The evaluation of different technologies to restore old cultivated lands

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Genesis 1 (1769 King James Version of the Holy Bible)

Gen. 1: 1: In the beginning God created the heaven and the earth.

Gen. 1: 26:. And God said, Let us make man in our image, after our likeness: and let them have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth. 27. So God created man in his *own* image, in the image of God created he him; male and female created he them. 28. And God blessed them, and God said unto them, Be fruitful, and multiply, and replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth. 29. And God said, Behold, I have given you every herb bearing seed, which *is* upon the face of all the earth, and every tree, in the which *is* the fruit of a tree yielding seed; to you it shall be for meat. 30. And to every beast of the earth, and to every fowl of the air, and to every thing that creepeth upon the earth, wherein *there is* life, *I have given* every green herb for meat: and it was so. 31. And God saw every thing that he had made, and, behold, *it was* very good. And the evening and the morning were the sixth day.

This dissertation is dedicated to my wife Annette and two daughters Annabelle and Angélique.

Uittreksel

Die evaluasie van verskillende tegnieke om ou landerye te restoureer

Soos wat die produksiekoste vir die verbouing van kontantgewasse styg en die regerings subsidies aan boere minder geword het en eventueel beïndig is, het die boere opgehou om die medium en lae potensiaal lande te bewerk. Die hedendaagse hoë insetkoste kan nie op die lande verhaal word nie. Van die lande is net gelos en lê braak vir 'n aantal jare. Gevolglik raak dit onproduktiewe landbougrond, wat nie vir gewas of diereproduksie gebruik word nie, aangesien dit so te sê geen weidingswaarde het nie (geen ekonomiese waarde nie).

Die volgende restourasietegnieke is toegepas in die twee ry wydtes (0.75m en 1.5m), met en sonder die toediening van Roundup: Kontrole, Rip; Rip en organise material (beesmis); Rip en hersaai (saadmengsel); Rip, organisie material en hersaai (saadmengsel); Rip en hersaai (*Digitaria eriantha*) en die vestiging van kovensionele *Digitaria eriantha* weiding.

Die ou landerye het vir ongeveer tien jaar braak gelê en die plantgemeenskap het hoofsaaklik grasspesies, soos *Aristida congesta* en *Eragrostis lehmanniana* bevat. Ander meerjarige grasspesies, soos *Themeda triandra* en *Cynodon hirsutus* het in kolle voorgekom.

Die suiwerheid van die saad in die saadmengsel gebruik is, het soos volg gewissel: *Cenhrus cilliaris* (97.9%), *Digitaria eriantha* (96.0%), *Eragrostis curvula* (95.4%), *Eragrostis chloromelas* (91.3%), *Chloris gayana* (85.6%), *Panicum maximum* (84.3%), *Themeda triandra* (72.5%) *en Cymbopogon excavatus* (44.7%). Die ontkieming van die saad het, soos volg gewissel: *Eragrostis curvula* (86%), *Themeda triandra* (76%), *Eragrostis chloromelas* (48%), *Cenchrus cilliaris* (35%), *Chloris gayana* (29%), *Digitaria eriantha* (19%), *Cymbopogon excavatus* (13%) en *Panicum maximum* (4%).

Die tandlosmaak (rip) aksie (al twee ry wydtes), het 'n positiewe invloed op die groei en vestiging van al die grasspesies gehad, veral die ingesaaide spesies.

Van al agt die ingesaaide spesies het net *Themeda triandra*, *Digitaria eriantha* en *Eragrostis curvula* goeie resultate gelewer. Die gebruik van organiese materiaal het gehelp met die aanvanklike vestiging van die ingesaaide grasspesies, maar die effek het oor die drie seisoene afgeplat.

Die smaller rye het die ingesaaide grasspesies bevoordeel, terwyl ander grasspesie soos *Eragrostis lehmanniana* deur die wye rye bevoordeel is.

Die vestiging van die konvensionele *Digitaria eriantha* aangeplante weiding was nie suksesvol nie en geen verklaring daarvoor kon gevind word nie.

Die gebruik van onkruiddoder het gehelp om die interspesiekompetisie tussen die saailinge (ingesaaide grasspesies) en die huidige plantegroei te verminder en die saailinge 'n beter kans op oorlewing gegee. Dit het egter ook ander smaaklike meerjarige grasspesies, wat reeds voorgekom het, soos *Themeda triandra* doodgemaak. Geen onkruiddoder moet gebruik word as daar reeds 'n goeie stand smaaklike grasspesies voorkom nie, maar dit kan wel gebruik word as daar baie eenjarige grasspesies en onkruid voorkom.

Die beskikbare begroting van die boer gaan 'n baie belangrike invloed hê op die keuse van watter restourasietegniek gebruik gaan word vir die restourasieaksie. Die rip en insaai van slegs *Digitaria eriantha* saad word sterk aanbeveel, aangesien dit 'n redelike goedkoop restourasietegniek is. Vir 'n verhoogde spesiediversiteit word die rip en insaai van *Themeda triandra*, *Digitaria eriantha* en *Eragrostis curvula* aanbeveel. Hierdie tegniek was van die goedkoopste, veral sonder 'n onkruiddoder.

Aangesien *Themeda triandra* 'n natuurlike grasspesie is en die saad nie kommersieël beskikbaar is nie, is dit moeilik bekombaar. Dit moet verkieslik in die omliggende omgewing, wat gerestoureer moet word, geoes word, om ekotipeveskille uit te skakel.

Die volgende tekortkominge is geidentifieseer, tydens die studie en daar word dus ook aanbeveel dat dit verdere navorsing vereis:

- Die potensiële verhoging in die inkomste van die boer uit die verhoogde weidingskapasiteit, moet in die ekonomiese ontleding ingewerk word,
- Die invloed van plantvoedingsstof tekort of ooraanbod en die invloed wat grondorganismes op die restourasieproses het, moet ondersoek word,
- Die afsnypunt waar die ou landerye sodanig herstel het, dat geen restourasie aksie enigsins 'n beduidende verskil sal maak om die weikapasiteit daarvan te verbeter nie moet bepaal word,
- Die plantopnames moet oor die hele gebied wat gerestoureer is gedoen word en nie net op die ripvoor nie, sodat die werklike weikapasiteit van die gebied bepaal kan word,
- Die invloed van beweiding op die gerestoureerde ou land moet bepaal word, om die volhoubaarheid daarvan te bepaal, en

- 'n Tegniek of apparaat moet ontwikkel word om te onderskei tussen die ingesaaide en natuurlike individue van dieselfde spesie wat ingesaai is.

Sleutelwoorde: Degradasie, restourasietegnieke, hersaai, suiwerheid en ontkieming van saadtoetse, ou landerye, grondbesit, LRAD (Land Redistribution for Agricultural Development), RDP (Reconstruction and Development Program), ekonomiese analiese, braaklê landerye, organiese materiaal.

Abstract

The evaluation of different technologies to restore old cultivated lands

As production costs for the cultivation of cash crops increased and government subsidies for farmers decreased and eventually stopped, the farmers stopped to cultivate the marginal to lower potential soils. The higher input costs could not be recouped form these lands and today, many of these old cultivated lands have been lying fallow for years. This resulted in unproductive land that could neither been used for the cultivation of crops nor for the grazing of livestock, as they have low grazing capacity value (economical value).

The following restoration technologies were evaluated to restore old cultivated lands in two row spacings (0.75m and 1.5M), with and without the application of Roundup (herbicide): control; rip; rip and the application of organic matter (cow dung); rip and re-seeding with a seed mixture; rip, re-seeding with a seed mixture and the application of organic matter (cow dung); rip and re-seeding with only *Digitaria eriantha* seed and the establishment of conventional *Digitaria eriantha* cultivated pasture.

The old cultivated lands used in this study lay fallow for approximately ten years and the species composition was mainly made up of species such as *Aristida congesta* and *Eragrostis lehmanniana*. Other perennial species, such as *Themeda triandra* and *Cynodon hirsutus* did occur in patches over the study area.

The purity, of the seed used in the re-seeded restoration technologies, varied as follows *Cenchrus cilliaris* (97.9%), *Digitaria eriantha* (96.0%), *Eragrostis curvula* (95.4%), *Eragrostis chloromelas* (91.3%), *Chloris gayana* (85.6%), *Panicum maximum* (84.3%), *Themeda triandra* (72.5%) and *Cymbopogon excavatus* (44.7%) and the germination also varied: *Eragrostis curvula* (86%), *Themeda triandra* (76%), *Eragrostis chloromelas* (48%), *Cenchrus cilliaris* (35%), *Chloris gayana* (29%), *Digitaria eriantha* (19%), *Cymbopogon excavatus* (13%) and *Panicum maximum* (4%).

The rip action (for both row widths) did have a positive influence on the growth and establishing of existing and re-seeded seedlings of the perennial species.

The re-seeded species that were established the most successfully were *Themeda triandra, Digitaria eriantha* and *Eragrostis curvula*. The application of organic material did help the initial

establishment of the re-seeded grass species, but the affect did decrease over the three seasons.

The narrow row spacing benefited the re-seeded grass species, while the wide row spacing did benefit the natural occurring grass species, such as *Eragrostis lehmanniana*.

The establishment of the conventional cultivated *Digitaria eriantha* pasture were unsuccessful and could not be explained.

The application of the herbicide (Roundup) did help to minimise the inter-species competition between the seedlings of the re-seeded grass species and the natural occurring species, thus bettering the seedlings survival rate. The natural occurring perennial grass species, such as *Themeda triandra* were also killed by the Roundup. Herbicide should not be applied if the old cultivated land already has a good stand of palatable grass species. It can be used to minimise the inter species competition, if there are lots of annual species present in the plant community of the old cultivated land, to be restored.

The farmer's available budget is an important factor when considering the type of restoration technology to restore old cultivated lands. The rip and re-seeding with *Digitaria eriantha* alone is highly recommended as it is a relatively cheap restoration technology. If the species diversity of the old cultivated land is to be enhanced more expensive technologies must be used, like the rip and re-seeding with a seed mixture (*Themeda triandra*, *Digitaria eriantha* and *Eragrostis curvula*). This technology was one of the cheapest, especially if no Roundup was applied.

Themeda triandra is a naturally occurring species and its seed was not commercially available, making it difficult to come by in the trade and the seeds must be harvested in the veld near the old arable land that is to be restored, to minimise the effect of ecotypes.

The following shortcomings were identified during the executing of this study and need further research:

- The potential increase in the farmers income, with the increased grazing capacity must be included in the economical analyses,
- The influence of an over supply or lack of plant nutrients and the influence of soil organisms must be researched,
- The threshold point where a restoration action will not better the veld condition further must be determined,
- The plant surveys must be done over the whole restored area in order to determine the true veld condition and not only on the rip furrows,

- The influence of grazing on the vegetation of the restored old cultivated lands must be researched and
- A survey technique or apparatus must be developed to distinguish between the re-seeded individual and the natural occurring plants of the same species in a restoration technique.

Keywords: Degradation, restoration technologies, re-seeding, purity and germination capacity tests, old cultivated land, land tenure, LRAD (Land Redistribution for Agricultural Development), RDP (Reconstruction and Development Program), economic analyses, fallow cultivated land and organic material.

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THE EVALUATION OF DIFFERENT TECHNOLOGIES TO RESTORE OLD CULTIVATED LANDS

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Chapter 1

INTRODUCTION AND LITERATURE OVERVIEW

1.1 Introduction

Since God gave humankind the command to go and work the land (e-Sword, 2007, Genesis 1:28), they started farming. Cain and Abel were the first farmers. Cain was a crop farmer and cultivated the land to produce crops, while Abel was a livestock farmer (e-Sword, 2007, Genesis. 4:2).

The origin of Agriculture has been described by numerous authors like Hyams (1952), Reed (1977), Herre and Röhrs (1977) and Wright (1977). Hyams (1952) described the origins of agriculture with a historical viewpoint. The Egyptians practiced tillage and livestock farming. The rise of machine-owning capitalists in Britain in the first half of the 19th century required hands to operate their rapidly growing factories. People settled in great numbers and food was brought to them in exchange for the machine minding (Hyams, 1952). In Africa, the tropical and subtropical jungle was cleared for the cultivation of crops. As the soil fertility declined and could not sustain the crops any more, the whole community moved on and cleared the next patch, leaving the jungle to return and restore the health of the cultivated section. The former condition (normal) condition of the cultivated section will only be reached over time (Hyams, 1952).

According to Herre and Röhrs (1977), agriculture also originated when the hunting of wild animals for food slowly and gradually evolved to the domestication of certain livestock species. This led to a regular production of livestock products. Due to climatic changes, plants were domesticated in different parts of the world. In Asia wheat, barley and other seed plants were domesticated, while wild cereals were domesticated in China. Europeans domesticated plants like maize, common beans, squash and amaranth, mainly in their natural habitats. Other plants, such as sweet potatoes, peanuts and manioc, were domesticated in other natural habitats (Wright, 1977).

A century after the scramble for Africa that set in motion the formation of peasantries over vast areas of rural Africa, structural adjustment and market linearization policies triggered a widespread erosion of these peasantries (Bryceson, 2002). According to Bryceson (2002), the World Bank stated in 2000 that parastatal marketing and blanket subsidized agricultural inputs are past history that could not and should not be resurrected. Rural policies that offer positive future-orientated, coordinated strategies that lay the foundation for occupational diversification and specialization were needed (Bryceson, 2002).

Farming was introduced to southern Africa by the early Bantu-speaking people. They practised mixed farming with cattle, sheep and goats and cultivated sorghum and millet. They cultivated their lands with iron hoes that they made themselves. As cattle are bulk grazers, their food requirements urged people with large livestock to move around continually to seek more grazing lands (National Department of Agriculture, 2005 (a)).

With the settlement of the first white farmers, more or less the same type of livestock farming was practised. They trekked further inland as soon as grazing and water became scarce. These farmers never made any lasting improvements on the land and only cultivated small areas around springs (National Department of Agriculture, 2005 (a)).

Only the western parts of the Cape colony was cultivated more intensively. The major types of farming enterprises practised in those days were grapes, fruit and grain cultivation (National Department of Agriculture, 2005 (a)). The Voortrekkers settled in other parts of South Africa in a relatively short time in the early 1820s. Livestock was improved with other types of breeds. In 1840 the African farmers came into contact with settler society, markets and magistrates and knowledge was transferred between them (National Department of Agriculture, 2005 (a)).

In the 20th century, maize farming rapidly expanded after the second Boer War (1899 to 1902), and land previously used for livestock farming was put under the plough. Other crops such as wheat, and in the Western Cape the production of citrus and deciduous fruit and dairy products, became more important. This led to a considerable improvement of soil cultivation and increased the use of mechanical power, which resulted in an increase in the soil degradation process and extensive soil erosion and drought effects became more serious (National Department of Agriculture, 2005 (a)).

The issue of land tenure arose as the European colonized the world. Even today it is still a very delicate and sensitive issue. When humankind was still practicing nomadic agriculture, a tribe communally owned all the land. As colonization of the world was started by the Europeans, they demanded that the natives of the specific country be granted the same portion of farmland as the Europeans, especially in North America. For the European colonists it seemed proper that each head of a family should own a piece of land, while the native Indians had no conception of land as property (Hyams, 1952).

Agricultural land ownership plays a major role in anti-poverty programs in South Africa and is both economically and politically motivated. With the history of South Africa, which included widespread racial land expropriation, there is a political need for racial restructuring of agricultural land ownership or land tenure. In original policy documents, the land redistribution program was demand led, which meant that only those who were able to evince considerable interest in and capacity to become productive farmers would be able to access the program (Zimmerman, 2000). Zimmerman (2000) elucidated to the barriers that stand in the way of poor households to participate in South Africa's land redistribution program, i.e. the level of risk to be borne by the potential beneficiaries, the up-front costs, the education and farming skills required for modern, viable farming, the need for rural services such as reticulated water and power, labour constraints and the difficulties of potential long-term moves. These barriers are not inseparable and with careful government policies to provide extension, capital and more, have to be addressed but could be overcome (Zimmerman, 2000).

Zimmerman (2000) said that the Land Redistribution program, as all economical policies, responds to both economical and political needs. The economic justification depends on two economically beneficial effects, namely efficiency-enhancement and/or poverty alleviation (Zimmerman, 2000). Van Zyl *et al.* (1996) stated that the motivation for the necessity of land reform in South Africa rested in the increased efficiency, increased growth and reduction of poverty. According to Van Zyl *et al.* (1996), the most obvious motivation is the un-sustainability, from a political, social, economic and equity point of view, of the present distribution ownership of agricultural land. Currently most large farms in South Africa are owned and operated by a small number of individuals or companies (86 % of agricultural land) (Van Zyl *et al.*, 1996).

The Land Reform Programme in South Africa should be able to address equity in land distribution and livelihood upgrading, the reduction of poverty, creation of rural employment and income-generating opportunities, inter alia raising the number of successful black agricultural producers and enhancing overall productivity, while maintaining sustainable natural resource management and utilization (Van Zyl, *et al.*, 1996).

There are currently numerous policies in South Africa to eradicate poverty in the post-apartheid era (Rogerson, 1999), such as the state-led Reconstruction and Development Programme (RDP), just after 1994. The RDP designed to rectify systematic socio-economical differentiation and discrimination, battled with and eventually gave way to the neo-liberal policy for Growth, Employment and Redistribution (GEAR) (Millstein, *et al.*, 2003). Policies such as Land reform, RDP, restitution and Land Redistribution for Agricultural Development (LRAD) are discussed below. Carter and May (1999) disaggregated and explored the economics of livelihood generations and class in rural South Africa. They pointed to the fact that the majority of South Africans live in poverty. The discrimination of the apartheids regime denied the black majority the opportunity to develop new assets as they were given restricted access to markets, infrastructure and education. Thus, it produced poverty and compressed social and economic class, especially in the rural locations, where the majority of black South Africans reside. Of all households in South Africa, 4.3% fell in the marginalized livelihood strategy class of which 81% depend dominantly on Agriculture (Carter and May, 1999).

The restitution of land has the vision to restore persons or communities disposed of property after 19 June 1913 as a result of past racially discriminatory laws and practises, or to receive a just and equitable redress, as described by the Department of Land Affairs (2005).

With the above-mentioned in mind, the present government developed different policies of which the Land Redistribution for Agricultural Development (LRAD) is the latest. This policy was designed to help previously disadvantaged citizens from African, Coloured and Indian communities to buy land or agricultural implements, especially for agricultural purposes (National Department of Agriculture, 2005 (b)). This program also has strategic objectives which include the following: to contribute to the redistribution of 30 % of the country's agricultural land over 15 years, improving nutrition and incomes of the rural poor who want to farm on any scale, de-congesting overcrowded former homeland areas and expanding opportunities for women and the youth who stay in rural areas. In the new political dispensation after 1994, greater emphasis was placed on small-scale development in agriculture (National Department of Agriculture, 2005 (b)).

The LRAD program deals with the redistribution of agricultural land and has two distinct parts; firstly, a part that deals with the transfer of agricultural land to specific individuals or groups and secondly, a part that deals with commonage projects, which aim to improve people's access to municipal and tribal land, primarily for grazing purposes (National Department of Agriculture, 2005 (b)).

In the light of the above–mentioned and the fact that 80 % of agricultural land in South Africa is mainly suited for extensive livestock farming (Statistics South Africa, 2004), it is evident that much attention and emphasis must be placed on this enterprise as a poverty elevating tool. Goat and sheep farming represented 53% of all agricultural land in South Africa in 2004 (Statistics South Africa, 2004). The Republic of South Africa covers an area of 122.3 million ha, with 48.5 million people (Statistics South Africa, 2007). Only 13% of the surface can be used for crop production. Of this, only 22 % is high potential cultivated land and only slightly over 1.2 million ha is under irrigation (National Department of Agriculture, 2005 (b)).

There were approximately 13 513 000 head of cattle in total, of which 2 253 000 were to be found in the Free State Province (16.7 %) of which 80% were large-stock units. A total number of 5 093 000 head of sheep (20.1% of the estimated 25.4 million head of sheep in the country) were found in the Free State Province. Milk production in the Free State Province contributed

8% to the total production in South African, while wool production contributed 22,4% to the total wool production (Statistics South Africa, 2004).

Poverty in South Africa, as reported by Statistics South Africa (2004), is widely spread over the country and in most of the Provinces the majority live under the bread line, which is about R 800 per month per household. From 1999/2000 to 2003/2004 the gross value of livestock production increased from nearly R20 million to nearly R31 million. In the 2003/2004 season, the gross value of livestock production contributed 43.9%; cash crops contributed 26.9% and horticultural products 29.2% to the gross agricultural income of the country (Statistics South Africa, 2004). Thus, livestock production is the biggest agricultural enterprise in South Africa.

Dorward *et al.* (2004) stated that, both in history and in theory, it is suggested that agriculture could play a major role in poverty reduction in poor agrarian economies. However, today this reduction faces new difficulties in different categories that are endogenous to today's poor rural areas. Other difficulties resulted from the broader global change and some are due to changes in the dominant policy environment, emphasizing liberalization and state withdrawal (Dorward *et al.*, 2004).

Drimie and Mini (2003) stated that food security lay at the heart of South Africa's conceptualisation of sustainable development and poverty reduction. The issue of food security, however, often becomes submerged in the intractable challenges facing development as it raises issues that are linked to a host of development concepts, particularly the Figureht against poverty, where the restoration of old cultivated lands could play a major role.

1.2 Old cultivated lands

Agricultural activities primarily have four effects on ecosystems. These effects include the following:

- Reduction in biodiversity: all other species that compete with the species produced in an agricultural system (plant or livestock) are eliminated from the system;
- Soil structure: the continuous tillage and fertilizer use affect the soil structure stability negatively by constantly removing the biological potential and reducing the soil organic material necessary for the nutrient supply. In most cases, this leads to increased rates of erosion;
- Soil water balance: the drainage of cultivated lands leads to the reduction of local pockets of variability, more or less waterlogged, where different species could have survived and

- Fertility: the use of fertilizer excludes the slower growing competitors and stress-tolerant plants, in combination with the above-mentioned effects of tillage (Harris, *et al*, 1996).

Farmers started to plough land mainly because of the following reasons: to control weeds, to present a suitable seedbed for crop plants, to incorporate organic residues into the soil and to conserve water (Brady, 1984). The short-term benefits are that the crop residues are more quickly incorporated, the soil loosened and the total soil pore space increased, thus making water and air absorption quicker. This provides an excellent seedbed and a good means of weed control (Brady, 1984). However, in the long-term the effects of tillage are generally undesirable. The rapid breakdown of the organic residues in the soil can hasten the reduction of soil organic matter content, which has an effect on the aggregate stability of the soil. The tractors and other heavy implements used also compact the soil heavily (Brady, 1984).

As production costs for the cultivation of cash crops increased, the government subsidies for farmers decreased and eventually stopped. This resulted in lower profit margins and also loss in income, as the farmer could not cover the input costs on the marginal to lower potential soils. The farmers abandoned these cultivated lands. Today, many of these old cultivated lands have been lying fallow for years. The situation resulted in unproductive land that could not be used either for the cultivation of crops or for the grazing of livestock, as they are neither rangeland nor cultivated lands any more.

The farming systems started to change to better the production of both crops and livestock. While the farming practices improved and changed over the years, not all of these farming practises were sustainably managed, resulting in the degradation of the ecosystems, mostly because of poor farming practices. In the days before the use of fertilizer, farmers used to plough deforested land and plant their crops. As soon as the production declined, they deforested the next part and so on. This resulted in lands, which in modern terms were soil types of moderate to low potential for the cultivation of cash crops, being ploughed (Hyams, 1952).

Poor rangeland conditions, such as in an overgrazed situation, can be compared to these old cultivated lands, mainly consisting of poor perennial or annual pioneer grasses with a low biomass production or yield. The first priorities of these types of species are to produce seed in order to ensure that they contribute to follow-up generations. These plants also have poorly developed root systems and are mostly short-lived with low contributions to the overall grazing capacity of the land (Jordaan, 2001).

In contrast with this, rangeland in a good condition usually consists of well-established and developed big tufted perennial type grasses. These grasses have excellently developed root systems with a high biomass and contribute highly to the grazing capacity (Jordaan, 2001).

Natural rangeland in a good condition is the cheapest fodder source, compared to poor rangeland as characterized by these old cultivated lands, which mainly consist of poor perennial or annual pioneer grasses with a low biomass production or yield (Jordaan, 2001).

In South Africa, large tufted perennial climax rangeland grass species are adapted to grow in soils with a very low nutrient status while pioneer rangeland grass species are opportunistic and adapted to grow faster in soils with a high nutrient status (Tainton, 1999). This is one of the reasons why old cultivated lands which were normally previously fertilized for crop production have a high cover of annual pioneer and weedy type species.

The growing human population and the demand for food are constantly putting more pressure on agricultural land and other natural resources. Climate change, erratic rainfall patterns and injudicious management strategies also contribute to the over-exploration and degradation of land in Southern Africa. If the process of land degradation is not halted, it will ultimately lead to desertification (Kellner, 2000 (a)).

Rangeland condition has a dramatic influence on the grazing capacity and therefore on the economy of a management unit. During the 1999/2000 season, good rangeland produced approximately 112% more fodder than poor rangeland in the Potchefstroom district (Jordaan, 2001). The good rangeland had 72.4% palatable species whereas the poor rangeland only had 13.7%. The grazing capacity was 4.8 ha / LSU for the good rangeland and 29.4 ha/LSU for the poor rangeland, respectively. This means that the grazing capacity of good rangeland was approximately six times higher than that of the poor rangeland (Janse van Rensburg, 1987 and Jordaan, 2001).

Developments in the farming industry in the past have resulted in higher demands on the soil as a natural resource. This has lead to over-utilisation of the rangeland and a decrease in the plant cover and its productivity (Snyman and Van Rensburg, 1986). South Africa cannot afford this continued deterioration in the condition of the rangeland, as besides the decline in productivity, the cost of actively rehabilitating the rangeland is extremely high (Snyman and Van Rensburg, 1986).

There are areas where good management on its own will not be sufficient to restore the condition of the rangeland. In these instances the landowner should implement biological and/or mechanical restoration methods (Kellner, 2000 (b)).

If the rangeland is in a poor condition, livestock has to be fed additional supplements, including licks, which have a further impact on the income that could be derived from the natural rangeland. Besides the fact that less livestock can be grazed on poor rangeland, it also contributes to the loss of soil, due to higher erosion on degraded lands. Previous studies have calculated that the topsoil loss in poor rangeland can be as much as 5 to 6 tonnes/ha (Jordaan, 2001). Thus, it is evident that rangeland in a poor condition, as in the case of old cultivated lands, should be restored.

As mentioned previously, old cultivated lands do not have any value for the farmer, since they cannot produce sufficient cash crops and the grazing capacity is very low.

The need for restoration of these old cultivated lands arose after realizing that the 'natural recovery' of these lands (to former levels of productivity) is either too slow or does not take place at all (Van Rooyen, 2000). Bradshaw (1997) stated that areas that have been derelict for 100 years are still missing species that occurred there previously, although these species have well-established populations not more than 50 km away. It is therefore important to accelerate the process of restoration and to increase the grazing capacity of these old cultivated lands.

The process of plant succession is divided into two main processes, namely: primary and secondary succession. Primary succession is initiated on bare areas that have never been vegetated, such as rock surfaces or newly formed ponds of water. The vegetation is normally made up of plants adapted to extreme conditions such as lichens and mosses. These plants slowly build up small quantities of soil and create microclimates for other species to colonize during a slow modification of the environment. Secondary succession occurs wherever a plant community has been disturbed and is no longer in equilibrium with the environment, where at least some residual effect of previous occupation by plants remains (Tainton, 1999). The destruction and the restoration of ecosystems may occur at rates imperceptible by man (Ulrich, 1978).

The process of succession can be described in four modes. These include:

- Facilitation, where early pioneer plants alter the soil and site characteristics to make it suitable for other species to establish, i.e. modifying the micro climate to be more tolerant to the other species;

- Tolerance, where slower-growing competitors eventually exclude the early dominant ruderal species;
- Inhibition, where pioneers exclude other plants until they naturally do not exist anymore, allowing the establishment of competitive species and
- Random, being the chance survival of different species on the same site which *de facto* has no adverse chemical status (Harris *et al.*, 1996).

There are large areas of previously cultivated lands in our country that were previously ploughed, but because of their low potential, many of these lands have been lying fallow for long periods. This phenomenon escalated in the last few years due to the high input costs for cash crops, especially in the previously self-governing areas such as Thaba-Nchu and Qwa-qwa. Even large commercial farmers that have been farming for generations depending on cultivated lands for crop production are now interested in restoring these old cultivated lands to natural rangeland since the input costs are too high and they would like to diversify their agricultural production system by including more grazing lands for livestock. Many of these cultivated lands are now characterized by very low grazing values and grazing capacities.

According to the findings of Snyman and Van Rensburg (1986), plant cover had a significant influence on runoff and soil losses. A pioneer rangeland had a greater soil loss than a climax rangeland, even though the climax rangeland was in a very poor condition with a basal cover of only 2.8%. Slopes did not have a significant influence on the amount of runoff and soil loss. Factors such as soil texture, organic matter content and soil moisture content before the start of a rain storm are also responsible for differences in soil loss and runoff (Snyman *et al.*, 1985). Natural rangeland in the climax stage uses moisture much more efficiently than rangeland in the pioneer stage (Snyman and Van Rensburg, 1986).

It is critical that farmers manage factors that influence the organic matter content, nutrient supply, soil coverage and soil compaction appropriately (Paniagua *et al.*, 1999). South Africa cannot afford this continued degradation in the condition of the rangeland, because beside the decline in productivity, the cost of restoring the rangeland is extremely high (Snyman and Van Rensburg, 1986).

1.3 Restoration technologies

The following definitions are used to describe certain terms and concepts in this study:

Degradation: According to the UNCCD (United Nations Convention to Combat Desertification, 1995), land degradation is described as a process where a reduction in or loss of productivity can be observed (UNCCD, 1995). Degradation is the change in rangeland status to a poorer condition (Kellner, 2000 (c)).

Land degradation is caused by human intervention (abuse of the environment through ignorance, bad management, agriculture and other human activities), political, industrial and historical issues and climatic variability's (UNCCD, 1995). There is an interrelationship between climatic variables and rangeland management. The biological, economical and sociological impacts must be managed to maximise the production in unfavourable conditions (Kellner, 2000 (c)).

The adoption of sustainable land restoration technologies is more likely when land tenure is secure (Turner, 2000).

Soil degradation is more tightly coupled to the land tenure system than rangeland degradation. Soil is consistently more eroded and the bush encroachment and alien plants problems are more acute in communal areas than in commercial areas (Hoffman, 1998).

The restoration of degraded rangelands is a long-term exercise which depends on the commitment of the range manager. Although it is a fairly basic and straightforward procedure, it is technically difficult to carry out (Kellner, 2000 (b)).

Restoration: According to Kellner *et al.* (1999), the restoration of degraded rangelands is the recovery of grasslands to their former sate, or to a self-sustaining ecosystem. Restoration is a process whereby degradation is slowed down, halted, and ultimately reversed (Kellner, 2000 (c)).

The purpose of restoration is to restore the degraded land to a functional self-sustaining ecosystem and increased potential, or to its previous capacity, and the enhancement of quality of life through: improved production, improved aesthetic value, improved water status and the maintenance of biodiversity (Kellner, 2000 (c); De Wet, 2001).

Degradation can be addressed by appropriate restoration technologies. A definition is offered by the Society of Ecological Restoration (SER, 2002): Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER, 2002). Harris *et al.* (1996) suggest that ecological restoration is the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems, is the process, to return an area to the state it was in prior to degradation of any sort, i.e. back to a fully-functioning self-sustaining ecosystem (De Wet, 2001).

The potential for restoration will also depend on the state and condition of the soil, as well as the composition of the soil seed bank. The similarity between the established grassland vegetation and the seed bank is often not more than 50-60%, which indicates that nearly half the species present in the vegetation does not contribute to the seed bank at all (Bakker and Berendse, 1999).

Essentially, three matters will need attention if a degraded land has to be restored:

- Remodelling the physical aspects of the habitat;
- Remodelling the chemical aspects, nutrients and toxicity and
- Replacing missing species or removing undesirable exotics (Bradshaw, 1997).

Factors that have a negative influence on restoration include -

- Multivariate conditions of restoration sites;
- Restoration demands long-term research, which is not accommodated for in the budgets of most academic and research institutes;
- Ignorance by land-users about this "new" concept of restoration;
- A lack of understanding of the principles of ecosystem and restoration functioning,
- Negative short-term cost/ benefit ratios once restoration has been applied;
- The absence of proven techniques that the landowner can refer to before applying certain restoration actions;
- Insufficient collaboration and cooperation among all parties involved in the restoration efforts and
- All aspects of the restoration plan are not always taken into account during implementation (Kellner, 2000 (a)).

Land restoration (rangeland restoration) occurs when a degraded area is returned to an improved and more natural condition. The restoration process should return the land to a fully-functioning self-sustaining ecosystem. Restoration can be achieved by mechanical and / or biological techniques (dealt with later on in this literature overview) and the aim is to increase the production potential and grazing capacity of the degraded rangeland for better livestock production (Kellner, 2000 (b)).

The success of ecosystem restoration can be judged according to the following five criteria:

- Sustainability: the restored ecosystem must be able to perpetuate itself;
- Invisibility: the restored community must not be invaded by species from outside, as natural communities are in general less easily invaded by new species (with other words the end result must be invisible and look like the other non degraded rangelands in the area);

- Productivity: the restored community must be as productive as the original;
- Nutrient retention: the restored community must not loose more nutrients than the original and
- Biotic interactions: the importance of key species is often revealed by its absence (Ewel, 1987).

Ecological restoration usually demands the deliberate re-establishment of plant species and subsequently the management of it to direct or suppress the succession process (Davy, 2002). All biological and mechanical restoration technologies can be divided in two categories, namely active and passive restoration technologies.

Restoration technology: The technologies that are used must be (a) understandable, (b) affordable, (c) acceptable and appropriate to the land user, and (d) sustainable over the long-term (Kellner, 2000 (c)).

1.3.1 Active and passive restoration

The following definitions were used for active and passive restoration:

Active restoration: Active restoration technologies entitle the use of physical actions taken to restore degraded rangelands, for example the applying of animal dung, re-seeding and the use of herbicides.

Passive restoration: Passive restoration technologies entitle only passive actions taken to restore degraded rangelands, for example the removal of the animals, in a heavily overgrazed area, that caused the degradation in the first place.

Both active and passive restoration technologies have their place in the restoration process of a degraded ecosystem. Active methods or technologies have been successful in the restoration of degraded ecosystems, for example in the Columbia River basin, often especially where the cause of the degradation was well understood. The management or elimination of these causes may be all that is needed to restore the area to a more desirable condition (McIver and Starr, 2001).

Active restoration technologies have inherent costs and risks involved, thus scientific literature suggests that the options should be examined first when deciding how a degraded area should be restored (McIver and Starr, 2001).

Passive restoration technologies include actions like the removal of the stresses that caused the original degradation, such as heavy overgrazing or air pollution and then allowing natural succession to take place (Milton and Dean, 1995).

In highly degraded land, passive restoration technologies have proven to be ineffective and active technologies should be used (McIver and Starr, 2001). Since the old cultivated lands have been disturbed by mechanical actions, passive restoration technologies on their own will not be successful in the restoration of these lands. Active restoration technologies must be used in combination with passive restoration technologies.

- **Active restoration technologies**

Active restoration technologies are, according to UNCCD (1995), those technologies or methods where humans intervene. These technologies can be divided into chemical, organic and structural restoration technologies. Chemical technologies include the application of fertilizer, the use of herbicide and seed enhancement. Organic technologies are divided into the practising of no-tillage, re-seeding, brush-packing, livestock dung application and the application of organic blocks. Structural technologies are technologies where the soil structure is manipulated to improve the seed bed for seedlings to establish. These technologies include the mechanical manipulation of the soil by making either furrows (Ripper, Cultivator or Split plough) or hollows (Ground disk or Dyker plough). Structural restoration technologies can also be applied by building other trapping structures (old tyres, stones, wire mesh and/or spread contours) or engineering structures such as silt dams, weirs, stone packs or dams (UNCCD, 1995).

