**	**29**	**1**	**0**	**2**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
D. eriantha	**6**	**14**	**4**	**14**	**5**	**23**	**4**	**8**	**0**	**0**	**0**	**0**	**3**	**2**	**0**	**0**	**0**	**0**
P. maximum	**2**	**5**	**6**	**14**	**2**	**14**	**6**	**7**	**2**	**1**	**3**	**0**	**0**	**4**	**1**	**0**	**0**	**0**
C. ciliaris	**1**	**0**	**1**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
D. aegyptium	35	25	27	16	23	21	55	34	54	63	30	50	49	38	51	49	26	28
A. congesta	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	0	1
S. nitens	17	12	4	8	2	0	4	5	0	4	1	7	17	22	3	12	41	61
C. virgata	9	10	6	6	21	7	4	6	2	3	27	11	11	16	4	17	1	0
U. mosambicensis	13	14	11	9	19	7	6	8	17	17	20	7	9	15	22	16	18	7
Forbs	2	1	20	1	0	1	2	0	12	1	5	6	6	2	13	1	11	1
E. trichophora	0	2	7	2	13	5	0	4	12	11	10	15	1	1	5	4	3	3
Other grasses	4	3	3	3	4	1	5	0	1	2	4	2	4	2	4	2	1	1
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Two PCA ordination analysis were carried out using the frequency variables of the first and second surveys. The results are given in Figs. 4.14 and 4.15. During the first survey, there were no specific associations of species to each other especially the sown-in species in the PCA ordination graph. According to the second axis, OSB is strongly positively correlated to *C. virgata*. A strong positive correlation among treatments R (rip only) and LOSB with *E. trichophora, U. mosambicensis*, and *C. gayana* exists on the second axis. Treatments LOS, OS, LOSB, LB, L and control are strongly correlated with *P. maximum, E. coracana*, *B. deflexa* and *A. congesta*, on axis 2.

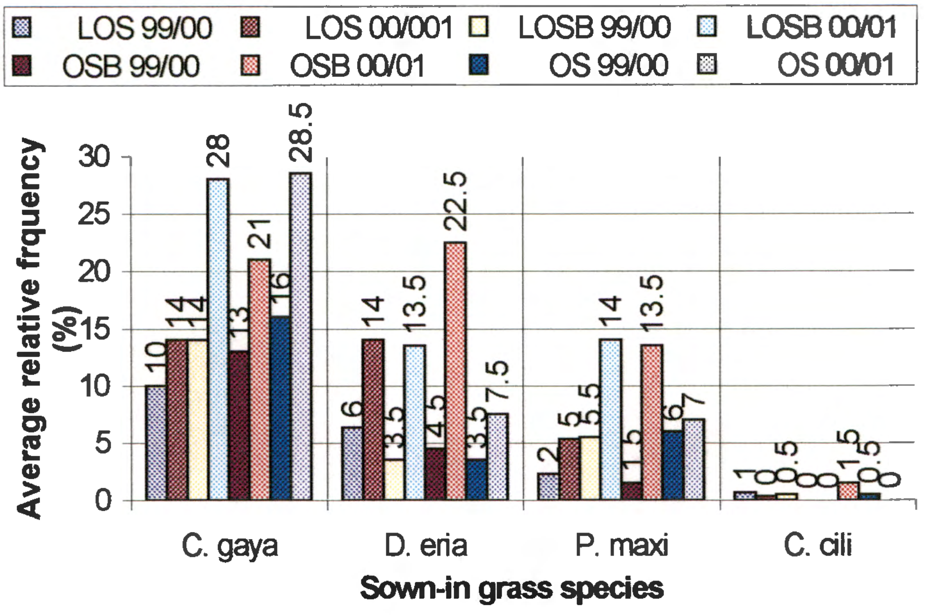

Figure 4.13 The average relative frequency(%) of the four sown-in grass species (*C. gayana, C. ciliaris, P. maximum* and *D. eriantha*) at SSPGR for the two-year (1999-2001) study period.

In the PCA ordination graph of the second survey there is a clear emergence of two different associations of species in two separate parts (Figure 4.14). On the first axis there is a strong positive correlation between the sown-in species, *D. eriantha*, *C. gayana* and *P. maximum* and the LOS, OS, LOSB, and OSB treatments. All the treatments have organic material as one of their components and all were sown-in. It is observed that the correlation among the seeded plots become stronger in the second survey. Thus over time the sown-in species will dominate the experimental site.

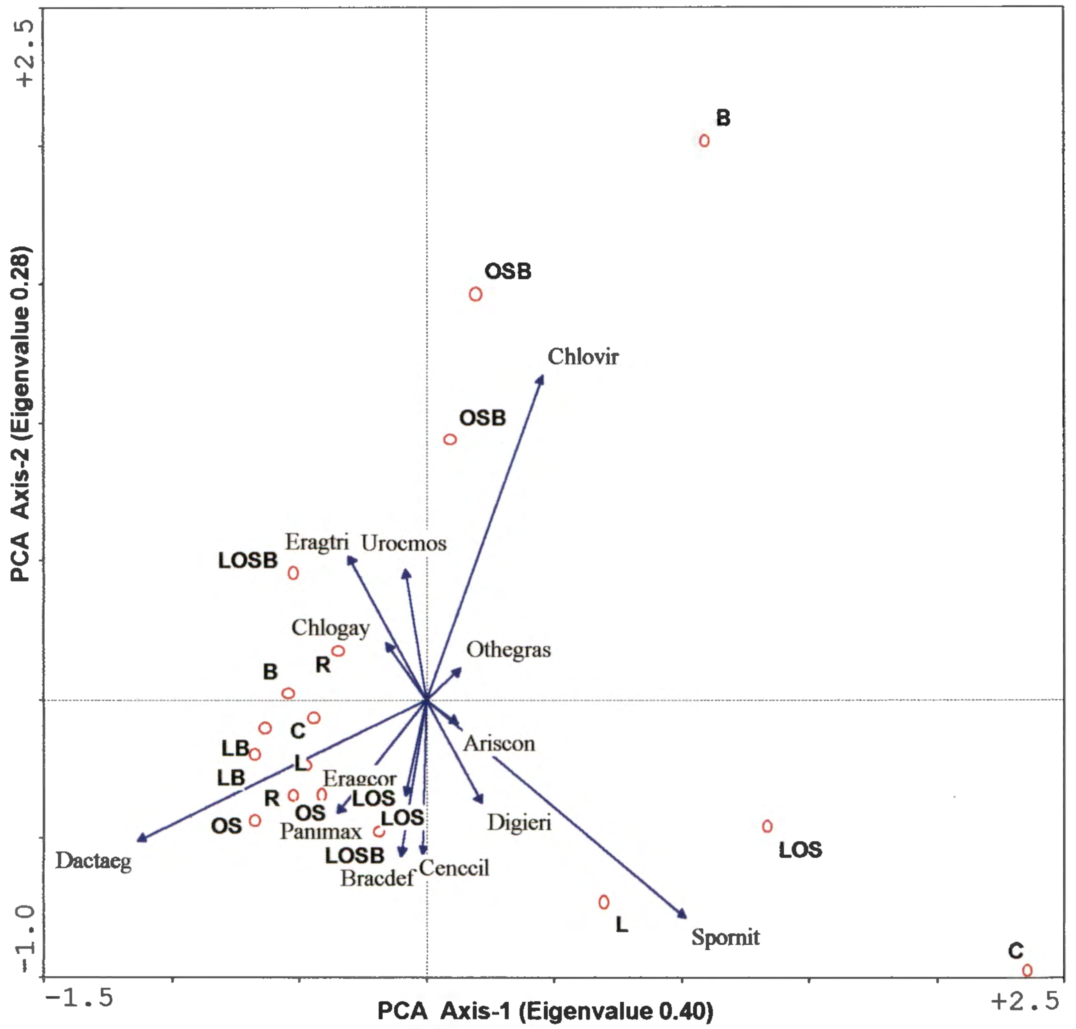

Figure 4.14 Species frequency by site association for the 19 Experimental sub-plots at Sabi Sand study site during the first survey 1999/2000.(*Chlogay= C.gayana; Dactaeg= D.aegyptium; Cenccil= C .ciliaris; Digieri= D. eriantha; Panimax= P.maximum; Eragcor=E. coracana; Chlovir= C.virgata; Spornit= Sporobolus nitens; Bracdef=Brachiaria deflexa; Urocmos= U. mosambicensis; Ariscon= A. congesta; Eragtri= E. trichophora;* Othegras=Other grass).

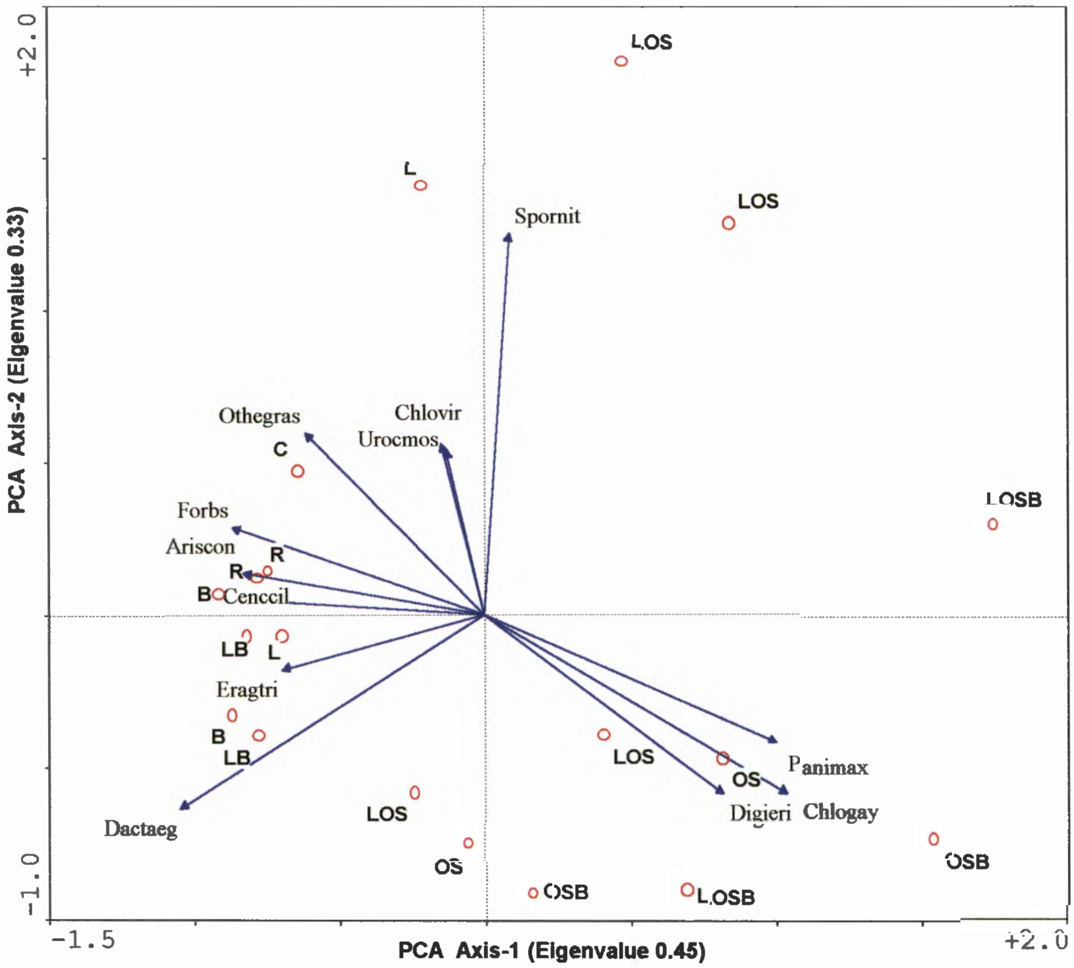

Figure 4.15 Species frequency by Site association for the 19 experimental sub-plots at SSPGR during the second survey 2000/2001 (*Chlogay= C.gayana; Dactaeg= D.aegyptium; Cenccil= C.ciliaris; Digieri= D. eriantha; Panimax= P.maximum; Cynodac= C. dactylon; Spornit= S.nitens; Urocmos= U. mosambicensis; Ariscon= A.congesta; Eragtri= E. trichophora; Chlovir= C. virgata;* Othegras=Other grass).

In both the first and second surveys, *D. aegyptium* and *E. trichophora* are strongly positively correlated to LB, L and B treatments (Fig. 4.14 & Fig. 4.15). From Table 4.7, the highest frequency of *D. aegyptium* (63%) during the second survey was recorded in LB treatment. This trend indicates that the lime favours *D. aegyptium* and its rapid establishment was stimulated by the rip cultivation. *Sporobolus nitens* (61%) is positively correlated to the control (C) plots where no ripping took place. It thrived well in the control plots because it often grows in open patches in compacted soils where few other grass species survive (Van Oudtshoorn, 1999). Other species correlated to the control plots in the second survey are: *U. mosambicensis, C. virgata* and other grasses. Forbs and *A. congesta* are correlated to R (rip only), while *D, aegyptium* is strongly correlated to LB (lime-brush). This trend of correlation explains how the rip (cultivation) action stimulated the development of seeds in the soil seed bank as well as species that were still in the sample plots.

4.2.2 Density

The average density of all the grass species at the SSPGR study site is given in Table 4.8. There were no noticeable differences among the average density of the sown-in grass species in all the sown-in treatment plots. This is indicative that their distribution is determined by the same environmental and soil factors (see Table 4.9 & Fig.4.22). *Chloris gayana* and *D. eriantha* were the dominant grass species in the four sown-in treatments. During the second survey in December 2000, the average density of *C. gayana* and *P. maximum* increased in all the sown-in plots. The average density of *D. eriantha* remained almost unchanged whereas *C. ciliaris* was totally absent in LOS, LOSB and OS treatments. The poor "performance" of the sown-in species, which was much weaker as compared to MGR, could have been caused by competition by the species that were present before the restoration such as *D. aegyptium* (Table 4.8). In LOS treatment, *D. eriantha* was the dominant species among the sown-in species with 5 plants/m^2, *D. aegyptium* (44 plants/m^2) and forbs (43 plants/m^2) were the most prominent species during the first survey. *Cenchrus ciliaris* was not represented in both the first and second survey in this treatment. Its absence could be attributed to grazing pressure due to its palatability or not establishing at all due to the water logged nature of the soil.

During the second survey, *C. gayana* was the dominant species among the sown-species in LOS. Apart from the two dominant species, forbs and *D. aegyptium,* which decreased in density even though retaining their dominance during the second survey, most of the remaining species included *S. nitens, C. virgata* and *U. mosambicensis,* increased in density. These species are pioneer species which were stimulated by the rip cultivation and the presence of organic material. In the LOSB treatment the distribution of the species density was similar to the LOS treatment, but it contained all the four sown-in species in the first survey and with higher density in the second survey. *Chloris gayana* and *P. maximum* increased in density, *C. ciliaris* decreased while *D. eriantha* remained unchanged. The co-dominant species in LOS treatment *D. aegyptium* had a relatively lower density in LOSB treatment and decreased even further in the second survey (Table 4.8). The densities of sown-in species in the OSB treatment were quite similar to those in LOSB but with a slight increase in the density of *D. eriantha* while *C. ciliaris* recorded its highest density (6 plants/m^2) during the second survey. Both treatments had brush as one of their components, for grazing protection. One major difference between OSB and LOSB was that the density of the species which were not sown-in were lower in LOSB in the first survey and almost all the species apart from the sown-in species had sharp decreases in their densities during the second survey. These species which recorded sharp decreases in their densities include, *D. aegyptium* (from 17 to 7plant/m^2), *C. virgata* (from 9 to 1plant/m^2), *S. nitens* (from 22 to 1 plant/m^2), and *U. mosambicensis* (11 to 3 plant/m^2). The decrease in densities of these specie could be as a result of drought leading to compaction of the soil.

Table 4.8 The average absolute density (plant/m^2) of all grass species at the SSPGR restoration site for the two-year experimental period (1999 to 2001).

	LOS		LOSB		OSB		OS		BL		B		L		R		C	
Year Species	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01	99/00	00/01
C. gayana	**2**	**7**	**2**	**12**	**1**	**12**	**3**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
C. ciliaris	**0**	**0**	**1**	**0**	**0**	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
D. eriatha	**5**	**6**	**11**	**11**	**13**	**12**	**1**	**8**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
P. maximum	**1**	**2**	**1**	**4**	**0**	**4**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
D. aegyptium	44	33	17	7	20	9	46	38	59	37	39	12	39	34	52	25	32	28
C. virgata	8	12	9	1	11	3	3	2	1	0	8	6	7	24	3	6	5	5
A. congesta	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
S. nitens	14	18	22	1	3	0	8	4	5	1	5	6	27	19	11	7	84	38
Forbs	43	42	33	20	24	20	42	28	29	23	41	24	32	29	24	16	41	18
Sedges	3	2	0	0	2	0	0	2	0	0	0	0	2	3	6	3	2	5
U. mosambicensis	7	12	11	3	18	2	7	2	10	7	5	1	14	11	20	5	2	3
E. trichophora	0	1	2	0	7	3	5	1	9	4	5	2	0	1	4	2	0	0
Pseudobrachiaria deflexa	0	3	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
Othergrasses	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

OSB and OS treatment had the same species composition and species richness with only *C. ciliaris* being completely absent in the

OS treatment. The good effect of brush packing was evident when comparing the OSB to the OS treatment. There was a relatively higher specie density in the OSB treatment as compared to the OS treatment with the exception of *D. aegyptium* and forbs. This proves that the species in OSB treatment were better protected from being grazed.
There was a very low species richness in BL, B, L, R and C treatments. None of them had any of the sown-in species with the exception of BL that had *D. eriantha* (1 plant/m^2) during the first survey and reduced to zero in the second survey.

A higher density of *D. aegyptium* and *S. nitens* was recorded in each of these 5 treatments where oversowing treatment never occurred. The density of *S. nitens* was relatively high (84 plants/m^2) during the first survey in the control plots where no treatment took place (Table 4.8). It is a pioneer plant that occurs in disturbed areas and often establishes well in compacted soils where few other plants survive. It is also not an important grazing grass especially for cattle, it has low leaf production and never under grazing pressure. *S. nitens* can therefore not be used in restoration in game reserves due to its poor grazing value. *Dactyloctenium aegyptium* on the other hand, is a useful pioneer grass that grows in disturbed places. According to van Oudtshoorn (1999) it is an annual tufted grass with roots on the lower nodes. It grows in disturbed places such as cultivated land. It is a palatable pioneer grass which can produce large quantities of seed and can quickly colonize disturbed areas due to its stoloniferous nature. *D. aegyptium* could be used instead of *C. gayana* to cut down cost since both species have similar ecological status in restoration in degraded duplex soils. Unfortunately, this is not possible because it grows for only one season and the seeds are not easy to come by in large quantities.

Two principal component analysis (PCA) were carried out at Sabi Sand private game reserve study site, using the density variables of the first and second survey. The results are presented in Fig. 4.19 & Fig. 4.20. In the first analysis for the first survey (March, 2000), 19 sub-plots on which the species were distributed were used (Fig. 4.19). The analysis was extracted from fourteen principal components with eigenvalues < 1.0 from the 19 variables which accounted for 91% of the total variance.

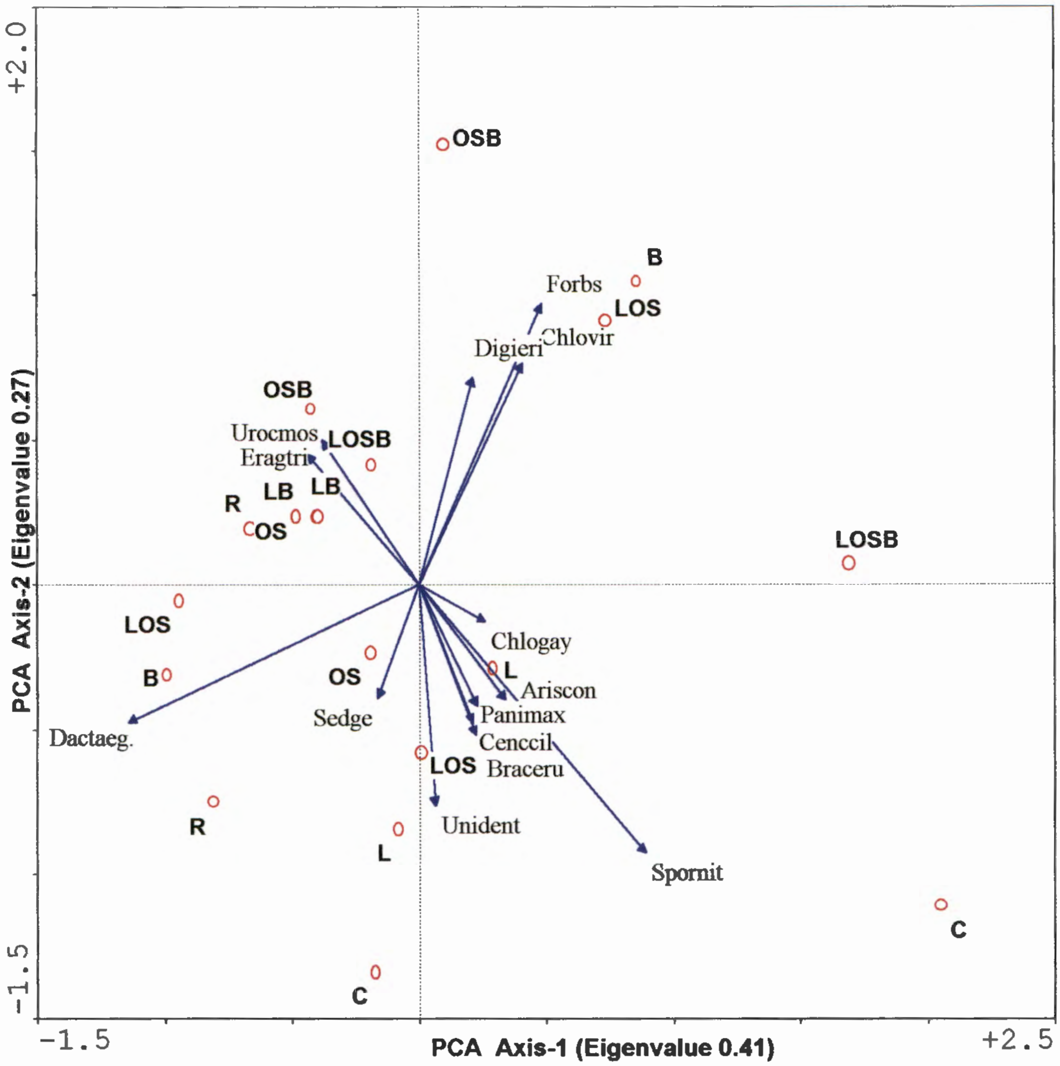

Figure 4.16 Species average density by treatment association for the 19 treatment plots at SSPGR study site in the first survey in 1999/2000 season. (*Chlogay= C. gayana; Cenccil=C.ciliaris; Digieri=D.eriantha; Panimax=P.maximum; Dactaeg= D.aegyptium; Chlovir=C.virgata; Spornit=S.nitens; Braceruf=B.eruciformis; Urocmos=U.mosambicensis; Ariscon=A.congesta; Eragtri=E.trichophora;* Unident=unidentified).