In the following section, only the restoration technologies used in this study will be discussed.

- **Biological restoration technologies**

  ⇨ **Organic material**

The use of biological restoration methods depends largely on the availability of the biological (organic) material, such as animal dung, twigs and branches for brush-packing and other material (Kellner, 2000 (b)).

Saggar *et al.* (2001) found substantial losses in soil carbon (C) and nitrogen (N) when converting natural pastures to cropping land. The conversion of pastures to cropping and the length of the cropping decreased the microbial biomass, C, N and microbial quotient, indicating a decreased turnover of organic matter. Pasture soils had twice the mineralization rates of short- and medium-term cultivated soils and four times those of long-term cropping soils (Saggar *et al.*, 2001).

Nitrogen does not occur in soil minerals, but is present in the organic fraction of soils where it is accumulated by biological processes. A large amount is stored in the organic matter, from which a small amount is annually released by mineralization. More nitrogen is needed for plant growth than any other plant nutrient (Bradshaw, 1997). Organic matter provides most of the nitrogen reserve in soils and it also has a positive effect on the soil structure by stabilizing the soil aggregates especially in high clay content soils (Harris, *et al*, 1996). Thus the application of organic material will have a positive effect to better the soil bed for the re-seeded and natural species in the area to be restored.

The application of organic material acts as a nutrient supply source, especially nitrogen. Cow dung worked into the soil can improve the nutrient status of the soil. This improves the growth of bigger grass tufts, thus there are smaller numbers of the specific grass species, with bigger tufts (Van der Merwe, 1997). These bigger grass tufts help to increase the productivity for higher grazing value and capacity (Boateng, 2002). One of the most common problems of degraded terrestrial environments is a lack of nutrients, particularly nitrogen (Bradshaw, 1997). Manure is rich in water and carbon compounds and improves the physical characteristics and water-holding capacities of the soils. Manure is an effective source of nutrients for most crops and provides mulch that will limit and remedy soil crusting, as well as regulate the soil temperature (Buys, 2002).

Montalvo *et al.* (2002) suggested that the ripping of soil must be combined with the addition of soil amendments to increase soil organic matter and nutrients in areas lacking topsoil and known to be very low in nutrients.

Through biological restoration using organic material such as animal dung, imbalances in soil organic matter and nutrient content in the old cultivated lands are rectified. The C and N content of the soil is increased, soil organic matter and subsequently the establishment and survival of the seedlings of the re-seeded species are enhanced.

⇨ **Re-seeding**

It might be necessary to aid the immigration process of desirable species by introducing them to the area to be restored (Bradshaw, 2000). Seed mixtures are widely used as a technology in the restoration of degraded land, where suitable grass species are selected and re-seeded, either by hand or with a planter. The re-seeding of overgrazed areas could increase the forage plant densities, but competing plants reduce seedling survival and grazing reduces seedling growth (Milton, 1994). The success of the re-seeding of degraded land depends greatly on the nature of the prevailing edaphic environment (e.g. rainfall and temperature) as this determines the successful germination and establishment of the seedlings. The success of re-seeding is greater during a high rainfall year (O'Connor, 1985). A suitable grass species should be selected for the local conditions, especially with regard to soil type (e.g. clay content), as well as the short- and long-term rainfall (Van der Merwe, 1997). Application of organic material has a positive effect in reducing the competition from resident species with the re-seeded species (Boateng, 2002). The re-seeded species respond better if combined with a rip treatment, whereby the soil is loosened, which increases the moisture content of the soil (Boateng, 2002).

The sizes and morphology of the seeds influence the re-seeding methods (small and large seed have different optimal seeding methods) which in turn influence the germination and the subsequent establishment of the plants (Montalvo *et al.*, 2002). Seeds can also be chaffy with awns or hair, which also affect the re-seeding procedure. Due to the nature and scale of re-seeding grass species, the seeds are commonly sown by hand.

- **Herbicide application in restoration**

Inter-specific and intra-specific competition between individual plants of the same species and plants from other species are very important factors in the successful germination and establishment of plants species, as they compete for soil nutrients, light, soil moisture and other growth essentials (Gilbertson, *et al.*, 1989).

The competition of the seedlings with other plant species must be limited as much as possible to enable the re-seeded species to germinate and establish. The competition with existing vegetation should be kept to a minimum in order to establish a satisfactory stand of more desirable vegetation. This can be done by trampling or burning (Van der Merwe, 1997) or the use of a broad-spectrum herbicide such as Roundup, which was used in this study. The cost and effect of the herbicide on the environment has to be carefully monitored and assessed over time.

- **Mechanical restoration technologies**

These methods involve the use of agricultural implements to cultivate the soil. This is done to break up the hard crusts of the compacted soil which form seals preventing water infiltration. The soil characteristics have a strong impact on plant establishment and sometimes overshadow the effects of the seeding method or ripping the soil (Montalvo *et al.*, 2002). A cultivation method allows water to penetrate and increases the water infiltration and water retention capacity of the soil. A better seed bed for the establishment of seedlings is then being prepared. Different types of implements, such as rippers (furrow cultivation) and dyker ploughs (hallow cultivation) can be used, depending on the type of soil (Boateng, 2002; Kellner, 2000 c; O'Connor, 1985; Whisenant, 2002). The depth of cultivation and distances between the cultivated areas (hallows or furrows) are also very important, as these factors influence the cost, time and results of restoration. A norm was set that the depth of cultivation should be at least 200 mm and the distance between the rows (furrows) should not be more than two metres (Van der Merwe, 1997). This will, however, depend on the topography, soil type, aim of the restoration and agricultural implements available. A cultivation method and higher soil moisture content also stimulates the germination and establishment of seeds that lie dormant in the soil seed bank (Boateng, 2002; Buys, 2002).

Better results (species frequency) can be obtained over a shorter period of time when combinations of restoration techniques are applied, e.g. cultivation, application of organic matter and re-seeding methods (Van den Berg, 2002). The economic viability of rangeland restoration techniques should, however, be thoroughly considered (Van der Merwe, 1997).

It is advised that the restored sites be protected from grazing, either by fencing or brush-packing to allow better seedling establishment and growth of adult plants (Boateng, 2002).

1.4 Aims of this study

The main aim of this trial was to identify the most cost-effective way of increasing the tempo of this natural process and to combat erosion and soil loss due to poor rangeland condition. In this study, some of the methods used for rangeland restoration were tested and evaluated for the restoration of old cultivated lands.

The specific aims of this study include to:

- Test the purity and germination of the seeds of the re-seeded species;
- Evaluate different restoration technologies to restore old cultivated lands with a row width of 0,75m (narrow) and 1,5m (wide);
- Evaluate the influence of the use of herbicide in the restoration of old cultivated lands;
- Analyse the economy of the different restoration technologies that were evaluated and
- Make recommendations on the restoration of old cultivated lands.

1.5 Format of the dissertation

This dissertation is divided into six chapters. The first chapter (this present chapter) is a general introduction to the study that describes the origin of agriculture; the origin of old cultivated lands and the present situation, a general discussion of restoration technologies and the aims of this study. In the second chapter, the study area is described in terms of the vegetation, the soil and climate. In the third chapter, the materials and methods (including the restoration technologies) used in this study are described. The results are given and discussed in the fourth chapter and in the fifth chapter, some general conclusion are made. The final chapter includes all the references used in this dissertation in alphabetical order. Some appendices accompany this thesis.

Chapter 2

Study area

The study was conducted on the experimental farm of the Glen Agricultural Institute near Bloemfontein. The study area is described according to the general location, biome for the region, general vegetation, climate, soil and the historical background and management of the study site.

2.1 Location

The study site was located on the experimental farm of the Glen Agricultural Institute. The Glen Agricultural Institute is managed by the Free State Provincial Department of Agriculture with the primary functions of training agricultural diploma students and agricultural research. A secondary function is to support farmers of the Free State Province and extension officers of the Department. The location of the Glen Agricultural Institute in the Republic of South Africa is shown in Figures 2.1 and 2.2.

The experimental farm of the Glen Agricultural Institute is situated about 30 km northeast of Bloemfontein in the Free State Province, on the Bloemfontein–Brandfort road (28.95° South and 26.33° East, at a height of 1304 m above sea level).

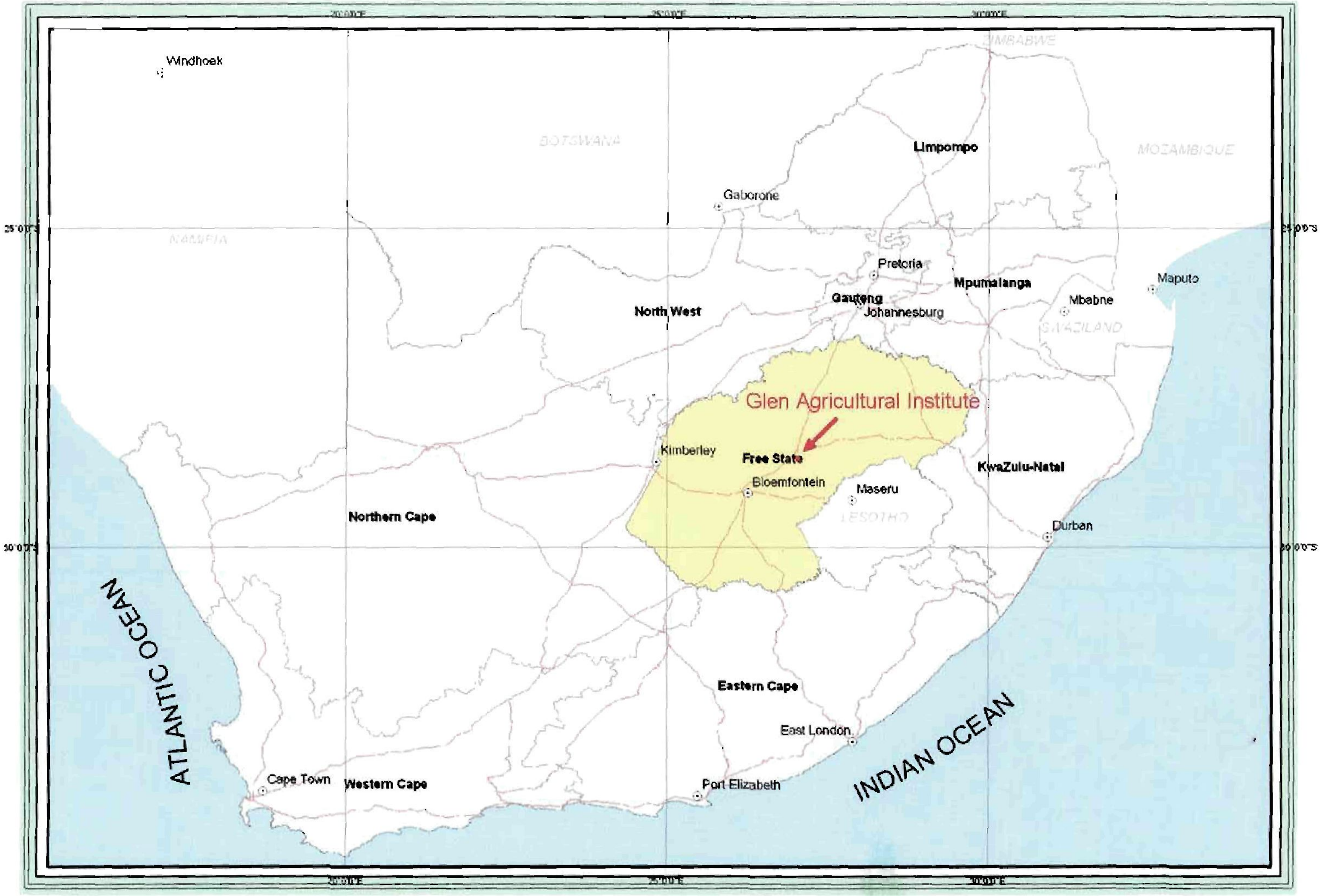

Figure 2.1 A map of the Republic of South Africa to show the location of the Free State Province, Bloemfontein and Glen Agricultural Institute.

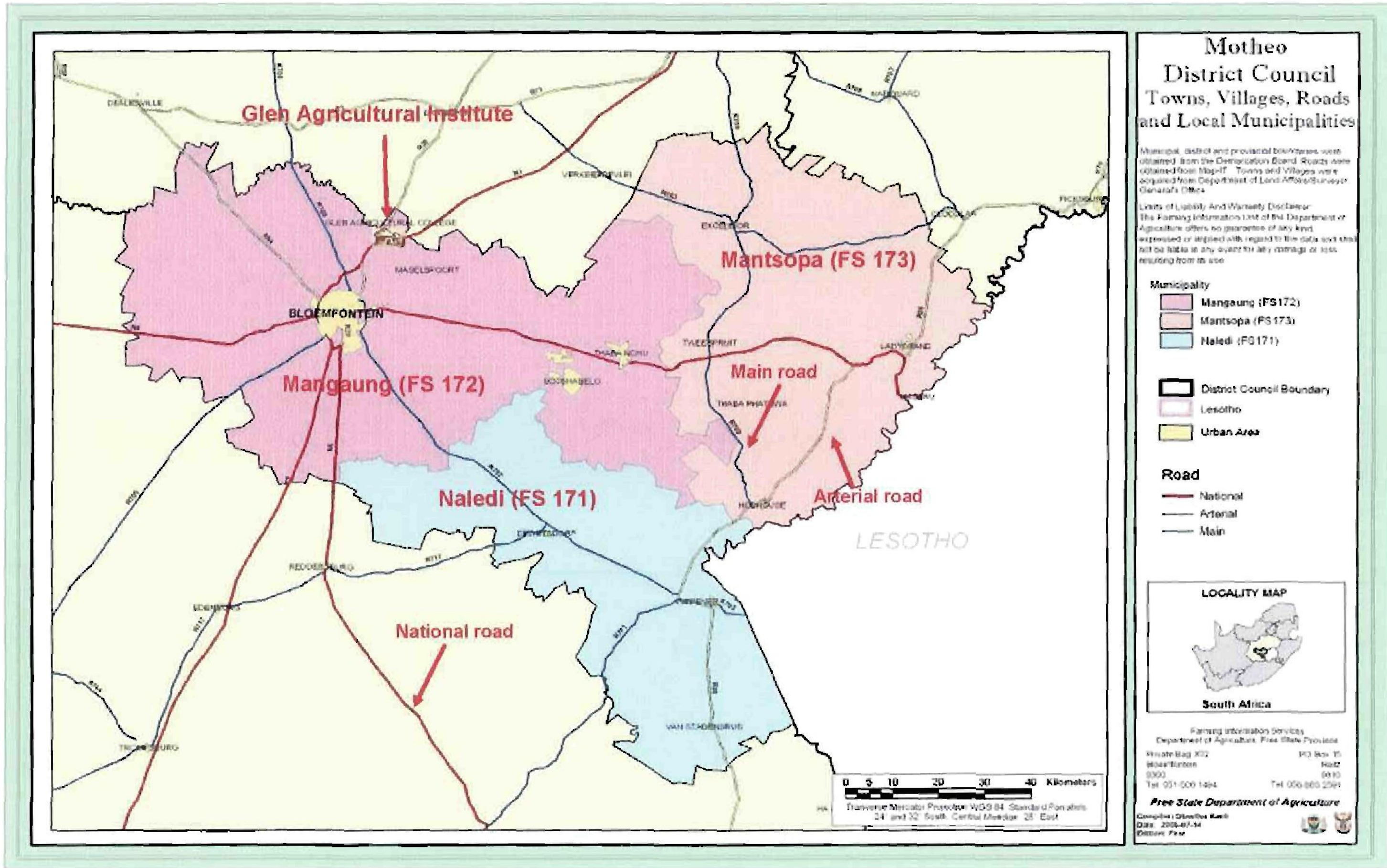

Figure 2.2 The location of Glen Agricultural Institute in the Motheo district of the Free State Province.

2.2 Biome

According to Rutherford and Westfall (1986, 1994), biomes are units that represent large, natural, reasonably homogeneous areas of the Earth's biotic and abiotic surface matter. A biome is a broad ecological unit that represents a major life zone extending over a large natural area.

The study area is situated in the central grassland biome of South Africa (Rutherford & Westfall, 1986, 1994) (Figure 2.3). The grassland biome is found mainly on the high central plateau of South Africa, 300 to 2850 m above sea level and covers approximately 343 000 km^2 or 16.5% of South Africa. The topography of this biome is mainly rolling, but can be mountainous (Rutherford & Westfall, 1986, 1994).

The grassland biome is physiognomically monolithic and is characterised by a strong dominance of hemi-cryptophytes of the Poaceae. The canopy cover of this biome is moisture dependant and decreases with lower mean rainfall. Grazing has a decisive influence on the vegetation in this biome (Rutherford & Westfall, 1986, 1994).

The vegetation follows a rainfall gradient that corresponds with the contributions to the 'sweet' and 'sour' grass plants and with the rangeland type classification of vegetation of South Africa (Acocks, 1988; Rutherford & Westfall, 1986, 1994). 'Sweet' grasses usually have a lower fibre content, maintain a higher above-ground nutrient level into the winter, and are more palatable for stock than 'sour' grasses (Rutherford & Westfall, 1986, 1994).

The most noteworthy species is *Themeda triandra*, which has a wide distribution in this biome. The grassland biome is dominated by C_4-grasses, except in the high Drakensberg mountainous region where C_3-grasses can also be dominant (Rutherford & Westfall, 1986, 1994). C_4-species are plants that produce four-carbon acids as the primary initial CO_2-fixation products in the photosynthesis process, whereas C_3-species fix CO_2 initially into 3-phosphoglyceric acid (3-PGA) (Salisbury & Ross, 1985).

The grassland biome is divided in two major natural divisions mainly based on moisture availability. These are the moist grassland, which forms the greater part of this biome, and the dry grassland. The moist grassland forms by far the greater part of the grassland biome and is dominated by sour, unpalatable grasses. The soils of the moist grassland tend to be leached and dystrophic, the plant canopy cover and the dry matter production are high and the frequency of rangeland fires is higher than in the dry grassland. In contrast with the moist grassland, the dry grassland is found in areas where sweet, palatable grasses are more common. The soils of the dry grassland are less leached and eutrophic; plant canopy cover, dry matter production and frequency of fire are lower than in the moist grassland (Rutherford & Westfall, 1986, 1994).

An important aspect of the grassland biome is that it is very important for the production of dairy, beef and wool (Rutherford & Westfall, 1986, 1994). The cultivation of cash crops is also a very important farming activity in this biome, which contains the whole maize triangle of South Africa (Rutherford & Westfall, 1986, 1994).

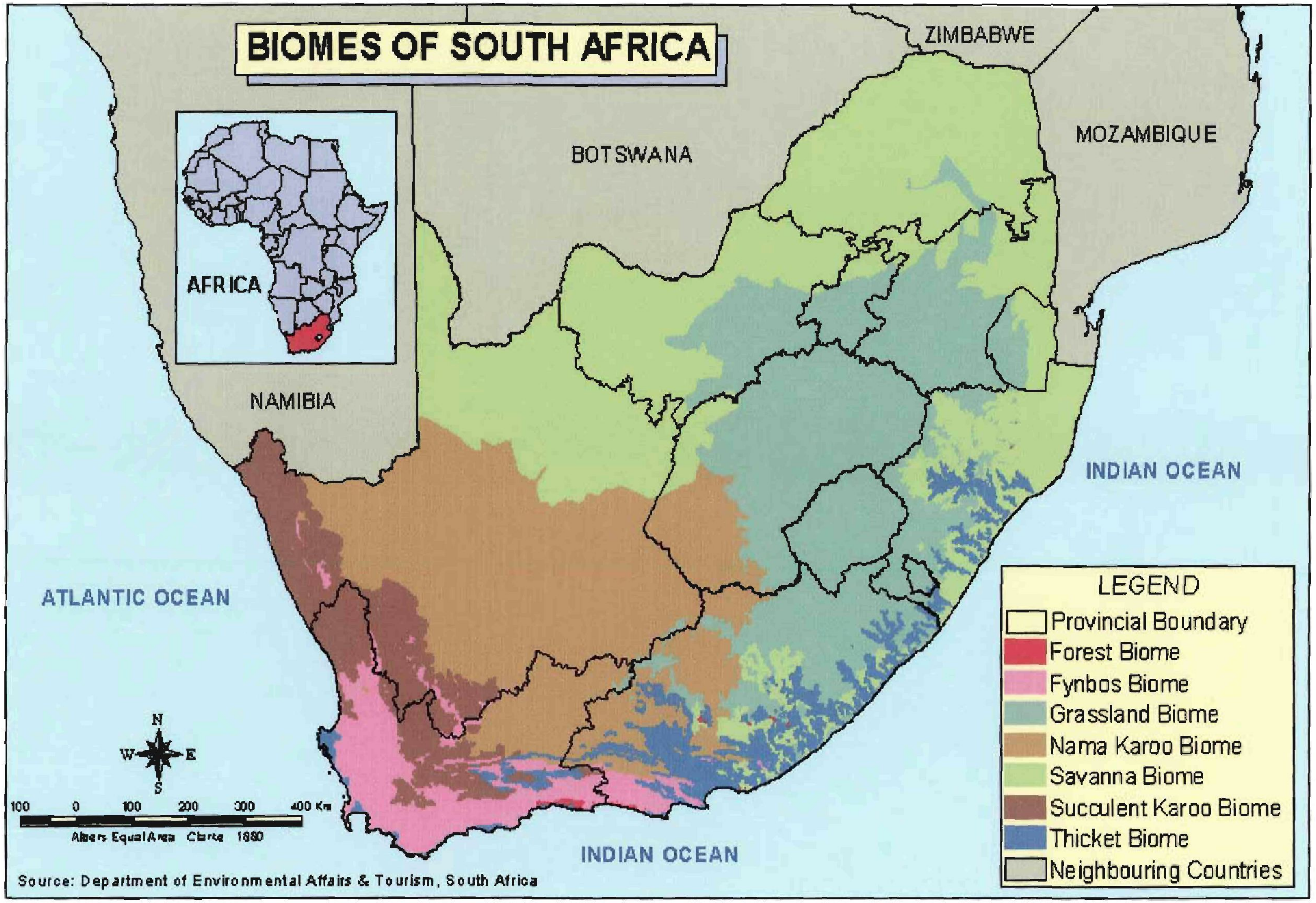

Figure 2.3 The biomes of South Africa (Rutherford & Westfall, 1994).

2.3 General vegetation and veld type

A veld type is an unit of vegetation with a range of variation small enough to permit the whole of it to have the same farming potential (Acocks, 1988). As mentioned in the above paragraph, the study area is situated in the 'sweet' grassland veld type which occurs on the upper plateau and the mountain tops at altitudes ranging from 1050 to over 3050 m above sea level, in regions that are too dry and/or frosty for the development of any kind of forest (Acocks, 1988).

The pure grass veld types are divided into different types according to the dominant species, height above sea level and the annual rainfall. The study area is situated in the central variation of the dry *Cymbopogon – Themeda* veld, Veld type No. 48 (Acocks, 1988). The dry *Cymbopogon – Themeda* veld lies at a lower elevation and is drier than the Transitional *Cymbopogon – Themeda* veld (Acocks, 1988). The central variation occupies very flat country at altitudes ranging from 1300 to 1350 m above sea level with an annual rainfall of 450 to 500 mm. The study site is situated at 1304 m above sea level and receives an annual long-term rainfall of 547.4 mm (Acocks, 1988).

The following species, arranged in order of most abundant to least abundant, generally occur in this grassland veld type: *Themeda triandra, Aristida congesta subsp. congesta, Eragrostis lehmanniana, E. superba, Cynodon dactylon, Setaria sphacelata, Tragus koeleriodes, Elionurus muticus, Anthephora pubescens, Cymbopogon excavatus, Eragrostis chloromelas, Heteropogon contortus, Digitaria argyrograpta, Pogonarthria squarrosa, Stachys spathulata, Chamaesyce inaequilatera, Triraphis andropogonoides, Anthospermum pumilum* subsp. *rigidum* and *Dicoma macrocephala* (Acocks, 1988).

Although presently small and localized, there are already signs of spring *Acacia spp.* and Karoo invasion in this variation of the dry *Cymbopogon – Themeda* veld (Acocks, 1988). The more arid parts of this veld are characterised by the high species abundance of species, such as *Aristida congesta subsp. congesta, Eragrostis lehmanniana* and *Tragus koeleriodes* (Acocks, 1988).

Mucina and Rutherford (2006) classified the vegetation of this region as the Bloemfontein Karroid Shrubland. This vegetation is mainly distributed in the Free State Province and extends over large distances between Bloemfontein in the southwest, Verkeerdevlei and Lindley in the southeast, Standerton in the northeast and Heilbron and Bultfontein in the northwest. The Gh 8-vegetation type is situated at an altitude of 1320 – 1840m above sea level, mostly at 1400 – 1440m.

The vegetation and landscape features include the plateaus or slightly sloping flanks of dolerite outcrops supporting low Shrubland. This Shrubland is dominated by dwarf, small-leaved karriod and succulent shrubs. The grasses of this vegetation type are restricted to depressions and crevices filled with fine soils. This vegetation type is characterized by the presence of abundant geophytic herbs, solitary or small shrub groups with *Diospyros austro-africana, Eeuclea sp.* and *Rhus spp.* occasionally present, especially in habitats where root penetration into deeper crevices is possible (Mucina and Rutherford, 2006).

The Gh 8-vegetation type is situated in the summer rainfall area, with an annual long-term rainfall of 550 mm to 570 mm. This vegetation type lies in the warm-temperature climate regime, although the winters can be very cold and frost incidence is high (40 days) (Mucina and Rutherford 2006).

The most important taxa include tall shrubs, succulent shrubs, succulent woody climbers, graminoides (Grasses), herbs, geophytic herbs and succulent herbs. The most commonly found grasses include, among others, *Aristida congesta, Heteropogon contortus, Digitaria eriantha, Eragrostis chloromelas, Themeda triandra, Tragus koeleriodes* and *T. racemosus* (Mucina and Rutherford 2006).

2.4 Climate

The South African Weather Services[1] and the Institute for Soil, Water and Climate[2] supplied the climate data for the long-term average rainfall and temperature for the study site (Table 2.1). The rainfall data for the 2002/2003, 2003/2004 and 2004/2005 growing seasons that are given in Table 2.2, is the average of three rain gauges that were placed at different locations on the research farm of the Glen Agricultural Institute. All of these rain gauges were placed in close proximity to the study site and gave a good indication of the rainfall received during the above-mentioned growing seasons.

The climate of the study site is semi-arid. The long-term average rainfall is 547.4 mm per annum (84 year data). The rainfall is spread over an average of 54.9 rain days per year. The annual rainfall is mainly in the form of thunderstorms, of which 80 % occur in the summer months between September and April.

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[1] South African Weather Service, Private bag x 097, Pretoria, 0001,
Website: http://www.weathersa.co.za

[2] Institute for Soil, Climate and water, Private bag x 01, Glen, 9360.

Table 2.1 The long-term average monthly climatic data of the Glen weather Station (Appendix A for the abbreviations use in this table).

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Ave
Rainfall	8.5	11.1	19.3	48.9	69.5	66.5	84.0	79.0	82.3	50.2	19.6	8.5	547.4
R days	1.1	1.4	2.1	5.0	6.3	6.7	7.7	7.9	7.7	5.1	2.5	1.3	54.9
Tmax	17.8	20.6	24.4	25.3	28.4	30.3	30.8	29.5	27.3	23.8	20.5	17.6	24.7
Tmin	-1.6	0.9	5.2	9.5	12.0	14.0	15.3	14.8	12.6	7.8	2.7	-1.2	7.7

The average date for the first frost is the 3rd of May and the last frost normally occurs as late as the 24th of September. The average length of the frost season is 145 days per year and this is spread over an average of 69 frost days per year[1]. The earliest date ever recorded for the first frost to occur is the 4th of February and the latest is 28th November.

The temperatures vary from -1.6°C in the winter to 30.8 °C in the summer months. The coldest temperature of -1.6 °C is in July (mid-winter) and the warmest temperature of 30.8 °C occurs in January (mid-summer). The average minimum temperature of the region is 7.7 °C and the average maximum temperature is 24.7 °C (Table 2.1).

The long-term average rainfall data and the average rainfall for the three rain gauges that were spread over the Glen Agricultural Institute's research farm are given in Table 2.2 (expressed as mm/month and total mm). Two of these rain gauges were in close proximity to the trial. The distribution of the rainfall over the growing season is described first and then the average rainfall for the three growing seasons is compared with the long-term average rainfall for the Glen Research station (Table 2.2 and Figure 2.4).

The rainfall data was given from the 2002/2003 season to the 2004/2005 season, but the vegetation sampling only started in March 2004. The carry over effect of the previous season (e.g. 2002/2003) will have an effect on the vegetation growth in the next season (e.g. 2003/2004). The results of the vegetation surveys will therefore be described for the next seasons (e.g. 2003/2004/, 2004/2005 and 2005/2006).

Table 2.2 The long-term average rainfall data (mm/month and total) of the Glen weather station and the average rainfall received (mm/month and total) at the study site on the Glen Research farm for the 3 seasons (2002-2005).

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Ave.	8.5	11.1	19.3	48.9	69.5	66.5	84.0	79.0	82.3	50.2	19.6	8.5	547.4
02/03	0.5	47.0	10.7	38.0	29.0	109.9	69.0	89.5	95.5	6.1	16.0	0.0	511.2
03/04	0.0	3.9	18.7	17.3	71.3	72.8	57.6	103.9	77.2	43.5	0.0	9.4	475.6
04/05	0.0	8.3	34.3	18.2	25.0	78.4	100.3	56.3	64.1	85.0	21.7	12.8	504.4

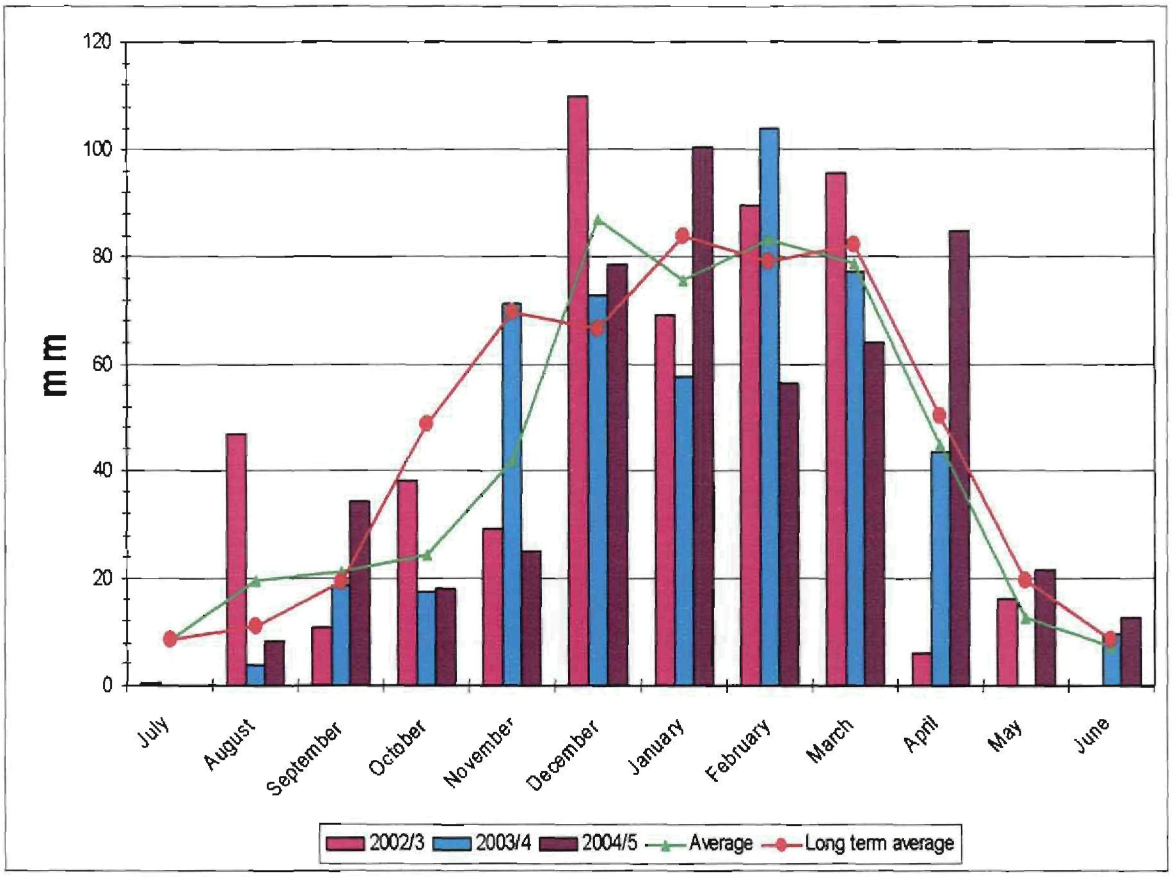

Figure 2.4 The average monthly and long-term rainfall (mm/month) for three growing seasons (2002-2005).

In the 2002/2003 growing season the study site received below-average rainfall in July and above-average rainfall in August. From September to the end of November it received less than the long-term average rainfall. December of that season was a particularly wet month, whereas January was dry with below the long-term average rainfall. February and March received above-average rainfall and April was a particularly dry month with a rainfall far below the long-term average. Although May of this growing season (2002/2003) was wetter than April, it still received below-average rainfall. In June the study site did not receive any rain. The total rainfall of 511.2 mm in the 2002/2003 season was lower than the long-term average of 547.4 mm (Table 2.2 and Figure 2.4).

In the 2003/2004 growing season the study site received no rainfall in July, in August it received less than the long-term average and in September, November and December it received more or less the same rainfall as the long-term average. January was dry with below-average rainfall and February the site received more than the long-term average rainfall. In March to April it received more or less the same rainfall as the long-term average. In May the study site did not receive any rainfall and in June the rainfall was more or less the same as the long-term average. The total rainfall for the 2003/2004 season at the study site was below the long-term average for the Glen weather station (Table 2.2 and Figure 2.4).

The 2004/2005 growing season initially received less than the average long-term rainfall (from July until the end of November), but in December and January the rainfall was higher than the long-term average. From January till the end of March, the study site received less than the long-term average rainfall. In April of this growing season the study site received nearly 41 % more rain than the long-term average. In May and June the study site received slightly more rainfall than the long-term average. The total rainfall for the whole of the 2004/2005 growing season (504, 4 mm) was less than the long-term average of 547, 4 mm (Table 2.2 and Figure 2.4).

The total rainfall received at the study site for all three seasons of this study was less than the total long-term average. If the average rainfall distribution curve for the three growing seasons is compared to that of the long-term average rainfall, the study site received above the long-term average rainfall from July to September. It received below average rainfall from October to end of December. The rainfall declined till below average in January and increased to above average in February. The rainfall declined to below the average from March to June.

2.5 Soil

The soil of the study site is of the Tukulu soil form which is a soil with an Ortic A-horizon and a neocutanic B-horizon below, on unspecified material, with signs of wetness (Soil Classification Working Group, 1991). The soil horizons are described in detail in Table 2.3 and Figure 2.5. Signs of wetness are associated with grey colours and indicate that the soil is saturated with water for a long time each year, leading to anaerobic conditions (South African Soil Classification Working Group, 1991).

The soil of the study site has an A-horizon with a dark red colour, with 16% clay and is classed as a sandy loam. The B_1-horizon has dark reddish brown colours, with 30% clay and is classed as sandy clay loam (South African Soil Classification Working Group, 1991).