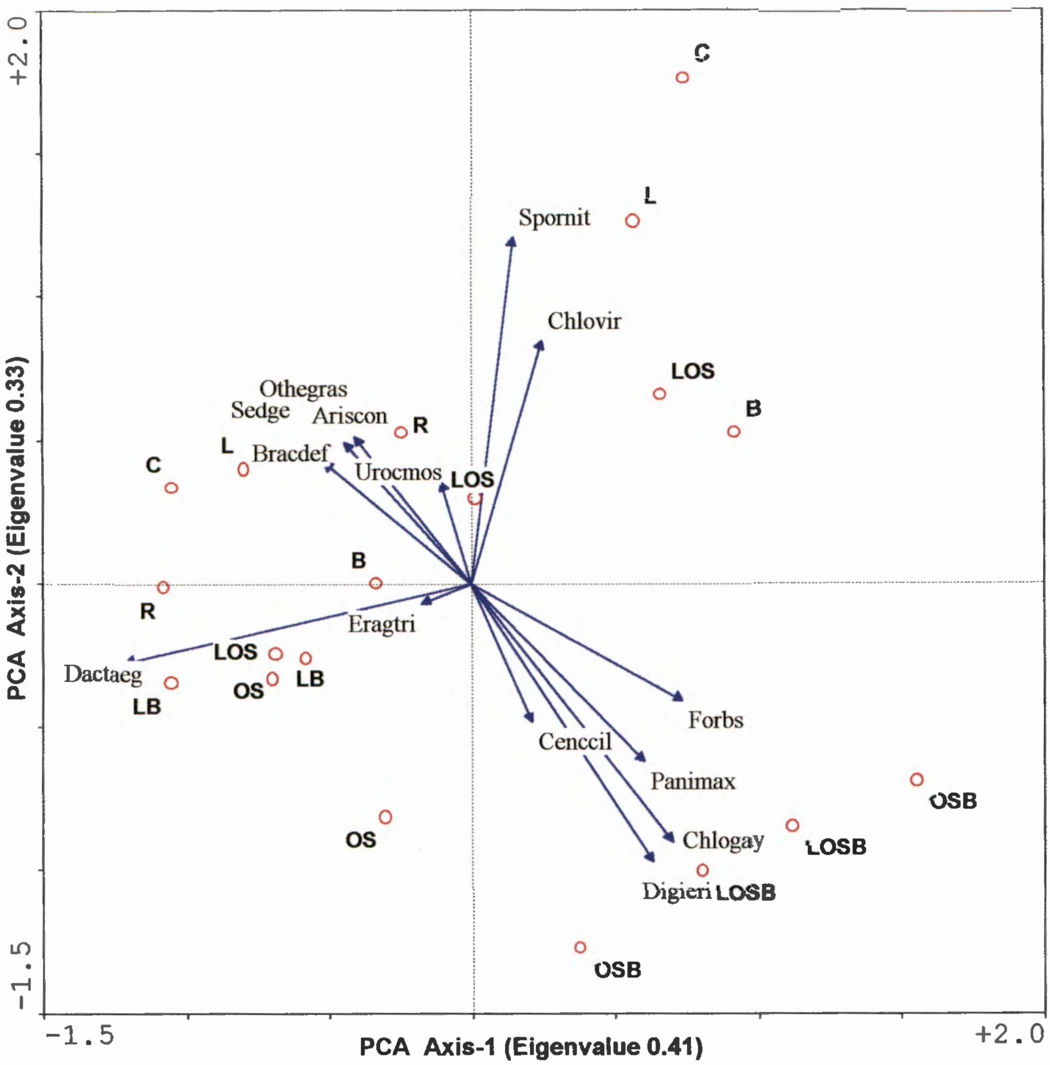

Figure 4.17 Species **relative density by treatment** association for the 19 treatment plots at SSPGR study site during the second survey in the 2000/2001 season. (*Chlogay=C.gayana; Cenccil=C.ciliaris; Digieri=D.eriantha; Panimax=P.maximum; Dactaeg= D.aegyptium; Chlovir=C.virgata; Spornit=S.nitens; Bracdef=B.deflexa; Urocmos=U.mosambicensis; Ariscon=A.congesta; Eragtri=E.trichophora;* Othegras=Other Grass).

In both the first and second surveys (Fig. 4.16 & Fig. 4.17) distinct species associations were formed, three in the first survey and two major ones in the second survey. The most important species in the first association in the first survey are forbs, *C. virgata and D. eriantha* with a strong positive correlation for LOS, OSB and B treatments according to the first axis. Thus brush favours palatable species.

There is also a strong positive correlation between treatments LOS and L with species such as *C. gayana, P. maximum, C. ciliaris, A. congesta and B. eruciformis*. *Sporobolus nitens* correlates with the control as the result in Table 4.8 has shown. It is to be emphasized once more that all the treated plots, except the control, were ripped. The control plots were dominated by *S. nitens* (an indication of a shallow E-horizon, De Wet, 1990), because the other species in the soil seed bank were not stimulated as no ripping took place. According to axis 2, there is a strong positive correlation between *U. mosambicensis* and *E. trichophora* with the treatments LOSB, OSB, and LB (Fig. 4.16). As indicated above, *U. mosambicensis* establishes well in lime and organic-rich duplex soils especially when stimulated through rip cultivation.

In the second survey, the treatments L, R and C are positively correlated with sedges, *A. congesta, U. mosambicensis* and *B. deflexa*. There is a strong correlation among treatments LOS, OS and LB with *D. aegyptium* and *E. trichophora* (Fig. 4.17).

4.2.3 Population dynamics of sown-in species

See 4.1.3
In the lime-organic-seed treatment (**LOS**), there were no seedlings for *C. gayana* during the first and the second surveys. It however had a relative high increase in the vegetative stage but a decrease in the reproductive stage (Fig 4.18). Without seedlings and with the lower density of reproductive growth stages, *C. gayana* and *P. maximum* (Fig. 4.18) are not viable and will therefore not be sustained in this treatment. While *D. eriantha* was represented very highly, *C. ciliaris* was represented very lowly in the seedling and vegetative growth stages.

In the **LOSB** treatment, *C. gayana* was represented in all the three growth stages, *C. ciliaris* was not represented in all the growth stages and there was no change in the distribution of *D. eriantha* and *P. maximum* as was in LOS treatment. *C. gayana* and *D. eriantha* were more suitable in LOSB treatment than LOS treatment (Fig. 4.19). The absence of *C. ciliaris* in this treatment, even though the species were protected by the brush, indicates that it is not suitable for this site and can be left out in future restoration projects at this area.

The species distribution in the different growth stages in the organic-seed **(OS)** treatment (Fig. 4.20) was similar to the LOS treatment. Only *C.gayana* and *D. eriantha* established in the vegetative growth stages. In this sown-in treatment *D. eriantha* for the first time produced a relatively high number of plants under the reproductive growth stage in the second season (2000/2001), with an average number of 10 plants/m^2. In the organic-seed-brush (**OSB**) treatment (Fig. 4.21) all the four grass species were better represented. *C. gayana* was represented in all the three growth stages during the second year. The establishment of all the four sown-in species in this treatment could be attributed to the good effect of the organic treatment on the soil and the protection of the seedlings by the brush.

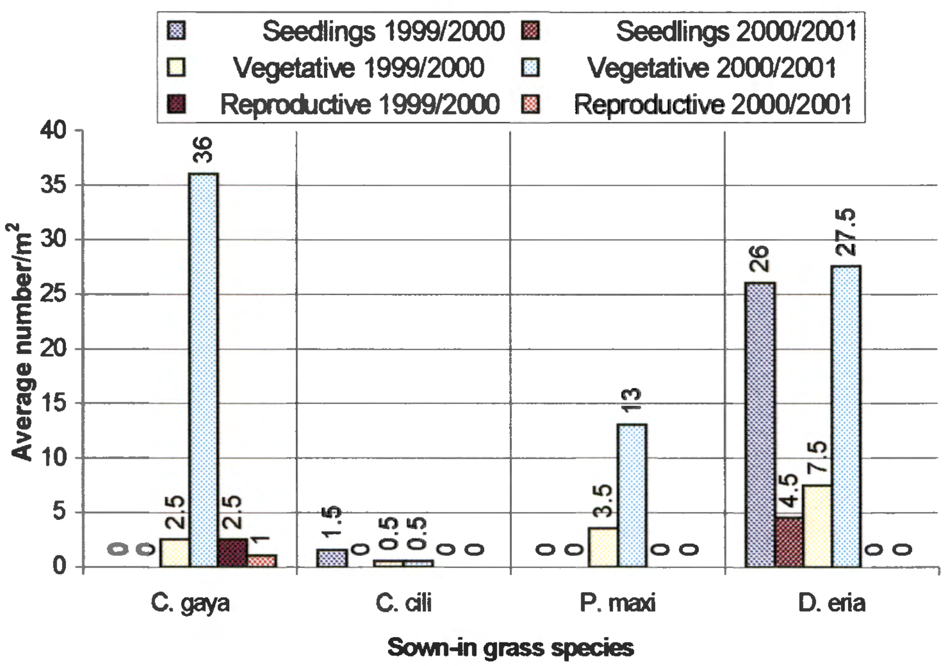

Figure 4.18 The average numbers of plants representing seedling, vegetative and reproductive growth stages of the lime-organic-seed (LOS) treatment SSPGR for the two-year study period (1999 to 2001).

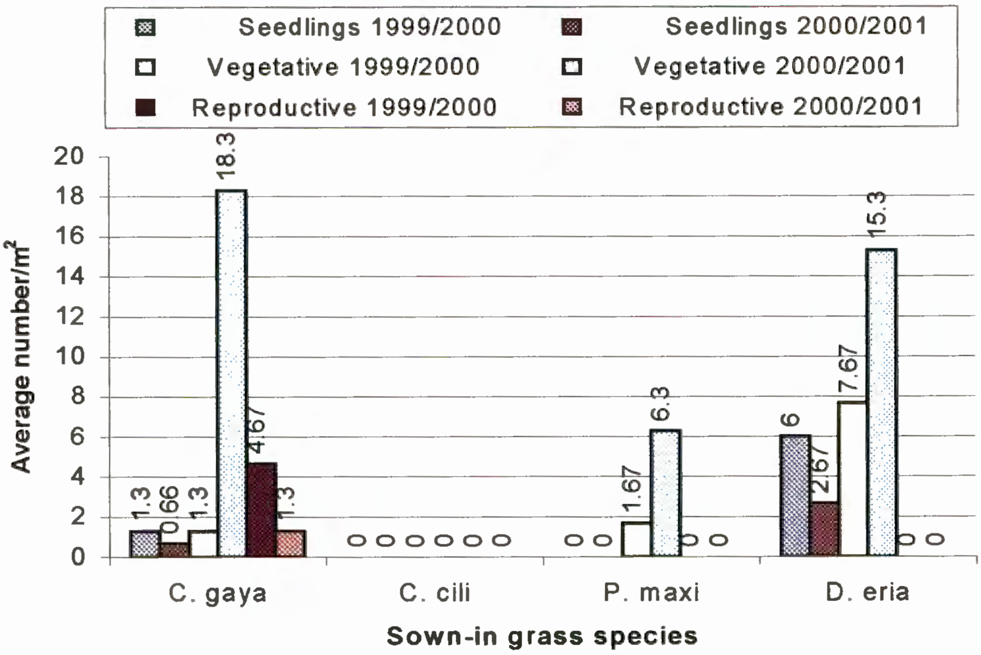

Figure 4.19: The average number of plants representing seedling, vegetative and reproductive growth stages of the lime-organic-seed-brush (LOSB) at SSPGR for the two-year study period (1999 to 2001).

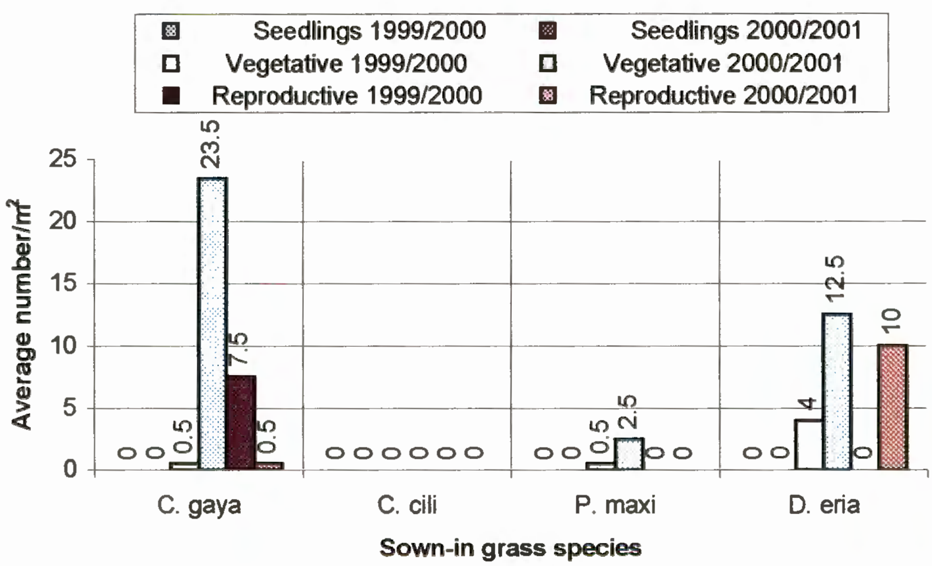

Figure 4.20: The average number of plants representing the seedling, vegetative and reproductive growth stages of the organic-seed (OS) treatment at SSPGR for the two-year study period (1999 to 2001).

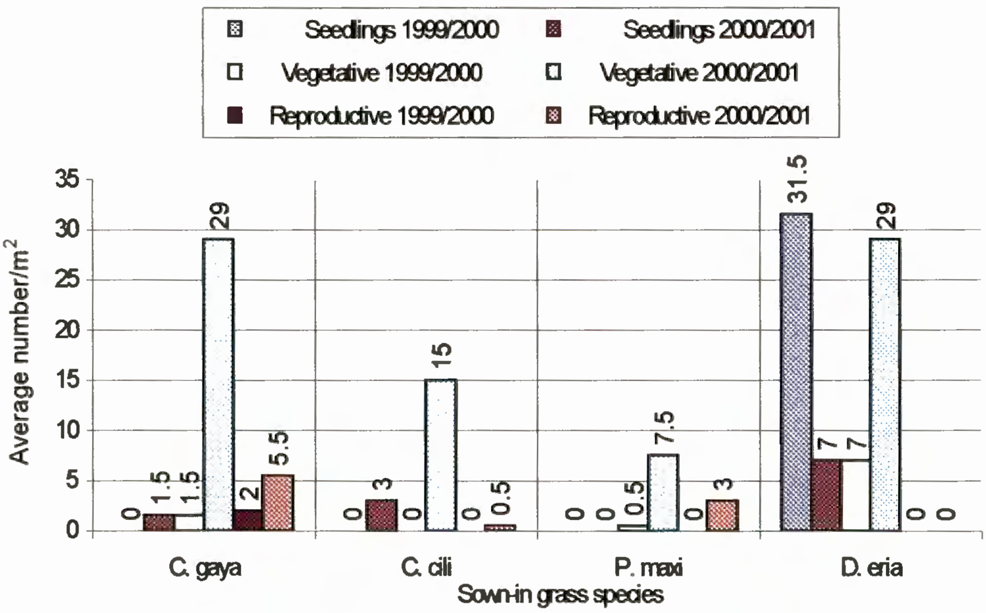

Figure 4.21: The average number of plant representing the seedlings, vegetative and reproductive growth stages of the organic-seed-brush (OSB)treatment at SSPGR for the two-year study period (1999 to 2001).

Panicum maximum was represented in the reproductive stage for the first time. Reproductive growth stages of the sown-in species were found only during the second survey on the treatment plots protected by brush. If sampling would have been carried out for a longer time period better results would have been achieved. *D. eriantha* though decreased in seedlings during the second year, increased in the vegetative growth stage and it is estimated that given enough time, it will even increase in the reproductive growth stage.

4.2.4 Soil type analysis.

The result of the analysis from the different treatment is given in Table 4.9 and graphically represented in Fig. 4.22. Among the soil fractions analysed in the samples, sand had the highest percentage ranging from 61.9% in the LOS treatment to 74% in the L treatment.

The concentration of clay in the E-horizon was relatively higher as compared to the results of the soil analysis from MGR. They ranged from 11% in the lime (L) treatment, 22.7% in the LOS treatment to 24% in the OS treatment. Silt was also included in the soil fraction ranging from 14.0% in the control where no treatment took place (Table 4.9), to 18.4% in the LOSB treatment.

Calcium concentration was the highest among the macro nutrients with 696.5mg/kg in ROSB treatment to 445 mg/kg in the control treatment (Table 4.9 & Fig. 4.22). According to Van Rensburg, (2001), the analytical values of calcium, sodium and magnesium from Sabi Sand were relatively high especially the concentration of sodium and magnesium which gave the soil the characteristics of a saline soil. The high concentration of calcium in the soil on the other hand was rather advantageous because calcium being a divalent, was needed to displace exchangeable sodium into solution and to keep the soil flocculated. The presence of high concentration of sodium and magnesium in the analysis of the soil sample led to the recommendation of the application of lime at the study site. MGR and SSPGR have more or less the same type of soil with regard to sand, clay, and silt but MGR is slightly higher in sand fraction than SSPGR. Generally, all the sites have the same trend with regard to soil characteristics. Therefore, the differences in species could not have been as a result of the initial soil characteristics.

Table 4.9 A summary of the analysis of the soil samples taken from the 19sub-plots of the nine experimental treatments at SSPGR. The macro-nutrients were measured in mg/kg while the soil fractions were measured in percentage (%).

	Average Soil Environmental condition (mg/kg)						Soil fraction (%)		
Treatments	P	K	Ca	Mg	Na	pH	Clay	Sand	Silt
LOSB	5.3	305.0	696.5	314.5	116.5	6.7	15.0	66.7	18.4
LOS	3.1	180.7	611.0	279.3	114.3	6.8	22.7	61.9	15.4
OSB	5.1	222.5	561.5	275.0	97.5	6.5	15.0	68.7	16.3
OS	5.3	220.5	207.0	199.0	109.0	6.5	24.0	66.3	14.8
LB	4.3	178.5	524.0	239.0	86.5	6.5	14.0	69.7	16.3
B	4.7	245.5	488.5	224.5	129.5	6.4	15.0	68.8	16.2
L	5.0	189.0	450.5	216.0	106.5	6.7	11.0	74.0	15.0
R	5.2	375.0	653.0	303.0	121.0	6.5	17.0	66.5	16.5
C	4.3	234.5	445.0	236.0	111.0	6.3	15.0	71.2	14.0

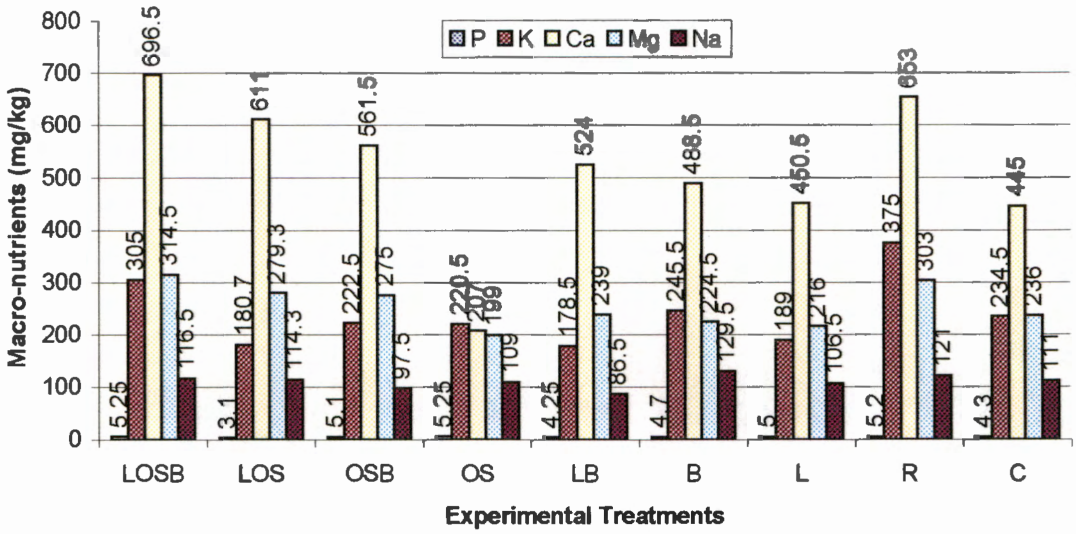

Figure 4.22: The composition of macro-nutrients (mg/kg) in the nine treatment plots at SSPGR (derived from Table 4.9).

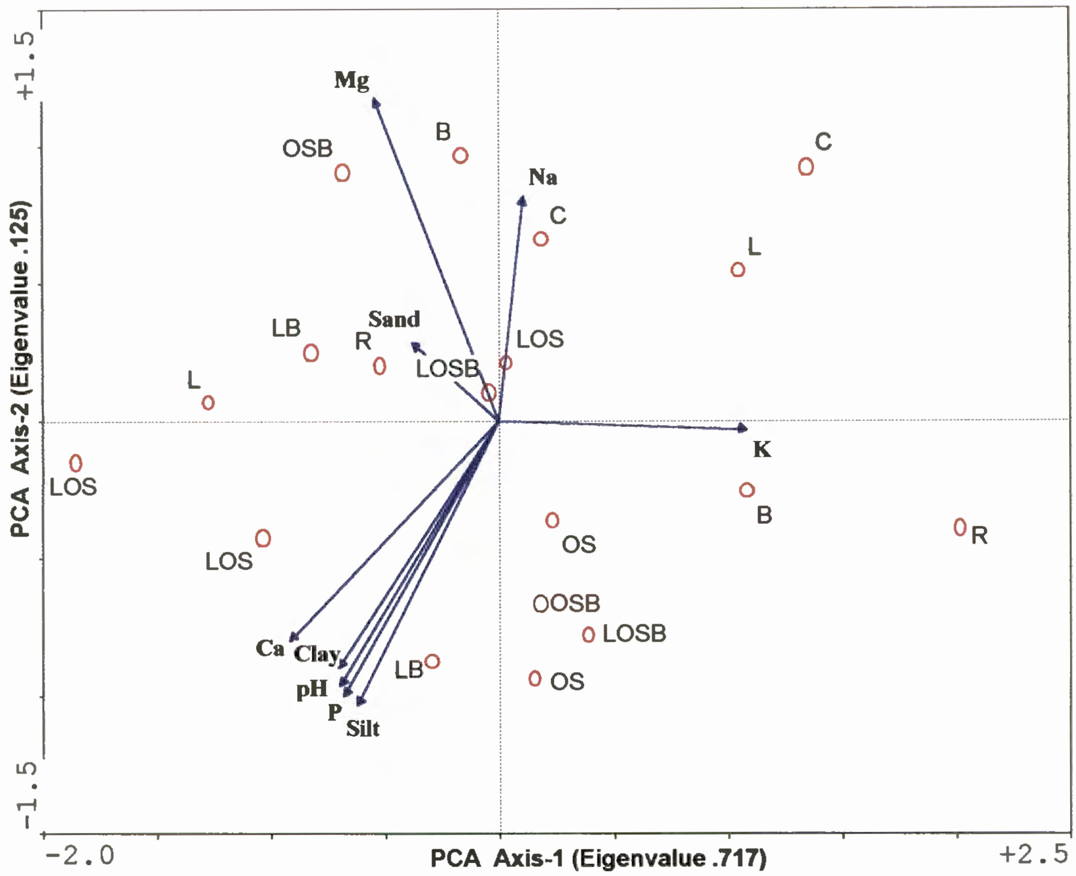

Figure 4.23: PCA ordination graph showing the correlation between soil environment and treatments at SSPGR study site.

According to axis 1 of the PCA ordination graph (Fig. 4.23), treatments B and R are positively correlated to potassium. Magnesium is positively correlated to OSB and B on the second axis. There is a strong positive correlation between sodium, control and LOS treatment. Ca, P and pH value are strongly correlated to clay and silt. The correlation of the macro nutrients in the ordination graph (Fig. 4.23), supports the fact that the soil at Sabi Sand study site is saline and its salinity is greatly linked to the sodium and magnesium concentration of the soil as shown in Table 4.9. The high density and frequency of *S. nitens* in the control (Tables 4.7 & 4.8), and the correlation between control and sodium (Fig. 4.23) confirm the observation made by van Oudsthoorn (1999), that *S. nitens* grows in saline (brackish) soil. This also confirms that the soil at SSPGR study site is a saline soil.

4.2.5 Environmental and soil variables with species frequency and density at SSGPR study site.

The correlation between environmental variables from Sabi Sand study site, are compared with species frequency and density with the environmental variables using a RDA ordination. Data of the second survey(2000/2001) were used. The ordination results are presented in Fig. 4.24 & Fig. 4.25.