The soil family is Dikeni, which means that the A-horizon is not bleached and the B-horizon has red colours and it is aluvic, because the ratio of clay percentage in the B_1-horizon to that in the A-horizon is greater than 1.3 and the A-horizon has more than 15% clay (South African Soil Classification Working Group, 1991).

The parent material of this soil is dolerite and the weathered dolerite is the restrictive layer. The soil had a gentle slope of 0 to 1 %, with a southern aspect.

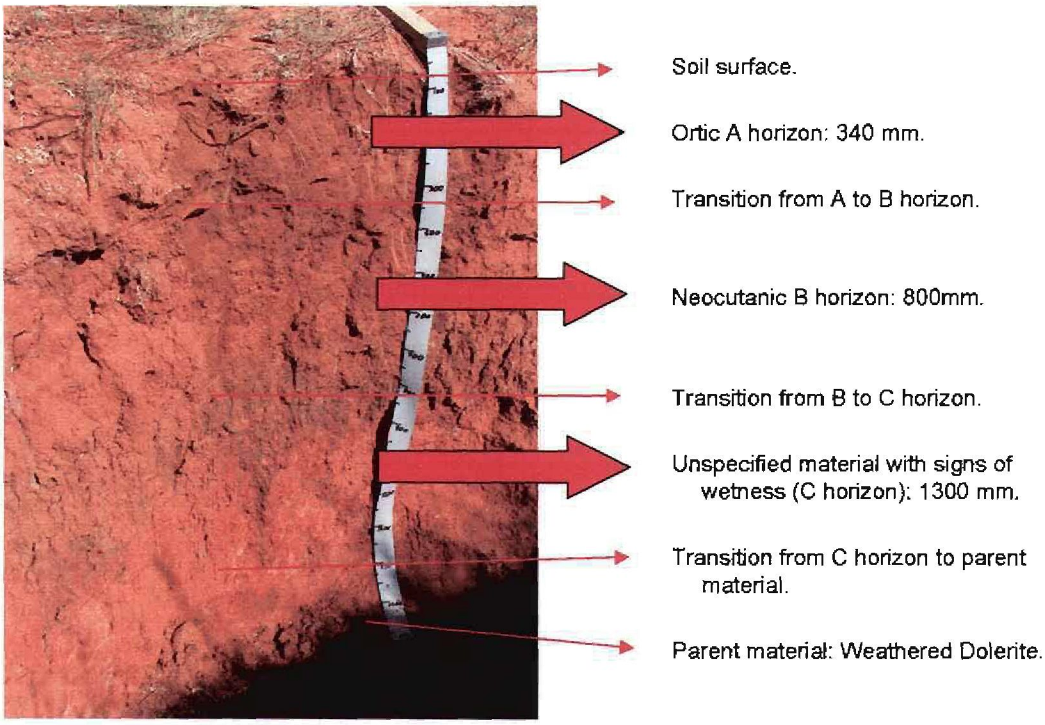

Figure 2.5 The soil profile of the trial site, with descriptions of the soil horizons at different depths.

Table 2.3 The description of the soil classification with different horizons as found at the study site (Appendix A: abbreviations).

A-horizon	**Clay content**	16 % (Clay & Silt)
	Colour	Moist, dark red (2.5 YR 3/6)
	Texture class	Sandy Loam
	Depth (mm)	340
	Name	Ortic A
B_1-horizon	**Clay content**	30 % (Clay & Silt)
	Colour	Moist dark reddish brown (5 YR 3/3)
	Texture class	Sandy clay loam
	Depth (mm)	800
	Name	Neocutanic B
C_1-horizon	**Clay content**	40 % (Clay & Silt)
	Colour	Moist yellowish red (5YR 5/6)
	Texture class	Sandy clay
	Depth (mm)	1300
	Name	Unspecified material with signs of wetness.
C_2-horizon	**Depth (mm)**	> 1300
	Name	Weathered Dolerite
Restrictive layer		Weathered Dolerite
Effective depth (mm)		± 1300

2.6 History and management of the study area

The study site was previously used for the production of dry land Lucerne from 1972 until 1980, where after it lay fallow until the 1991/1992 growing season. After 1992 it was used for the production of wheat for only one year, till 1993. From 1993 until 2003, it lay fallow again. No cultivation or grazing of these old cultivated lands took place in the 10 year period from 1993 to 2003. The area was regarded as an "old cultivated land" since only crop production occurred on it in the past. (Personal communication: Izak Venter[3] and Piet Goosen[4]). The study was conducted in 2 camps of 76 m x 219 m. One of the camps was used for the Roundup application and no Roundup was applied on the other.

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Chapter 3

Material and methods

3.1 Selection of the study site

After careful consideration of the situation that most of the farmers in the Free State Province were facing when they had to restore old cultivated lands, a suitable study site on the experimental farm of the Glen Agricultural Institute was selected that corresponded well to the old cultivated lands of the farmers. The selection of the study site was done on the following criteria: It was an old cultivated land that was laying fallow for a long period, it has already been fenced, all the technical inputs needed (organic material, tractors, implements and labour) were readily available and it represented the situation on most of the farms in the Free State Province. Since the study site formed part of a previous trial, it was fenced into camps. Two of these camps were selected for the two main restoration applications, namely the application of herbicide and that without the use of herbicide. The study site selection was done after collaboration with stakeholders and officials of the Department of Agriculture.

3.2 Restoration technologies applied

A combination of restoration technologies was applied in this study and evaluated against each other. Better results (species frequency) can be obtained over a shorter period of time when a combination of restoration technologies are used, e.g. cultivation, the application of organic material and re-seeding of important grass species (Van den Berg, 2002).

The following restoration technologies or combination of restoration technologies were evaluated in this study, in two row spacings (0.75m and 1.5m) and with and without the application of herbicide (Roundup), namely:

- A control plot (C);
- Rip (R);
- Rip and the application of organic material (RO);
- Rip and re-seeding with a seed mixture (RS) (Table 3.1);
- Rip, the application of organic material and re-seeding with a seed mixture (RSO) (Table 3.1);
- Rip and re-seeding only with *Digitaria eriantha* seed (RD) and
- The establishment of conventionally cultivated *Digitaria eriantha* pastures, without the use of fertilizer (P).

Three replicates were applied for each of the above-mentioned restoration technologies or combination of restoration technologies. All the restoration applications were done without the use of herbicide and with the use of herbicide.

The herbicide was used to minimise the competition with the existing vegetation in order to establish a satisfactory stand of more desirable vegetation, especially after re-seeding was carried out. Competition can be minimized by trampling or burning (Van der Merwe, 1997) or the use of fire. The latter is very risky in the drier parts of the Free State Province and difficult to manage. It was therefore decided to use herbicide instead. The common name for the herbicide used is Roundup, which has an active ingredient of Glyphosate: Isopropylamine salt (Glysine) (480g/l). The reason for the use of Roundup is that it is a widely and commonly used herbicide on the farms and it is readily available (see 3.2.6 for more explanations).

3.2.1 Rip

The ripping, sub-soiler or tilling treatment effect varies widely and can be both positive and negative, depending of the type of soil. In an East African study, ripping depleted the soil moisture, because it increased the surface area for evaporation (O'Connor, 1985). However, different trials produced different results. In a trial in a red loamy soil, an initial improvement in the herbaceous sward soon disappeared and after nine years the treatment resembled the control, with an increase in the bare ground patches (O'Connor, 1985). Ripping a red soil in an area of Zimbabwe, however, resulted in the establishment of a perennial grass cover, including "climax" species, after only four years (O'Connor, 1985).

O'Connor (1985) suggested that the effect of ripping depends on seasonal rainfall, as high rainfall promotes sufficient germination and/or establishment of residual soil seed bank reserves.

Ripping also breaks compacted soil surfaces and promotes water infiltration and retention capacity and aerates the soil to a certain depth (Van der Merwe & Kellner, 1999). A better seed bed for the establishment of seedlings can also be prepared. Mechanical restoration technologies such as ripping involve the use of agricultural implements to cultivate the soil. Different types of implement, such as rippers (furrow type cultivation) and dyker ploughs (hollow type cultivation) can be used, depending on the soil type (Boateng, 2002; Kellner, 2000).

The depth of cultivation and distances between the cultivated areas (hollows or furrows) are also very important, as these factors influence the results of restoration to a considerable extent. A norm was set that the depth of cultivation should be at least 200 mm and the distance between the rows (furrows) not more than two meters (Van der Merwe, 1997). De Wet (2001) and Buys (2002) found that deep ripping can increase the growth and reproductive potential of over-sown species and may improve the long-term success of re-seeding projects.

A cultivation method also stimulates the germination and establishment of seeds that lie dormant in the soil seed bank (Boateng, 2002). Before any restoration work starts, the soil must be properly loosened to ensure good results.

Soil is mechanically manipulated with the objective of promoting good till and in turn high crop production. Farmers have tilled the soil for centuries for the following reasons: to control weeds, to present a suitable seedbed for crop plants and to incorporate organic residues into the soil (Brady, 1984). This soil manipulation technique is widely used in modern agriculture.

In this study, ripping was done to a depth of at least 200 mm and with a row spacing of 0.75m and 1.5m, respectively. The rip action formed part of all the restoration combinations, described before, except for the control bi-plot and the conventionally cultivated pasture establishment. The rip action and the furrows created for re-seeding are shown in Figures 3.1 and 3.2.

Figure 3.1 The rip action applied in this study, by means of a one tine ripper.

Figure 3.2 The rip furrows created for re-seeding and breaking of soil compaction (after re-seeding and slightly compacted again).

3.2.2 Re-seeding

The effect of re-seeding depends highly on the mean annual rainfall as this influences the germination and initial establishment of the new seedlings (O'Connor, 1985). The germination also depends on the seeding rate, depth of seeding and type of application. The re-seeding actions were done in March 2003.

All the seeds were sown by hand on the banks of the rip furrows. The furrows were covered and slightly compacted by the tractor wheel method. The covering of the seeds and the compaction of the soil was done by the tractor wheels, to ensure that a close contact between the seed and the soil was created, as this helps with water absorption and the germination process of the seed. The re-seeding action is shown in Figure 3.3.

Figure 3.3 The re-seeding action by hand in the furrows made by the ripper.

- **Seed mixture**

A seed mixture was used to re-seed the old cultivated lands. As one of the aims of this study was to increase the cover and density of the grass sward for increased grazing capacity, a grass species mixture should be selected that suits the local conditions, especially with regard to soil type, as well as the short- and long-term rainfall (Van der Merwe, 1997).

The choice of species used in the seed mixture was done by Dr. Mias van der Westhuizen[5], because he had done extensive research on quantifying rangeland condition and the use of

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degradation gradients for grazing evaluation in semi-arid regions (Personal communication). His expertise was used to identify the suitable species that resembled rangeland in a good condition, to be used for re-seeding. The seeding ratios for each of the species were supplied by Dr. Faan van Wyk[6] (Personal communication). The grass seed mixture and the seeding ratios are given in Table 3.1.

Some of the seeds were commercially available and some were harvested in the rangeland. The harvested seeds included: *Themeda triandra, Cymbopogon excavatus* and *Eragrostis chloromelas* (Table 3.1). According to Van den Berg (2002), many restoration efforts involve planting a diverse mixture of species that are native to the area and are collected close to the study site. The availability of local ecotypes is often a major concern to restoration activities (Van den Berg, 2002). The origin of the harvested seed is often not known. The seed of *Themeda triandra* used in this study came from the Harrismith area of the Fee State Province (Personal Communication: Faan van Wyk[7]).

All the seeds were cleaned from chaff and trash by the Seed Company. There are certain advantages for buying locally derived seeds from a registered seed company. These include aspects such as that large quantities of seeds are available below the costs of seed collection by individuals and that the seeds have less chaff and trash and are more pure, which results in reduced bulk. Some seed companies, such as Advance Seed make use of seed coating to enhance germination (Van den Berg, 2002). The term "seed coating" or "enhancing" is used to describe three general methods to treat the seeds to benefit it after harvesting but before sowing i.e. pre-sowing hydration treatments, coating technologies and seed conditioning (Van den Berg, 2002). The following seeds used in this study were coated or enhanced (treated): *Panicum maximum, Chloris gayana* and *Digitaria eriantha*.

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[7] Dr. Faan van Wyk, Eko Rehab, P. O. Box 19752, Noordbrug, 2522, Tel. 018 297 7320, Fax. 018 293 2258

Table 3.1 The grass seed type, seeding ratios and % of seed mixture of re-seeding species, as well as whether the seeds were treated (coated) or not. The Afrikaans and English names are also given.

Scientific name	Afrikaans name	English name	Ratio*	%	Coated
Digitaria eriantha	Smutsvingergras	Smuts finger grass	5	29.5	Yes
Cenchrus cilliaris (gayndah)	Bloubuffelgras	Blue buffalo grass	3	17.6	No
Chloris gayana	Rhodesgras	Rhodes grass	3	17.6	Yes
Themeda triandra	Rooigras	Red grass	2	11.7	No
Eragrostis chloromelas	Krulblaargras	Curly leaf grass	1	5.9	No
Cymbopogon excavatus	Breëblaarterpentyn=gras	Broad-leaf Turpentine grass	1	5.9	No
Eragrostis curvula	Oulandsgras	Weeping love grass	1	5.9	No
Panicum maximum	Gewone buffelsgras	Guinea grass	1	5.9	Yes
Total	(* Ratio in kg / ha)		**17**	**100**	

- **Grass species used in the seed mixture**

A short description of the seed types used in the restoration trials are given below.

➢ *Digitaria eriantha* Steud.

This perennial grass with a high dry material production and digestibility is well utilized by grazers. It is widely used as cultivated pastures for hay production. This grass species has a high grazing value and it is a decreaser species. Decreaser species are species that are dominant in rangeland with a good condition and decrease if the rangeland is mismanaged (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). This grass is a grazing grass that can be used from mid to late summer and keeps its palatability till late in winter, even if it dies due to frost. It is mainly used as standing hay (Dickinson, *et al.*, 1997).

A monoculture with *Digitaria eriantha* was also used in this study. The same seed as in the seed mixture was used in a restoration trial at a seeding ratio of 5 kg per hectare. The main reason for the use of a monoculture was to reduce the cost of the restoration technology and to evaluate the use of only the one species that is normally used by local land users in the restoration of old cultivated lands.

- *Cenchrus cilliaris* var. *gayndah* L.

This grass is a perennial grass and has a high dry material production. It is used in the drier parts of the country for grazing as well as haymaking. Its grazing value is normally high and it is a decreaser species (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). It is very drought-resistant and can stool fast through under ground rhizomes (Dickinson, *et al*, 1997).

- *Chloris gayana* Kunth.

This grass is a perennial grass that is indigenous to India. It is highly palatable with a high leaf production and has a moderate nutritional value. It is widely used to control erosion and produce fodder in cultivated pastures. It has a high grazing value and is classified as an increaser 2 b under natural conditions (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). An increaser 2 b grass species is a grass species that increases under moderate overgrazing (Van Oudtshoorn, 1991). This grass species is very popular as a cultivated pasture grass due to the fact that it is easily established, has a high seed production and a creeping growth form (Dickinson *et al.*, 1997).

- *Themeda triandra* Forssk.

Themeda triandra is a perennial grass that occurs in almost any rangeland type, but is a familiar sight in undisturbed climax grass rangeland in moderate to higher rainfall areas. This grass is generally regarded as one of the best grazing grasses as it is very palatable and has a high leaf production. Its palatability is low in winter. It is classified as a decreaser species, as it decreases in number under poor rangeland management. Its grazing value varies from high to very high and is preferred by almost every grazer (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991).

- *Eragrostis chloromelas* Schrad.

This perennial grass is a reasonability palatable species that occurs in disturbed places like overgrazed or trampled rangeland and road reserves. It is a palatable grass species that can sustain heavy grazing. Its grazing value is moderate and it is classified as increaser 2 b or 2 c (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). An increaser 2 b species increase in number under moderate overgrazing and an increaser 2 c species increase in number under heavy overgrazing (Van Oudtshoorn, 1991).

- *Eragrostis curvula* Schrad.

This perennial grass is used as cultivated pastures as it is one of the most economically important grasses in South Africa. Some of the selection lines have a high dry matter production and give early grazing in spring. Its palatability is moderate to low, but it is generally used as grazing, hay and to maintain soil conservation structures. It is classified as an increaser 2 b species (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). This grass is the most widely used cultivated pastures species, but is not frost resistant. After the winter period, it starts to grow again in spring, thus giving it the advantage that it is green very early in the season before the other grasses. The quality of this grass species is dependant on the soil nutrient status. Under a lower soil nutrient status it can result in a grazing with lower quality that is unacceptable to animals (Dickinson, et al, 1997).

- *Cymbopogon excavatus* Hochst.

Cymbopogon excavatus is a perennial grass that grows on most soil types, but prefers stony sandy soils in disturbed as well as undisturbed rangeland. It is an aromatic grass with a turpentine smell, which makes it unpalatable. This grass will only be grazed when it is young and after a rangeland fire. The grazing value of this grass is low. It is classifies as an increaser 1 species (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). An increaser 1 species is a grass species that is dormant in rangeland with a poor condition and increases in number under underutilization or selective grazing (Van Oudtshoorn, 1991).

This species was included in the seed mixture after consultation with Dr. Mias van der Westhuizen[8] and Dr. Faan van Wyk[9]. *Cymbopogon excavatus* does occur naturally in the *Cymbopogon – Themeda* veld (Acocks, 1988) or Bloemfontein Karroid Shrubland (Mucina and Rutherford, 2006) and since one of the objectives of this study was to restore the old cultivated lands to natural veld it was decided to include this species in the seed mixture.

- *Panicum maximum* Jacq.

This is a perennial grass with a varying grazing value and it is classified as a decreaser species. It is a very palatable and important grazing grass and it produces standing hay of a high quality (Van Oudtshoorn, 1991; Gibbs Russell, *et al.*, 1991). This grass species is frost resistant and the minimum rainfall needed to cultivate it is 500 mm per annum (Dickinson, *et al.*, 1997).

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[9] Dr. Faan van Wyk, Eko Rehab, P. O. Box 19752, Noordbrug, 2522, Tel. 018 297 7320, Fax. 018 293 2258

3.2.3 Application of organic material

One of the most common problems of degraded lands is the lack of nutrients, particularly nitrogen (Bradshaw, 1997). Manure improves the physical characteristics of the soils (chemical and physical), improves its water-holding capacities, provides nutrients and mulch, limits soil crusting and regulates the soil temperature (Buys, 2002 and Obi & Ebo, 1995). The application of organic material into the soil improves the nutrient status of the soil (Van der Merwe, 1997) and will increase the establishment and growth rate of over-sown (re-seeded) species as well as existing plants (Ngolwe & Fleissner, 2002). The grass plants develop bigger tufts that help to increase the productivity for a higher grazing value and capacity (Boateng, 2002). Organic material supplies appreciable quantities of nitrogen, phosphorus and sulphur to the soil. It also decreases phosphorus fixation and micronutrient leaching. Organic material increases the carbon content of the soil, helps in the aeration of soil and improves the retention of water in degraded soil (Obi & Ebo, 1995).

In this study, cow-dung was applied as an organic material supplement. The dung was applied by hand into the rip furrows at a rate of 5.77 tonnes per hectare. The rate was determine by the size of the buckets that was use to spread the dung in the rip furrows (one bucket per rip furrow per plot).

3.2.4 Conventional cultivated *Digitaria eriantha* pastures

The main characteristics of this species were discussed in the previous section.

The seedbed for the establishment of cultivated pastures must be level, weed free, firm and fine, because most of the grass seeds used as cultivated pastures are small (Dickinson *et al.*, 1997).

In this study, one experimental plot was hand-sown after the seedbed was prepared with a ripper to a depth of 200 mm. After that the plot was ploughed, the soil aggregates were broken up with a disc plough and finally harrowed with a power harrow. The soil was rolled before and after the sowing. The seed was sown just underneath the soil surface in rows with a 1 m row width. The re-seeding process and seedbed preparation for this application are shown in Figure 3.4.

Figure 3.4 The seeding action and seedbed preparation of the conventional cultivated *Digitaria eriantha* restoration technologies.

3.2.5 Control restoration technology

No restoration application was carried out in the control plot. It was to serve as a point of reference for the change in species composition for the applied restoration technologies.

3.2.6 Application of herbicide

As mentioned before, Roundup Ultra was applied in half the experimental plots before the restoration technologies were applied. This was done to help eliminate competition of the newly established re-seeded seedlings, as well as those seedlings that germinated from the soil seed bank, for light, water and nutrients. Roundup Ultra is a water soluble concentrate that is non selective, in other words it kills all living plants. It is a systemic post-emergence herbicide with Glyphosate (Isopropylamine salt: Glysine) as active ingredient. It works only on the active growing state of the plants and it moves only from leaves to roots, through the stems, but not from the roots to leaves. It is usually used to control perennial and annual weeds in cash crops (Roundup Ultra booklet, October 2001).

Glyphosate has a waiting period of 14 days before any seedlings can be planted or seeds be sown. It is classified as being slightly hazardous, meaning that the LD_{50} levels (lethal dosage which will kill 50 % of a test group of animals) for the rat is between 500 and 4000 mg/kg body mass, depending on the way it is taken and the physical state of the formulation. Caution should be taken when it is applied (Technical Advisory Service, 2004).

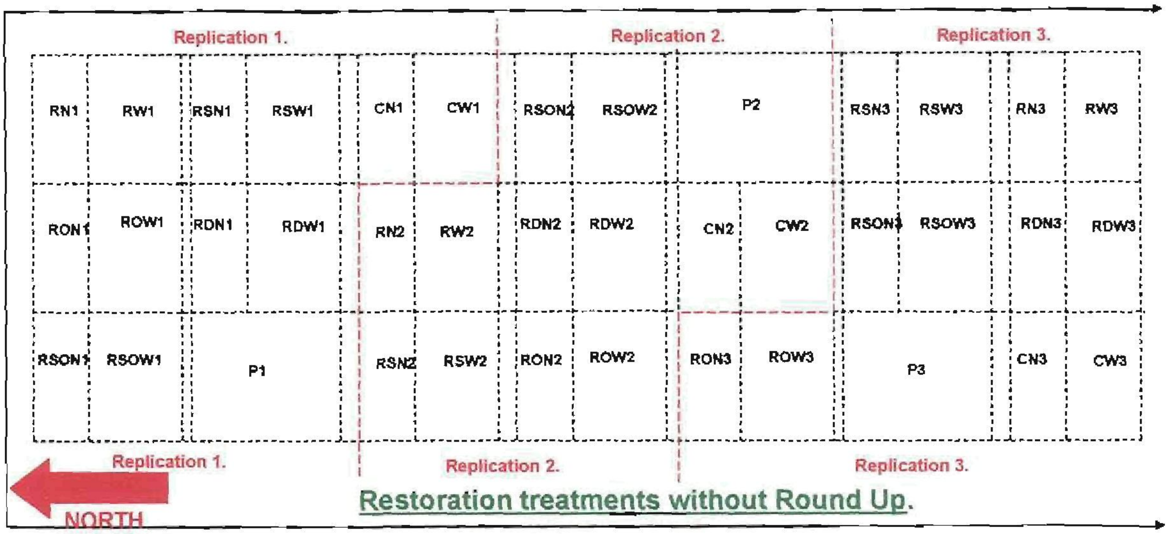
The Roundup was applied at herbicide:water ratio of 6.0 l : 600 l / ha. A wetter-sticker (Nu-film) was used to increase the working of the herbicide, as it increases the capacity of the herbicide to stick onto the plant leaves and increases the absorption of the herbicide by the plant. Mr. Jan Richter (Personal communication[10]) recommended the ratio of the herbicide. It was applied with a normal herbicide sprayer mounted on the three point of a tractor. The sprayer used had an 8 m boom, with 16 nozzles and a 500 l tank. The tractor sprayed the herbicide at a constant speed of 10 km / h and sprayed evenly over the whole camp.

3.3 Plot layout

The plot layout was designed statistically in a standard random block design, with the practical limitations of the tractors and implements used kept in mind. This included aspects such as leaving enough spaces for the tractor and providing enough space for it to turn without disturbing the control plots by riding over them and damaging the plants or compacting the plots unnecessarily. The traffic with the tractor within a certain plot was kept to a minimum.

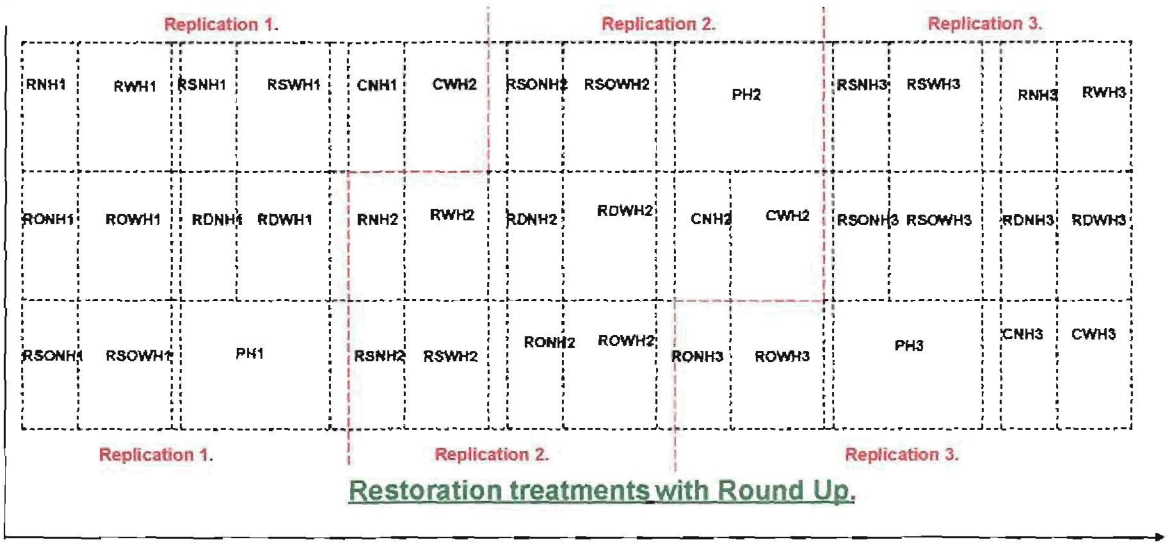
Two camps were of the same size, namely: 76.7 m by 219.7 m. The areas were divided into blocks of 20 x 28 m. These blocks were further divided into two sub-plots for the different row spacing of 0.75 m and 1.5 m, respectively. The plot layouts for the study sites with and without Roundup application are given in Figures 3.5 and 3.6.

[10] Jan Richter, Department of Agriculture, Free State Province, Private bag X 01, Glen 9360, Tel. 051 861 1157, Fax. 051 861 2052.



RN:	Rip, 0.5 m rows.	RW:	Rip, 1.5 m rows.
RSN:	Rip, seed mixture, 0.5 m rows.	RSW:	Rip, seed mixture, 1.5 m rows.
RON:	Rip, organic material, 0.5 m rows.	ROW:	Rip, organic material, 1.5 m rows.
RSON:	Rip, seed mixture, organic material, 0.75 m rows	RSOW:	Rip, seed mixture, organic material, 1.5 m rows
RDN:	Rip, *Digitaria eriantha*, 0.75 m rows.	RDW:	Rip, *Digitaria eriantha* 1.5 m rows.
CN:	Control, 0.75 m rows.	CW:	Control, 1.5 m rows.
P:	Planted pasture.	1 – 3:	Replications.

Figure 3.5 The plot trial layout of the no-Roundup restoration technologies, showing the three replications of the different restoration technologies applied.



RNH:	Rip, 0.5 m rows, herbicide herbicide.	RWH:	Rip, 1.5 m rows herbicide.
RSNH:	Rip, seed mixture, 0.5 m rows herbicide.	RSWH:	Rip, seed mixture, 1.5 m rows herbicide.
RONH:	Rip, organic material, 0.5 m rows herbicide.	ROWH:	Rip, organic material, 1.5 m rows herbicide.
RSONH:	Rip, seed mixture, organic material, 0.75 m rows	RSOWH:	Rip, seed mixture, organic material, 1.5 m rows herbicide
RDNH:	Rip, *Digitaria eriantha*, 0.75 m rows herbicide.	RDWH:	Rip, *Digitaria eriantha*, 1.5 m rows herbicide.
CNH:	Control, 0.75 m rows herbicide.	CWH:	Control, 1.5 m rows herbicide
PH:	Planted pasture herbicide.	1 – 3	Replications.

Figure 3.6 The plot trial layout of the Roundup restoration technologies, showing the three replications of the different restoration technologies applied.

3.4 Vegetation sampling procedures

The vegetation was sampled by means of two methods, namely with a wheel-point apparatus method and the quadrate method (Kent and Coker, 1996; Mueller-Dombios and Ellenberg, 1974; Sutherland, 1996 and Tidmarsh and Havenga, 1955). The wheel-point apparatus was used to determine the species frequency and basal cover and the quadrate method was used to determine the species density. Sampling of the vegetation was done on the rip furrows to determine the success of the restoration technology.

It is important that the species are as fully represented as possible and that the "minimal area" of the plant community, which is the smallest area on which the species composition of the plant community in question is adequately represented, is correctly determined (Mueller-Dombois and Ellenberg, 1974). With this in mind, a total number of 100 wheel-point surveys and twenty quadrate surveys were carried out in each subplot (Figure. 3.7 and 3.8). A subplot represents the application of a restoration technology or a combination of restoration technologies applied. The total areas of the subplots differ slightly, depending on the row width of the rip action, namely 195 m^2 (0.0195 ha) for the 0.75 m rip row spacing and 330 m^2 (0.033 ha) for the 1.5 m rip row spacing. Taken into account that twenty 0.5 m x 0.5 m (0.25 m^2) quadrates were surveyed per subplot, a total area of 5 m^2 was surveyed per subplot, thus 2.56 % and 1.52 % of the total area for the 0.75 m and 1.5 m rip row spacing, respectively.

The shape, size and number of quadrates are important when this method is used to sample a plant community (Barbour *et al.*, 1987). There are no specific rules that can be applied to determine the size and number of the quadrates to be used to survey a particular plant community, as it depends on the characteristics of that particular community (Barbour *et al.*, 1987; Gilbertson *et al.*, 1989). A general rule of thumb that can be applied is that the larger the plants to be surveyed, the larger the quadrate and vice versa (Gilbertson *et al.*, 1989). When grassland vegetation are to be surveyed, small quadrates of 0.5 x 0.5 m to 1 x 1 m are suitable (Gilbertson *et al.*, 1989). Mueller-Dombois and Ellenberg (1974) stated that the minimal area to be sampled can only be determined if the plant community is relatively homogeneous and not fragmented. As the plant community of the study site for this study consisted primarily of old cultivated lands, its composition was very homogeneous and therefore a minimal area could be determined.

The minimal area for this study was calculated to be 100 wheel point surveys and twenty 0.25 m^2 quadrates per subplot. Small 0.5 x 0.5 m metal quadrates (made from 8 mm metal rods) were used and all the grass species inside the quadrate were recorded and counted to determine the density. It was decided to use 0.5 m x 0.5 m (0.25 m^2) quadrates because of the characteristics of the plant community, namely small grass species, mainly consisting of pioneer grasses and a small number of larger tufted climax-perennial grass species. The survey technique is shown in Figure 3.7

Figure 3.7 The quadrate survey of 0.5 x 0.5 m done in this study to determine the density of all grass species per restoration technology.

The wheel-point method is a point method where the quadrates, used to sample a plant community, are reduced to no dimension and it becomes an infinitely small point. The points are in practice sharp metal tips and this method is used to determine the basal cover and species frequency of the plant community (Barbour *et al.*, 1987). Barbour *et al.* (1987) described the method by using a frame with metal pens, used as markers. The method used in this study is an expansion of the frame as described by Barbour *et al.* (1987), called the wheel-point apparatus. The wheel acts as a rotating frame (Tidmarsh and Havenga, 1955).

This point method is widely used to survey and measure semi-open grassland and Karoo vegetation in South Africa and makes use of an apparatus called a wheel-point apparatus. The wheel-point apparatus looks like a bicycle wheel without the rim and tyre. The apparatus moves directly on the spokes and one or more of the spokes are marked (Tidmarsh and Havenga, 1955).

The plant species nearest to the marked spoke (in a radius of 30 cm) is recorded (Tidmarsh and Havenga, 1955). In this study, a wheel-point apparatus, made with a circumference of three meters was used, with two spokes marked (1.5 m intervals) (Figure 3.8).

The wheel-point apparatus gives systematic samples in straight lines, giving direct unbiased estimates of the mean with a standard deviation that conforms to the binomial distribution of the plant species, irrespective of the pattern of vegetation (Tidmarsh and Havenga, 1955). This is only true if the distance between the points and the lines is greater than the cross sectional lengths of the individuals and the area sampled is adequately covered by the spread of sampling points (Tidmarsh and Havenga, 1955).

(a) (b)

Figure 3.8 The wheel-point apparatus used in this study and how the surveys were carried out at the trial site.

3.4.1 Before restoration application

Before the restoration experiments were established, a survey was carried out at the study site to get a good account of the species that were already present on the old cultivated land. The frequency and basal cover of the grass sward was determined. This survey was conducted on 3 March 2003.

- **Frequency surveys**

In order to make an accurate estimation of the rangeland condition before any restoration technologies were applied, a 600 point wheel-point survey was carried out randomly over the total study area for both the Roundup and no-Roundup treatments. All species of the grass and herbaceous layer were recorded. Only frequency and basal cover measurements were recorded.

- **Basal cover**

Tidmarsh and Havenga (1955) stated that a clear definition of a "strike" be formulated before any surveys are done. In this study, a "strike" is defined as follows: When the tuft of the grass species is directly underneath one of the markers on the apparatus, in other words, it is physically touched by the marker; it is recorded as a "strike". The basal cover recordings were done simultaneously with the frequency survey.

The percentage cover is calculated as the number of strikes divided by the total number of points (surveyed) multiplied by 100 (Barbour *et al.*, 1987). This calculation was done per species and as the total basal cover for the whole subplot. The basal covers of the individual species were added up to get the total basal cover per subplot.

3.4.2 After restoration application

The following vegetation parameters were sampled after the restoration experiments were carried out in March/April of 2004, March/April 2005 and March/April 2006.

- **Frequency surveys**

For the after restoration application the wheel-point method as described before was used to determine the frequency of the grass species in each subplot. Because of the small area of the subplots, only 100 survey points were recorded to ensure that the plot was surveyed adequately. This survey was done on the rip furrows to determine the success and the establishment rates of especially the re-seeded species of each restoration technology (the germination of newly established seed, either re-seeded or naturally accruing species) (See section 3.4.1 for the technique description).

- **Basal cover**

The wheel-point method described above was also used to determine the basal cover of the grass species in each subplot and the same technique that was described for the basal cover of the before restoration application was used to determine the basal cover (Section 3.4.1).

- **Density surveys**

Species density was determined by using the quadrate method described before. Because of the poor germination of the conventionally planted pasture (P and PH in Figure 3.5 and 3.6); no density surveys were carried out at this subplot (See section 3.4.1 for the technique description).

3.5 Soil sampling

3.5.1 Soil classification

The soil was classified by digging four soil-profile pits at the study site more or less in the middle of the two camps. The South African soil classification system was used to classify and describe the soil (Soil classification Workgroup, 1991). According to this workgroup, the soil profile must be described and classified to a depth of 1.5 m. The soil was classified in each of the four soil-profile pits. Since the soil was more or less uniform over the total study area, only one soil-profile pit was used to describe and classify the soil according to certain characteristics such as soil horizon, colour, depth, structure, texture, clay content, etc.