According to axis 1 of the species frequency-environmental ordination (Fig. 4.24), sodium is strongly positively correlated to *E. tricophora* and *D. aegytium, S. nitens, U. mosambicensis and C. virgata* are strongly correlated to sand. Other species positively correlated to sand are *C. ciliaris, A. congesta,* other grasses and forbs. *Panicum maximum, C. gayana and D. eriantha* (all sown-in) are correlated to Ca, Silt and clay. Sodium is negatively correlated to Mg.

In the species density-environmental ordination graph (Fig. 4.25), the correlation of the sown-in species with calcium and silt followed the same trend as in the frequency-environmental ordination graph but the interspecies correlation is now stronger. There is a strong correlation between *P. maximum, C. gayana* and *D. eriantha* with the environmental variables calcium and silt. Sand is still correlated to *C. virgata, A. congesta barbicoides, S. nitens* and also to *B. deflexa* and sedge. Sodium is strongly positively correlated to *D. aegytium.* From the two ordination graphs, it can be deduced that Ca with silt or Ca with sand and silt favour the sown-in species *P. maximum, C. gayana* and *D. eriantha*. Sodium favours *D. aegytium.* The high average density and relative frequency of *D. aegytium* (Tables 4.7 &4.8) in all the plots at SSPGR are strongly linked to the high concentration of sodium (Table 4.9) at the site.

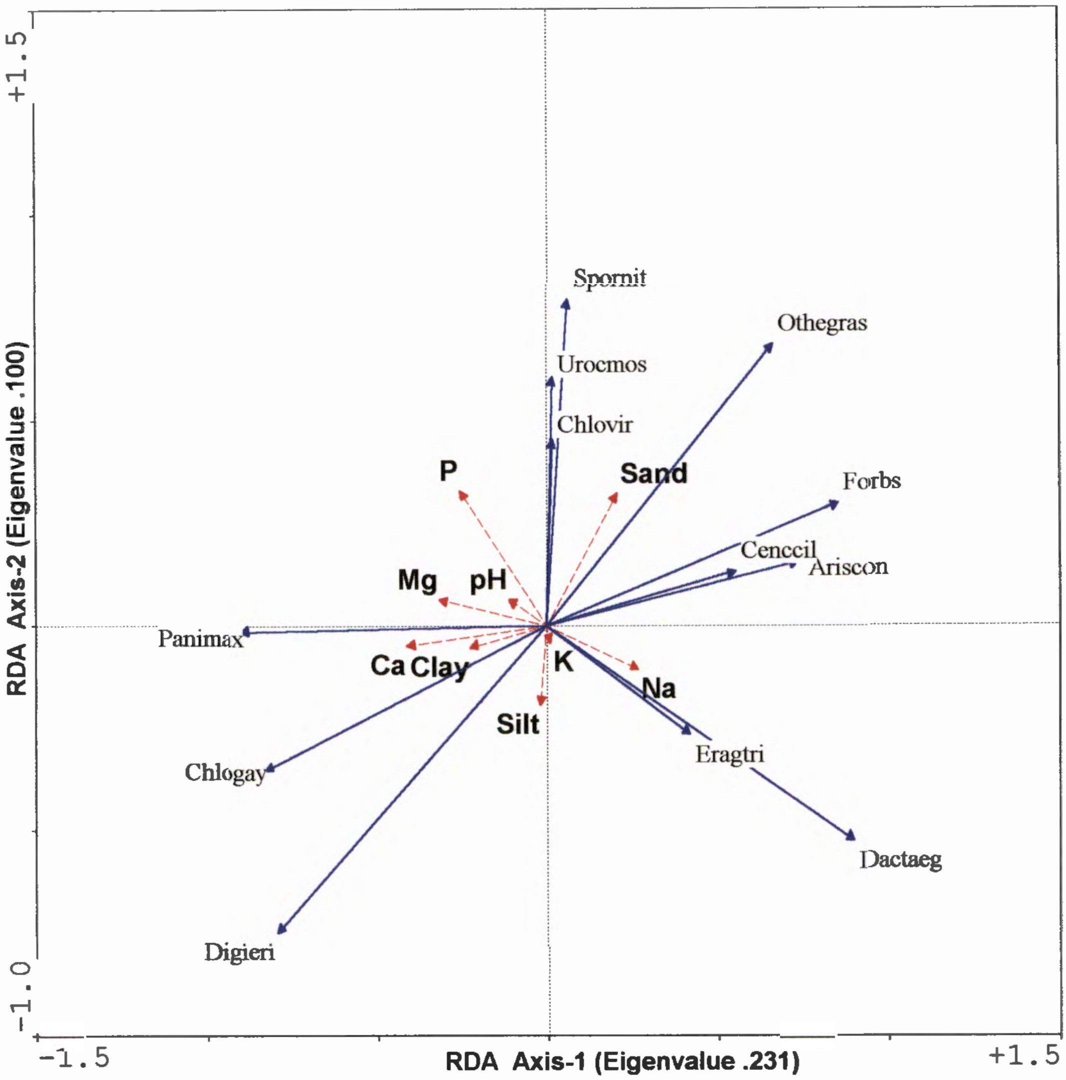

Figure 4.24: Biplot based on redundancy analysis (RDA) showing correlation between grass species **frequency** and **environmental variables** at the SSPGR study site during the second survey in December 2000. (*Chlogay=C.gayana; Cenccil=C.ciliaris; Digieri=D.eriantha; Panimax=P.maximum; Dactaeg= D.aegyptium; Chlovir=C.virgata; Spornit=S.nitens; Urocmos=U.mosambicensis; Ariscon=A.congesta; Eragtri=E.trichophora;* Othegras=Other grass).

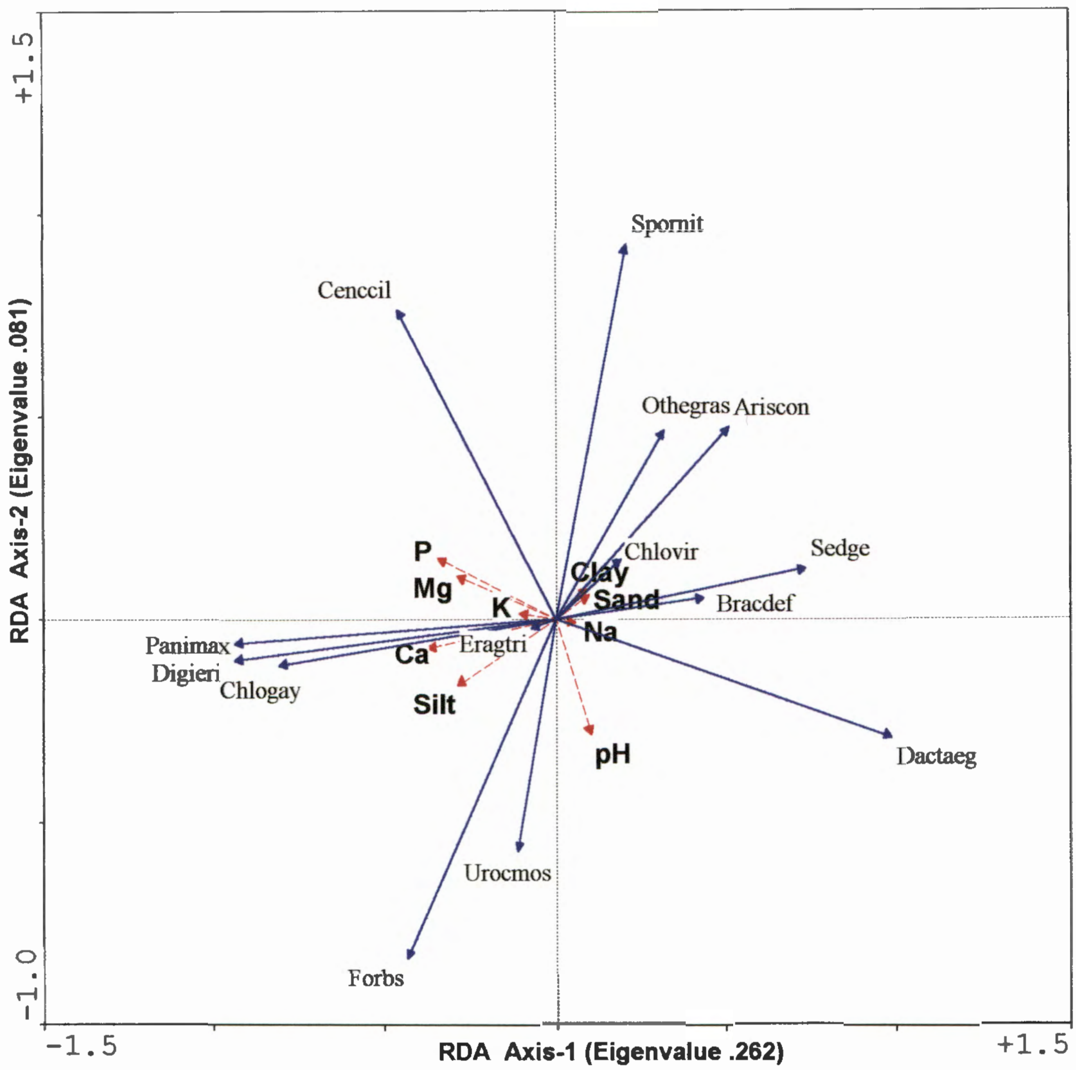

Figure 25: Biplot based on redundancy analysis (RDA) showing correlation between grass species **density** and **environmental variables** at the SSPGR study site during the second survey in December 2000. (*Chlogay=C.gayana; Cenccil=C.ciliaris; Digieri=D. eriantha; Panimax=P.maximum; Dactaeg= D.aegyptium; Chlovir=C.virgata; Spornit=S.nitens; Bracdef=B.deflexa; Urocmos=U.mosambicensis; Ariscon=A.congesta; Eragtri=E.trichophora;* Othegras=Other grass).

4.2.6 Importance Value

The importance value (I V) of the sown-in grass species in the current study, was calculated from the relative frequency and the relative density (See Table 4.10). According to the ranking of the grass species in Table 4.10, the dominant sown-in grass species at Sabi Sand was *C. gayana* followed by *D. eriantha*.

Table 4.10: Importance value (IV) of the sown-in grass species in the sown-in treatments, LOS, LOSB, OSB and OS with their ranks (IV R) calculated from relative frequency (%) (RF) and relative density (%) (RD) during the first survey March 2000 at SSPGR.

Treatments	LOS					LOSB			
Specie	RF	RD	IV	IV R		RF	RD	IV	IV R
C. gayana	10	2.1	12	1		14	1.5	16	1
C. ciliaris	0.7	0	0.7	4		0.5	0.6	1.1	4
D. eriantha	6.3	3.2	9.5	2		3.5	10	14	2
P.maximum	2.3	0.4	2.7	3		5.5	1.1	6.6	3
Treatments	OSB					OS			
SPECIES	RF	RD	IV	IV R		RF	RD	IV	IV R
C. gayana	13	1.2	14	2		16	2.4	18	1
C. ciliaris	0	0	0	4		0.5	0	0.5	4
D. eriantha	4.5	13	17	1		3.5	1.2	4.7	3
P.maximum	1.5	0.2	1.7	3		6	0.1	6.1	2

For the lime-organic-seed (LOS) , lime-organic-brush (LOSB) and organic-seed (OS) treatments, the IV of *C.gayana* was ranked 1. This explains that *C. gayana* is a very good species to have in a seed mixture especially in the short term. It has a higher frequency and density as a result of its stoloniferous growth form. *D. eriantha* was ranked 1 in the organic-seed-brush treatment and 2 after *C. gayana* in both LOS and LOSB treatments. Due to less crown cover in the seeded treatments, the seedlings of *D. eriantha* established well at SSPGR study site and competed with *C. gayana* and other resident species. It was therefore well adapted to this site especially in the OSB treatment where its seedlings were protected from grazing. *Panicum maximum* was ranked 3 in all the sown-in treatments with the exception of OS where it was ranked 2 after *C.gayana*. The establishment of *C. ciliaris* was very poor at SSPGR study site. It was ranked 4 in all the four sown-in treatments.