3.5.2 Soil analyses

The chemical and physical characteristic were analysed according to the standard soil chemical analyses methods, described by the laboratories of the Free State Province Department of Agriculture[11] and the Agricultural Research Council's Small Grain Institute[12]. The following chemical and physical analyses were done:

Physical analyses included clay percentage and particle size distribution. Particle size distribution (sand, silk and loam), was done by dispersing the soil sample in an aqueous suspension. The soil samples were sieved to determine the sand fraction. The clay and loam fractions were determined with a hydrometer when the soil is dispersed in an aqueous medium (Hillel, 1982)

The chemical soil analyses included:

- The macro-element content (P, K, Ca, Mg, and Na). Phosphorus (P) was extracted with Bray 1 solution and the other cations were extracted with NH_4OAc solution. The solutions

[11] Free State Department of Agriculture Soil and Water Laboratory, Private bag x 01, Glen 9360, Tel. 051 861 1147

[12] ARC-Small Grains Institute, Soil Analyses laboratory, Private bag x 29, Bethlehem, 9700, tel. 058 307 3501

were used to extract the cations from the soil and dissolve them so that they can be analysed by an atom absorption spectrophotometer (Hesse, 1972);

- Cation exchange capacity was determined by the same method as described above;
- Ca:Mg ratio (calculated from the above);
- (Ca + Mg):K ratio (calculated from the above);
- The micro-element content (Zn, Cu, Fe and Mn). The EDTA (Ethylenediaminetetracetic acid) method was used to determine the micronutrient content of the soil;
- pH (KCl): KCl was used as a buffer to measure the pH of the soil (Hesse, 1972) and
- Carbon content was determined with the Hawley-Black method by oxidation of the element to carbon dioxide, which is then determined either gravimetrically or volumetrically (Hesse, 1972).

3.6 Data analyses

3.6.1 Vegetation

The raw data, as given in appendix B, was analysed using data analyses methods (Analysis of variance (ANOVA) and Multivariate).

Each sample study site in the data set was described by the frequency, basal cover and density of the different plant species in each subplot. The data was entered into a spreadsheet and analysed with the use of multivariate analysis methods.

The data from the frequency, density and basal cover recordings was statistically analysed by Mrs. M. F. Smit[13] and Mrs. L. Morey[14] of the Agricultural Research Council (ARC) Biometry Unit in Pretoria. They made use of the statistical program, GenStat (2000). The differences between the species frequency, densities and basal cover were tested for an analysis of variance (ANOVA). The treatment variances were stabilised by using the $\log_{10}$ transformation. The treatment and species means were used in the analysis and were separated using Fisher's protected t-test least significant difference (LSD) at 5 % level of significance (Snedecor and Cochran, 1980).

Community data are complex, (involving noise, redundancy, relationships and outliers), bulky (many samples) and the investigator might have a particular question or interest, but the answer is not directly clear due to the variety of the data sets. The purposes of the research and

[13] Mrs. M. F. Smit, ARC Biometry Unit, Private bag x 519, Silverton, Pretoria 0127, Tel. (012) 842 4238, Fax. (012) 842 5143, Cell: 083 306 2753, e-mail: MarieS@ing1.agric.za

[14] Mrs. L. Morey, ARC Biometry Unit, Private bag x 519, Silverton, Pretoria 0127, Tel. (012) 842 4152, Fax. (012) 842 4153, e-mail: LiesIM@ing1.agric.za

required formats for the presentation of the results normally demand a variety of multivariate analysis techniques (Kent and Coker, 1996). Multivariate analysis provides the researcher with advantages like objectivity, speed and low cost, effective correlation with other factors, relevance to a variety of present and potential research interests and compatibility and comparability with related studies (Kent and Coker, 1994). Multivariate analysis helps the ecologist to discover structures and trends in the data and it provides a relatively objective, easy summarization of the data (Gauch, 1982; Kent and Coker, 1994). Both of these facilitate the ecologist's comprehension of the data and provide a means for effective communication of results (Gauch, 1982).

Ordination techniques that were used to analyse the data in this study are multivariate analyses techniques, because ordination represents samples and species relationships as faithfully as possible in a low-dimensional space (Gauch, 1982). Ordination is effective in showing relationships, reducing noise, can help identify outliers and it summarizes data redundancy by placing similar entities in proximity (Kent and Coker, 1994). The Principal Component Analysis (PCA) technique, in the CANOCO statistical program (Ter Braak, 1987 – 1992), was used for the analysis of species composition data in this study.

As the data set of this study, for a particular restoration technology, was plant species composition represented by the frequency, basal cover and density for each species, few absences in the data and little species turnover along the gradient occurred, hence a PCA ordination technique could be used (Leps and Smilauer 2003). In this study the ordination axes was extracted in order to describe the main compositional gradients. The Eigen-values were calculated for a particular axis as a measure of the variance captured in a particular axis.

3.6.2 Soil

The soil was only analysed for the nutrient content, both macro and micro-elements, carbon content, pH and particle size distribution for information purposes and to aid in the classification process. The data for the whole study area is given in Tables and/or Graphs in the next chapter of this dissertation.

3.7 Seed viability of seed used in the re-seeding application

3.7.1 Introduction

The seeds that were used for the re-seeding experiment in this study were sent to the National Department of Agriculture's seed testing laboratory in Roodeplaat[15] for germination and purity tests. The analyses were carried out according to the rules set by the International Seed Testing Association (ISTA[16], 1985).

Since some of the seeds, like *Themeda triandra,* were harvested in the rangeland and the seeds were never certified by any laboratory, it was important to test it for purity and germination. It is very important to use good, viable seeds in the re-seeding process, because the number of seeds and their germination play a major role in determining the restoration success of a particular restoration technology (Marañón, 1998). Crocker and Barton (1957) suggested that there are numerous factors that influence the germination of seeds, such as temperature (seeds germinate usually at temperatures of between 15° to 30 ° C), maturity (some seeds mature over a period, like *Themeda triandra*, which has a higher germination if it was stored over a winter period) (Faan van Wyk[17]) and seed size (smaller seeds produce smaller plants and root systems).

Some of the commercial pasture seeds used in this study was "coated" with chemicals to reduce the damage by fungal or insect attack during storage and germination (Crocker and Barton, 1957). This chemical coat not only protects the seed on the shelf, but also after it has been sown. Coated or enhanced seeds are supplied by Advance Seed Company in Krugersdorp, South Africa.

Seed samples were tested to confirm that the labels on the seed bags and its content do match. Van den Berg (2002) stated that it is a good policy to test the seed yourself or to have it done by an authorised seed testing laboratory before restoration technologies that include re-seeding treatments are applied.

The laboratory tests depend heavily on the given sample and every effort should be made that the sample is representative of the whole seed lot (Van den Berg, 2002). Only a very small

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[15] Seed Quality Control Laboratory, National Department of Agriculture, Directorate Plant Production, Private Bag x 250, Pretoria 0001, Tel. 012 808 5383

[16] International Seed Testing Association, Secretariat, P. O. Box 412, 8046, Zurich CH-Switzerland. Tel: +411 377 6000, e-mail: istach@iprolink.ch

[17] Dr. Faan van Wyk, Eko Rehab, P. O. Box 19752, Noordbrug, 2522, Tel. 018 297 7320, Fax. 018 293 2258

sample is tested, because of the practicality of it. Due to the fact that seeds are rarely pure, it is very important to sort it to obtain the correct material for the tests (MacKay, 1972).

3.7.2 Material and methods

Only two types of analysis were done on the seeds samples sent to the laboratory for testing, namely purity and germination.

- **Purity analysis**

According to Van den Berg (2002), the objectives of the purity analysis is firstly to determine the percentage composition by weight of the sample being tested and the composition of the seed lot, and secondly to identify the various species of seeds and inert particles present in the sample. The purity of seeds is important, because it must not contain other impurities such as soil, chaff and weed seed. As it is nearly impossible to remove every impurity from the seeds during the cleaning process, standards were set to determine the allowed composition of the seed, such as pure seed, other impurities and weed seed (Van den Berg, 2002). The germination test was done on the pure seed component alone and therefore the two tests complement each other.

According to Obed Phahladira of the National Department of Agriculture's Seed laboratory, the seed and impurities were divided by hand into different groups of impurities and then counted and expressed as a percentage (Personal communication[18])

- **Germination analysis**

Germination of seeds in the laboratory involves the emergence and development of the seedling to a stage where its essential structures indicate whether or not it is able to develop further into a viable plant under favourable conditions in the field under natural conditions (MacKay, 1972).

The main objective of the germination test, as set by ISTA (1985), is to determine the maximum germination capacity of the seed and to provide results that can be used to compare the value of different seed lots. In the laboratory methods, the external conditions are controlled to give the most regular, rapid and complete germination for the majority of the samples of a particular species (ISTA, 1985).

[18] Obed Phahladira, Seed Testing, National Department of Agriculture, Private bag X 250, Pretoria 0001, Tel. 012 808 5052, Fax. 012 808 5383.

The results are indicated as a percentage of pure seeds which produce seedlings that are capable of continued development into mature plants, when they are germinated under standardised conditions. The conditions must be standardised so that the results are reproducible (MacKay, 1972).

There are different germination methods which include both paper and sand germination. The seed test laboratory of the National Department of Agriculture did the purity and germination test according to the ISTA rules with four replications of 100 seeds and used the following methods for the different grass species (Obed Phahladira, Personal communication[19]).

Chloris gayana: coated seed: top paper method with a 14 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 30° C for 8 hours a day during the 21 day test period.

Digitaria eriantha: coated seed: top paper method with a 12.5 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 30° C for 8 hours a day during the 14 day test period.

Panicum maximum: coated seed: top paper method with a 12.5 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 30° C for 8 hours a day during the 28 day test period.

Eragrostis chloromelas: uncoated seed: top paper method with a 12.5 ml KNO_3 (potassium nitrate) solution to moisten the substrate and seeds were kept at 20° C for 16 hours and 30° C for 8 hours a day during the 21 day test period.

Eragrostis curvula: uncoated seed: top paper method with a 12.5 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 35° C for 8 hours a day during the 21 day test period.

Themeda triandra: uncoated seed: top paper method with a 50 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 30° C for 8 hours a day during the 20 day test period.

[19] Obed Phahladira, Seed Testing, National Department of Agriculture, Private bag X 250, Pretoria 0001, Tel. 012 808 5052, Fax. 012 808 5383.

Cymbopogon excavatus: uncoated seed: top paper method with a 12.5 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 30° C for 8 hours a day during the 28 day test period.

Cenchrus cilliaris: uncoated seed: top paper method with a 50 ml KNO_3 (potassium nitrate) solution to moisten the substrate. The seeds were kept at 20° C for 16 hours and at 30° C for 8 hours a day during the 29 day test period.

3.8 Economic analyses of the restoration applications

The cost for all the restoration technologies applied and the conventionally planted pasture was calculated by an agricultural economist of the Free State Province Department of Agriculture, (Mr. C. Fourie, and Personal communication[20]). The calculations were based on Figures given in the Mechanisation Guide 2007, which was compiled by Le Roux (2007).

The following criteria were used to calculate the costs of each of the restoration technologies:

- Working width of the implement (row spacing);
- The speed of the tractor when the cultivation action was done;
- The land efficiency of the tractor and implement;
- The work tempo (ha/day);
- The number of days to work 100 ha, the depreciation of both the tractor and the implement;
- The interest on both the tractor and the implement;
- Diverse costs on both the tractor and implement;
- Total fixed cost per action (R/ha);
- Fuel required per action (l/ha) and fuel costs per action (R/ha);
- Maintenance and reparations on both the tractor and implement;
- The total running cost per action and the labour per action.

[20] Carel Fourie, Department of Agriculture, Free State Province, Private bag X 01, Glen 9360, Tel. 051 506 1546, Fax. 051 448 4068.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results of the data analysis of this study will be described in this chapter: The viability (seed purity and seed germination) of the seed types used in the re-seeding restoration trials (for both coated and uncoated seeds), the soil analyses results and the results of the vegetation sampling (density, frequency and basal cover) at the study site. The vegetation of the study site will be described according to the initial vegetation, as well as the vegetation of the different restoration technologies after the restoration technologies were applied. The vegetation data after the application of the restoration technologies will be described according to the five (5) most important species found in each restoration technology that was applied in this study. The importance value (IV) was calculated for each grass species to determine the five most important species.

The different restoration technologies will be described in the following order:

1) Control (C),
2) Rip (R),
3) Rip and the application of organic material (RO),
4) Rip and re-seeding with a seed mixture (RS),
5) Rip, re-seeding with a seed mixture and the application of organic material (RSO),
6) Rip and re-seeding only with *Digitaria eriantha* seed (RD) and
7) Conventionally cultivated *Digitaria eriantha* pastures restoration technology (P).

The plant communities will be described according to the frequency data for each technology applied in terms of the re-seeded species (where applicable), natural occurring species, narrow (0.75m) and wide (1.5m) row spacings and the application of Roundup.

The rainfall data and the soil classification results were already discussed in Chapter 2 of this dissertation.

4.2 Seed viability

All the seeds that were used in the re-seeding trial were tested for purity and germination potential. These tests were carried out by the National Department of Agriculture in their seed quality control laboratory[21]. The results of the seed tests for both coated and uncoated seeds are given in Table 4.1 and Table 4.2.

4.2.1 Seed Purity

The purity of the seeds was tested to determine the amount of viable seed and to separate it from the other material, such as broken seeds, sterile seeds, chaff and floral parts. Only pure seeds were used in the germination tests. The following definitions of the terms will be used to describe the purity of the seeds that were used in the re-seeding trials (ISTA, 1985).

Pure seed

This is seed in the sample that is of the kind stated in the description of the sample.

Inert material

This is material that includes the following:

- Derived from seeds which may also resemble seed, e. g. sclerotia;
- Derived from other parts of the plant but not seed, e. g. leaves and stalks;
- Derived from living organisms but not plants, e.g. insects; and
- Not derived from living organisms, e.g. soil and stones.

Other seed

This is any other seeds found in the sample that is not of the kind that was specified on the label of the seed lot. The other seeds are subdivided into two groups, namely: weed seed and other seed.

The eight species (coated and uncoated) used in the re-seeding restoration technologies ranked according to purity as follows: *Cenchrus cilliaris* (97.9%, uncoated), *Digitaria eriantha* (96.0%, coated), *Eragrostis curvula* (95.4%, uncoated), *Eragrostis chloromelas* (91.3 %, uncoated), *Chloris gayana* (85.6%, coated), *Panicum maximum* (84.3%, coated), *Themeda triandra* (72.6%, uncoated) and *Cymbopogon excavatus* (44.7%, uncoated) (Table 4.1 and 4.2).

The seeds were not pure; because of other inert material and other seed present in the seed lot, for example the seed of the *Cyperus* sp. was present in the seeds of *Eragrostis curvula* (Table

[21] Seed Quality Control Laboratory, National Department of Agriculture, Directorate Plant Production, Private Bag x 250, Pretoria 0001, Tel. 012 808 5383

4.2). The inert material percentage was 3.7; 3.1 and 1.7 % respectively for *Digitaria eriantha*, *Chloris gayana* and *Panicum maximum*. This inert material was mainly coating material, floral parts, stalks, plant material and sterile units of other plants' seed. The seeds of *Digitaria eriantha* had the highest percentage of inert material, namely 3.7%. the inert material of the uncoated seeds, were mainly broken and sterile units of the grass species' seeds, sterile units of other species' seeds, chaff, flower parts, stalks and dead plant and insect material, stones and soil parts (3.7% for *Digitaria eriantha*, 3.1% for *Chloris gayana*, 1.7% for *Panicum maximum*, 2.1% for *Cenchrus cilliaris*, 4.5% for *Eragrostis curvula*, 7.8% for *Eragrostis chloromelas*, 27.4% for *Themeda triandra* and 55% for *Cymbopogon excavatus*). The purity of *Cymbopogon excavatus* (55%) and *Themeda triandra* (27.4%) were the lowest, because it was bought from Eko Rehab[22] and the seeds were uncertified.

Table 4.1 The results of the purity tests and the description of the inert material components found in the coated seeds.

Seed kind	Pure coated (%)	Inert material (%)	Uncoated seeds (%)
Digitaria eriantha	96.0	3.7	0.3
Chloris gayana	85.6	3.1	11.3
Panicum maximum	84.3	1.7	14.0
Seed kind	**Inert material**		**Uncoated seed**
Digitaria eriantha	Coating material, flower parts, stalks and insect pieces.		*Digitaria eriantha*
Chloris gayana	Coating material, flower parts, stalks, plant material and sterile units of other seed.		*Cynodon dactylon*, *Dactylectenium aegyptium* and *Conyza* sp *and Chloris gayana.*
Panicum maximum	Coating material and stalks.		*Panicum maximum.*

[22] Eko Rehab, P. O. Box 19752, Noordbrug, 2522, Tel. 018 297 7320, Fax. 018 293 2258

Table 4.2 The results of the purity tests and the description of the inert material components found in the uncoated seeds.

Seed kind	Pure seed (%)	Inert material (%)	Weed seeds (%)	Other crop (%)
Cenchrus cilliaris	97.9	2.1		
Eragrostis curvula	95.4	4.5	0.1	
Eragrostis chloromelas	91.3	7.8	0.8	0.1
Themeda triandra	72.5	27.4		
Cymbopogon excavatus	44.7	55.0	0.3	

Seed kind	Inert material	Other seed types
Cenchrus cilliaris	Stalks, stones, dead insects, chaff and plant material.	1 x *Urochloa* spp.
Eragrostis curvula	Nematode galls, broken seed and flower parts.	1 x *Cyperus* sp.
Eragrostis chloromelas	Broken units, sterile units, sterile units of other seed, chaff, flower parts, stalks, dead insects and plant material.	11 x *Plantago lanceolata*, 13 x *Verbena officinalis*, 1 x *Chenopodium* sp., 1 x *Digitaria* sp., 8 x *Cynodon dactylon* and 1 x *Eragrostis plana*
Themeda triandra	Plant material, stalks, and chaff, soil and flower parts.	
Cymbopogon excavatus	Broken units, sterile units, sterile units of other seed, chaff, flower parts, stalks and plant material.	1 x *Setaria* sp., 9 x *Eragrostis* spp., 1 x *Eragrostis plana*, 1 x *Panicum* sp. and 1 x *Hyperthelia dissolute.*

4.2.2 Seed Germination

The results for the germination of the seeds used in the re-seeding restoration technologies are given in Table 4.3.

The definitions of the terms used in Table 4.3 are as follows (ISTA, 2007):

Normal seedlings

Normal seedlings are seedlings that show potential for continued development into satisfactory plants when grown in good quality soil and under favourable conditions of moisture, temperature and light (ISTA, 2007),

Abnormal seedlings

These are seedlings that do not show the potential to develop into a normal plant when grown under the same conditions as for normal seedlings (ISTA, 2007),

Ungerminated seeds

These are those seeds that did not germinated by the end of the test period when tested under the optimum conditions (ISTA, 2007),

In Table 4.3 the species with the highest germination percentage were *Eragrostis curvula* (86%), followed by *Themeda triandra* (76%), *Eragrostis chloromelas* (48%), *Cenchrus cilliaris* (25%), *Chloris gayana* (29%), *Digitaria eriantha* (19%), *Cymbopogon excavatus* (13%) and *Panicum maximum* (4%) germination rate.

The high percentage of ungerminated seeds could be attributed to the fact that the exact ages of the seeds were not known when they were used in the re-seeding restoration trials. The percentage of abnormal seeds was low for all of the species types. The germination rate of each of the different species was correlated with the frequency, basal cover and density of the grass species that established during the trials over the 3 growing seasons.

The occurrence of the high percentage of ungerminated seeds in the seed lots of species, such as *Cymbopogon excavatus* (87%), *Panicum maximum* (95%), *Digitaria eriantha* (79%) and *Chloris gayana* (70%) could be due to the fact that all the seeds were bought from Eko Rehab[23] and it was handled a lot. *Cymbopogon excavatus* (87%) is a natural occurring species and was harvested in the rangeland and therefore the seeds were uncertified. The fact that some of these species' seed was uncertified was a contributing fact to the poor performance (*Cymbopogon excavatus*, 87% and *Chloris gayana*, 70%).

[23] Eko Rehab, P. O. Box 19752, Noordbrug, 2522, Tel. 018 297 7320, Fax. 018 293 2258

Table 4.3 The germination of the eight species used in the re-seeding restoration technology of this trial.

Seed kind	Seedlings (%)		Ungerminated seeds (%)
	Normal	Abnormal	
Eragrostis curvula	86	0	14
Themeda triandra	76	6	18
Eragrostis chloromelas	48	2	50
Cenchrus cilliaris	35	6	59
Chloris gayana	29	1	70
Digitaria eriantha	19	2	79
Cymbopogon excavatus	13	0	87
Panicum maximum	4	1	95

4.3 Soil analyses

The soil classification was already been discussed in Chapter 2 of this dissertation. Both chemical and physical analyses were carried out to determine the soil nutrient content, the soil physical properties and to classify the soil, into soil types.

The soil analyses results (Table 4.5) were correlated with the norms in Table 4.4. Both the macro- and micro nutrients were determined, as was the pH (KCl), the sand, and clay and loam percentage. Soil samples were taken on three depths (100 mm, 300 mm and >500 mm).

According to the soil analyses the pH (KCl) of the soil increases slightly with depth, from 100 mm to the > 500 mm depth, ranging from 4.8 to 5.3. The pH of the soil is important as the availability of soils nutrients such as Sodium (Na), Phosphorus (P), Manganese (Mg) and Calcium (Ca) is pH dependant. Nitrogen is available, to the plants, from a soil pH value of 4 up to 5.8, where after it stabilises. Calcium (Ca) and Magnesium are available at a pH range of more or less 6.5 to 8.6. Phosphorus is available, to the plants from pH 6 to 7, where after it declines slightly too a pH value of about 8.8. Potassium (K) is available at a range of pH above 6. Iron (Fe), Magnesium (Mg) and Copper (Cu) are available at low pH of 5.5 and it decline sharp from 5.5 (Brady, 1984 and Barber, 1984). According to these norms and the pH of the soil analyses in all three layers N, Fe, Mg and Cu will be available to the plants but not Ca, P and K, causing a deficiency of these three macro-nutrients (Table 4.5).

According to the norms given by the ARC's laboratory that analysed the soil, the macro-nutrient (P, K, Ca, Mg and Na) content of the soil is shown in Table 4.5. The P content of the soil was low and the K content high throughout the soil profile. The Ca content was moderately high in the A-horizon and high in the subsoil horizons. The Mg content of the soil was high throughout all the samples and the Na content was moderate, throughout the soil horizon. If the nutrient levels are described as a percentage of the CEC (describe later on in this section) the levels of K were all in the set range of 6 – 12%, the A-horizon's 15.67% is above the norm and the subsoil horizons were in the norm. The set norm for Ca was 55 – 75% and the levels of both the A- and B1-horizons were in the norm and that of the B2-horizon was below the norm. All levels of Mg were above the set norms of 20 – 30%. The levels of Na were all within the set norm of below 5 for the whole soil profile (Table 4.5).

Brady (1984) suggested the following levels for micro-nutrients: for Zinc (Zn) levels of more than 500 mg/kg is toxic for plants and less than 30 mg/kg will cause a deficiency. For Copper (Cu) levels of more than 14 mg/kg is toxic and levels less than 60 mg/kg will cause a deficiency and for Manganese (Mn) levels of more than 690 mg/kg is toxic and levels of less than 94 mg/kg will cause a deficiency. In the study site, only N and Fe, Mg and Cu will be available for the plants and deficiencies of Ca, P and K were encountered (Table 4.5).

The carbon content of the A and B_2 horizons of the soil of the study site was very low fluctuating between 0.42% and 0.59% respectively (Table 4.5). According to Buys (1988) the total organic material content of the soil can be calculated by multiplying the carbon content with 1.72, thus the total organic material content of the soils was fluctuating between 0.72% and 1.01%. Soil organic material encourages the granulation of the soil, while it reduces properties, like plasticity and cohesion and increasing the water-holding capacity. The CEC is increased when the soil organic matter is increased and the supply and availability of soil nutrients is increased (Brady, 1984). Thus the low organic matter content lowered the soil nutrient availability for the plants, growing in the soil. A soil crust formed when the water-holding and cohesion were reduced, thus making it hard for plants to germinate and establish in these types of soils.

The ratio of Ca plus Mg to K ((Ca + Mg)/K) should be between 10 and 20% according to Buys (1988). The ratios for the soil of the study site were therefore below the norm (Table 4.5). Ca, Mg and K is in equilibrium with each other in the soil solution, Ca and Mg must increase as the square of their concentrations to keep these ratios constant (Barber, 1984). The (Ca + Mg)/K ratio for these soils are 6.87%, 9.57% and 9.12% respectively, thus it is below the norm. This resulted in a nutrient deficiency of these plant nutrients, such as wilted leafs.

The *cation exchange capacity* (CEC) is a measure of the total sum of all the pH exchangeable cations on the soil (Brady, 1984 and Van der Walt and Van Rooyen, 1990). This gives an indication of the soil fertility. The CEC of the soils of the study site varied between 6.83 and 8.96

$cmol_ckg^{-1}$. This is influenced by pH, soil texture and organic material. The finer the soil texture, the organic material content and pH of the soil, the higher the CEC (Brady, 1984).

According to the particle size distributions chart (Brady, 1984), taken as an average for the A, B_1 and the B_2-horizons, the soil are described as follows: the A-horizon is a sandy loam soil, the B_1 and B_2-horizon are both sandy clay. The clay fraction of this soil on average increased slightly with soil depth from 17.33% to 35.33%. The sand fraction of this soil on average decreased slightly with soil depth from 60.33% to 42.67%. The loam fraction of this soil on average decreased slightly with soil depth from 22.33% to 18.67% (Table 4.5).

Table 4.4 The norms for the soil results (Appendix A: abbreviations).

Norms	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn (HCl)**
Result as % of CEC	*	6-12	55-75	20-30	<5	*
Low	<15	<60	<200	<40	<10	<1.5
Medium	15-25	60-80	200-400	40-80	10-30	1.5-2.0
Medium-high	25-35	80-120	400-800	80-120	30-50	2.0-6.0
High	>35	>120	>800	>120	>50	>6.0

pH					
Extremely acid	<3.5	Strong acid	3.8-4.0	Moderate acid	4.3-4.5
Very strong acid	3.5-3.8	Acid	4.0-4.3	Slightly acid	4.5-5.0

Table 4.5 The average values of the soil analyses per depth at the study site (Appendix A: abbreviations).

Results	A-horizon	B_1-horizon	B_2-horizon
Depth taken (mm)	100	300	> 500
pH (KCl)	4.8	5.1	5.3
P (mg/kg)	10.63	1.0	0.12
K (mg/kg)	353.80	294.57	349.80
Result as % of CEC	15.67	9.33	11.67
Ca (mg/kg)	673.00	810.67	861.33
Result as % of CEC	49.33	50.67	49.00
Mg (mg/kg)	303.10	348.53	451.10
Result as % of CEC	33.33	39.00	38.67
Na (mg/kg)	12.23	10.73	14.20
Result as % of CEC	1.00	1.00	0.67
Zn (EDTA) (mg/kg)	0.19	0.07	0.05
Cu (EDTA) (mg/kg)	0.63	1.01	1.0
Fe (EDTA) (mg/kg)	30.96	32.06	30.52
Mn (EDTA) (mg/kg)	71.39	71.29	59.41
C (%)	0.42	0.46	0.59
(Ca + Mg)/K	6.87	9.57	9.12
Ca/Mg	1.56	1.30	1.33
CEC ($cmol_c kg^{-1}$)	6.83	7.98	8.96
Sand (%)	60.33	56.00	42.67
Clay (%)	17.33	24.67	35.33
Loam (%)	22.33	19.33	18.67

4.4 Vegetation data before restoration technologies was applied

An initial vegetation sampling was carried out over the total trial area before any restoration technologies were applied. The frequency and basal cover of the vegetation was determined for the total study site in the experimental camps, one treated with Roundup herbicide and one not treated by herbicide. The different grass species were identified, whereas all the shrubs and weed species were grouped together under the same species group (Table 4.6 and 4.7).

Because of the lack of a scientifically accepted method to distinguished between the natural occurring and the re-seeded individual tufts of the same grass species an assumption was made that if the individual tuft occurred on the rip furrow in a re-seeding restoration technology plot, that individual tuft was re-seeded.

4.4.1 Frequency

The initial frequency of all perennial grasses in both the camps where no-Roundup and Roundup restoration technologies were applied was low. High palatability and ecological value species, such as *Themeda triandra* (3.64%) had a low frequency value, but species with low palatability such as *Eragrostis lehmanniana* (11.24%) had a high frequency value (Table 4.6).

The frequency value of annual species, such as *Aristida congesta* was 5.79 and 12.44%, respectively for the camp where no Roundup was applied and the camp where this herbicide was applied. Other annual species, such as *Urochloa panicoides* (7.27 and 5.56% respectively) had a high frequency in both camps but it was higher for the camp where no herbicide was applied (Table 4.6).

The following grass species had the highest frequency values for the perennial grasses: *Eragrostis lehmanniana* (11.24 and 7.2% for the camp where no herbicide was applied and the herbicide camp respectively) and *Themeda triandra* (3.64 and 7.86) (Table 4.6).

The frequency of shrubs species was high at 56.2% in the no-Roundup restoration technology camp and 34.37% in the camp where Roundup was used (Table 4.6).

Table 4.6 The results of the annual, perennial, weed and shrub species for the two camps, before the restoration technologies were applied (Frequency % data: no-Roundup and Roundup).

Species	Total Frequency (%)	
	No Roundup	Roundup
Annual species		
Aristida congesta subsp. congesta	5.79%	12.44%
Chloris virgata	0.50%	0.33%
Tragus berteronianus	3.31%	3.60%
Urochloa panicoides	7.27%	5.56%
Perennial species		
Cynodon hirsutus	0.00%	4.42%
Elionurus muticus	0.17%	0.49%
Eragrostis chloromelas	0.83%	3.60%
Eragrostis gummiflua	2.48%	1.15%
Eragrostis lehmanniana	11.24%	7.20%
Heteropogon contortus	0.66%	1.80%
Panicum maximum	1.16%	0.16%
Sporobolus fimbriatus	4.13%	14.89%
Themeda triandra	3.64%	7.86%
Tragus koeleriodes	0.33%	1.31%
Shrub and Weed species		
Shrub species	56.20%	34.37%
Weed species	2.31%	0.82%

4.4.2 Basal cover

In the no-Roundup restoration technology camp the basal cover over all of the species was very low, with a total basal cover for the camp of 3.8%. The camp where Roundup was applied had a total basal cover of 7.86% and some of the individual species (like *Panicum maximum*) had relative high basal covers of 2.29% (Table 4.7).

Table 4.7 The results of the initial vegetation composition for the two camps, before the restoration technologies were applied (Basal cover data: no-Roundup and Roundup).

Species	Total Frequency (%) per camp	
	No Roundup	Roundup
Annual species		
Aristida congesta subsp. congesta	0.17%	0.82%
Chloris virgata	0.00%	0.00%
Tragus berteronianus	0.99%	0.49%
Urochloa panicoides	0.66%	0.49%
Perennial species		
Cynodon hirsutus	0.00%	0.49%
Elionurus muticus	0.00%	0.16%
Eragrostis chloromelas	0.00%	0.00%
Eragrostis gummiflua	0.17%	0.16%
Eragrostis lehmanniana	0.17%	0.16%
Heteropogon contortus	0.00%	0.16%
Panicum maximum	0.17%	2.29%
Sporobolus fimbriatus	0.00%	0.00%
Themeda triandra	0.50%	0.98%
Tragus koeleriodes	0.00	0.33%
Shrub and Weed species		
Shrub spp.	0.99%	1.31%
Weed sp.	0.00%	0.00%

4.5 Vegetation data after the restoration technologies were applied

The results of the vegetation sampling data will be discussed in the following order: The data and results that were used to calculate the importance value (IV) by using the average values of frequency, density and basal cover after all 3 seasons, namely: 2003/4, 2004/5 and 2005/6.

The Importance values of only the five most important species are given and ranked accordingly. The importance values were calculating by the sum of the frequency, basal cover and density values for each species and give an indication of the species relative importance in terms of its contribution in a uniform sample plot (Kent and Coker, 1996).

In order to simplify the complex data sheets and calculations, only the five most important species were used to identify and describe the trends in the data sets.

4.5.1 Importance Values of species for the different restoration technologies

The results for the Importance value are discussed as follows: The Importance values (IV) for the five highest ranked re-seeded and natural occurring grass species for each of the different restoration technologies are given in Table 4.8 to 4.14. The Importance value of the different species is given in brackets after the species name. The data is described in the following sequence: no-Roundup, 0.75m and no-Roundup 1.5m, 0.75m Roundup and 1.5m Roundup.

1) Control restoration technology (C)

Eragrostis lehmanniana occurred naturally and had a high IV in all control sites (55.82 / 57.04 / 56.20 / 59.00), as well as *Aristida congesta* (52.93 / 51.74 / 27.17 / 33.66), *Cynodon hirsutus* (16.99 / 26.23 / 26.23 / 12.24) and *Tragus berteronianus* (12.72 / 15.44 / 16.12 / 62.21). *Themeda triandra* (35.53 / 18.72) occurred in both the narrow and wide row spacings, without the application of Roundup (CN and CW), whereas *Chloris virgata* (22.08 / 14.97) only occurred in the Roundup applied control sites (CNH and CWH) (Table 4.8). Roundup is widely used to combat the presents of grass species in cash crops, for example *Panicum maximum* can be controlled with a 6l / ha application (Roundup booklet). Roundup was applied at the same rate (6l / ha) (Chapter 3), therefore all the grass species were effected by the herbicide application. Most of the annual grass species is pioneer grasses and were the first grass species to establish, after the Roundup application. This explained the occurrence of *Themeda triandra* only in the control sites where no Roundup was applied. The application of herbicide could lead to the increase in frequency and density of less desirable species, such as *Chloris virgata* and *Tragus berteronianus* (Table 4.8).

Eragrostis lehmanniana, Tragus berteronianus and *Aristida congesta* had a high frequency value due to the large number of smaller tufts. *Cynodon hirsutus* had a high frequency and density value due to its growth form of making shoots, with a large number of small tufts and its patchiness in the study site. *Chloris virgata* only occurred in the Roundup control plot, because it occurred in patches in the veld (Appendix B, table B 13 and B 14).

The frequency and density of perennial species (*Eragrostis lehmanniana* and *Themeda triandra*) and the annual species (*Aristida congesta*) were high, but the basal cover low. This could be attributed to the fact that these species had small or young tufts with low basal cover (Table 4.8).

Table 4.8 The calculation of the importance value and ranking of the five most important grass species of the control restoration technologies (Appendix A: abbreviations).

CN		Freq.	Basal.	Dens.	IV	Rank.
Natural Species	*Eragrostis lehmanniana*	27.88	1.03	26.91	55.82	1
	Aristida congesta	23.80	0.93	28.20	52.93	2
	Themeda triandra	22.50	1.65	11.38	35.53	3
	Cynodon hirsutus	6.37	0.78	9.85	16.99	4
	Tragus berteronianus	4.25	0.31	8.16	12.72	5
CW		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural Species	*Eragrostis lehmanniana*	31.22	1.33	24.48	57.04	1
	Aristida congesta	21.57	0.61	29.57	51.74	2
	Cynodon hirsutus	9.83	2.36	14.04	26.23	3
	Themeda triandra	13.23	1.41	4.08	18.72	4
	Tragus berteronianus	6.73	0.11	8.60	15.44	5
CNH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural Species	*Tragus berteronianus*	27.85	0.48	33.32	61.65	1
	Eragrostis lehmanniana	31.54	1.81	22.85	56.20	2
	Aristida congesta	12.82	0.31	14.04	27.17	3
	Chloris virgata	11.44	0.51	10.13	22.08	4
	Cynodon hirsutus	5.38	0.88	9.87	16.12	5
CWH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural Species	*Tragus berteronianus*	25.59	0.73	35.90	62.21	1
	Eragrostis lehmanniana	33.41	1.74	23.85	59.00	2
	Aristida congesta	16.16	0.85	16.65	33.66	3
	Chloris virgata	7.99	0.73	6.25	14.97	4
	Cynodon hirsutus	4.79	0.20	7.25	12.24	5

2) Rip restoration technology (R)

The following three grass species were found in all four rip restoration technologies: *Eragrostis lehmanniana, Aristida congesta* and *Urochloa panicoides*. The IV of these species were *Eragrostis lehmanniana* 59.97, 62.56, 75.81 and 73.34; *Aristida congesta* 47.69, 40.01, 29.28 and 28.12 and *Urochloa panicoides* 13.17, 17.22, 22.58 and 21.68 respectively for RN, RW, RNH and RWH. *Eragrostis lehmanniana* was ranked first as most important species in all the rip restoration treatments due to the high frequency and density values. *Themeda triandra* (18.12/21.79) occurred in three of the rip restoration technologies, namely RN, RW and RWH. The IV of *Cynodon hirsutus* was 33.06 and 14.45 respectively for the RN and RW rip treatments. The IV of *Tragus berteronianus* that occurred in RNH and RWH were 39.89 and 49.41 respectively. *Chloris virgata* (10.99) only occurred in the RNH rip restoration technology (Table 4.9).

For both *Eragrostis lehmanniana* and *Themeda triandra*, the frequency value had the largest contribution towards the Importance values (IV) and for *Aristida congesta, Cynodon hirsutus* and *Tragus berteronianus* the density values attributed the most to the IV. For *Chloris virgata*, the frequency and density values attributed the most towards the IV (Table 4.9). In cases where the frequency values were smaller than the density values the grass tufts where much smaller, mostly indicating higher seedling assurances.

No clear differences between the narrow and wide row applications could be observed. In both applications, species such as *Eragrostis lehmanniana* and *Aristida congesta* had high IV; with *Tragus berteronianus* second highest IV in both trials where herbicide was used.

The very high frequency and density values of *Eragrostis lehmanniana* could be explained by the fact that it did occur in large numbers over the whole study site, before any of the restoration technologies were applied.

Table 4.9 The calculation of the importance value and ranking of the five most important grass species of the rip restoration technologies (Appendix A: abbreviations).

RN		Freq.	Basal.	Dens.	IV	Rank.
Natural species	*Eragrostis lehmanniana*	33.88	0.82	25.27	59.97	1
	Aristida congesta	18.73	1.21	27.75	47.69	2
	Cynodon hirsutus	12.29	1.55	19.22	33.06	3
	Urochloa panicoides	6.68	0.00	6.49	13.17	4
	Themeda triandra	11.32	0.93	5.87	18.12	5
RW		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural species	*Eragrostis lehmanniana*	31.19	1.39	29.99	62.56	1
	Aristida congesta	18.67	0.44	20.91	40.01	2
	Cynodon hirsutus	8.91	1.64	14.45	25.00	3
	Themeda triandra	13.01	1.03	7.75	21.79	4
	Urochloa panicoides	9.39	0.11	7.72	17.22	5

Table 4.9 (continues) The calculation of the importance value and ranking of the five most important grass species of the rip restoration technologies (Appendix A: abbreviations).

RNH		Freq.	Basal.	Dens.	IV	Rank.
Natural species	*Eragrostis lehmanniana*	38.30	2.43	35.08	75.81	1
	Tragus berteronianus	19.65	0.18	20.05	39.89	2
	Aristida congesta	14.73	0.68	13.88	29.28	3
	Urochloa panicoides	9.44	0.48	12.65	22.58	4
	Chloris virgata	5.54	0.56	4.89	10.99	5
RWH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural species	*Eragrostis lehmanniana*	37.94	2.31	33.09	73.34	1
	Tragus berteronianus	23.30	0.62	25.50	49.41	2
	Aristida congesta	14.81	0.41	12.91	28.12	3
	Urochloa panicoides	8.07	0.23	13.38	21.68	4
	Themeda triandra	5.77	0.21	4.70	10.68	5

3) Rip and the application of organic material restoration technology (RO)

Eragrostis lehmanniana had IV of 68.43, 63.26, 69.12 and 63.25; *Aristida congesta* had IV of 45.54, 50.77, 34.16 and 26.98 and *Tragus berteronianus* had IV of 34.27, 29.25, 42.49 and 53.14 respectively. These species occurred in all four of the rip and the application of organic material restoration technologies, whereas *Themeda triandra* (16.92 / 26.80) occurred in both the RON and ROW restoration technologies. *Cynodon hirsutus* occurred in the RON and the ROWH restoration treatments (11.45 / 14.65) and *Urochloa panicoides* (11.22 / 29.44 / 24.15) occurred in ROW and both RONH and ROWH restoration technologies. *Chloris virgata* (12.44) only occurred in RONH (Table 4.10).

The high frequency and density values of the species occurring in these restoration technologies attributed to the high IV's of the species mentioned in the previous section. This indicates the plants had a large number of small or young tufted grass plants.

Eragrostis lehmanniana had high IV in all four the rip and the application of organic material restoration technologies. *Aristida congesta* had the second highest IV in the treatments without the application of herbicide where as *Tragus berteronianus* had the second highest IV in the trials with the application of Roundup.

Table 4.10 The calculation of the importance value and ranking of the five most important grass species of the rip and the application of organic material restoration technologies (Appendix A: abbreviations).

RON		Freq.	Basal.	Dens.	IV	Rank.
Natural species	*Eragrostis lehmanniana*	36.26	0.51	31.66	68.43	1
	Aristida congesta	18.64	0.09	26.80	45.54	2
	Tragus berteronianus	17.53	0.28	16.46	34.27	3
	Themeda triandra	10.46	0.55	5.90	16.92	4
	Cynodon hirsutus	4.01	0.09	7.34	11.45	5
ROW		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural species	*Eragrostis lehmanniana*	32.42	1.75	29.09	63.26	1
	Aristida congesta	21.82	1.10	27.85	50.77	2
	Tragus berteronianus	12.42	0.53	16.30	29.25	3
	Themeda triandra	17.24	1.90	7.67	26.80	4
	Urochloa panicoides	5.48	0.11	5.63	11.22	5
RONH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural species	*Eragrostis lehmanniana*	39.35	0.80	28.97	69.12	1
	Tragus berteronianus	16.91	0.40	25.17	42.49	2
	Aristida congesta	15.45	0.58	18.13	34.16	3
	Urochloa panicoides	13.43	0.09	15.92	29.44	4
	Chloris virgata	7.39	0.20	4.85	12.44	5
ROWH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Natural species	*Eragrostis lehmanniana*	33.02	1.54	28.70	63.25	1
	Tragus berteronianus	23.66	0.47	29.01	53.14	2
	Aristida congesta	14.74	0.59	11.65	26.98	3
	Urochloa panicoides	11.01	0.72	12.43	24.15	4
	Cynodon hirsutus	5.08	0.00	9.57	14.65	5

4) Rip and re-seeding with a seed mixture restoration technology (RS)

Of the eight grass species that were re-seeded in the rip and seed mixture restoration technologies the following five species were the only grass species that germinated and established in all four rip and re-seeding with a seed mixture restoration technologies: *Themeda triandra, Digitaria eriantha, Eragrostis curvula, Cenchrus cilliaris* and *Cymbopogon excavatus.* The IV for these five species were *Themeda triandra* 45.11, 32.42, 42.15 and 42.15; *Digitaria eriantha* 39.09, 28.15, 38.32 and 35.16; *Eragrostis curvula* 23.17, 17.24, 29.49 and

29.49; *Cenchrus cilliaris* 1.49, 1.11, 1.18 and 1.56 and *Cymbopogon excavatus* 0.47, 1.13, 0.76 and 0.48, respectively (RSN, RSW, RSNH and RSWH) (Table 4.11).

Themeda triandra, Digitaria eriantha and *Eragrostis curvula* ranked first, second and third had the highest IV's of the re-seeded grass species in all the restoration treatments, both narrow and wide rows. The IV of *Themeda triandra, Digitaria eriantha* and *Eragrostis curvula* were high, because of these species high frequency, basal cover and density values. The fact that the IV's of species such as *Themeda triandra* and *Eragrostis curvula* were high could be attributed to the fact that these species had a very high germination percentage (76% and 86% respectively). Despite *Digitaria eriantha* low germination percentage of only 19 % it had a high IV due to the high frequency values of this species in all the re-seeding trial sites. These high values indicate larger tufted grasses for these species (Table 4.11). The low frequency, basal cover and density values of *Cenchrus cilliaris* and *Cymbopogon excavatus* attributed to their low IV and were due to its poor germination (Table 4.3).

All the natural occurring grass species had larger density values, indicating smaller but more abundant individual plant tufts. *Eragrostis lehmanniana* had IV's of 45.04, 54.65, 42.80 and 46.84 respectively. The IV of *Aristida congesta* was 23.08, 32.14, 9.26 and 11.96, respectively and *Tragus berteronianus* had IV's of 12.75, 10.45, 15.25 and 24.56. *Urochloa panicoides* had IV's of 7.83, 8.52, 10.74 and 13.87, respectively. These species occurred in all four restoration technologies. *Cynodon hirsutus* (6.14 / 15.41 / 2.36) occurred in the RNS, RSW and RSNH. *Chloris virgata* (3.34) only occurred in RWH (Table 4.11). The fact that the later two species only occurred in some of the trial sites could be best explained by the patchiness of these species, it did occur in patches over the two camps where the restoration technologies were applied (Appendix B: Table B 13 and B 14).

Eragrostis lehmanniana and *Aristida congesta* had high frequency and density values indicating that these species had a large number of small or young tufts, where as the species, such as *Tragus berteronianus* and *Urochloa panicoides*, with low IV had low frequency, basal cover and density values. This indicates that these species had a small number of small or young tufts (Table 4.11).

Eragrostis lehmanniana and *Aristida congesta* ranked first and second of the natural occurring species. *Tragus berteronianus* ranked second highest IV in the herbicide treated trials. This species occurred in large numbers, with low basal cover values, before any restoration technologies were applied (Tables 4.11, 4.5 and 4.6).

Table 4.11 The calculation of the importance value and ranking of the five most important grass species of the rip and re-seeding with a seed mixture restoration technologies (Appendix A: abbreviations).

RSN		Freq.	Basal.	Dens.	IV	Rank.
Re-seeded Species	*Themeda triandra*	24.80	3.16	17.15	45.11	1
	Digitaria eriantha	26.56	5.21	7.31	39.09	2
	Eragrostis curvula	12.90	0.64	9.63	23.17	3
	Cenchrus cilliaris	1.23	0.10	0.16	1.49	4
	Cymbopogon excavatus	0.27	0.00	0.20	0.47	5
Natural Species	*Eragrostis lehmanniana*	15.48	0.59	28.98	45.04	1
	Aristida congesta	7.43	0.00	15.66	23.08	2
	Tragus berteronianus	6.35	0.00	6.40	12.75	3
	Urochloa panicoides	2.45	0.10	5.27	7.83	4
	Cynodon hirsutus	1.80	0.00	4.34	6.14	5
RSW		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded Species	*Themeda triandra*	19.89	2.98	9.55	32.42	1
	Digitaria eriantha	17.70	3.41	7.04	28.15	2
	Eragrostis curvula	10.21	0.97	6.06	17.24	3
	Cymbopogon excavatus	0.70	0.20	0.22	1.13	4
	Cenchrus cilliaris	0.80	0.09	0.22	1.11	5
Natural Species	*Eragrostis lehmanniana*	22.83	0.73	31.10	54.65	1
	Aristida congesta	11.30	0.19	20.65	32.14	2
	Cynodon hirsutus	5.91	0.74	8.76	15.41	3
	Tragus berteronianus	4.80	0.10	5.55	10.45	4
	Urochloa panicoides	2.86	0.00	5.66	8.52	5
RSNH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded Species	*Themeda triandra*	33.80	4.87	19.02	57.69	1
	Digitaria eriantha	23.45	5.69	9.18	38.32	2
	Eragrostis curvula	15.53	1.23	15.77	32.52	3
	Cenchrus cilliaris	0.51	0.11	0.56	1.18	4
	Cymbopogon excavatus	0.38	0.00	0.38	0.76	5
Natural Species	*Eragrostis lehmanniana*	14.37	0.65	27.79	42.80	1
	Tragus berteronianus	4.76	0.00	10.49	15.25	2
	Urochloa panicoides	2.37	0.00	8.37	10.74	3
	Aristida congesta	3.72	0.08	5.47	9.26	4
	Cynodon hirsutus	0.31	0.00	2.06	2.36	5

Table 4.11 (continues) The calculation of the importance value and ranking of the five most important grass species of the rip and re-seeding with a seed mixture restoration technologies (Appendix A: abbreviations).

RSWH		Freq.	Basal.	Dens.	IV	Rank.
Re-seeded Species	*Themeda triandra*	23.26	4.14	14.75	42.15	1
	Digitaria eriantha	22.02	4.68	8.46	35.16	2
	Eragrostis curvula	16.83	1.63	11.04	29.49	3
	Cenchrus cilliaris	0.60	0.19	0.77	1.56	4
	Cymbopogon excavatus	0.48	0.00	0.00	0.48	5
Natural Species	*Eragrostis lehmanniana*	15.24	0.82	30.78	46.84	1
	Tragus berteronianus	9.42	0.47	14.68	24.56	2
	Urochloa panicoides	4.55	0.00	9.31	13.87	3
	Aristida congesta	4.42	0.00	7.54	11.96	4
	Chloris virgata	2.60	0.09	0.65	3.34	5

5) Rip, re-seeding with a seed mixture and the application of organic material restoration technology (RSO)

The same re-seeded grass species as for the previous restoration technology were applicable for this restoration technology. This together with the fact that the frequency, basal cover and density values were more or less the same as that of the same trial without the application of organic material indicates that the application of organic material had very little effect on the establishment of especially re-seeded grass species.

The same five species for both the re-seeded and naturally occurring grass species attributed towards the importance values for all four of these restoration technologies as in the previous restoration technologies. The frequency together with the high basal cover values of the re-seeded grass species indicated that the individual plants were big strong tufts except for *Eragrostis curvula*, where the density was higher than the frequency, indicating smaller seedling plant tufts. *Themeda triandra* occurred especially in the no-Roundup restoration technologies (Table 4.12).

Ranked from the highest to lowest IV for the re-seeded species in all four restoration treatments are *Themeda triandra* (39.80 / 37.28 / 39.56 / 42.47), *Digitaria eriantha* (37.04 / 32.24 / 33.74 / 36.43), *Eragrostis curvula* (21.89 / 12.81 / 30.09 / 23.38), *Cenchrus cilliaris* (0.71 / 2.09 / 1.42 / 1.90) and *Cymbopogon excavatus* (0.54 / 0.53 / 0.83 / 0.83) (Table 4.12).

As for the re-seeding without the application of organic material restoration technologies, the IV's of species such as *Themeda triandra* and *Eragrostis curvula* were high and could be attributed to the fact that these species had a very high germination percentage (76% and 86% respectively). *Digitaria eriantha* ranked second, despite its low germination percentage of only 19 % due to the high frequency values of this species in all the re-seeding trial sites. These high values indicate larger tufted grasses for these species (Table 4.12). The low frequency, basal cover and density values of *Cenchrus cilliaris* and *Cymbopogon excavatus* attributed to their low IV and were due to its poor germination rates (Table 4.3).

Eragrostis lehmanniana ranked first with the highest IV of all natural occurring species (49.10 / 55.34 / 36.74 / 48.80), followed by *Aristida congesta* (27.42 / 29.18 / 9.60 / 12.02), *Tragus berteronianus* (14.06 / 12.23 / 20.17 / 23.03), *Urochloa panicoides* (10.11 / 12.00 / 7.39 / 12.55) and *Cynodon hirsutus* (5.59 / 7.77 / 27.28 / 2.93) (Table 4.12).

The same trend was observed for this restoration technology than the previous restoration technology, namely that the natural occurring species occurred in large numbers, with low basal cover values, before any restoration technologies was applied (Tables 4.12, 4.5 and 4.6).

Table 4.12 The calculation of the importance value and ranking of the five most important grass species of the rip, re-seeding with a seed mixture and the application of organic material restoration technologies (Appendix A: abbreviations).

RSON		Freq.	Basal.	Dens.	IV	Rank.
Re-seeded Species	*Themeda triandra*	25.36	6.87	7.58	39.80	1
	Digitaria eriantha	18.89	2.85	15.30	37.04	2
	Eragrostis curvula	9.31	0.51	12.06	21.89	3
	Cenchrus cilliaris	0.41	0.00	0.30	0.71	4
	Cymbopogon excavatus	0.40	0.00	0.15	0.54	5
Natural Species	*Eragrostis lehmanniana*	21.99	0.59	26.51	49.10	1
	Aristida congesta	9.23	0.00	18.18	27.42	2
	Tragus berteronianus	6.19	0.00	7.87	14.06	3
	Urochloa panicoides	5.19	0.00	4.93	10.11	4
	Cynodon hirsutus	0.71	0.00	4.89	5.59	5

Table 4.12 (continues) The calculation of the importance value and ranking of the five most important grass species of the rip, re-seeding with a seed mixture and the application of organic material restoration technologies (Appendix A: abbreviations).

RSOW		Freq.	Basal.	Dens.	IV	Rank.
Re-seeded Species	*Themeda triandra*	21.21	3.03	13.03	37.28	1
	Digitaria eriantha	21.79	4.10	6.36	32.24	2
	Eragrostis curvula	5.10	0.38	7.34	12.81	3
	Cenchrus cilliaris	1.21	0.00	0.89	2.09	4
	Cymbopogon excavatus	0.36	0.00	0.17	0.53	5
Natural Species	*Eragrostis lehmanniana*	24.40	0.60	30.34	55.34	1
	Aristida congesta	8.72	0.18	20.27	29.18	2
	Tragus berteronianus	6.25	0.10	5.88	12.23	3
	Urochloa panicoides	5.19	0.20	6.61	12.00	4
	Cynodon hirsutus	2.95	0.21	4.61	7.77	5
RSONH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded Species	*Themeda triandra*	23.77	3.52	12.28	39.56	1
	Digitaria eriantha	20.55	4.46	8.73	33.74	2
	Eragrostis curvula	14.03	1.11	14.95	30.09	3
	Cenchrus cilliaris	0.92	0.07	0.43	1.42	4
	Cymbopogon excavatus	0.60	0.10	0.13	0.83	5
Natural Species	*Eragrostis lehmanniana*	15.68	0.75	20.31	36.74	1
	Cynodon hirsutus	10.04	0.25	16.99	27.28	2
	Tragus berteronianus	6.13	0.07	13.98	20.17	3
	Aristida congesta	4.07	0.19	5.34	9.60	4
	Urochloa panicoides	2.44	0.00	4.95	7.39	5
RSOWH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded Species	*Themeda triandra*	24.32	3.68	14.47	42.47	1
	Digitaria eriantha	23.31	4.35	8.77	36.43	2
	Eragrostis curvula	11.20	0.47	11.70	23.38	3
	Cenchrus cilliaris	0.88	0.10	0.92	1.90	4
	Cymbopogon excavatus	0.29	0.10	0.18	0.57	5
Natural Species	*Eragrostis lehmanniana*	19.15	0.55	29.10	48.80	1
	Tragus berteronianus	9.80	0.22	13.01	23.03	2
	Urochloa panicoides	4.14	0.00	8.41	12.55	3
	Aristida congesta	3.70	0.10	8.22	12.02	4
	Cynodon hirsutus	0.81	0.56	1.55	2.93	5

6) Rip and re-seeding with only *Digitaria eriantha* seed restoration technology (RD)

Although *Digitaria eriantha* had high IV's of 58.13, 37.62, 58.08 and 48.06 it did not have the highest IV in all the treatments. *Eragrostis lehmanniana* (62.63 / 56.52 / 44.45 / 49.61) had the highest importance values for most of these restoration technologies, with high density and basal cover values, except for the narrow row treatment where herbicide was applied. *Digitaria eriantha* had the highest frequency values for most of the restoration technologies. The reason for this was due to the fact that *Eragrostis lehmanniana* had high values for both the frequency and densities, while *Digitaria eriantha* only had high values for frequency. This is due to the fact that *Eragrostis lehmanniana* had a large number of smaller individual tufts, whereas *Digitaria eriantha* had a smaller number of larger tufts.

Of all the natural occurring species *Eragrostis lehmanniana* and *Aristida congesta* were the highest in the narrow and wide row applications but *Tragus berteronianus* had the second highest IV in the herbicide applied sites as for most of the previously discussed restoration trials. This trend could be best explained by the fact that *Eragrostis lehmanniana* and *Aristida congesta* had relative high frequency and density values. *Tragus berteronianus* ranked higher in the restoration technologies, where Roundup was applied, was due fact that this is a pioneer grass species that established first after a disturbance.

Eragrostis lehmanniana (62.63 / 56.52 / 44.45 / 49.61), *Aristida congesta* (27.90 / 30.48 / 18.49 / 32.61), *Tragus berteronianus* (14.53 / 17.16 / 41.37 / 42.62) and *Themeda triandra* (14.21 / 17.64 / 17.64) occurred in all four of these restoration technologies. *Urochloa panicoides* (12.02 / 13.82 / 16.44) only occurred in RN, RNH and RWH. *Cynodon hirsutus* (24.49) only occurred in the RW and *Chloris virgata* (8.04) only occurred in the RWH. This is due to the patchiness of the species in the original plant community, before any restoration technologies were applied (Appendix B: Table B 13 and B 14).

Table 4.13 The calculation of the importance value and ranking of the five most important grass species of the rip and re-seeding with only *Digitaria eriantha* restoration technologies (Appendix A: abbreviations).

RDN		Freq.	Basal.	Dens.	IV	Rank.
Re-seeded	*Digitaria eriantha*	37.81	8.16	12.17	58.13	1
Natural Species	*Eragrostis lehmanniana*	24.63	1.39	36.61	62.63	1
	Aristida congesta	10.20	0.08	17.62	27.90	2
	Tragus berteronianus	6.67	0.00	7.86	14.53	3
	Themeda triandra	8.38	0.78	5.05	14.21	4
	Urochloa panicoides	4.33	0.00	7.69	12.02	5
RDW		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded	*Digitaria eriantha*	24.76	5.62	7.24	37.62	1
Natural Species	*Eragrostis lehmanniana*	24.78	0.79	30.94	56.52	1
	Aristida congesta	9.76	0.00	20.72	30.48	2
	Cynodon hirsutus	8.77	0.88	14.84	24.49	3
	Themeda triandra	11.19	0.90	6.46	18.54	4
	Tragus berteronianus	8.19	0.20	8.78	17.16	5
RDNH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded	*Digitaria eriantha*	36.68	9.62	11.78	58.08	1
Natural Species	*Eragrostis lehmanniana*	21.67	0.84	21.94	44.45	1
	Tragus berteronianus	16.21	0.17	24.99	41.37	2
	Aristida congesta	7.38	0.19	10.91	18.49	3
	Themeda triandra	7.59	0.84	9.20	17.64	4
	Urochloa panicoides	4.48	0.00	9.34	13.82	5
RDWH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded	*Digitaria eriantha*	29.72	7.74	10.60	48.06	1
Natural Species	*Eragrostis lehmanniana*	23.92	1.26	24.43	49.61	1
	Tragus berteronianus	16.74	0.20	25.68	42.62	2
	Aristida congesta	13.87	0.00	18.75	32.61	3
	Urochloa panicoides	5.93	0.00	10.51	16.44	4
	Chloris virgata	4.59	0.28	3.17	8.04	5

7) Conventional cultivated *Digitaria eriantha* pasture restoration technology (P)

The seedbed preparation for the conventional *Digitaria eriantha* pasture restoration technology was described in chapter 3 under section 3.2.4. The success of this restoration technology was however poor. The reason for the low *Digitaria eriantha* germination and establishment rates are unknown, because the same seed was used for al the re-seeding technologies where *Digitaria eriantha* seed was used. Despite of its low germination rate it did establish well in all the other technologies, where it was used. This could be attributed to the germination rate of the *Digitaria eriantha* seed (19%) (Table 4.3) and the fact that the study site did receive only 22.1 mm of rain from April to June 2003 (Table 2.2 and Figure 2.4), after this restoration technology was applied. When the soil seedbed was prepared the soil dried out, because of the complete removal of all vegetation and the fine particular size of the soil granules.

The frequency, basal cover and density values for the re-seeded *Digitaria eriantha* were poor, due to the poor germination and establishment rates (See Table 4.3). The importance values of the re-seeded *Digitaria eriantha* and other perennial grass species were very low and that of the pioneer annual grasses, such as *Tragus berteronianus* and *Urochloa panicoides* very high (Table 4.14). The small numbers of *Digitaria eriantha* plants that did germinate and establish in this restoration technology plots were out competed by the large number of other, mostly annual, grass species that germinated and established, most probably from the soil seed bank.

Table 4.14 The calculation of the Importance value and ranking of the five most important grass species of the conventional *Digitaria eriantha* cultivated pasture restoration technologies (Appendix A: abbreviations).

P		Freq.	Basal.	Dens.	IV	Rank.
Re-seeded	*Digitaria eriantha*	2.54	0.83	*	3.37	1
Natural Species	*Tragus berteronianus*	28.86	0.69	*	29.55	1
	Aristida congesta	27.23	0.27	*	27.50	2
	Urochloa panicoides	24.05	0.63	*	24.68	3
	Eragrostis lehmanniana	6.40	0.27	*	6.67	4
	Chloris virgata	5.42	0.48	*	5.89	5
PH		**Freq.**	**Basal.**	**Dens.**	**IV**	**Rank.**
Re-seeded	*Digitaria eriantha*	3.55	0.76	*	4.31	1
Natural Species	*Urochloa panicoides*	22.71	0.09	*	22.80	1
	Chloris virgata	12.36	0.39	*	12.75	2
	Aristida congesta	11.62	0.20	*	11.82	3
	Eragrostis lehmanniana	3.71	0.08	*	3.79	4
	Themeda triandra	1.00	0.08	*	1.08	5

4.5.2 Frequency data of the species over the three seasons and the average of the seasons

Only the frequency data of the 5 most important grass species will be discussed in this section for the 3 different seasons (2003/4, 2004/5 and 2005/6) as well as the average over the three seasons, as they show the best trends towards species establishment for each restoration technology. The data will be discussed according to the changes in species composition for the different restoration technologies. The trends will be described according to the five most important grass species (re-seeded and naturally occurring grass species).

Because there is no scientific method available to distinguish between the re-seeded individual grass tufts and the natural occurring individual grass tufts of the same grass species. A general assumption was made that all the grass tufts of the re-seeded grass species, present on the rip furrow will be regarded as been re-seeded in the re-seeded restoration technologies.

Most of the natural occurring species were also present in the surveys carried out in the initial species composition before any restoration technologies were applied (Table 4.6 and 4.7). In some trials only two species were monitored, such as *Cynodon hirsutus* and *Themeda triandra*, which could be attributed to the patchiness of these species in the trials (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season)

The study site received more than the long-term average rainfall in December and January of the 2004/5 season and the carry over effect in the soil water content could be seen in the higher frequency values of all the grass species especially in March of the 2004/5 season when the vegetation surveys were carried out (Table 2.2 and Figure 2.5).

Three species, with a low ranking importance value occurred in almost all the sites where the different restoration technologies were assessed. These include *Cynodon hirsutus*, *Aristida congesta* and *Chloris virgata.* These grass species will only be mentioned in the discussion of the different restoration technologies, because of their general occurrence and overall low importance value (IV) in each trial area.

The trends in species composition changes for the restoration technologies are therefore discussed in the same order as for the previous section and explained by Tables 4.15 to 4.22 and Figures 4.1 to 4.9.

1) Control restoration technology (C)

- <u>The grass species</u>

The species abundance of *Eragrostis lehmanniana* increased from the 2003/04 season, from 23% to 31.34% in the 2004/05 season and slightly decreased in the 2005/06 season to 29.30% for the both the row spacings and no-Roundup control restoration technology, but declined for the Roundup control restoration technology. The average frequency value for *Eragrostis lehmanniana* was slightly higher for the Roundup applied trials (33.41% and 31.54% for RNH and CWH and 27.88% and 31.22% for CN and CW) (Table 4.15 and Figure 4.1a, f, l and q). This could be attributed to the fact that *Eragrostis lehmanniana* had a high abundance in these plots, before the restoration technologies were applied (Table 4.5).

The frequency value of *Tragus berteronianus* declined drastically from the 2003/04 season (11.27%, 17.73%, 46.42% and 43.20% respectively) to the 2005/06 season (0.32%, 0%, 6.48% and 5.87% respectively). The average species abundance for this species was higher for the Roundup restoration technologies (27.85% and 25.59%) than the no-Roundup restoration technologies (4.25% and 6.73%). The high abundance of *Tragus berteronianus* in the Roundup applied trial sites could best explained by the fact that it is a pioneer grass species that is one of the first grass species to establish on bare ground and that there was no competition with other perennial grass species, such as *Themeda triandra*, because of the application of Roundup (Table 4.15 and Figure 4.1e, j, k and p). The average species abundance for *Tragus berteronianus* over the three seasons for CNH and CWH (27.87% and 25.59%) was much higher than that of CN and CW (4.25% and 6.73%).

Themeda triandra, which was not re-seeded but occurred in the initial vegetation composition (Table 4.6), only occurred in the no-Roundup control restoration technology (Table 4.15 and Figure 4.1c and i). Although the initial (before restoration technologies were applied) species abundance of *Themeda triandra* was higher in the Roundup treated trial sites than the trial sites that were not treated with Roundup, it did not ranked amongst the five most important species after the restoration technologies were applied. This could be explained by the non selective working of Roundup that killed of most of the grass species (as mentioned in the previous section, Roundup is widely used to control grass species in cash crop lands), especially the more desirable grass species, such as *Themeda triandra*. The average frequency value over the three seasons (2003/04, 2004/05 and 2005/06) of the narrow (0.75m) row spacing was higher than the wide (1.5m) row spacing (22.5% and 13.32% respectively) (Table 4.15 and Figure 4.1 c and i).

The species abundance of *Cynodon hirsutus* increased slightly over the three seasons for all four restoration technologies from 5.27% to 7.39% for CN, 8.57 % to 12.3% for CW, 4.09% to 7.41% for CNH and 4.97% to 5.92% for CWH. This could be due to the initial occurrence of this species before any restoration technologies were applied (Table 4.5 and 4.15 and Figure 4.1d, h, o and t). There was no clear reason for the decline of the frequency value of *Cynodon hirsutus* for the 2004/05 season (Table 4.15 and Figure 4.1t). The average frequency value for *Cynodon hirsutus* was higher for the no Roundup restoration technologies than the Roundup applied technologies (6.37% and 9.83% versus 5.38% and 4.79%, respectively) (Table 4.15 and Figure 4.1d, h, o and t).

The species abundance of *Aristida congesta* drastically increased from the 2003/04 (23% and 29.23%) season to the 2004/05 (31.34% and 36.51%) and decreased to the 2005/06 (29.3% and 27.93%) season due to the increase of other perennial grasses with bigger tufts, such as *Themeda triandra*. The average frequency value of *Aristida congesta* was higher for the no Roundup than the Roundup applied restoration trials, 23.8%, 21.57%, 12.82% and 16.16% respectively for CN, CW, CNH and CWH (Table 4.15 and Figure 4.1b, g, m and r). This could be best explained by the fact that the Roundup did reduce the frequency value *Aristida congesta*.

Chloris virgata occurred only in the Roundup control restoration technologies. The frequency value of *Chloris virgata* increased from the 2003/04 to the 2005/06 season, from 6.02% to 16.76% for CNH. For CWH the frequency value increased from the 2003/04 to the 2004/05 season from 7.23% to 9.56% and decreased in the 2005/06 season to 7.18%. This could be attributed to the patchiness of this species over the whole trial site and the fact that *Chloris virgata* is an annual grass species that vary in frequency value from season to season (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season) The average frequency value was higher for the narrow than the wide row spacing (Table 4.15 and Figure 4.1s).

- Comparison between the applied control restoration technologies

In the no-Roundup control restoration technology plots, *Eragrostis lehmanniana* and *Aristida congesta* ranked first and second for both the narrow and wide row spacings (Table 4.15 and Figure 4.1a, f, l, q, b, g, m and r). The species abundance of both *Eragrostis lehmanniana* and *Aristida congesta* were higher in the 2004/05 season for both the row spacings. The reason for this increase in species abundance in the 2004/05 season could be attributed to the higher than average rainfall received at the study site during December and January of that season. (Table 2.2 and Figure 4.1a, f l and q). *Themeda triandra* ranked under the 5 most important grass species and only occurred in this control restoration technology trial. On the other hand the grass species composition of the no-Roundup control plots was characterized by the presence of more perennial grass species, such as *Themeda triandra* (Table 4.15 and Figure 4.1c and i).

In the Roundup control restoration technology plots *Tragus berteronianus* ranked first and *Eragrostis lehmanniana* second in both the row spacings. The species abundance of *Tragus berteronianus* decreased over the three seasons, where as that of *Eragrostis lehmanniana* increased over the same period (Table 4.15 and Figure 4.1 k, p, l and q). This could be explained by the fact that the smaller tufted *Tragus berteronianus* competed poorly against the bigger tufted grass species, such as *Eragrostis lehmanniana.* The grass species composition was characterized by high numbers of mainly annual grass species, such as *Tragus berteronianus*, due to the fact that the bigger, well established perennial grass species, such as *Themeda triandra* where removed from the initial plant community with the application of the non selective Roundup (Table 4.15 and Figure 4.1 c and i).