4.2.7 The response of other grass species in all the treatment plots.

The grass species that were present at the SSPGR experimental site before the ripping treatment included *E. rigidior*, *E. trichophora* and *U. mosambicensis, D. aegyptium* and *S. nitens*. During the first and second surveys a number of other species were encountered but these five species were well represented in most of the sub-plots. *Dactyloctenium aegyptium* and *S. nitens* had relatively high frequencies in the sown-in treatment-plots during the first year but as the sown-in species increased in their basal cover, the frequencies of *D. aegyptium* and *S. nitens* decreased in the sown-in plots while they increased in the other treatment plots (Table 4.7). Like the other two species mentioned above, *U. mosambicensis, E. rigidior* and *E. trichophora,* even though appeared in the sown-in sub-plots, they could not compete with the sown-in grass species but rather established in the other treatment plots with not sown-in treatments. *E. trichophora* and *E. rigidior* were both prominent in the rip-seed treatment plots. They both showed a trend of reduction in the sown-in plots but this trend was also recorded in all the other treatment plots. (Table. 4.7).

The following trend prevailed with regards to species that were not among the seed mixture used in the sown in sub-plots: the LOS treatment was dominated by *D. aegyptium, S. nitens,* and *U. mosambicensis*. In all the plots high numbers of *S. nitens* and *U. mosambicensis* were found. This indicates that the rip cultivation stimulated the establishment and growth of these two and other species. The same species were prominent in LOSB treatment but only in the first year. The highest average relative frequency (%) of *D. aegyptium* in the sown-in sub-plots was recorded in the OS treatment. *Dactyloctenium aegyptium, S. nitens, U. mosambicensis* and *E. trichophora* were also prominent in OSB treatment (Table 4.7).

4.3 Comparison and summary of result between the two study sites: MGR & SSPGR.

The study sites MGR, located on a degraded duplex soil type on a gentle slope, and SSPGR, on an eroded low lying duplex soil, have similar climatic conditions. The loamy sand or sandy loam top soil had been removed by erosion leaving a shallow E-horizon at SSPGR and plot C at MGR (see Fig. 4.26). The depth of the E-horizon at MGR (150mm to 200mm) is similar to the E-horizon at SSPGR but the B-horizon at MGR (140mm to 160mm) is relatively deeper than the B-horizon at SSPGR. The MGR study site represents a fenced restoration site while SSPGR study site falls under the grazed open rangeland condition. Sabi Sand private game reserve (SSPGR) trial had more treatments than the MGR study site trial.

At both study sites the rip plough cultivation stimulated a rapid growth and ground cover especially where colonising species such as *C. gayana* were sown (Fig. 4.27 & Fig. 4.28). The density of the vegetation at SSPGR (the grazed area) was good as a result of the ripping but much less than that of MGR (boma). Due to the lesser vegetation at SSPGR the soil surface at some places was exposed (gaps) (Fig. 4.31).

The lack of equal treatments and replications (which is a short coming in this study) make it difficult to compare the results from the two study sites. Nevertheless, rip-organic-seed (ROS) in MGR can be compared with organic-seed-brush (OSB)In SSPGR as both treatments were ripped and protected from grazing. The ROS with a fence and OSB with brush. They were both treated with the same quantity of seed from the same seed mixture.

During the two surveys the average density of *C. gayana* increased from 37.1 to 41.7 plants/m^2 in ROS but 1.0 to 12 plants/m^2 in OSB; *C. ciliaris* from 17.6 to 24.4 plants/m^2 in ROS but 0 to 6.0 plants/m^2 in OSB. *Panicum maximum* increased from 9.2 to 22.3 plants/m^2 in ROS and 0 to 4.0 plants/m^2 in OSB. Among the sown-in species, only *D. eriantha* recorded a higher average density in OSB (12 to 13 plants/m^2) above that of ROS (0 to 9.1 plants/m^2). Unlike the MGR study site, none of the sown-in species at SSPGR, was recorded in the plots with no over-sown treatment. The absence of *P. maximum* from these treatment plots at SSPGR is an indication that, the site was very degraded with less seeds in the seed bank of the eroded top soil. The density of the vegetation fluctuated with the seasons and grazing intensity but rarely reached even half the levels obtained at the MGR study site, the ungrazed fenced site, during the second survey (see Tables 4.2 & 4.8), an observation also made by Cunningham (1974).

The relative frequencies of the species of the species from SSPGR as compared to MGR followed the same trend as the density results, with higher relative frequencies recorded in MGR. Among the other species which occurred at both sites, only *U. mosambicensis* and forbs were present in all the treatment plots at both study sites. The result from this comparison confirms that the top soil at MGR was richer in seeds from the soil seed bank. It further confirms that apart from *C. ciliaris*, which could not establish in the waterlogged situation, other species protected against grazing with brush, were also negatively affected by the waterlogged situation, which contributed to their low average densities and relative frequencies at SSPGR.

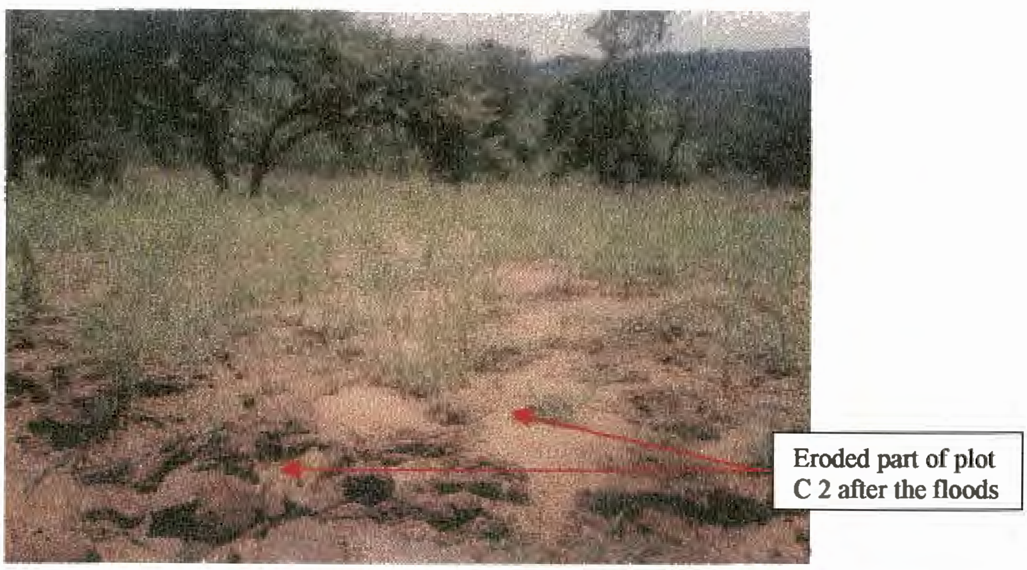

Figure 4.26: A severe erosion at MGR (boma) as a result of rip plough cultivation followed by the flood in February 2000 (see Fig. 4.27, the same area after ten months).

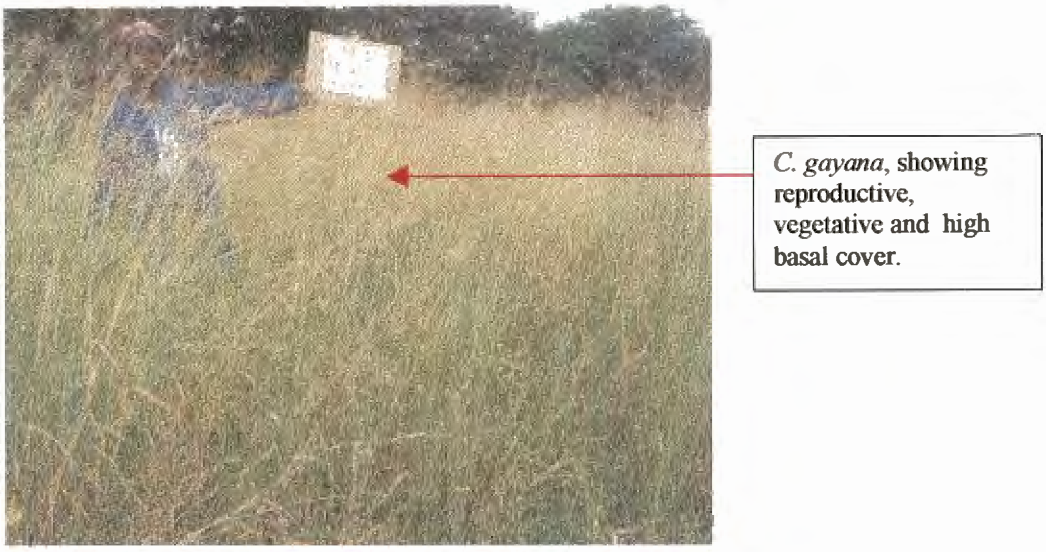

Figure 4.27: A sub plot at MGR (boma) showing the dominant species, *C. gayana* in a rip-organic-seed treatment.

Figure 4.28: A sub plot at MGR (boma) showing the dominant species, *C. gayana* and *C. ciliaris* in a rip-seed treatment.

Figure 4.29: A sub plot at MGR (boma) showing forbs as the dominant species, in the rip-organic treatment.

Figure 4.30: A sub plot at MGR (boma) showing *P. maximum* in a rip-brush treatment.

Figure4.31: A sub-plot at SSPGR showing less basal cover and some bare patches.

The vegetation and the production of organic matter at MGR study site in the rip-organic-seed treatments plots assisted moisture to penetrate the soil. After the 2000 Mpumalanga floods, soil cracking followed water penetration along the furrows in the ripped areas with large amount of soil caving in along sub-plots A4 and C2 (Fig. 4.26). Thus rip plough cultivation, with all its benefits, if not applied at the correct season, can lead to increased erosion and creation of "dongas".

At the MGR study site, *C. gayana* and *C. ciliaris* dominated in the rip-organic-seed (ROS) and rip-seed (RS) treatments. At the SSPGR study site a different picture prevailed, *Chloris gayana,* even though still dominated in some of the sown-in treatments, had less average relative frequency and density. *Digitaria eriantha* was very prominent at the SSPGR study site. It was the dominant species in OSB treatments (Fig. 4.32), co-dominant with *C. gayana* in LOSB treatment and well represented in the other sown-in treatment plots. The *C. ciliaris* was completely reduced or absent in the sown-in treatment plots. This could probably be a result of the study site being either water logged for some months from the floods which prevented the roots from establishing or it could be as a result of overgrazing. *D. aegyptium* and *S. nitens* were not among the grass mixture used in the restoration but benefited greatly from the rip plough treatment method at SSPGR. They dominated most of the treatment plots and the control plots at SSPGR yet both species were less represented at MGR. They might have been destroyed when the MGR study site was sprayed with herbicides one year prior to the establishment of the plots. According to De Wet (1999) an increase in the frequency of *S. nitens* is a sign of degradation due to the reduction of the depth of the E-horizon through erosion.

Figure 4.32: A sub-plot at SSPGR with rip-organic-seed-brush treatment showing *D. eriantha* as the dominant sown-in species prevented from being grazed through brush packing.

A major factor that brought about the higher species establishment at MGR than at SSPGR is the fact that MGR, is a fenced denuded area while the SSPGR site represents an open heavy degraded rangeland. In the case of MGR, the herbicide sprayed a year prior to the trials, removed the problem of competition with other species. The fence played a major role for, it gave the seedlings enough time for root development and a good chance to establish. The site at SSPGR was near a water point, Dam III. This led to the convergence and grazing by the free roaming animals at the study site which in turn prevented most of the seedlings of the sown-in species from developing to a vegetative stage. *Cenchrus ciliaris* for example established only in the lime-organic-seed-brush treatment where the seedlings were protected by the brush from being grazed.

From the results of the two study sites, the following can be deduced:
The rip plough technique in this study proved to be appropriate in restoring a degraded duplex soil types. This technique helped to stimulate the establishment of seedlings from the soil seed bank as well as seedlings of the sown-in species.
Brush packing is a very good technique that protected the seedlings from the soil seed bank as well as seedlings of the sown-in species from being grazed. In the absence of fencing, brush packing is very effective against game animals if the brushes are properly arranged as was explained and done in this study.
The seed in the seed mixture used in this study proved to be very suitable for the restoration of degraded duplex soil types at the two study sites. *Chloris gayana* for example is quicker in colonising bare areas in a short term as was seen at both sites, while *D. eriantha* takes over after two years for a along term establishment and colonisation. The strength of the rooting system of *C. ciliaris* in binding soil particles and reducing erosion was demonstrated at the MGR study site. The application of organic matter helped to restore the lost nutrients in the shallow E-horizon at both sites.
The combined ecological importance of all the techniques used in this study in restoring degraded duplex soil types is clearly portrayed through the results from both sites.