Table 4.15 The frequency of species (%) for the control restoration technology per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

CN	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	23.00	31.34	29.30	27.88
Aristida congesta	20.71	29.32	21.38	23.80
Themeda triandra	16.77	19.34	31.39	22.50
Cynodon hirsutus	5.27	6.44	7.39	6.37
Tragus berteronianus	11.27	1.17	0.32	4.25
CW	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	29.23	36.51	27.93	31.22
Aristida congesta	13.31	27.68	23.71	21.57
Cynodon hirsutus	8.57	8.63	12.30	9.83
Themeda triandra	10.67	13.15	15.88	13.23
Tragus berteronianus	17.73	2.46	0.00	6.73
CNH	**03-04**	**04-05**	**05-06**	**Ave**
Tragus berteronianus	46.42	30.64	6.48	27.85
Eragrostis lehmanniana	12.86	38.94	42.83	31.54
Aristida congesta	8.76	12.44	17.28	12.82
Chloris virgata	6.02	11.54	16.76	11.44
Cynodon hirsutus	4.09	4.63	7.41	5.38
CWH	**03-04**	**04-05**	**05-06**	**Ave**
Tragus berteronianus	43.20	27.69	5.87	25.59
Eragrostis lehmanniana	14.78	43.29	42.16	33.41
Aristida congesta	13.93	10.61	23.94	16.16
Chloris virgata	7.23	9.56	7.18	7.99
Cynodon hirsutus	4.97	3.48	5.92	4.79

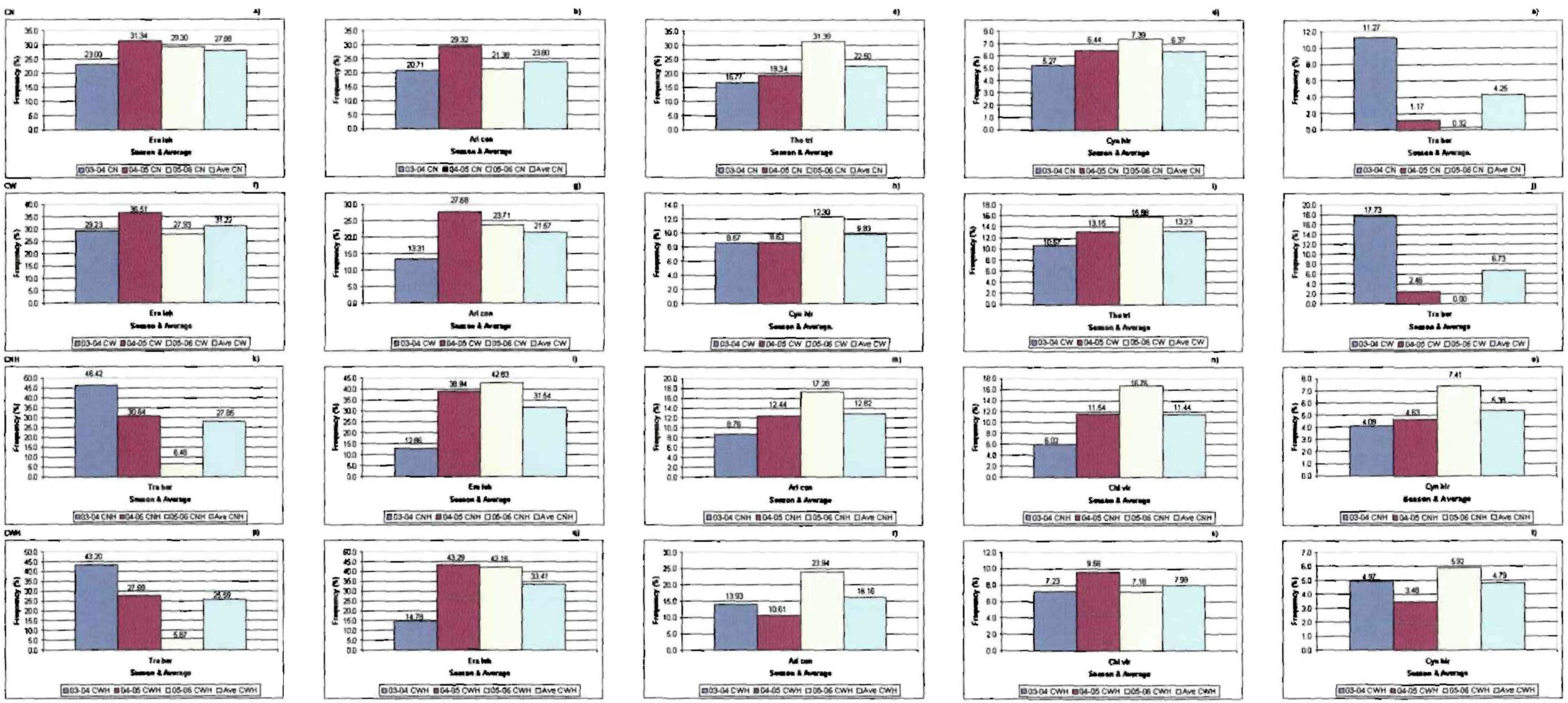

Figure 4.1 The species frequency (%) for the control restoration technology (C) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

2) Rip restoration technology (R)

- The grass species

The species abundance of *Eragrostis lehmanniana*, increased drastically in the 2004/05 season (22.6%, 18.8%, 27.43% and 24.45% to 39.27, 36.49, 42.56 and 41.72 for RN, RW, RNH and RWH, respectively) where after it stabilised over the last season (2005/06). The reason for this drastically increase in the species abundance of *Eragrostis lehmanniana* could be attributed to the fact that the ripping of the soil stimulated the seeds in the soil and created an proper habitat for the seedlings to established in the 2004/05 season. This effect stabilised in the 2005/06 season as the rip farrows started to close up and thus the small increase of the species abundance of this species from the 2004/05 season to 2005/06 season. The species abundance for the three seasons and the average over the three seasons of *Eragrostis lehmanniana* was slightly higher in the Roundup treated plots than the rip plots, because the competition with other species was less. The average frequency value of all four rip restoration trials was more or less the same for *Eragrostis lehmanniana* (33.88%, 31.19%, 38.30% and 37.94%) (Table 4.16 and Figure 4.2 a, f, k and p).

The frequency value of *Aristida congesta* was more or less the same for the 2003/04 and 2004/05 seasons (21.33% and 21.65%) but decreased drastically in the 2005/06 season (13.21%) for RN, this could be due to the fact that other bigger tufted species, such as *Themeda triandra* increased in size and number. The species abundance of *Aristida congesta* increased from the 2003/04 to the 2004/05 seasons and declined in the 2005/06 season (16.53%, 21.88% and 17.29%) for RW. This trend could be best explained by the effect of the rip action on the seedlings of this species, namely: the initial loosening of the soil by the rip action benefited the seedlings in the 2004/05 season, but this effect was not carried over to the 2005/06 season. The frequency value for *Aristida congesta* increased over the three seasons for the Roundup treated plots (10.13% to 22.23% for RNH and 12.15% to 18.72% for RWH). This could be attributed to the fact that the competition with other species was eliminated by the application of Roundup. The average frequency value over the three seasons (2003/04 to 2005/06) for *Aristida congesta* was lower for the rip restoration trials, where Roundup was applied than the no Roundup trials (Table 4.16 and Figure 4.2b, g, m and r).

Themeda triandra occurred in the narrow and wide row spacing rip restoration technology trials and in the wide (1.5m) row spacing of the Roundup treated rip restoration technology trial. The species abundance increased throughout the three seasons for all the rip restoration technologies where it did occur (4.53% to 16.02%, 4.47% to 19.73% and 1.56% to 11.24% for RN, RW and RWH, respectively), due to the fact that the initial loosening of the soil benefited the germination of seedlings, it established well and developed strong tufted plants. The average frequency value for RN was 11.32%, for RW it was 13.01% and it was drastically lower for RWH at 5.77 % (Table 4.16 and Figure 4.2e, I and t). The average frequency value for *Themeda triandra* was much higher for the restoration trials, where no Roundup was applied than those were Roundup was applied (11.32% for RN, 13.01% for RW and 5.77% for RWH) (Table 4.16 and Figure 4.2e, I and t).

Cynodon hirsutus ranked third for both narrow and wide row spacings for the rip restoration technologies and was absent in the rip restoration technologies, where Roundup was used technology. The species abundance of *Cynodon hirsutus* increased from 8.52% to 14.5% for RN and from 9.05% to 10.56% for RW over the three seasons (2003/04 to 2005/06). The reason for *Cynodon hirsutus* to occur only in the rip restoration trials could be best explained by the patchiness of this species over the whole trial site. The average frequency value of this species was 6.68% for RN and 13.01% for RW respectively (Table 4.5 and Table 4.16 and Figure 4.2c and h) (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season).

Tragus berteronianus ranked second for both the Roundup rip restoration technologies and was absent in the rip restoration technologies. The species abundance of this grass species drastically declined from the 2004/05 season to the 2005/06 season for both the Roundup rip restoration technologies (24.73% to 6.65 for RNH and 32.62% to 5.16% for RWH) and its average frequency value over the three seasons was 19.65% and 23.3% respectively for RNH and RWH. This could be attributed to the fact that this is an annual grass species and a poor competitor with other species (Table 4.16 and Figure 4.2l and q). *Urochloa panicoides* decreased in all the rip restoration technologies (19.71%, 25.13%, 25.9% and 22.43%, respectively to 0%) over the three seasons and on average it occurred more or less even in all the rip restoration trial sites (6.68%, 9.39%, 9.44% and 8.07%), due to the fact that this is an annual grass species (Table 4.16 and Figure 4.2d, j, n and s). *Chloris virgata* only occurred in the narrow row rip restoration technology, where Roundup was applied and it increased from 3.59% to 6.43% over the three seasons, with an average of 5.54% over the three seasons. This species occurred in patches over the whole trial site and this could explain the reason for it only to occur in RNH (Table 4.5 and Table 4.16 and Figure 4.2o).

- <u>Comparison between the applied rip restoration technologies</u>

The grass species compositions of the narrow and wide rip restoration technologies were characterized by high abundance of mainly annual grass species. *Themeda triandra* increased in species abundance over the three seasons (4.53%, 4.47% and 1.56% to 16.02%, 19.73% and 11.24%, respectively for RN, RW and RWH) (Table 4.16 and Figure 4.2).

The grass species compositions in the rip restoration trials, where Roundup was used were characterized by the presence of mostly annual grass species (Table 4.16 and Figure 4.2).

The grass species composition did not differ much between the no-Roundup and Roundup rip restoration technologies (Table 4.16 and Figure 4.2).

Table 4.16 The frequency of species (%) for the rip restoration technology per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RN	03-04	04-05	05-06	Ave
Eragrostis lehmanniana	22.60	39.27	39.77	33.88
Aristida congesta	21.33	21.65	13.21	18.73
Cynodon hirsutus	8.52	13.84	14.50	12.29
Urochloa panicoides	19.71	0.31	0.00	6.68
Themeda triandra	4.53	13.42	16.02	11.32
RW	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	18.80	36.49	38.27	31.19
Aristida congesta	16.83	21.88	17.29	18.67
Cynodon hirsutus	9.05	7.11	10.56	8.91
Themeda triandra	4.47	14.83	19.73	13.01
Urochloa panicoides	25.13	3.03	0.00	9.39
RNH	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	27.43	42.56	44.91	38.30
Tragus berteronianus	24.73	27.58	6.65	19.65
Aristida congesta	10.13	11.83	22.23	14.73
Urochloa panicoides	25.90	2.43	0.00	9.44
Chloris virgata	3.59	6.60	6.43	5.54
RWH	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	24.45	41.72	47.64	37.94
Tragus berteronianus	32.62	32.11	5.16	23.30
Aristida congesta	12.15	13.54	18.72	14.81
Urochloa panicoides	22.43	1.47	0.31	8.07
Themeda triandra	1.56	4.52	11.24	5.77

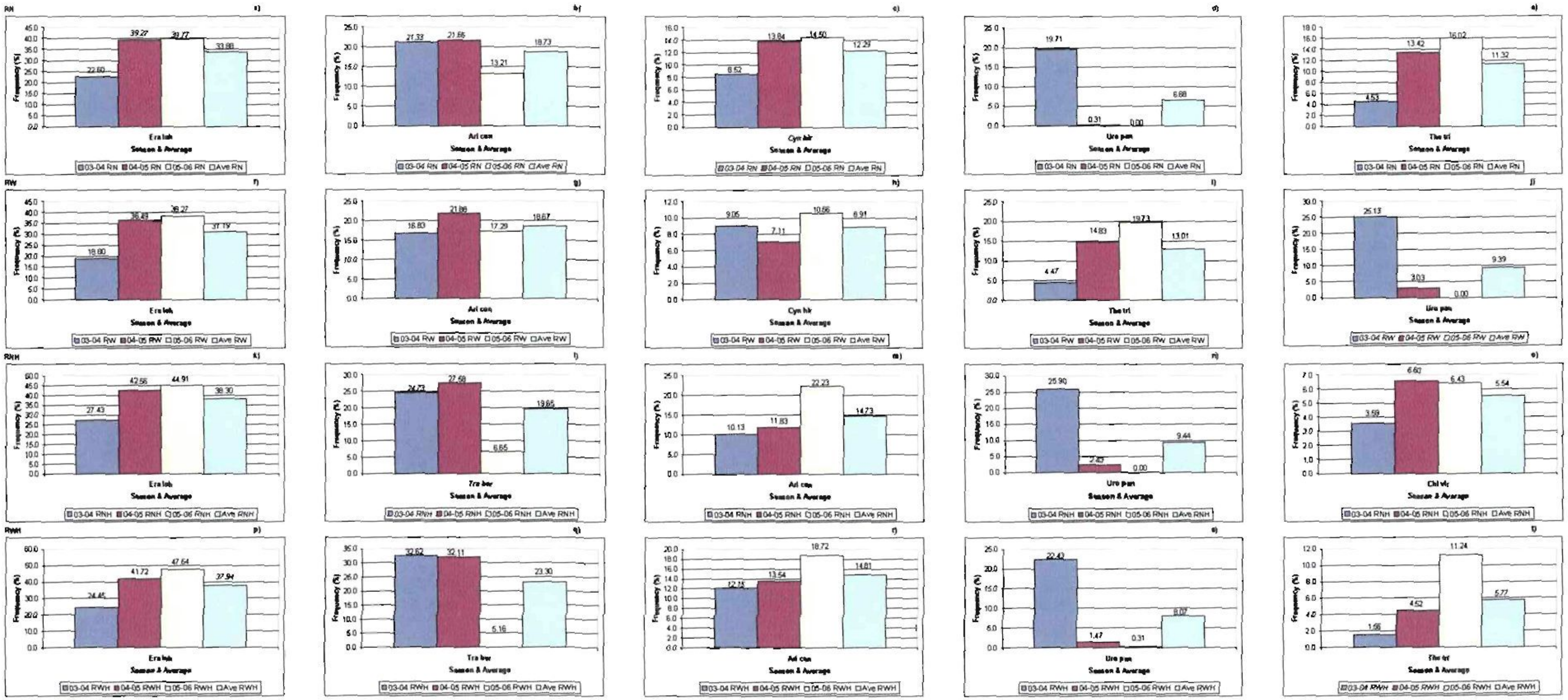

Figure 4.2 *The species frequency (%) for the rip restoration technology (R) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).*

3) Rip and the application of organic material restoration technology (RO)

- The grass species

Eragrostis lehmanniana increased in abundance in all four of the rip and the application of organic material trials over the three seasons from 27.38% to 42.9%, 21.83% to 36.94%, 27.55% to 45.43% and 21.29% to 35.38% for RON, ROW, RONH and ROWH, respectively and the average frequency values were 36.26%, 32.42%, 39.35% and 33.02%, respectively. The increase in the frequency value of *Eragrostis lehmanniana* could be attributed to the fact that there was a high abundance of this species before the application of the restoration technologies and that the rip action loosen the soil and help the germination and establishment of seedlings (Table 4.17 and Figure 4.3a, f, k and p).

The species abundance value of *Aristida congesta* increased drastically from the 2003/04 season to the 2004/05 season (16.59% to 22.34% and 17.44% to 27.24% for RN and RW, respectively) and decreased in the 2005/06 season (to 17.0 and 20.78%, respectively). The species abundance of the annual species, decreased as the perennial species' abundance increased, due to the higher rainfall that the trial site received during December and January of the 2004/05 season (Table 2.2 and 4.17 and Figures 2.5 and 4.3b and g). The species abundance of *Aristida congesta* did steadily increase for RSO trials, where Roundup was applied (from 9.75% to 23.0% for RNH and from 12.73% to 20.34% for RWH) over the three seasons (Table 4.17 and Figure 4.3m and r). The average frequency values were higher for the RSO trials, where no Roundup was applied than those where Roundup was applied (18.68%, 21.82%, 15.45% and 14.74%, respectively for RON, ROW, RONH and ROWH).

The species abundance of the annual grass species, such as *Tragus berteronianus* and *Urochloa panicoides* decreased from the 2003/04 to the 2005/06 season in all four the trials, due to the increase of the species abundance of the perennial grass species. In the case of *Tragus berteronianus* this decrease was drastically, for example from 29.28% in the 2003/04 season to 2.42% in the 2005/06 season (Table 4.17 and Figure 4.3c, h, l, q, j, n and s). The average species abundance values over the three seasons of *Tragus berteronianus* were 17.53%, 12.42%, 16.91% and 23.66%, respectively for RON, ROW, RONH and ROWH.

Themeda triandra was only found in the no-Roundup rip and the application of organic material restoration technologies and ranked fourth. The species abundance value of this species drastically increased over the three seasons for both the row spacings (5.51% to 14.79% for RON and 7.96% to 24.44% for ROW). The average frequency value of ROW (17.74%) was higher than that of RON (10.46%) (Table 4.17 and Figure 4.3d and i).

- <u>Comparison between the applied rip and the application of organic material restoration technologies</u>

Themeda triandra occurred in RON and ROW and its species abundance steadily increased over the three seasons. *Aristida congesta* and *Tragus berteronianus* are annual grass species and they occurred in all four of the rip and the application of organic material restoration technologies. The species abundance of *Tragus berteronianus* did decrease over the three seasons (Table 4.17 and Figure 4.3).

There was no perennial grass species with a high grazing value present in the grass communities in the two trials where Roundup was used. The species abundance of the annual pioneer grass species, such as *Aristida congesta* increased over the three seasons indicating that the soil of the RO restoration technologies, where Roundup was used was still not able to support the establishment of perennial climax grass species (Table 4.17 and Figure 4.3).

The species composition of the grass communities of the no-Roundup species were in a better state than that of the Roundup rip and the application of organic material, with at least the presence of *Themeda triandra*. Organic material had no influence in the species abundance of all four rip and the application of organic material that was the same with the rip restoration technologies (Table 4.17 and Figure 4.3).

Table 4.17 The frequency of species (%) for the rip and the application of organic material restoration technology per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RON	03-04	04-05	05-06	Ave
Eragrostis lehmanniana	27.38	38.50	42.90	36.26
Aristida congesta	16.59	22.34	17.00	18.64
Tragus berteronianus	28.87	14.32	9.41	17.53
Themeda triandra	5.51	11.09	14.79	10.46
Cynodon hirsutus	3.28	4.24	4.53	4.01
ROW	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	21.83	38.49	36.94	32.42
Aristida congesta	17.44	27.24	20.78	21.82
Tragus berteronianus	29.28	5.56	2.42	12.42
Themeda triandra	7.96	19.31	24.44	17.24
Urochloa panicoides	16.44	0.00	0.00	5.48
RONH	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	27.55	45.07	45.43	39.35
Tragus berteronianus	16.37	27.72	6.65	16.91
Aristida congesta	9.75	13.59	23.00	15.45
Urochloa panicoides	37.83	2.15	0.31	13.43
Chloris virgata	4.33	7.81	10.03	7.39
ROWH	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	21.29	42.39	35.38	33.02
Tragus berteronianus	28.75	27.03	15.20	23.66
Aristida congesta	12.73	11.14	20.34	14.74
Urochloa panicoides	28.84	3.58	0.60	11.01
Cynodon hirsutus	2.72	3.33	9.18	5.08

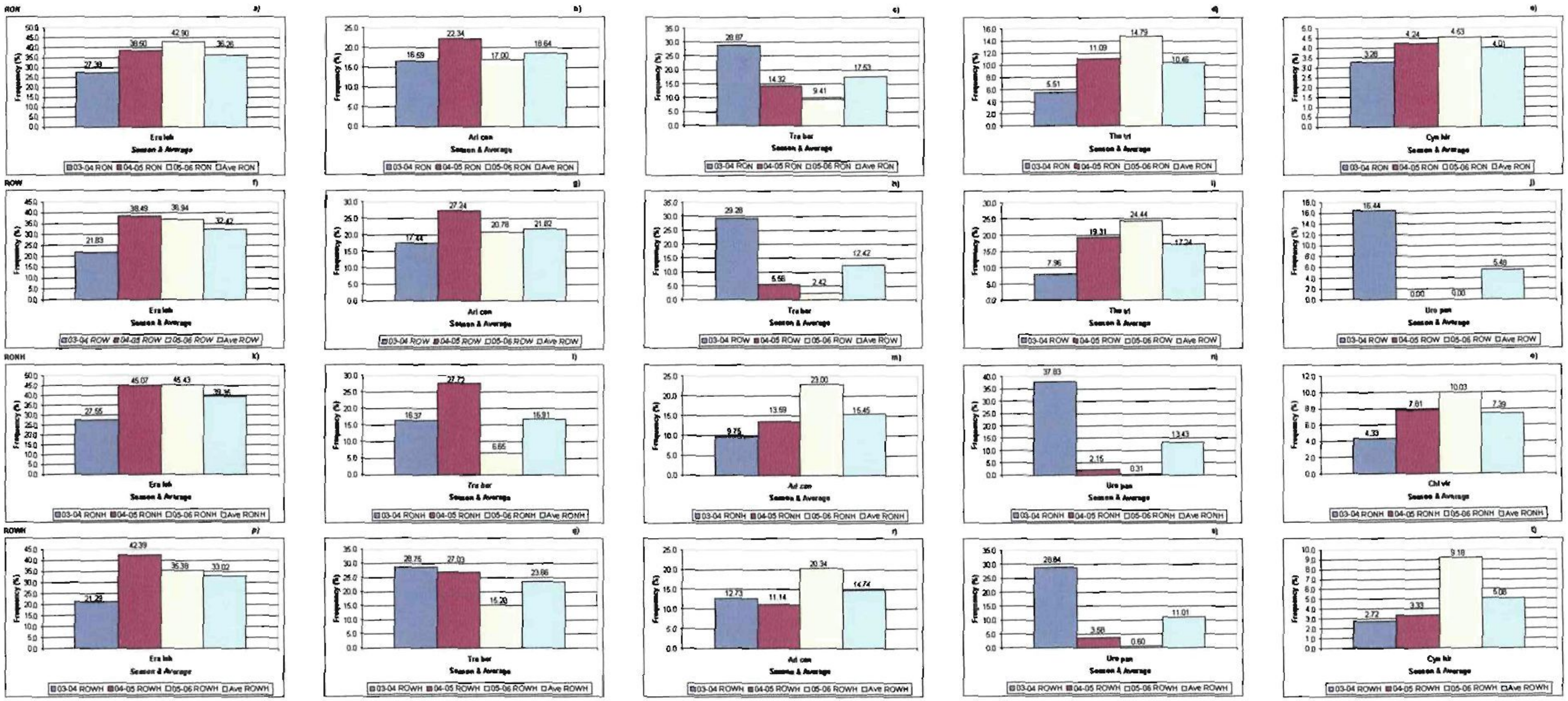

Figure 4.3 The species frequency (%) for the rip and the application of organic material restoration technology (RO) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

4) Rip and re-seeding with a seed mixture restoration technology (RS)

- The re-seeded grass species

Of all eight re-seeded grass species the five most important species, in the order of importance, were *Themeda triandra* (The triS), *Digitaria eriantha* (Dig eriS), *Eragrostis curvula* (Era curS), *Cenchrus cilliaris* (Cen cilS) and *Cymbopogon excavatus* (Cym excS) (Table 4.18). Two of the other species, namely *Chloris gayana* and *Panicum maximum*, did not germinate at all, due to very low germination rates of these two species (29% and 4%, respectively) (Table 4.3). *Eragrostis chloromelas* was grouped with *Eragrostis curvula*, because of the fact that *Eragrostis chloromelas* was not commercially available and it is often regarded similar to *Eragrostis curvula* (Van Oudtshoorn, 1991; Gibbs, *et al.*, 1991) (Table 4.18 and Figure 4.4a to t).

Themeda triandra was the most important species in all the different restoration technologies and it had a species abundance that increased over the three seasons (18.79% to 28.7%, 8.57% to 26.58%, 24.73% to 37.63% and 16.46% to 30.20% for RSN, RSW, RSNH and RSWH, respectively). The average species abundance value was higher for the narrow row spacing than for the wide row spacing and it was higher in the trials where Roundup was used (24.8%, 19.89%, 33.8% and 23.26%, respectively for RSN, RSW, RSNH and RSWH) (Table 4.18 and Figure 4.4a, f, k and p). The fact that the species abundance of *Themeda triandra* did increase over the three seasons could be attributed to the fact that the germination rate was 76% and that the ripping of the soil did aid in the establishment of the seedlings (Table 4.3 and Table 4.18 and Figure 4.4b, g, l and q). The species abundance of *Themeda triandra* increased, due to the higher rainfall that the trial site received during December and January of the 2004/05 season (Table 2.2).

The species abundance of *Digitaria eriantha* increased over the three seasons for all restoration technologies (19.39 to 35.04, 14.89 to 25.0, 12.52 to 32.22 and 13.98 to 30.59% for RSN, RSW, RSNH and RSWH, respectively). The average value was higher for the narrow row spacing especially in the no-Roundup rip and the re-seeding with a seed mixture restoration technology (Table 4.18 and Figure 4.4b, g, l and q). Despite of the fact that the germination of *Digitaria eriantha* was very low (19%), it did established well and responded positively in all the re-seeded restoration technologies (Table 4.3 and Table 4.18 and Figure 4.4b, g, l and q).

Eragrostis curvula was the only re-seeded species of which the frequency value decreased over the three seasons, 22.94% to 7.3% (RSN), 13.61% to 9.07% (RSW), 29.74% to 7.01% (RSNH) and 29.97% to 10.34% (RSWH) (Table 4.18 and Figure 4.4). The average value for RSN was 12.9%, for RSW it was 10.21%, for RSNH it was 15.53% and for RSWH it was 16.83% (Table

4.18 and Figure 4.4 c, h, m and r). The fact that the frequency value for this species decreased over the three years could be best explained by *Eragrostis curvula's* close association with other re-seeded species, such as *Themeda triandra* and *Digitaria eriantha. Themeda triandra* and *Digitaria eriantha* are strong competitors for space and soil nutrients with the *Eragrostis curvula* plants. This resulted in the *Eragrostis curvula* plants being pushed out and their numbers decline over time. The fact that the average frequency value of *Eragrostis curvula* was higher for the restoration technologies where Roundup was used show that the application of this herbicide did have a positive effect on the establishment of this species.

The species abundance of *Cenchrus cilliaris* and *Cymbopogon excavatus* was very poor over the three seasons in all four the rip and the re-seeding with a seed mixture restoration technologies and did not contribute significantly to the overall species composition. The results of especially *Cymbopogon excavatus* were mixed. The frequency values of these two species did increase over the three seasons (Table 4.18 and Figure 4.4d, I, n, s, e, j, o and t).

- <u>Comparison between the applied rip and re-seeding with a seed mixture restoration technologies with regard to the re-seeded grass species</u>

The species abundance for both *Themeda triandra* and *Digitaria eriantha* increased over the three seasons for all four the rip and re-seeding restoration trials. The species composition for all four the rip and re-seeding trials was the same, as well as the importance value rankings of the species. The species abundance of the re-seeded species, such as *Themeda triandra* for both the narrow (0.75m) row spacings (no-Roundup and Roundup) of the RS restoration technologies was slightly better (24.8% vs. 19.89%, for RSN and RSNH, respectively), than the wide (1.5m) row spacing (33.8% vs. 23.26%, for RSW and RSWH, respectively). *Cenchrus cilliaris* and *Cymbopogon excavatus* had a very poor species abundance for all the rip and re-seeding (seed mixture) restoration technologies (Table 4.18 and Figure 4.4).

Table 4.18 The frequency of species (%) for the rip and the re-seeding with a seed mixture restoration technology (Re-seeded grass species) per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RSN (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	18.79	26.89	28.70	24.80
Digitaria eriantha	19.39	25.26	35.04	26.56
Eragrostis curvula	22.94	8.45	7.30	12.90
Cenchrus cilliaris	0.33	1.27	2.10	1.23
Cymbopogon excavatus	0.33	0.49	0.00	0.27
RSW (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	8.57	24.51	26.58	19.89
Digitaria eriantha	14.89	13.22	25.00	17.70
Eragrostis curvula	13.61	7.94	9.07	10.21
Cenchrus cilliaris	0.99	0.55	0.86	0.80
Cymbopogon excavatus	0.30	0.31	1.51	0.70
RSNH (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	24.73	39.05	37.63	33.80
Digitaria eriantha	12.52	25.62	32.22	23.45
Eragrostis curvula	29.74	9.82	7.01	15.53
Cenchrus cilliaris	0.00	0.00	1.53	0.51
Cymbopogon excavatus	0.00	0.23	0.92	0.38
RSWH (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	16.46	23.12	30.20	23.26
Digitaria eriantha	13.98	21.48	30.59	22.02
Eragrostis curvula	29.97	10.17	10.34	16.83
Cenchrus cilliaris	0.00	0.51	1.27	0.60
Cymbopogon excavatus	0.00	0.78	0.66	0.48

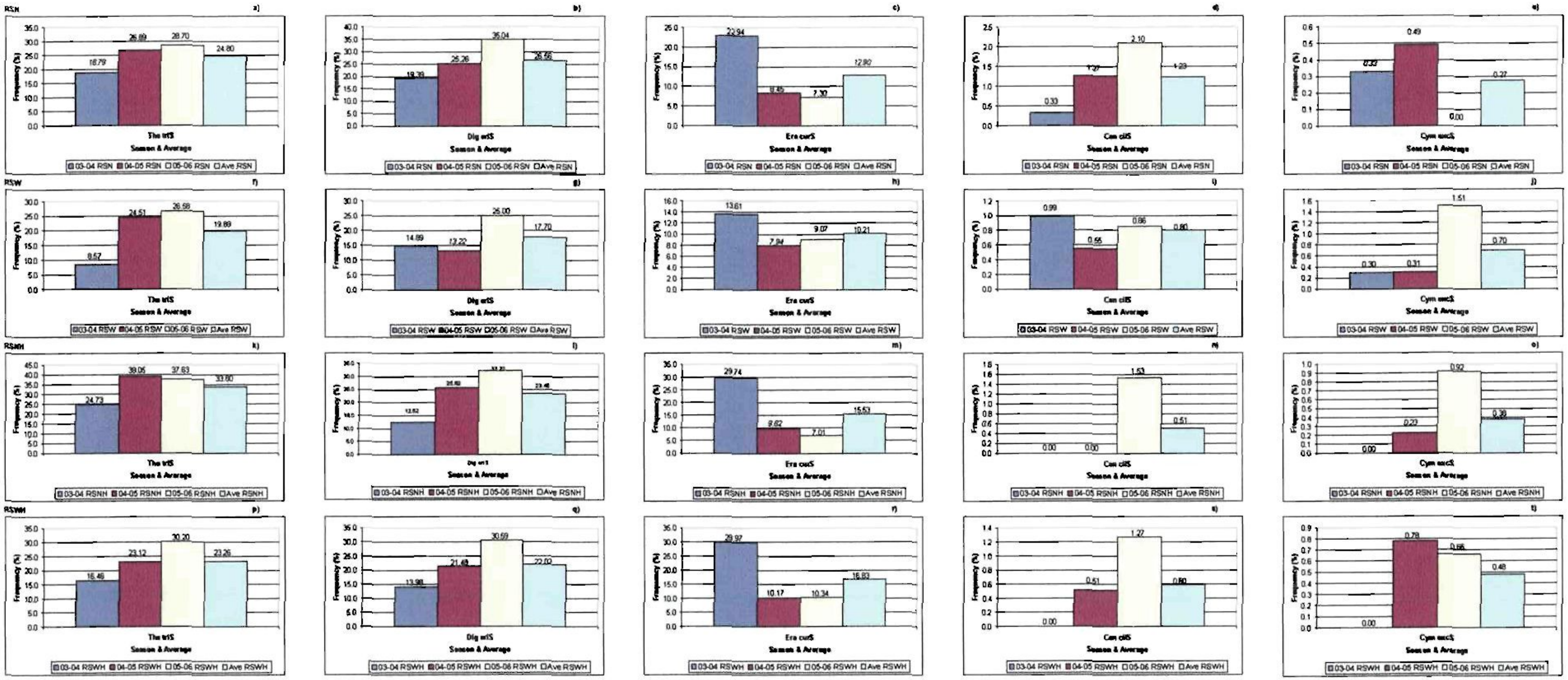

Figure 4.4 The species frequency (%) for the rip and the re-seeding with a seed mixture (re-seeded grass species) restoration technology (RS) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

- The natural occurring grass species

Eragrostis lehmanniana was the most important natural occurring species in all four the different restoration technologies and the species abundance increased drastically from the 2003/04 to the 2004/05 seasons and then decreased in the 2005/06 season: for RSN from 5.23% to 20.34 to 20.85%, for RSW from 15.51% to 27.65% to 25.34%, for RSNH from 9.45% to 18.94% to 14.69% and for RSWH from 9.54% to 25.22% to 10.95% (Table 4.19 and Figure 4.5a, f, k and p). The average species abundance values were more or less equal, except for the wide row spacing without the application of Roundup that was higher than the rest. These values were 15.48%, 22.83%, 14.37% and 15.24%, respectively (Table 4.19 and Figure 4.5a, f, k and p).

The frequency values of *Aristida congesta* decreased in general for all four of the re-seeded trials over the three seasons (11.41% to 1.8% for RSN, 13.45% to 5.08% for RSW and 8.07% to 0.95% for RSNH), except for RSWH, where it initially decreased from 2003/04 (5.47%) to 2003/04 (2.60%) and increased in the 2005/06 season (18%). There was no clear explanation for this trend in the frequency value of *Aristida congesta* other than the patchiness of this species in the restoration trial sites (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season). The average frequency value of this was much higher (7.43% and 11.30%, respectively) for the restoration technologies where no Roundup was used, than those were Roundup was applied (3.72% and 4.42%, respectively) (Table 4.19 and Figure 4.5b, g, n and s).

The species abundance value of *Tragus berteronianus* in general, decreased over the three seasons for all of these restoration technologies. The initial (2203/04 season) frequency values for this species were high and it drastically decreased in the second (2003/04) and third (2005/06) season (Table 4.19 and Figure 4.5d, i, l and q).

The species abundance value for *Urochloa panicoides* decreased drastically for all of the re-seeded restoration technologies. *Urochloa panicoides* had a high frequency value in the 2003/04 season (7.36%, 8.57%, 7.11% and 13.4%, respectively for RSN, RSW, RSNH and RSWH). The average species abundance of this species was more or less the same for these four re-seeded restoration trials (2.45%, 2.86%, 2.37% and 4.55%) (Table 4.19 and Figure 4.5c, j, m and r).

Cynodon hirsutus did not occur in the 1, 5 m restoration technology trial site, where Roundup was used. The species abundance of *Cynodon hirsutus* decreased from the 2003/04 season (2.18%) to the 2004/05 season (0.87%) and increased in the 2005/06 season (2.35%) for the RSN treatment. The species abundance of this species decreased over the three seasons

(7.92% to 4.79%) for RSW and increased for RSNH (0% to 0.92%) (Table 4.19 and Figure 4.5e, h and o). The fact that the species abundance value over the three seasons and the average value for the three seasons vary so much for this species, could be contributed to the patchiness of *Cynodon hirsutus* (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season).

Chloris virgata occurred only in the 1.5m row spacing with the application of Roundup restoration trial. Its species abundance was very low, with an average of only 2.6% over the three seasons (2203/04 to 2005/06) (Table 4.19 and Figure 4.5t).

- Comparison between the applied rip and re-seeding with a seed mixture restoration technologies in terms of the natural occurring grass species

The grass species composition of the natural occurring grass species were the same as for the only rip and rip with the application of organic material, with *Eragrostis lehmanniana* ranking first and the two annual grass species (*Aristida congesta* and *Tragus berteronianus*) ranked second or third, within the four most important ranked grass species, respectively. The species abundance of *Eragrostis lehmanniana* was higher in the second season (2004/05), due to the higher rainfall (January and February 2005) the study site received in the months before the plant surveys were conducted. Nearly all of the annual grass species decreased in species abundance, as the competition with the perennial grass species increased Table 4.19 and Figure 4.5a, f, k and p).

Table 4.19 The frequency of species (%) for the rip and the re-seeding with a seed mixture restoration technology (natural species) per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RSN (Natural)	03-04	04-05	05-06	Ave
Eragrostis lehmanniana	5.23	20.34	20.86	15.48
Aristida congesta	11.41	9.07	1.80	7.43
Tragus berteronianus	11.38	7.35	0.30	6.35
Urochloa panicoides	7.36	0.00	0.00	2.45
Cynodon hirsutus	2.18	0.87	2.35	1.80
RSNH (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	15.51	27.65	25.34	22.83
Aristida congesta	13.45	15.37	5.08	11.30
Cynodon hirsutus	7.92	5.03	4.79	5.91
Tragus berteronianus	10.74	3.35	0.30	4.80
Urochloa panicoides	8.57	0.00	0.00	2.86
RSW (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	9.46	18.94	14.69	14.37
Tragus berteronianus	7.57	3.51	3.20	4.76
Urochloa panicoides	7.11	0.00	0.00	2.37
Aristida congesta	8.07	2.12	0.95	3.72
Cynodon hirsutus	0.00	0.00	0.92	0.31
RSWH (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	9.54	25.22	10.95	15.24
Tragus berteronianus	10.02	11.54	6.69	9.42
Urochloa panicoides	13.40	0.26	0.00	4.55
Aristida congesta	5.47	2.60	5.18	4.42
Chloris virgata	0.86	4.08	2.86	2.60

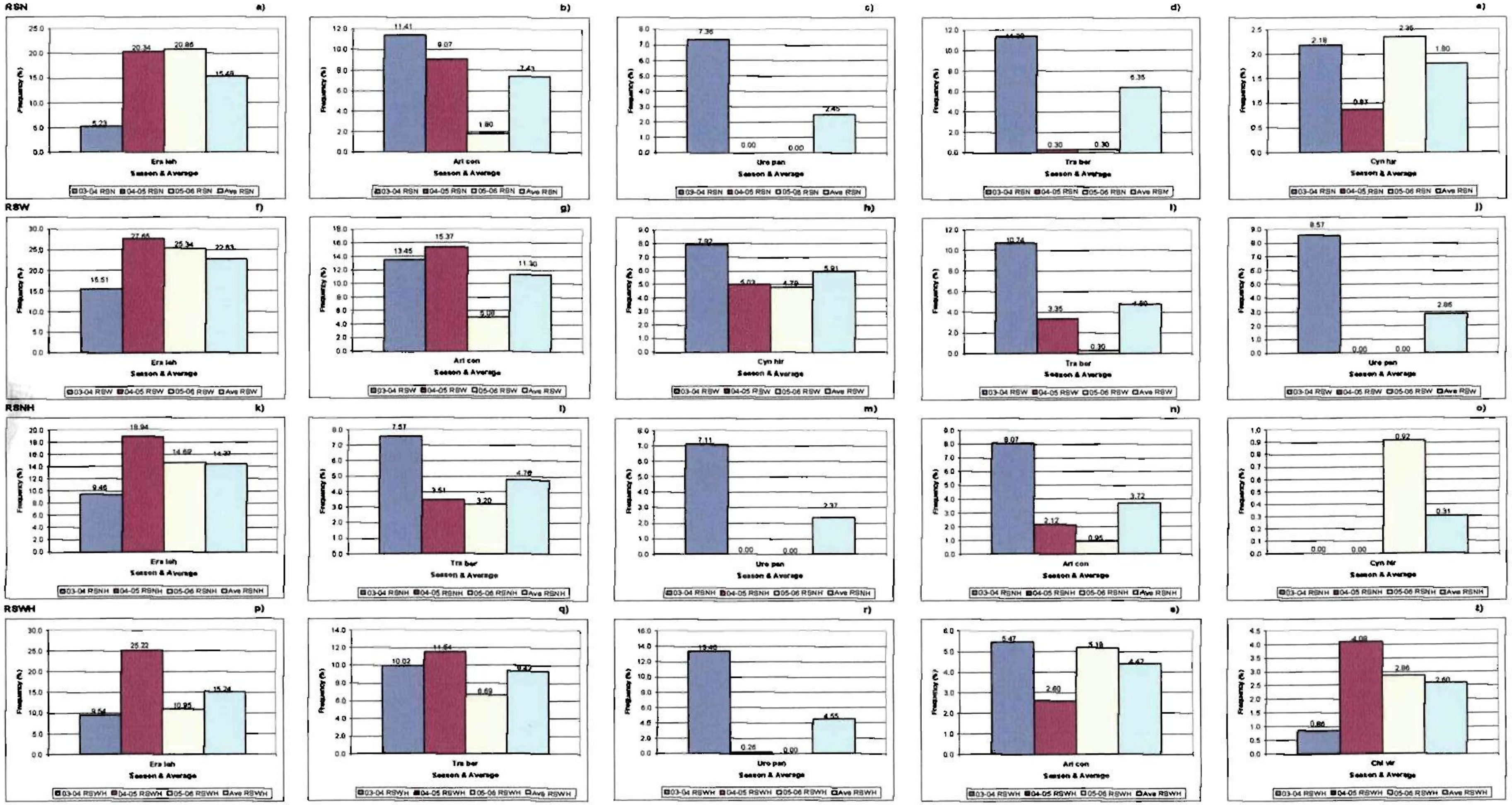

Figure 4.5 The species frequency (%) for the rip and the re-seeding with a seed mixture (natural grass species) restoration technology (RS) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

5) Rip, re-seeding with a seed mixture and the application of organic material restoration technology (RSO)

- The re-seeded grass species

The same five re-seeded grass species of all eight re-seeded grass species as for the RS trials where no organic material was applied ranked as the five most important species from the highest to the lowest IV as follows: *Themeda triandra, Digitaria eriantha, Eragrostis curvula, Cenchrus cilliaris* and *Cymbopogon excavatus* (Table 4.20 and Figure 4.6).

Of the re-seeded grass species *Themeda triandra* was the most important species in three of the restoration technologies and ranked second in the 0.75m row spacing, where no Roundup was applied. The species abundance did increase over the three seasons: 10.45% to 25.77%, 9.82% to 30.34%, 15.07% to 29.72% and 11.7% to 33.08% for RSON, RSOW, RSONH and RSOWH, respectively. The fact the re-seeded restorations trials with the application of organic material where Roundup was used had a higher species abundance for *Themeda triandra* could be attributed to the fact that the applied organic material in combination with the elimination of the competition with other plants benefited the germination of the re-seeded seed and the establishment of the seedlings. The average species abundances of this species were 25.36% for RSON, 23.77% for RSONH, 21.21% for RSOW and 24.32% RSOWH, respectively. Thus the 0.75m row spacing had higher species abundance for the no Roundup applied treatment than the roundup applied treatment and the 1.5m row spacing was higher for the Roundup treatment than the no Roundup applied treatment (Table 4.20 and Figure 4.8b, f, k and p).

Digitaria eriantha occurred in all four of these restoration technologies. The species abundance of this species did increase over the three seasons as follows: RSON from 18.89% to 34.75%, RSOW from 11.92% to 30.44%, RSONH from 12.13% to 26.42% and RSOWH from 17.33% to 26.55%. The average frequency value was higher for the wide row spacing especially in the restoration trials where Roundup was applied (Table 4.20 and Figure 4.6a, g, I and q). As *Digitaria eriantha* and *Themeda triandra* occurred in close association with each other they responded the same and their frequency values increased over the three seasons (2003/04 to 2005/06).

The species abundance of the re-seeded *Eragrostis curvula* decreased for most of the organic material applied re-seeded restoration trials from the 2003/04 season to the 2004/05 season (16.19% to 4.03%, 7.35% to 2.34% and 20.81% to 5.71%, for RSON, RSOW and RSOWH, respectively) and it increased in the 2005/06 season to 7.72%, 5.6% and 7.09%, respectively. The species abundance for *Eragrostis curvula* decreased over the three seasons for RSONH from 20.96% to 7.62%. The species abundance of *Eragrostis curvula* decreased as the species abundance of the other re-seeded species, such as *Digitaria eriantha* and *Themeda triandra* increased. The average frequency value was slightly higher in the 0.75m row spacing than the 1.5m row spacing for both the no-Roundup and the Roundup restoration technologies. The average value of *Eragrostis curvula* was much higher for the Roundup than the no-Roundup restoration technologies (14.03% and 11.20% for the Roundup trials versus the 9.31% and 5.10% for the trials where no Roundup was used), this indicated that the elimination of the competition did have an positive effect on the germination and establishment of this species (Table 4.20 and Figure 4.6c, h, m and r).

The contribution of *Cenchrus cilliaris* and *Cymbopogon excavatus* to the overall species composition of the re-seeded restoration technologies, where organic material was applied, as for the re-seeded trials, discussed in the previous section, was very low. The frequency value of *Cenchrus cilliaris* increased over the three seasons (0.31% to 0.62%, 0.31% to 2.33%, 0% to 1.85% and 0% to 2.38%, respectively). The average species abundance for this species was more or less the same for RSON (0.41%), RSONH (0.92%) and RSOWH (0.88%) and slightly higher for RSOW (1.21%) (Table 4.20 and Figure 4.6d, I, n and s). The species success of the re-seeding of *Cymbopogon excavatus* was mixed as could be observed from the frequency data over the three seasons (2003/04 to 2005/06). The frequency value of *Cymbopogon excavatus* increased for the 2003/04 season for both RSON and RSOW (0% to 0.88% and 0% to 0.79%, respectively) and it decreased in the 2005/06 season to 0.31% and 0.30% respectively. On the other hand the frequency value for RSONH and RSOWH increased over the three seasons (from 0% to 1.16% and 0% to 0.60%, respectively. This indicated the application of Roundup did have a positive effect on the establishment of *Cymbopogon excavatus* (Table 4.20 and Figure 4.6e, j, o and t).

- <u>Comparison between the applied rip, re-seeding with a seed mixture and the application of organic material restoration technologies in terms of the re-seeded grass species</u>

The species abundance of the re-seeded grass species: *Digitaria eriantha*, *Themeda triandra* and *Eragrostis curvula* were much higher than those of *Cenchrus cilliaris* and *Cymbopogon excavatus*. The species abundance of *Digitaria eriantha* and *Themeda triandra* increased over the three seasons and that of *Eragrostis curvula* decreased, due to the fact that the competitive effect of *Digitaria eriantha* and *Themeda triandra* is higher than that of *Eragrostis curvula* that caused an increase of these two species (Table 4.20 and Figure 4.6a, f, k, p, b, g, I, q, c, h, m and r).

The species abundance of *Cenchrus cilliaris* and *Cymbopogon excavatus* increased over the three seasons, but its contribution towards the overall grass species composition of these restoration technologies were not significant (Table 4.20 and Figure 4.6).

Table 4.20 The frequency of species (%) for the rip, the re-seeding with a seed mixture and the application of organic material restoration technology (Re-seeded grass species) per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RSON (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Digitaria eriantha	12.98	28.34	34.75	25.36
Themeda triandra	10.45	20.45	25.77	18.89
Eragrostis curvula	16.19	4.03	7.72	9.31
Cenchrus cilliaris	0.31	0.30	0.62	0.41
Cymbopogon excavatus	0.00	0.88	0.31	0.40
RSOW (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	9.82	23.47	30.34	21.21
Digitaria eriantha	11.92	22.99	30.44	21.79
Eragrostis curvula	7.35	2.34	5.60	5.10
Cenchrus cilliaris	0.31	0.99	2.33	1.21
Cymbopogon excavatus	0.00	0.79	0.30	0.36
RSONH (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	15.07	26.50	29.72	23.77
Digitaria eriantha	12.13	23.10	26.42	20.55
Eragrostis curvula	20.96	13.62	7.52	14.03
Cenchrus cilliaris	0.00	0.91	1.85	0.92
Cymbopogon excavatus	0.00	0.62	1.16	0.60
RSOWH (Re-seeded)	**03-04**	**04-05**	**05-06**	**Ave**
Themeda triandra	11.70	28.17	33.08	24.32
Digitaria eriantha	17.33	23.93	28.66	23.31
Eragrostis curvula	20.81	5.71	7.09	11.20
Cenchrus cilliaris	0.00	0.27	2.38	0.88
Cymbopogon excavatus	0.00	0.27	0.60	0.29

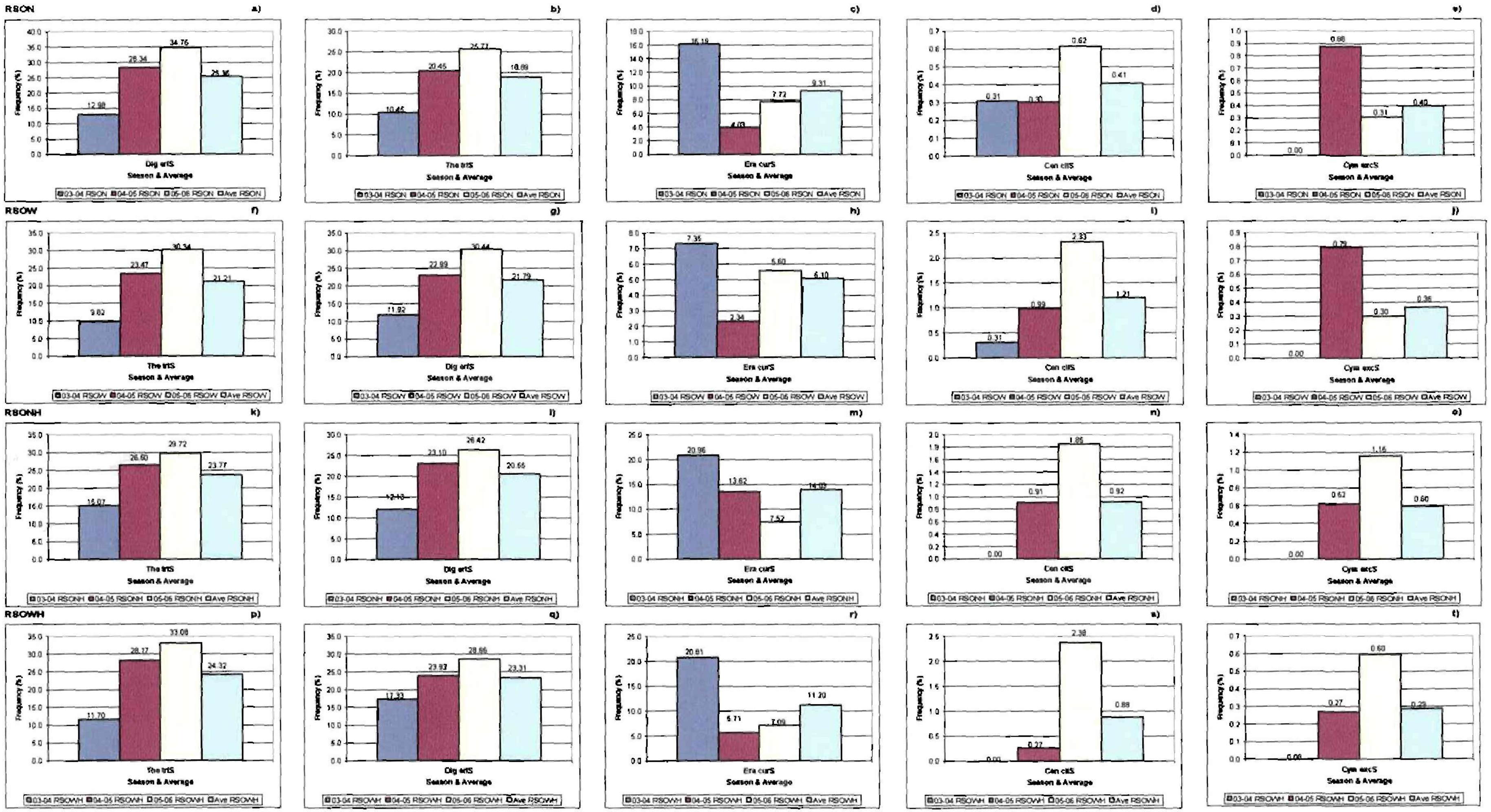

Figure 4.6 The species frequency (%) for the rip, the re-seeding with a seed mixture (re-seeded grass species) and the application of organic material restoration technology (RSO) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

- The natural occurring grass species

Eragrostis lehmanniana had the highest IV in all the RSO restoration technologies. The frequency value of this species increased drastically from the 2003/04 to the 2004/05 season (1.085% to 30.32%, 21.10% to 31.35% and 10.67% to 25.99%) for RSON, RSOW and RSOWH and decreased in the 2005/06 season to 21.99%, 20.76% and 20.79%, respectively, where as it steadily increased over the three seasons for RSONH from 6.43% to 21.45% (Table 4.21 and Figure 4.7a, f, k and p). This could be best explained by the higher rainfall the study site received during January and February of the 2005/05 season, just before the vegetation surveys were done (Table 2.2 and Figure 2.5). The average frequency value was higher for the restoration technologies where no Roundup was applied (21.99% and 24.4%) as that of the Roundup applied treatments (15.68% and 19.15%) (Table 4.21 and Figure 4.7a, f, k and p).

The frequency value of *Aristida congesta* decreased in general in all four the RSO restoration technologies (14.75% to 3.82%, 10.19% to 5.03%, 8.03% to 1.68% and 5.65% to 2.66%) over the three seasons. This could be best explained by the fact that *Aristida congesta* is an annual grass species that compete poorly with perennial species, such as *Digitaria eriantha* and *Themeda triandra*. The average frequency value of the three seasons (2003/04 to 2005/06) was higher for the restoration trial where no Roundup was used (9.23% and 8.72% versus 4.07% and 2.66%). This could be attributed to the non selective working of the Roundup, killing all living plants (Table 4.21 and Figure 4.7 b, g, n and s).

Tragus berteronianus occurred in all of the RSO restoration trials and it species abundance decreased form 14.55% to 0%, 15.26% to 0%, 12.5% to 1.4% and 17.58% to 1.17 for RSON, RSOW, RSONH and RSOWH, respectively, from the 2003/04 to the 2005/06 season. The average species abundance of this species was more or less the same for all the RSO restoration trials (Table 4.21 and Figure 4.7c, h, m and q). The reason for the decrease in the species abundance of this species could be attributed to the fact that *Tragus berteronianus* is an annual species with fluctuating species abundance, according to the environmental conditions.

The same trend was observed for *Urochloa panicoides*, with a species abundance value that decreased drastically to a zero value, over the three seasons (from 15.56%, 15.57%, 7.11% and 28.84%, respectively to 0%). The average frequency value RSO restoration trials was the same and slightly higher for the RSO trials, where Roundup was used, especially in the wide row spacing (Table 4.21 and Figure 4.7d, I, o and r). This could be best explained due to the initial patchiness of this species and the fact that it is an annual species (Table 4.5) (Appendix

B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season).

Cynodon hirsutus occurred in patches over the whole study site, before any restoration technologies were applied (Table 4.5) and that could explain its species abundance in all four of the RSO restoration trials. The frequency value of this species decreased for RSON (0.95% to 0.31%) and RSONH (13.93% to 8.21%) over the three seasons, where as it increased for RSOW (2.73% to 3.19%) and RSOWH 0.29% to 1.48%) (Table 4.21 and Figure 4.7e, j, l and t). There was no explanation why the frequency value of *Cynodon hirsutus* decreased in the narrow rows and increased in the wide rows, except that it could be because the wide rows created more open spaces and less competition.

- <u>Comparison between the applied rip, re-seeding with a seed mixture and the application of organic material restoration technologies in terms of the natural occurring grass species</u>

The grass species composition of these restoration technologies were the same as for the rip, without the application of organic material.

Eragrostis lehmanniana was ranked first (natural seed) with the highest IV for all the RSO restoration technologies and it had the highest frequency values of all the natural occurring species. *Aristida congesta* and *Tragus berteronianus* were ranked under the five most important natural occurring grass species for all of these restoration technologies. The species abundance of all the annual grass species, such as *Aristida congesta* and *Tragus berteronianus* decreased over the three seasons and that of the perennials species, such as *Eragrostis lehmanniana* increased (Table 4.21 and Figure 4.7).

Table 4.21 The frequency of species (%) for the rip, re-seeding with a seed mixture and the application of organic material restoration technology (natural species) per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RSON (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	10.85	30.32	24.82	21.99
Aristida congesta	14.75	9.13	3.82	9.23
Tragus berteronianus	14.55	4.01	0.00	6.19
Urochloa panicoides	15.56	0.00	0.00	5.19
Cynodon hirsutus	0.95	0.85	0.31	0.71
RSONH (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	21.10	31.35	20.76	24.40
Aristida congesta	10.19	10.95	5.03	8.72
Tragus berteronianus	15.26	3.47	0.00	6.25
Urochloa panicoides	15.57	0.00	0.00	5.19
Cynodon hirsutus	2.73	2.92	3.19	2.95
RSOW (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	6.43	19.14	21.45	15.68
Cynodon hirsutus	13.93	7.98	8.21	10.04
Tragus berteronianus	12.50	4.49	1.40	6.13
Aristida congesta	8.03	2.50	1.68	4.07
Urochloa panicoides	7.11	0.21	0.00	2.44
RSOWH (Natural)	**03-04**	**04-05**	**05-06**	**Ave**
Eragrostis lehmanniana	10.67	25.99	20.79	19.15
Tragus berteronianus	17.58	10.65	1.17	9.80
Urochloa panicoides	28.84	3.58	0.60	11.01
Aristida congesta	5.65	2.78	2.66	3.70
Cynodon hirsutus	0.29	0.66	1.48	0.81

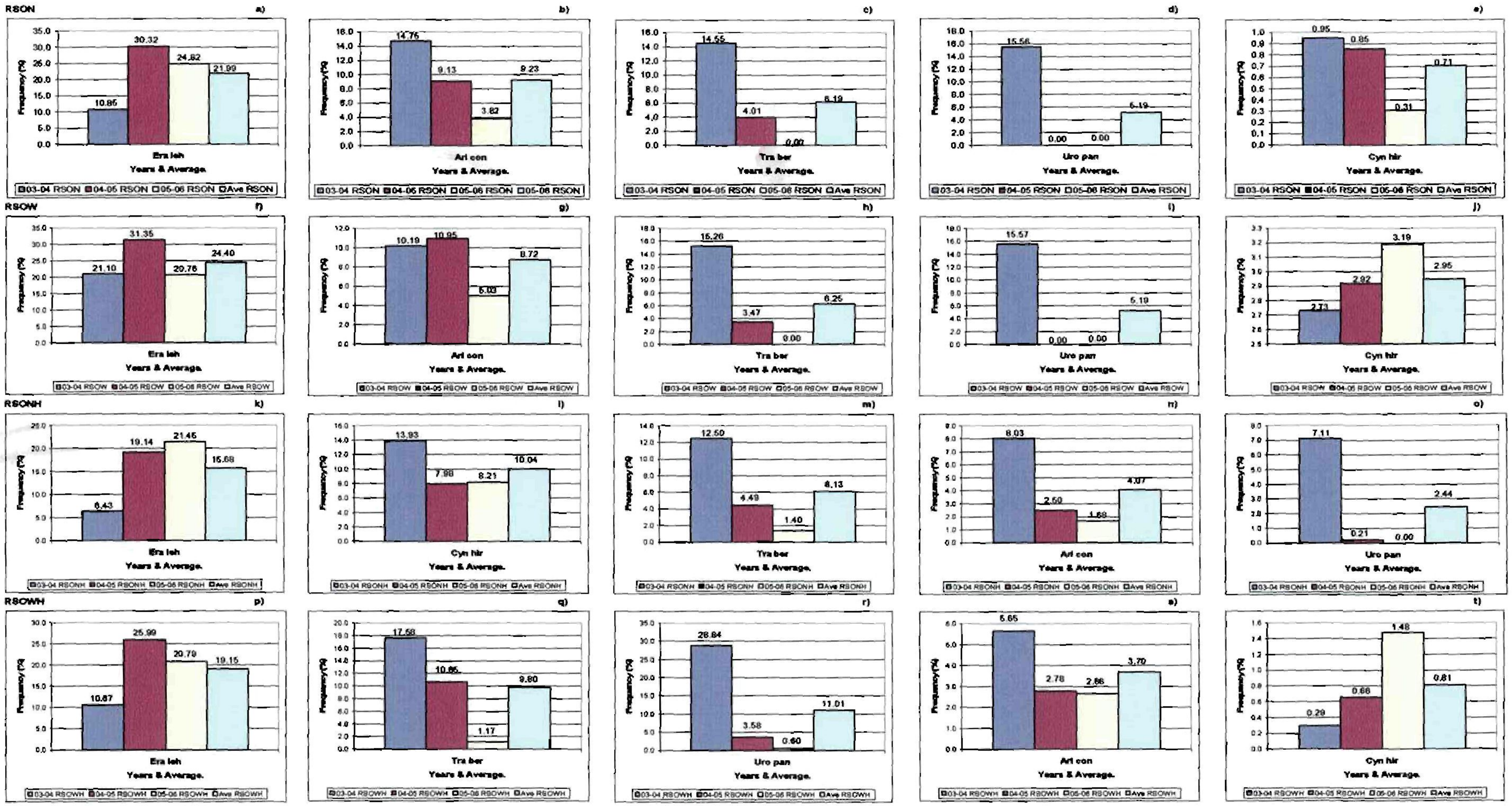

Figure 4.7 The species frequency (%) for the rip, the re-seeding with a seed mixture (natural grass species) and the application of organic material restoration technology (RSO) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

6) Rip and re-seeding with only *Digitaria eriantha* seed restoration technology (RD)

- <u>The grass species</u>

Although *Digitaria eriantha* was re-seeded in this restoration technology it was only ranked first in the narrow (0.75m) row spacing where Roundup was used. The frequency value did increase over the three seasons from 28.1% to 46.31%, 13.54% to 35.42%, 27.01% to 44.42% and 17.45% to 41.08%, for RDN, RDW, RDNH and RDWH, respectively (Table 4.22 and Figure 4.8a, g, m and s). The average frequency values for RDN, RDW, RDNH and RDWH were 37.81%, 24.76%, 36.68% and 29.72%, respectively (Table 4.22 and Figure 4.8a, g, m and s). The reason for the increasing in the frequency value of *Digitaria eriantha* could be attributed to the fact that the ripping of the soil aided in the germination of the re-seeded seed and the establishment of the seedlings.

Eragrostis lehmanniana ranked the first with the highest IV of the natural occurring species for this restoration technology. In RDN, RDW, and RDWH the species abundance of this species increased from the 2003/04 to the 2005/06 season (12.6% to 30.47%, 14.98% to 31.84% and 11.09% to 31.2%) and stayed stable or decreased slightly in the 2005/06 season (30.47%, 27.52% and 29.46%). The species abundance of *Eragrostis lehmanniana* increased over the three seasons for RDNH from 14.83% to 27.45% (Table 4.22 and Figure 4.8b, h, n and t). This could be best explained by the fact that as the species abundance of the other species, such as *Digitaria eriantha* increased the species abundance of *Eragrostis lehmanniana* decreased, because of the competition with these species. The frequency value of *Eragrostis lehmanniana* was more or less the same for all four of these restoration trials, meaning that the application of Roundup and the row spacing did not affect the occurrence of this species much.

The species abundance of *Aristida congesta* increased from the 2003/04 to the 2004/05 (11.22% to 13.84% and 5.59% to 12.41%) season and it decreased in the 2005/06 season to 5.53% and 7.27%, respectively for the restoration technologies where no Roundup was used. The species abundance for *Aristida congesta* decreased for RDNH (8.83% to 6.73%) over the three seasons and it increased for RDWH (11.86% to 15.42%) (Table 4.22 and Figure 4.8c, I, p and v). Due to the different reaction of this species in the different restoration trials, there was no clear explanation for this other than it could be contributed to the species abundance of the other species in the plant community: as the species abundance of species, such as *Digitaria eriantha* increased the species abundance of *Aristida congesta* decreased.

The species abundance of the other two annual species, namely *Tragus berteronianus* and *Urochloa panicoides* decreased over the three seasons, from 17.12% to 0.62% (RDN), 19.07%

to 0.6% (RDW), 29.88% to 1.24% (RDNH) and 36.198% to 1.21% (RDWH) for *Tragus berteronianus*. The average frequency value over the three seasons for *Tragus berteronianus* was more or less the same for the these restoration technologies, showing no one of these technologies benefited this species (Table 4.22 and Figure 4.8 d, l, p and v). The frequency value of *Urochloa panicoides* also decreased over the three seasons for this restoration technology (12.96%, 12.81% and 19.94% to 0% for RDN, RDNH and RDWH, respectively) and the average over the three seasons was the same (Table 4.22 and Figures 4.8 f, r and w). This decrease of these annual species' species abundance could be attributed to an increase of the species abundance of climax grass species, such as *Digitaria eriantha* as the habitat better for the climax species to establish. As the habitat become more favourable for perennial climax grass species it becomes less favourable for the pioneer annual species.

Themeda triandra occurred in three of the restoration technologies, namely RDN, RDW and RDNH. The species abundance of this species did increase over the three seasons for RDN and RDNH (6.36% to 10.16% and 2.07% to 13.12%, respectively), over the three seasons. For RDW the species abundance did initially increase from the 2003/04 (7.38%) to the 2004/05 season (14.01%), where after it did stabilise or decreased slightly in the 2005/06 season (12.18%). The reason why it only occurred in some of the restoration sites could be best explained by the patchiness in which this species occurred over the trial site. The average species abundance of *Themeda triandra* was higher in the wide row spacing, due to the patchiness of it (Table 4.22 and Figure 4.8e, k and q) (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season).

Cynodon hirsutus only occurred in RDW and *Chloris virgata* only in RDWH, due to the patchiness of these species occurrence (Table 4.22 and Figure 4.8j and x) (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season).

- Comparison between the grass species in the rip and re-seeding with *Digitaria eriantha* seed restoration technologies

The species abundance of *Digitaria eriantha* was low and it did not ranked as one of the five most important grass species, except for the narrow row spacing, where Roundup was used (Table 4.22 and Figure 4.8a, g, m and s). The narrow row spacing did benefit the *Digitaria eriantha*, because of the higher average species abundance of the narrow row spacing. There was not much difference between the restoration trials where Roundup was not used and those where it was used.

In most of these restoration technologies the natural occurring *Eragrostis lehmanniana* was ranked first with the highest IV. The average species abundance value of this grass species over the three seasons was more or less the same, indicating that this species was not benefited by either of these restoration technologies (Table 4.22 and Figure 4.8b, h, n and u).

The species abundance of the annual grass species such as *Aristida congesta*, *Tragus berteronianus* and *Urochloa panicoides* either stayed the same or decreased over the three seasons (Table 4.22 and Figure 4.8). This indicates that the species abundance of the annual species decreased as the perennial species increase.

Cynodon hirsutus and *Chloris virgata* only occurred in patches in the trial sites (Table 4.22 and Figure 4.8). These species could not be used as indicators of the success of the restoration technology, as it only occurred in two separate restoration trial sites.

Table 4.22 The frequency of species (%) for the rip and re-seeding with *Digitaria eriantha* seed restoration technology per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

RDN	03-04	04-05	05-06	Ave
Digitaria eriantha	28.10	39.00	46.31	37.81
Eragrostis lehmanniana	12.60	30.83	30.47	24.63
Aristida congesta	11.22	13.84	5.53	10.20
Tragus berteronianus	17.12	2.28	0.62	6.67
Themeda triandra	6.38	8.61	10.16	8.38
Urochloa panicoides	12.98	0.00	0.00	4.33
RDW	**03-04**	**04-05**	**05-06**	**Ave**
Digitaria eriantha	13.54	25.32	35.42	24.76
Eragrostis lehmanniana	14.98	31.84	27.52	24.78
Aristida congesta	9.59	12.41	7.27	9.76
Cynodon hirsutus	7.66	6.91	11.76	8.77
Themeda triandra	7.38	14.01	12.18	11.19
Tragus berteronianus	19.07	4.89	0.60	8.19
RDNH	**03-04**	**04-05**	**05-06**	**Ave**
Digitaria eriantha	27.01	38.61	44.42	36.68
Eragrostis lehmanniana	14.53	23.02	27.45	21.67
Tragus berteronianus	29.88	17.50	1.24	16.21
Aristida congesta	8.83	6.59	6.73	7.38
Themeda triandra	2.07	7.59	13.12	7.59
Urochloa panicoides	12.81	0.63	0.00	4.48
RDWH	**03-04**	**04-05**	**05-06**	**Ave**
Digitaria eriantha	17.45	30.63	41.08	29.72
Eragrostis lehmanniana	11.09	31.20	29.46	23.92
Tragus berteronianus	36.19	12.82	1.21	16.74
Aristida congesta	11.86	14.31	15.42	13.87
Urochloa panicoides	16.94	0.84	0.00	5.93
Chloris virgata	3.70	7.04	3.04	4.59

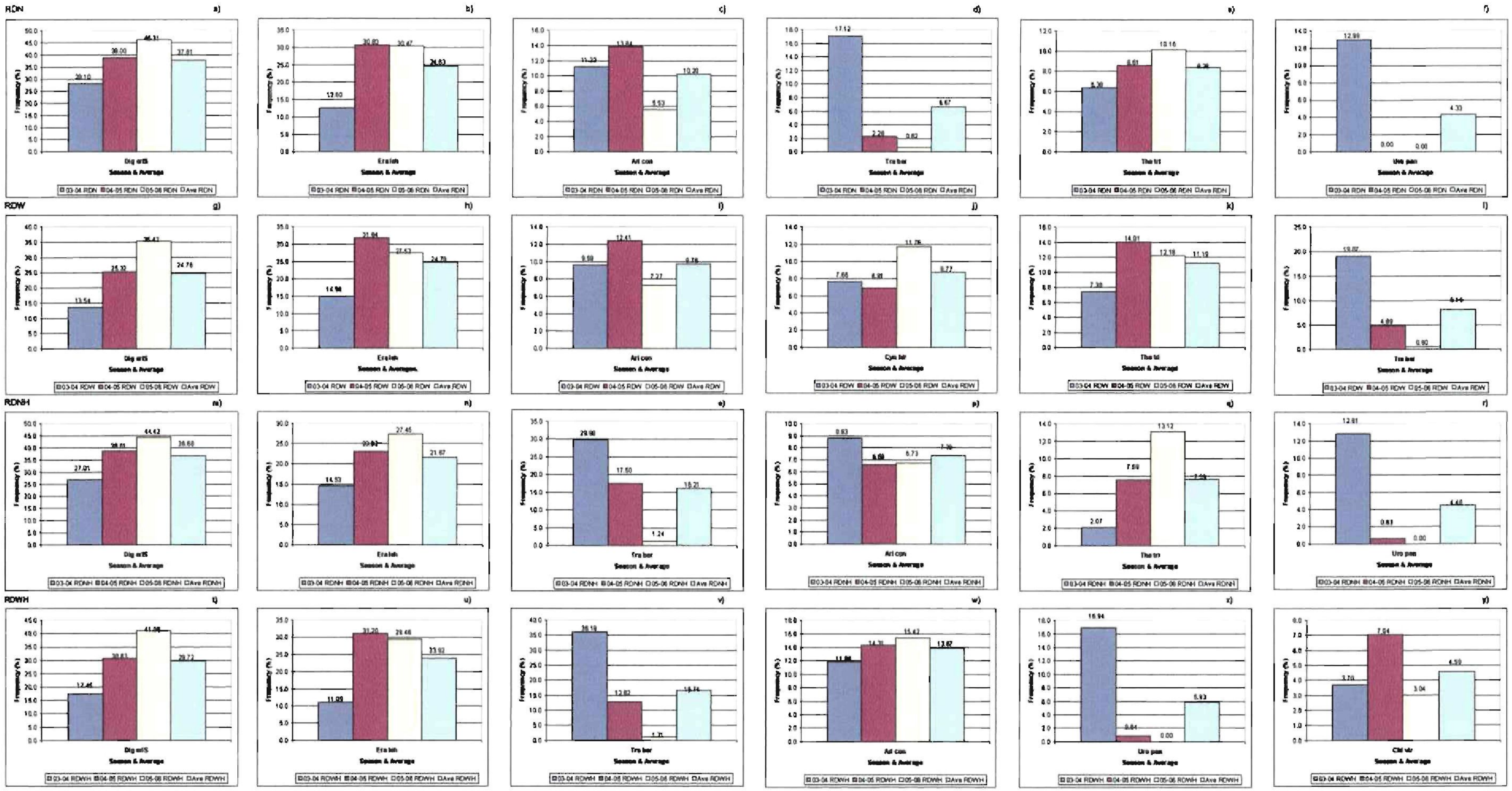

Figure 4.8 The species frequency (%) for the rip, the re-seeding with *Digitaria eriantha* seed restoration technology (RD) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

7) Conventional cultivated *Digitaria eriantha* pasture restoration technology (P)

- The grass species

The species germination of the *Digitaria eriantha* seeds was poor, in the conventionally cultivated pasture seedbed. Other species such as *Tragus berteronianus, Aristida congesta, Urochloa panicoides, Eragrostis lehmanniana* and *Chloris virgata* had higher species abundance values as the re-seeded *Digitaria eriantha* species (Table 4.23 and Figure 4.9), the presents of the other species in this restorations technologies, could be attributed to the soil seed bank.