Chapter 5

Conclusion and recommendation

5.1 Introduction

According to Van Oudtshoorn (1999), grasses are adapted to specific environmental conditions. Changes in the grass species composition is linked to changes in environmental condition. This sensitivity to specific environmental conditions makes grasses good indicators of range condition and they are therefore used as such.

It is clear from this study that duplex soils are beset with serious physical and chemical problems especially in the Mpumalanga Province in South Africa. The unfortunate part of these problems is that, most of the land users, especially in the communally managed areas, seem not to realise the seriousness of the situation. Due to lack of awareness and ignorance, the land users tend not to comment on the predominant processes and environmental factors that produce and ameliorate them. It is therefore very important to include an awareness and educational programmes in the next research project with regard to the productivity of degraded lands in the short term and to its sustainability it in the long term.

The two study sites for this investigation fall within a duplex ecological unit (a shallow sandy surface or E-horizon which overlies a prismacutanic horizon) in Mpumalanga Province in South Africa. The problem with this type of soil is that during heavy rainfall, the underlying clay layer absorbs water and swells up blocking further infiltration. This leads to more water accumulating at the surface of the B-horizon. The E-horizon, which is then separated from the B-horizon by the water, is easily eroded, leading to the formation of gullies and "dongas", loss of plant nutrients (soil organic materials), poor water infiltration, destruction of macro and micro pore spaces, poor aeration and vegetation cover. A loss in vegetation cover will increase the possibility of serious degradation effects. If degradation has past a certain threshold, the possibility for recovering by normal successional processes is highly unlikely. The recovery process, especially higher vegetation cover and biodiversity will only be enhanced by certain restoration treatments.

According to Oades *et al.*, (1981), duplex soils are characterized by low organic matter contents and are acidic in the higher rainfall areas.

As any restoration practice is expensive, the most appropriate technology must be implemented in order to cut cost and achieve results in the shortest possible time. Having cost reduction in mind, the brush packing and application of organic matter (buffalo and rhino dung) techniques which are considered to be relatively less expensive technologies were used. These were done to enhance the achievement of some of the objectives stated below.

The **objectives** of this study therefore were:

1. To evaluate a number of restoration technologies and strategies, in the restoration of degraded duplex soil types.
2. To evaluate different grass species that can be used for restoration in degraded duplex soils, and
3. To use the plots as demonstration sites for raising awareness to local communities, range managers, farmers and researchers .

- To address the above mentioned objectives, demonstration sites were established in which a number of restoration technologies, which include over-sowing practices were evaluated.
- The demonstration sites were established at MGR and SSPGR representing degraded duplex type of soil.
- The density, frequency and population dynamics of the sown-in species were monitored over two seasons (the 1999/2000 season in March 2000 and 2000/2001 season in December 2000).

5. 2 Restoration technologies at the two study areas

In this study, the two sown-in treatments rip-organic-seed (ROS) and rip-seed (RS) were carried out at Mthethomusha game reserve (MGR), the fenced sited. Four sown-in treatments, LOSB, LOS, OSB and OS were involved at SSPGR. All these plots were treated with ripping. The rip plough treatment was effective and promoted the establishment and growth of all the species but the control plots, where ripping never took place, had a lower species richness during the 1999/2000 and the 2000/2001 seasons (Table 4.8). The rip plough cultivation method improved the soil conditions for better seedling establishment.

Application of organic material in plots at both study sites had a positive effect in reducing competition from resident species (SSPGR) with the sown-in species. The sown-in species developed larger tufts than the resident species. This observation supports the findings of Sheley *et al.* (1999). It must be remembered, that one of the aims was to increase the productivity for higher grazing value and capacity with this restoration. It was therefore important to increase the establishment and abundance of large tufted, palatable, decreaser type of species. The rip plough cultivation method and organic material treatment successfully established a climax perennial grass cover (Fig. 4.33 & Fig. 4.34). Rip plough cultivation at both sites stimulated the germination and establishment of most species in the soil seed bank which led to higher resilience in all treatment plots except the control plots.

It was observed that *C. gayana, C. ciliaris* and *D. eriantha* at SSPGR responded rapidly in sub-plots with rip-organic-seed application as compared to rip-seed application. This is due to the good influence of organic material on the soil which include, improvement of soil structure, reduction of soil erosion, regulating effect on soil temperature, reduction of plasticity, cohesion, and stickiness of clay soils and helping the soil to store more moisture (FAO)[3]. According to Berendse (1990), the accumulation of soil organic matter leads to an accelerated increase in nitrogen mineralization during succession. In this study, the increase in nitrogen supply through the application of organic treatment, favoured the fast growing perennial and other grasses, (in this case the *C. gayana*, *P. maximum* and *C. ciliaris*). The disadvantage is that these grasses can out-compete a great variety of slow-growing species adapted to nutrient-poor soils resulting in a strong decline in plant species richness (Bakker & Berendse, 1999).

The difference between the relative frequencies of all the sown-in species with the exception C.gayana in the two treatments OSB and OS could be the brush packing effect. It prevented the grazing of the seedlings in OSB. This is a good indication that, for a better establishment of species in the restoration of degraded rangelands

[3] Food and Agriculture Organization of the United Nations. Land and Water Development Series, No.8. Rome, Italy.

which are not fenced, brush packing is an appropriate technique that could be used in protecting the seedlings from the grazers and allowing them to develop into vegetative and reproductive stages.

The analytical values of the environmental variables from MGR study site indicated a slight deficiency in phosphorus (Fig. 4.9; Table 4.5). The percentage of sand fraction at MGR is also high which led to the leaching of phosphorus at the site. At SSPGR the concentrations of Na and Mg were higher than they were at MGR.
This confirms the salinity of the area hence the application of the dolomitic lime. However, the application of dolomitic lime did not have any major effect on the species diversity and density because the same treatment components with no lime application were even richer in species composition and density (Table 4.3). A closer observation revealed that, the magnesium content of the soil at the SSPGR study site was relatively higher than that at MGR study site (Tables 4.5 & 4.9), which means that the salinity of the soil at the SSPGR could have been contributed jointly by the excess of magnesium and sodium ions (see section 3.2.2.3). In future, restoration at Sabi Sand private game reserve, the application of gypsum should be recommended instead of dolomitic lime because gypsum (CaSO42H2O) is soluble enough to maintain Ca at a useful concentration (Brady & Weil, 1996; Jayawardine & Blackwell. 1985; Van Rensburg, 1999).

The distribution of the sown-in grass species at SSPGR was associated with specific macro-nutrient elements. *C.gayana*, *P. maximum* and, *D. eriantha* are strongly positively correlated to Ca during the first and second surveys. *D. aegyptium* and *E trichophora* establish well in sodium rich soil, while *S. nitens, U. mosambicensis and C. virgata* are positively correlated to a more sandy soil (Figs. 4.27 & 4.28).

5.3 Grass species dynamics

The sown-in grass species responded to the rip-organic treatment so well that their establishment overshadowed and out-competed the other species from the soil seed bank and prevented them from establishing. The increase in crown, basal cover and species richness in these two treatments were lower than the other treatments with no oversowing. However, the grass species richness at SSPGR was higher among the sown-in treatment plots. The higher species richness at SSPGR is due to the fact that, the site was not bare before the ripping cultivation so there were residence species already in place. Furthermore, the competition in the sown-in treatment plots was not high because a lot of gaps existed among the sown-in species for other species to establish and grow. It should be noted once more that all the treatment plots were ripped with the exception of the control plots.

At MGR study site, in both sown-in treatments (rip-organic-seed and rip-seed), the dominant grass was *C. gayana* (Table 4.4). Even though *C. gayana* was the dominant species, according to Friedman ANOVA test, the increase in its total density for the two year period was not significant. However it had a significant increase among the five treatments during the first survey and the second survey as indicated by the Kruskal-Wallis ANOVA test. *Chloris gayana* was outstanding in its rapid response to both rip plough cultivation and organic material treatment by spreading to cover the soil surface. The growth pattern of *C. gayana,* ensured that its stems (stolons) and leaves interacted with the flow of water at the ground surface. This resulted in higher interception, storage and higher volume of water for infiltration. this also proves that *C. gayana* is indeed a species to be used as a soil stabiliser, especially during the first 2-3 years of restoration where bare patches are still present. It also provided greater roughness on the flow of air and water, reducing its velocity. Other species with significant increase at MGR study site included *C. ciliaris*, *D. eriantha* and *P. maximum*. *C. ciliaris* had a significant increase in the total density among the five treatments during the first season as well as the second season. *Digitaria eriantha* had no significant increase among the different treatments during the first year but quite a significant increase in the second year. According to the ANOVA/MANOVA test, *P. maximum* and *D. eriantha* were the only species among the sown-in species, that had a significant increase during the two year study period.

In the case of SSPGR study site, *D. eriantha* followed by *C. gayana* became the dominant grass among the sown-in grass species. In the sown-in treatments, *D. aegyptium* and forbs, even though were not among the sown-in species, benefited from the rip plough treatment and became the dominant species. One of the shortcomings of this study is that the frequency and density data from SSPGR were unfortunately not in triplicate and could not be used in statistical analysis.

The growth and death of plants after germination through time and space is one way of measuring the sustainability of a plant population. The presence of all three growth stages, seedling, vegetative and reproductive, was regarded as an indication of a healthy, sustainable population in this study.

At the MGR study site, three out of four of the sown-in species, *C. gayana, C. ciliaris* and *P. maximum*, were represented in all the three growth stages in the rip-organic-seed treatment in both 1999/2000 and 2000/2001 seasons. In the rip-seed (RS) treatment however, all the four sown-in species including *D. eriantha*, were represented in all the three growth stages in both seasons (Table 4.3 & 4.4; Fig. 4.7 & Fig. 4.8). The reason why *D. eriantha* was not so prominent in the first season is that it is known to have a higher germination percentage in the second year after sowing (see 4.1.3). Its relative higher density in the seedling and vegetative growth stages in the RS treatment during the second season confirms the observation made by Dannhauser (1987) and Fair (1986).

At the SSPGR study site, only one out of four of the sown-in species, *C. gayana* was represented in the seedling, vegetative and reproductive growth stages in the organic-seed and lime-organic-seed-brush treatments in both 1999/2000 and 2000/2001 seasons. It was followed by *D. eriantha* which, though was not represented in the reproductive stage, had a relatively higher abundance in the seedling and vegetative stages in both the lime-organic-seed-brush (LOSB) and organic-seed (OS) treatments (Fig. 4.22 & Fig. 4.23) for both seasons. Given enough time, *D. eriantha* would have been represented in the reproductive growth stage. This is due to the fact that the seeds of *D. eriantha* take a longer time to germinate (Dannhauser, 1987; Fair, 1986).

It is known that *D. eriantha*, once established will be a vigorous grower with a high competitive ability, suppressing species occurring with it for a long time. *C. ciliaris* and *P. maximum* were not represented in all three growth stages in any of the sown-in treatments, and are therefore not considered as sustainable populations. The poor establishment of *C. ciliaris* could be attributed to the fact that it is a deep-rooted grass that prefers a deeper B-horizon (see section 3.1.3). The shallowness of the depth of the B-horizon at SSPGR (see section 3.3) could therefore not have been conducive.

On the other hand the soil at MGR study site was the ideal soil for its establishment.

A major factor that brought about the higher species establishment and sustainability at MGR (boma) as compared to SSPGR (see Figs. 4.34 & 4.38) is the fact that MGR study site was fenced and the species were not subjected to grazing. The ratio between palatable and unpalatable species therefore increased in the direction of palatable species supporting the findings of Kellner (1995). The fence played a major role at MGR, it gave the seedlings enough time for root development and a good chance to establish with no interference from animals. The SSPGR study site on the other hand, represented an open heavy degraded area. The grazing of the free roaming animals at the study site prevented most of the seedlings of the sown-in species from establishing and developing into vegetative and reproductive stages. *C. ciliaris* for example established only in the lime-organic-seed-brush treatment where the seedlings were protected by the brush from being grazed (Table 4.8). It is therefore recommended that restoration sites in game reserves and communally managed areas should be fenced or be subjected to the brush packing treatment technique if over-sowing treatment is involved.

Adaptation of species: *U. mosambicensis* and *P. maximum* were present in most of the sub-plots in MGR and SSPGR. This is an indication that they are widely adapted to these areas and possibly to this soil type, duplex soil. The distribution of the sown-in grass species was also correlated to specific macro-nutrient elements. The macro-nutrient elements, calcium and magnesium were strongly positively associated to clay and positively correlated to *P. maximum*, *C. gayana* and *C. ciliaris* in sodium-rich soils (Figs. 4.1 & 12).

5.3.1 Grass seed mixture in over-sowing treatment

Sabi Sand is a low lying area with lots of water but no run-off leading to water logging of the low-lying site. This could have negatively influenced the establishment of *C. ciliaris* and the other sown-in species as they are not adapted to these conditions.
According to Figs. 4.22 & 4.24, only *C. gayana* and *D. eriantha* had viable population in SSPGR study site, and only if protected by branches through brush packing.

5.3.2 Other grasses

The frequency of species, at Mthethomusha game reserve, characterized by the presence of low ecological status species, such as *Aristida congesta* sub species *barbicollis, Melinis repens* and *E. trichophora* (Table 4.1) decreased because of the rip plough cultivation method. These species are mostly weak perennials that sprouted from the soil seed bank after being stimulated by the rip cultivation. As weak perennial species, most of them died after the first season and were not encountered during the second season.

Considering the soil and climatological information and the grass species that had benefited from the rip plough cultivation method, the following species are recommended for restoration of degraded areas of similar environmental conditions: *C. gayana, C. ciliaris, D. eriantha, U. mosambicensis, C. dactylon* and *E. rigidior*. A mixture of these types of grass covers a wide range of uses, providing highly palatable grasses (*P. maximum, U. mosambicensis and C. ciliaris),* supplementary fodder (*E. curvula* and *E. rigidior.*) and stabilising agents (*C. gayana, C. dactylon and E. trichophora*), and increasing the overall species richness and ecological stability. In the short term, all the sown-in species excluding *D. eriantha* are viable populations which is a good sign for enriching the soil seed bank.

It is therefore recommended that, instead of oversowing only the four grass species in the mixture used in the current study, some of the above mentioned species can be added, and especially if the objective is for a rapid prevention of erosion then the *C. gayana* fraction in the seed mixture can be increased to allow a quick but temporary colonization of the area by *C. gayana* before species like *D. eriantha* establishes and dominates as expected. It is further recommended that due to the high sand fraction in the soil at MGR study site, rip plough cultivation should be done in September to allow the seedlings to establish and cover the soil surface before the summer rains, between December and March (see Figs. 2.2 & 2.4). The loosening of the soil will stimulate the rapid establishment of the sown-in species which will in turn prevent the entire ripped area from being eroded (see Figs. 4.33 & 4.35). This will depend on the moisture regime of the soil and conditions favorable for the seedling to establish and colonize the area before the summer rains. As for MGR, the frequency of species, at SSPGR, characterized by low ecological status species, such as *A. congesta* sub-species *barbicollis*, and *Melinis repens* (see Table 4.7) decreased because of the rip plough cultivation method.

At SSPGR a lot of vegetation which, included *D. aegyptium* were present before the treatment. This could have been a contributing factor to the high abundance of this species (dominant species) which could also have influenced the establishment of the sown-in species due to too much competition between the already existing species at the site.

One adverse effect on restoration is that in most cases these species are more adapted for the establishment of cultivated pastures for which the seed beds are prepared with high fertilizer inputs, and not for restoring degraded natural pastures with low soil nutrients. Purchasing of seeds from merchants also makes restoration very costly over the short-term. Choosing the correct and most adapted species and seed mixture for a particular environment is therefore of the utmost importance. Furthermore, instead of oversowing all four of the grass mixture used in the study, only *D. eriantha*, *C. gayana,* and *P. maximum* can be used, because *C. ciliaris* did not establish at this study site. This will also reduce the cost.

5.4 Recommendation for restoration

From the above mentioned results it is recommended that the following restoration techniques be used in degraded duplex type of soils.

- Using rip-organic (RO) treatment. At least rip plough cultivation should be implemented to stimulate the soil seed species.
- Rip-organic-seed(ROS) treatment. If seed is used then the species *C. gayana* which an ideal species for 2 to 3 years for soil stabilization.
- For a viable, sustainable population for a long term, species which are represented in seedling, vegetative and reproductive growth stages are required. For this purpose, *C. gayana, C. ciliaris, P. maximum* and *D. eriantha* are recommended.
- Restored sites have to be protected against grazing either by fencing or brush.
- For soil amelioration of these high sodic soils gypsum is recommended instead of dolomitic lime.
- Considering the soil (environmental) and climatological information and the grass species that had benefited from the rip plough

cultivation method, the following species are recommended for restoration of degraded areas of similar environmental conditions: *D. eriantha*, *C. gayana*, *D.* aegyptium, *U. mosambicensis, C. dactylon, E. trichophora* and *E. rigidior*.

- Seeds of these grass species, however, are not easily obtained in large quantities. In game reserves where the animals have free access to the entire land, most grass species are grazed at their vegetative stages and not allowed to flower and produce seeds. Seed companies do not sell most of these seeds and harvesting them manually by the land users themselves is too labour- and cost intensive. With restoration, land users therefore have no alternative but to rely only on seeds that are available from seed companies.
- If the soil seed bank analysis indicates sufficient seedlings in the seed bank, only rip or rip-organic will be enough to increase the abundance of species such as *P. maximum, D. aegyptium, U. mosambicensis, E. trichophora* and *E. rigidior*.
- Do not use *C. ciliaris* in a water logged area,

5.5 Demonstration site for awareness raising

There are several reasons why restoration fails:
(1) the multivariate conditions of restoration sites, which seems forbidden to the scientists desire for the precise experimental setup for basic research, rather than a more applied approach that serves the needs of the land user and complies with the complexity of ecosystem functioning. (ii) Restoration demands a long-term research, which does not accommodate academic and research institutes budgets as well as the need for interdisciplinary collaboration. (iii) Ignorance by land users about this "new" concept of restoration and inadequate understanding of the principles of ecosystem and restoration functioning. (iv) Negative short term cost-benefit ratios once restoration has been applied. (v) The absence of proven techniques that the land user can refer to before applying a certain restoration technology. (vi) Insufficient collaboration and co-operation among all parties involved in restoration efforts – failure to implement all aspects of the restoration plan and a lack of a bottom-up, grassroots, community-based, participatory approach, especially in the unprivileged and undeveloped communally managed areas in Africa (Kellner, 2000). It is therefore of utmost importance to involve the local land users in every restoration attempt.

The land users at both sites were deeply involved in the setting up of the demonstration sites. At MGR (boma), the Range manager took part in ripping the soil (Fig. 3.3). The Parks Board officials in charge of the Buffalo project at the boma, supplied the buffalo dung for the organic material treatment and the truck for transporting the woody branches for the brush packing. At SSPGR, the officials from Inyati Game Lodge and Ulusaba Lodge, who jointly share the management of the study site, took part in the ripping cultivation, the collection and application of the organic matter (rhino dung) as well as the application of lime. Rangers were always present when work was being done at the field and in some instances rangers from Ulusaba lodge were also involved in the monitoring. There were constant consultation and discussion with range managers at meetings before and during the site establishment.

Figure 5.1 Members of the local community contributing to the setting up of the restoration site at MGR study site.

Some members from the local community around MGR were at first employed to cut branches for the brush packing as a form of job creation. They contributed greatly towards the setting up of the restoration site (Fig. 5.1) and were later trained to do the brush packing (Fig. 3.6) and monitoring throughout the two monitoring seasons 1999/2000 and 2000/2001 (Fig. 3.9). They were later encouraged to implement and also show others in the community, the restoration technology they have acquired through their involvement at the study site. The period for the study was too short to involve other stake holders such as agricultural extension workers, schools (learners and educators) and farmers at the demonstration sites for the awareness and education and training programme. Community involvement through the awareness programme was to follow at a later stage but, due to time constraint that did not form part of this study.

5.6 Areas for further research and recommendations.

- At present, South African scientists rely heavily on overseas criteria, especially those of Australia, Europe and USA to gain insight into problems pertaining to the field of physical land degradation, including **duplex soils**. In view of the fact that there is a vast difference between South African soils types and climate and those of the countries mentioned above, it is very important to establish a local criteria. It is known in South Africa that more research is being done in the cultivation agricultural sector on duplex soils, however, this is not extended to the open, natural rangelands.
- Most research in South Africa has concentrated on other soil types but less on duplex soil types so in future, greater emphasis should be given to research on duplex soils especially in Mpumalanga province.
- Past experience shows that there is no single factor, or even 2 or 3 factors which can be addressed to overcome problems in crop production in duplex soils (Gardner, *et al.*,1992). Instead, a systems approach to conservation land management at game reserves and farm level at both communal and commercial must be developed and applied so that factors affecting the soil's physical, chemical and biological fertility are adequately addressed.
- For a better interpretation of the results over the long term, more than two samples for frequencies, densities and environmental surveys per growing season should be done over a longer time period in different seasons.
- Restoration technologies applied need to be monitored over a longer time period in different and more seasons.
- An in-depth economic analysis must be done for all the restoration practices applied.
- In future, research on more soil sample analysis should be done. This must indicate the CEC and the nitrogen content of the soil.
- In future research, seed purity and seed germination test as well as soil seed bank analysis should be carried out in advance in order to incorporate their results into the final result.

The aims for restoration as stated above include the increase in vegetation cover, increase in production for higher grazing capacity and reducing the rate of erosion. Among the problems of the study sites for this study were how to reduce erosion (at MGR) and increase vegetation cover, and increase production for higher grazing capacity. Different restoration techniques (see 3.1.2 & 3.2.2) were applied at the sites to find out which of them were suitable for the site. Among the restoration techniques employed at both sites were rip cultivation, brush packing, lime application, oversowing of treatment and application of organic material. Enhanced seed of *C. gayana, C. ciliaris*, *D. eriantha* and *P. maximum* were also used. The restoration at both sites was carried out for a two-year period.

Some short comings encountered, among which were unequal application of treatments at both sites. This made the comparison of some of the treatments at both sites impossible. For example, lime application at SSPGR study site, which was not applied at MGR study site could not be compared. Secondly, the unequal number of replicate of treatments at both sites made it difficult to compare the statistical analysis of both sites.

It was part of the objectives to use the sites as demonstration sites for awareness programme for the rural communities, land owners and agricultural extension offices. Due to time constraints, this part has to be done at a later stage and therefore could not be included in this study.
Both sites of the current study are located in remote parts of Mpumalanga and require special transport (4-wheel drive) to get there. This made visits to the sites more expensive, a factor that caused visits to the sites to be curtailed.

Despite all these shortcomings and constraints, the result of the two-year study period at both sites has proved to be a success. The erosion at MGR study site was brought under control four months after the restoration. This is due to the effect of the rip cultivation and organic treatments at the site causing a rapid colonization of the sown-in species and species from the soil seed bank. This was confirmed by the land users, Mpumalanga Parks Board officials in charge of the boma. They even requested that the grass at the MGR study site should be cut to a manageable height immediately after the second survey. According to them, the erosion at the site was well under control due to the vegetation cover as a result of the restoration.

The fact that the species composition in both study areas improved (see sections 4.1.2 & 4.2.2), proves that the restoration of the veld condition at both study sites had a positive effect on the pasture. Even though the two-season monitoring period is too short a time to give a clear indication of a long term outcome of the study areas, with proper management and the right climatic conditions, the grazing capacity especially at SSPGR study site should improve.

The experience from the current study at both sites have shown that with proper restoration techniques, most of the degraded areas in Mpumalanga and South Africa as a whole can be scientifically restored. It was also noted that computer programmes such as CANOCO (Ter Braak, 1987-1992) and STATISTICA for windows (Statsoft, Inc., 1999) are appropriate tools to aid restoration programmes. The positive results from this study have also shown that most of the degraded rangelands in the previously disadvantaged areas can be restored if the appropriate restoration techniques are used.

CHAPTER 6

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