The species abundance value of the re-seeded *Digitaria eriantha* was slightly higher for the restoration technologies, where Roundup was used than those where no Roundup was applied and it increased over the three seasons (0% to 5.07% and 0.87% to 7.37%) (Table 4.23 and Figure 4.9a and g). The poor results of this restoration technology were already discussed in section 4.5 (IV) section 7. It could be attributed to the poor germination rate of the *Digitaria eriantha* seed used in this restoration trial that was only 19% and contained 79% dead seeds in the seed batch (Table 4.3). When the soil seedbed was prepared the soil dried out, because of the complete removal of all vegetation and the fine particular size of the soil granules.

Tragus berteronianus occurred only in the conventional cultivated *Digitaria eriantha* restoration trial, where no Roundup was used. The species abundance value increased from the 2003/04 to the 2004/05 season from 26.6% to 45.63% and decreased in the 2005/06 season to 14.05%, due to the fact that this is an annual species (Table 4.23 and Figure 4.9b).

Aristida congesta ranked the second most important species for the no-Roundup restoration technologies and third in the Roundup restoration technologies. The species abundance of this species increased over the three seasons from 3.77% to 49.1% and 1.47% to 27.22%, respectively for P and PH and its average species abundance was higher for the no-Roundup restoration technologies than the one where Roundup was used (27.23% and 11.62%, respectively) (Table 4.23 and Figure 4.9c and j).

Urochloa panicoides occurred in both the roundup and the no-Roundup treatments and its frequency value decreased from the 2003/04 to the 2005/06 season from 67.11% to 1.63% for P and it increased from 03% to 1.88% for PH (Table 4.23 and Figure 4.9 d and l). There was no clear explanation for this trend, but it could be attributed to the soil seed bank of the soil and the fact that this is an annual grass species.

The species abundance of *Eragrostis lehmanniana* increased over the three seasons from 0.61% to 11.12% and 1.99% to 26.07% for P and PH, respectively. The average species abundance value was lower for P (6.4%) than PH (12.36%) (Table 4.23 and Figure 4.9 e and j). This could be due to the high species abundance value of this species in the trial site, before any restoration technologies were applied (Table 4.5).

Chloris virgata occurred in both of these restoration technologies and its frequency values increased for P from 0.32% to 8.36% and decreased for PH from 56.68% to 2.44% over the three seasons. The average frequency value for *Chloris virgata* was lower for P than PH despite the fact that the frequency value increased for P and decreased for PH over the three seasons, due to the high frequency value for PH in the 2003/04 season. This is an annual species and this could explain its frequency value change (Table 4.23 and Figure 4.9f and h).

Themeda triandra only occurred in PH, due to the fact that it did occur in the trial site before any restoration technologies were applied (Table 4.5 and 4.23 and Figure 4.9k).

- <u>Comparison between the two herbicide applications of the conventional cultivated *Digitaria eriantha* pasture restoration technologies</u>

The grass species composition of both the no-Roundup and Roundup conventional cultivated *Digitaria eriantha* pasture restoration technologies were characterized by high abundance values for the annual grass species, such as *Aristida congesta* (27.23% and 11.62%), *Tragus berteronianus* (28.86%) and *Urochloa panicoides* (24.05% and 1%).

Table 4.23 The frequency of species (%) in the conventional *Digitaria eriantha* pastures per season and the average for the 3 seasons for this restoration technology (Appendix A: abbreviations).

P	03-04	04-05	05-06	Ave
Digitaria eriantha	0.00	2.55	5.07	2.54
Tragus berteronianus	26.90	45.63	14.05	28.86
Aristida congesta	3.77	28.83	49.10	27.23
Urochloa panicoides	67.11	3.42	1.63	24.05
Eragrostis lehmanniana	0.61	7.47	11.12	6.40
Chloris virgata	0.32	7.57	8.36	5.42
PH	**03-04**	**04-05**	**05-06**	**Ave**
Digitaria eriantha	0.87	2.41	7.37	3.55
Urochloa panicoides	56.68	8.99	2.44	22.71
Chloris virgata	1.99	9.00	26.07	12.36
Aristida congesta	1.47	6.16	27.22	11.62
Eragrostis lehmanniana	0.90	6.19	4.05	3.71
Themeda triandra	0.30	0.82	1.88	1.00

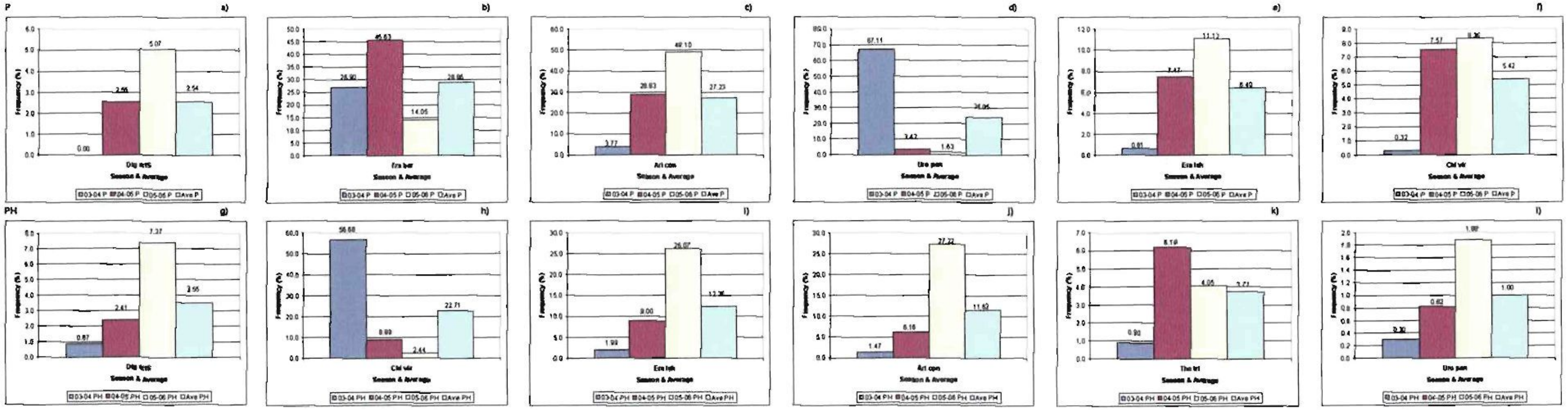

Figure 4.9 The species frequency (%) for the establishment of conventional cultivated *Digitaria eriantha* pastures restoration technology (P) of the five most important grass species for each restoration technology, per season and the average of the 3 seasons (Appendix A for the abbreviations used in this Figure).

4.5.3 Comparison between the different restoration technologies in terms of the frequency data

1) Natural occurring species

Eragrostis lehmanniana occurred in all the restoration technologies. The species abundance of *Eragrostis lehmanniana* increased over the three seasons. It was the most important naturally occurring species in all the restoration technology trials, except in the conventionally cultivated pasture trial where it was ranked second and fourth in the no-Roundup and Roundup restoration technologies respectively. The species abundance of this species increased sharply in the first season and then stabilised in the third season. In some cases, such as the rip and the re-seeded restoration technologies, the species abundance value of this grass species declined in the third season. This suggested that *Eragrostis lehmanniana* is a poor competitor with other grasses, especially when other perennial grass species such as *Themeda triandra* and *Digitaria eriantha* form part of the re-seeding mixture. The latter two grass species increased over the three seasons and might out-compete *Eragrostis lehmanniana* over time.

Aristida congesta occurred in all the restoration technologies, applied in this trial. It was the second most important species in all the no-Roundup and the third most important species in the Roundup restoration technologies. This species abundance increased drastically in the first season and then decreased in the third season in all the trials. The species abundance of *Aristida congesta* decreased in both the combination of restoration trials where a seed mixture was re-seeded. The species abundance of *Aristida congesta* decreased in the rip and re-seeded with *Digitaria eriantha* seed restoration trials, except for the 1.5m Roundup restoration technologies, where it increased. It also increased in the conventionally cultivated *Digitaria eriantha* pasture restoration technologies.

The species abundance of *Themeda triandra* that occurred naturally in the restoration technologies increased over the three season period, for all the restoration technologies where it was present.

In all the restoration technology trials where *Cynodon hirsutus* occurred, the grass species abundance increased, except for the 0.75m row spacing of the rip, re-seeded with a seed mixture and organic material application, where it decreased. This grass species formed natural patches, before any restoration technologies were applied. It was ranked between the third and fifth most important naturally occurring species in the combination of restoration technologies.

Tragus berteronianus occurred in nearly all the restoration technologies where this species decreased, except for the rip restoration technology where it increased when Roundup was applied. In the cultivated pasture restoration technologies it initially increased from 2003/04 to the 2004/05 season and decreased drastically in the 2005/06 season.

The species abundance for *Urochloa panicoides* decreased in all the restoration technologies and it did not occur in the control restoration technology at all.

Chloris virgata occurred in nearly all the restoration technologies as the fourth and fifth most important species.

The occurrence of *Themeda triandra, Cynodon hirsutus, Urochloa panicoides* and *Chloris virgata* occurred in patches over the study site and this could explain why these species only occurred in some of the restoration technologies (Appendix B: Table B13 and B14 for the detailed trial layout plan, with the percentage frequency for each species of the first season).

2) Re-seeded grass species

In all the restoration technologies where *Digitaria eriantha* was re-seeded as part of a seed mixture, it always ranked the second most important re-seeded grass species and its abundance increased over the three seasons from 2003/04 to 2005/06. In the restoration technologies where only *Digitaria eriantha* was re-seeded it was ranked the second most important species, except in the Roundup application technologies where it was ranked as the most important species. The species abundance of *Digitaria eriantha* also increased in these restoration technologies over the three seasons.

In the trials where seed was re-seeded *Themeda triandra* was ranked as the most important species in all the restoration technology trials, except for the narrow (0.75m) no Roundup application it was ranked as the second most important species. The species abundance of *Themeda triandra* increased over the three seasons in most of these restoration technologies.

Eragrostis curvula was ranked the third most important species in all the restoration technology trials when a seed mixture was used. The species abundance decreased from the first to the second season and increased in the third season, except for the 0.75m no-Roundup and Roundup, and the 1.5m row spacing Roundup restoration technologies where it decreased, without the application of organic material. Where organic material was applied, the species abundance decreased only for the 1.5m row spacing, for the Roundup restoration technologies, over the three seasons. In all the other restoration technology trials, the species abundance increased in the third season after it decreased from season one to season two.

The species abundance for *Cenchrus cilliaris* increased for most of the restoration technologies where it was re-seeded as part of a seed mixture. It was ranked the fourth most important re-seeded grass species. Although it was ranked fourth, its role in the overall species composition was very small, with a low importance value.

The species abundance of *Cymbopogon excavatus* fluctuated over the three season period, depending on the restoration technologies where it was re-seeded as part of a seed mixture. This species was ranked the fifth most important re-seeded grass species, the lowest of all ranked species for all the restoration technologies.

The increase and fluctuation in the species abundance of both *Cenchrus cilliaris* and *Cymbopogon excavatus* species was low and insignificant to really play an important role in the improvement of the overall species composition of the plant community.

3) Comparison between the grass species of the different restoration technologies

In all the restoration technologies where a seed mixture was used to re-seed grass species, the species abundance of the re-seeded grass species increased over the three seasons. Only *Themeda triandra*, *Digitaria eriantha* and *Eragrostis curvula* showed increases in their species abundance. The reason why only these species occurred in these restoration technology plots could be attributed to its high purity and germination percentages (Table 4.2 and 4.3).

The application of organic material benefited the re-seeded grass species initially and helped with the establishment of the seedlings. The reason for the poor effect of the organic material, over a longer period could be attributed to the fact that the cow dung was collected from a dairy. Because of the cow dung was washed out of the dairy, with lots of water, resulted in the loss of nutrients, due to the leaching of the cow dung.

The species abundance of the re-seeded grass species was higher for the no-Roundup applied restoration technologies, than the species abundance of the Roundup restoration technologies, due to the fact that the presents of the other species created a more suitable micro climate for the seedlings of the re-seeded grass species to germinate and establish.

The re-seeding of *Digitaria eriantha* in the conventional *Digitaria eriantha* pasture restoration technologies was not successful. The species abundance value of this grass species was very low and insignificant. There were also no differences between the no-Roundup and Roundup restoration technologies.

The Roundup restoration technologies benefited the species abundance of the annual natural occurring grass species more than the no-Roundup technologies. The rip restoration technologies benefited both perennial and annuals grass species. The species abundance of some grass species, such as *Urochloa panicoides* and *Tragus berteronianus* decreased over the three seasons.

4.6 Comparison between the restoration technologies

4.6.1 Multivariate analysis

Two types of statistical analyses were used to compare the different restoration technologies regarding the two row spacings, ie. narrow (0.75m) and wide (1.5m) rows. These included Multivariate data analyses and ANOVA.

The results of the multivariate vegetation data analysis, using Principal Correspondence Analyses (PCA) techniques in the CANOCO statistical computer program are given in the following section (Ter Braak, 1987; Ter Braak, 1988 and Ter Braak and Verdonschod, 1992). All the graphs shown in this chapter are bi-plots of the PCA ordination. The ordination graphs are used to correlate the restoration technologies and average frequency of the grass species (re-seeded and natural) for all three seasons with each other.

1) Narrow row spacing (0.75m) and the no-Roundup restoration technologies

There is a large difference where grasses were re-seeded and all the other restoration trials as shown by the x-axis (Eigen value: 0.553). A higher correlation between the non-seeded plots exists as shown by the y-axis (Eigen value: 0.274). The rip treatment had a positive affect on the establishment and growth of new and existing perennial species.

In this PCA ordination bi-plot a positive strong correlation between the re-seeded grass species and the restoration technologies where a seed mixture is used, is shown on the X-axis (Eigen value: 0.553) (Figure 4.10). The natural occurring grass species are correlated with the control (CN) and the rip (RN) and rip and application of organic material restoration technologies (RON), such as *Heteropogon contortus* (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) (Figure 4.10). A positive correlation also exists between the annual species (*Aristida congesta* (*Ari con*), *Tragus berteronianus* (*Tra* ber) and *Urochloa panicoides* (*Uro pan*)) and the conventional *Digitaria eriantha* (*Dig eriS*) cultivated pasture restoration technologies (P). This means that little or no *Digitaria eriantha* (*Dig eriS*) or other perennials species occurred in these plots over the three seasons sampling period (Also see Table 4.23). This is in correlation with the frequency data, as discussed in section 4.5.2 (p 112). The perennial grass species are found in all the rip restoration technologies. The occurrence of *Digitaria eriantha* (*Dig eriS*) was the highest in the restoration technologies where it was re-seed, together with a rip restoration application.

It is therefore evident that the re-seeded species dominated in the seeded plots and no other annual or perennial natural occurring grass species. The positive effect of the re-seeding application is herby explained.

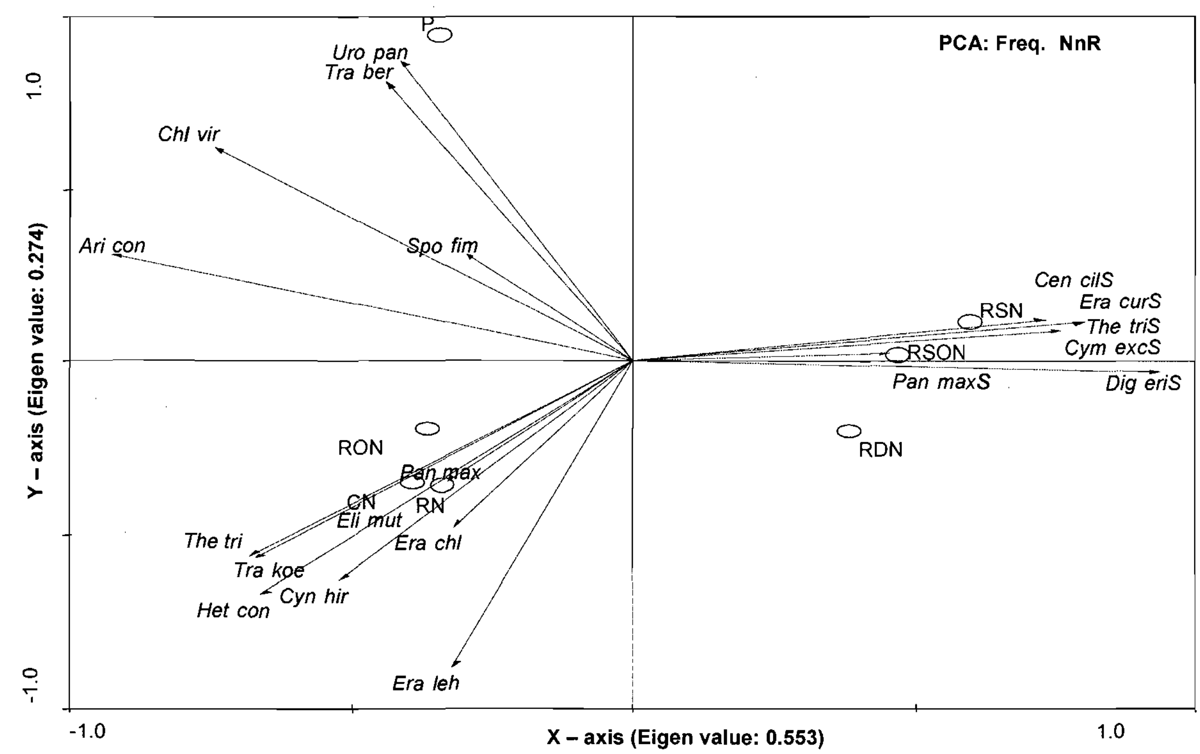

Figure 4.10 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three season of the natural occurring and re-seeded grass species of the 0.75m row spacing, no-Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

2) Narrow row spacing (0.75m) and the Roundup restoration technologies

Similar results as for the no-Roundup application were observed. As for the previous restoration technologies a positive correlation between the re-seeded species and their respective restoration technologies are shown on the X-axis (Eigen value: 0.592) (Figure 4.11). The annual species dominated in the conventional *Digitaria eriantha* cultivated pasture restoration technology (PH) and the perennial naturally occurring species, such as *Heteropogon contortus* (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*), *Aristida congesta (Ari con*) and *Eragrostis lehmanniana* (*Era leh*) had a positive correlation with the control (CNH), rip (RN) and rip and the application of organic material restoration technologies (RONH). *Cynodon hirsutus* (*Cyn hir*) is associated more with the re-seeded restoration technologies, however not so strong. This can be attributed to the fact that *Cynodon hirsutus* (*Cyn hir*) already occurred in these plots before the restoration trials were started (Table 4.6).

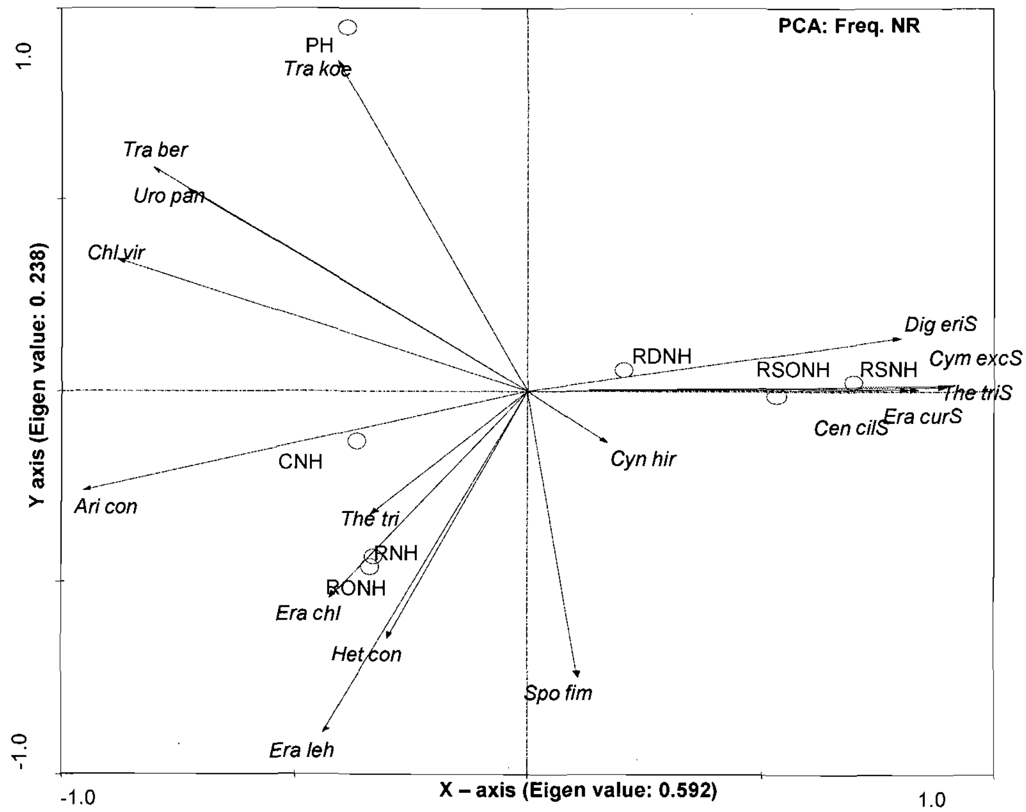

Figure 4.11 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 0.75m row spacing, Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

3) Wide row spacing (1.5m) and the no-Roundup restoration technologies

A very strong positive correlation on the X-axis (Eigen value: 0.778) exists between the re-seeded grass species in all the re-seeded restoration technologies, on the right-hand side of the X-axis and the naturally occurring species and the non-seeded species on the left-hand side of the x-axis (Figure 4.12). The correlation between the *Digitaria eriantha* re-seeded (*Dig eriS*)

(RDW) and the other seed mixture re-seeded trials was however not so strong (RSW and RSOW). *Panicum maximum (Pan max)* that occurred naturally in the plots before was positive correlated with the rip and re-seeding with *Digitaria eriantha* (*Dig eriS*) seed restoration technology (RDW). There was a strong positive correlation between both the annual and perennial naturally occurring species and the non-seeded restoration technologies (CW and RW) (Figure 4.12).

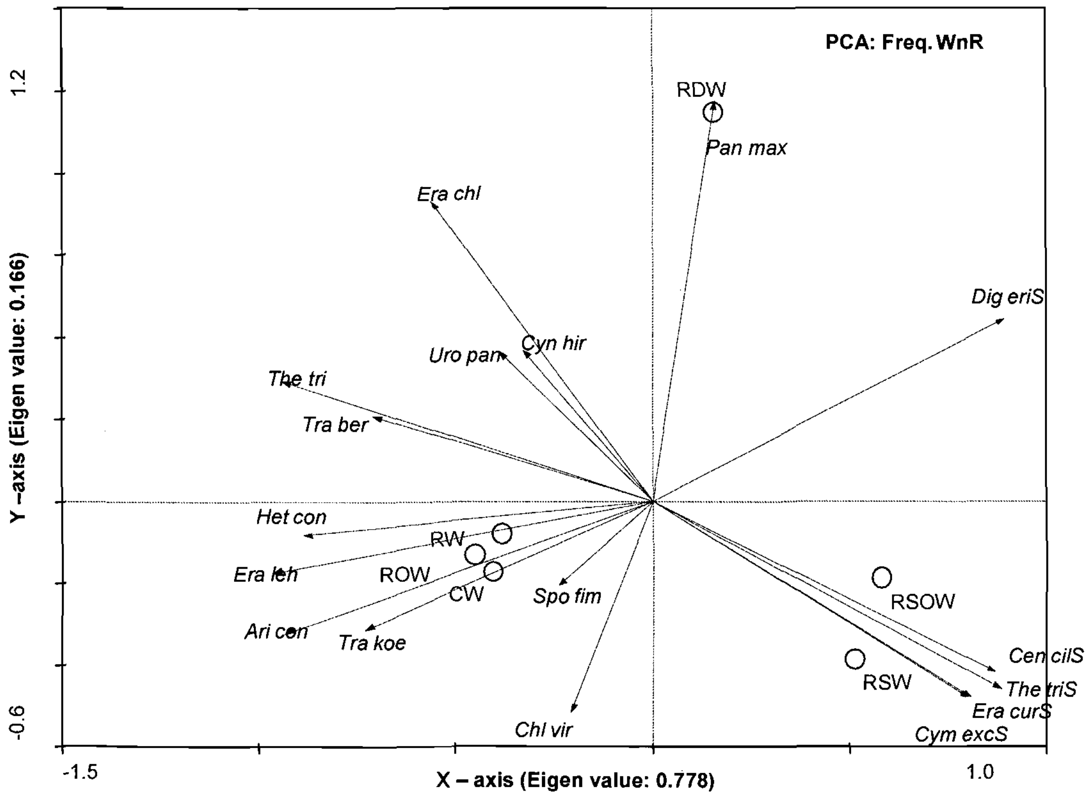

Figure 4.12 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 1.5m row spacing, no-Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

4) Wide row spacing (1.5m) and the Roundup restoration technologies

The same tendency as previous can be observed in this graph (Figure 4.13). There was a very strong positive correlation between the re-seeded grass species on the right hand side of the X-axis in the re-seeded restoration technologies (RSWH and RSOWH) and the naturally occurring species and the non-seeded restoration technologies (RWH) on the left hand side of this axis (Eigen value: 0.817). As before the correlation between the rip and *Digitaria eriantha* (*Dig eriS*) re-seeded restoration technology was not so positive with all the other re-seeded restoration treatments. Both the naturally occurring annual and perennial species, such as *Heteropogon* contortus (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) were positively correlated with the control (CW), rip (RW) and rip and the application of organic material (ROW) restoration technologies (Figure 4.13).

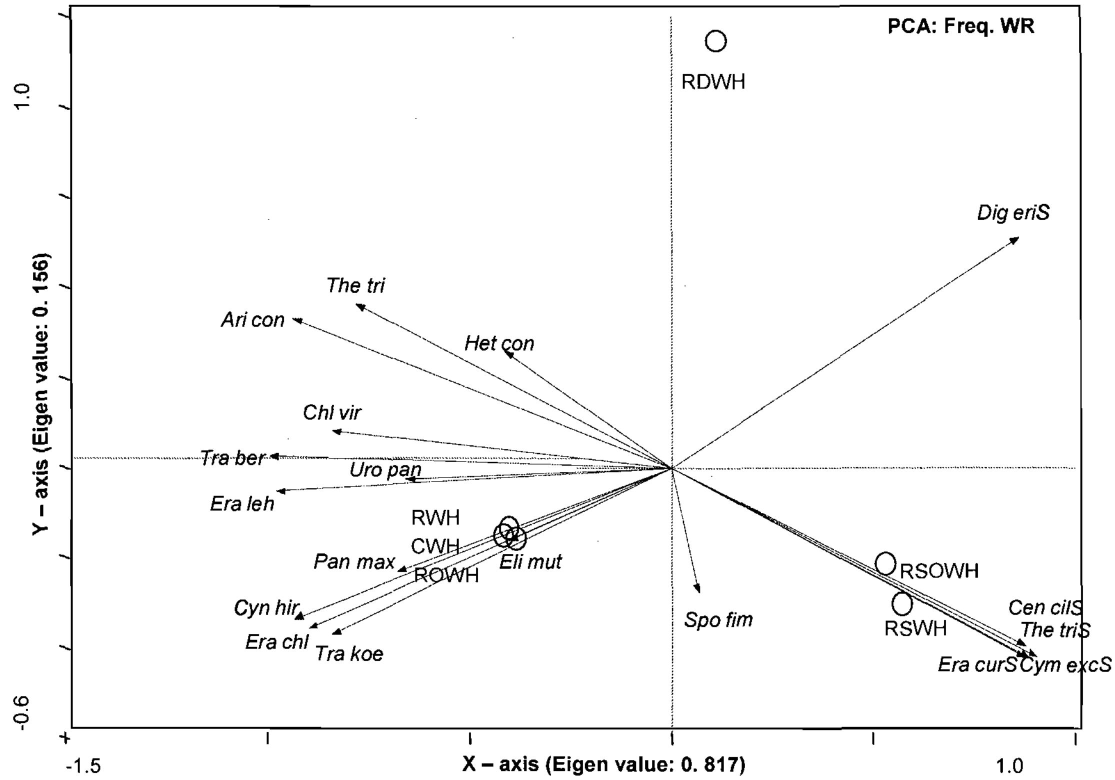

Figure 4.13 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 1.5m row spacing, Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

5) Narrow (0.75m) row spacing: no-Roundup vs. Roundup restoration technologies

On the X-axis (Eigen value: 0.515) a strong positive correlation between the re-seeded grass species and all the re-seeding restoration technologies for both the no-Roundup and Roundup restoration technologies are shown (Figure 4.14). Natural occurring perennial grass species were better correlated to the no-Roundup restoration technologies for both the rip (RN) and the rip and the application of organic material (RON) restoration technologies, to the left of the x-axis. Perennial grass species, such as *Heteropogon contortus* (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) were more positively correlated to the Roundup application restoration technologies. The Roundup application could have a negative affect on the perennial grasses over the three seasons. Only the annual grass species correlated with the conventional cultivated *Digitaria eriantha* (*Dig eriS*) pasture restoration technologies for both the no-Roundup and Roundup restoration technologies (Figure 4.14).

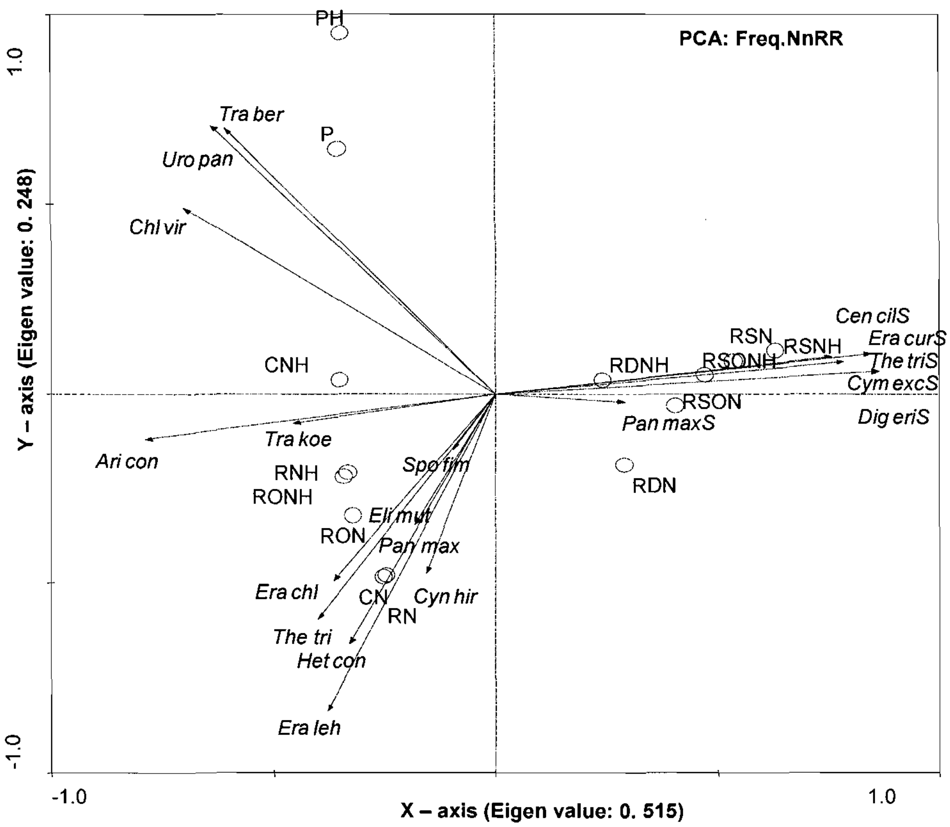

Figure 4.14 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 0.75m row spacing, showing the comparison between the no-Roundup and Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

6) Wide (1.5m) row spacing: no-Roundup vs. Roundup restoration technologies

As for the previous description the X-axis showed strong positive correlation between the re-seeded restoration technologies (RSN, RSNH, RSW, RSWH, RSON, RSONH, RSOW, RSOWH and RDN, RDNH, RDW and RDWH) and the re-seeded grass species (Eigen value: 0, 682) (Figure 4.15). As for the narrow row spacing the re-seeded grass species, such as *Themeda triandra* (*The triS*), *Digitaria eriantha* (*Dig eriS*) and *Eragrostis curvula* (*Era curS*) correlated positively with the re-seeding restoration technologies (RSW, RSWH, RSOW and RSOWH), for both the no-Roundup and Roundup restoration technologies, except for *Elionurus muticus* (*Eli mut*) and the annual grass species, such as *Tragus berteronianus* (Tra ber) and *Chloris virgata* (*Chl vir*) correlated with the Roundup restoration technologies. Most of the natural occurring perennial grass species were better correlated with the no-Roundup restoration technologies (Figure 4.15).

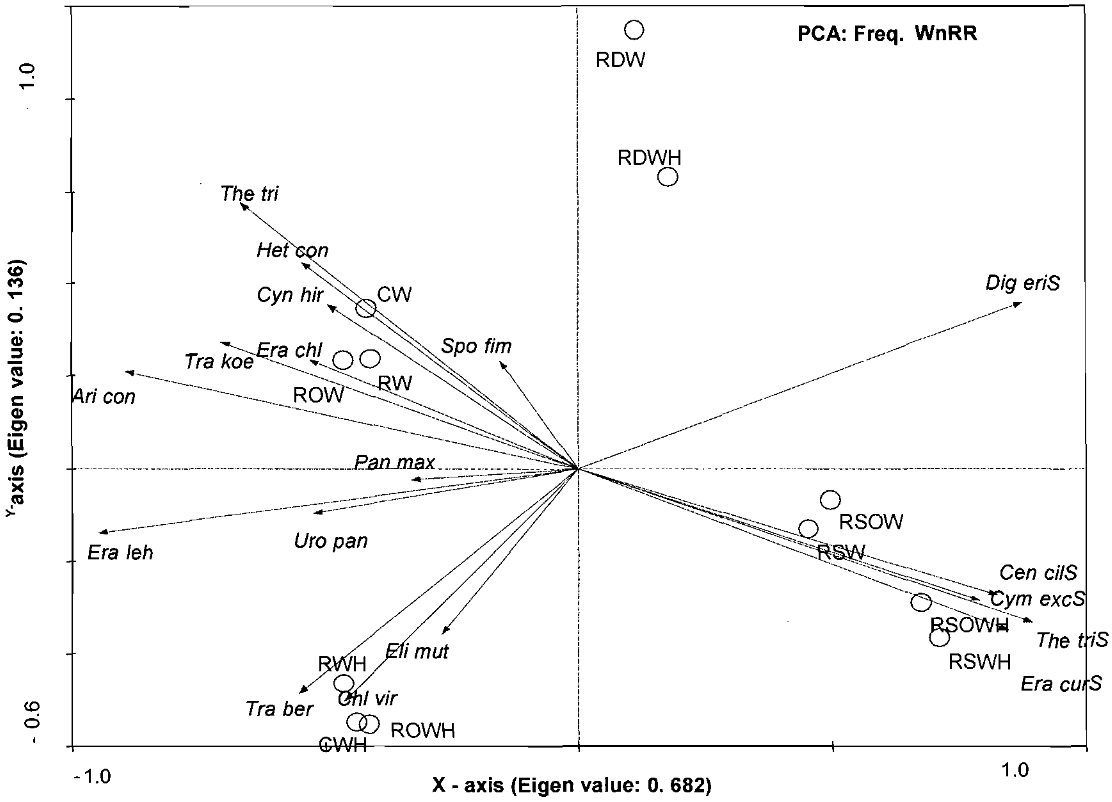

Figure 4.15 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 1.5m row spacing, showing the comparison between the no-Roundup and Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

7) Narrow (0.75m) and wide (1.5m) row spacing with the no-Roundup restoration technologies

No clear distinction could be made between the narrow and wide row spacings for the re-seeded restoration technologies (RSN, RSW, RON and ROW) (Figure 4.16). All the re-seeded grass species, such as *Themeda triandra* (*The triS*), *Digitaria eriantha* (*Dig eriS*) and *Eragrostis curvula* (*Era curS*) correlated positively with the restoration technologies where re-seeding was done (RSN, RSW, RON and ROW), as shown by the grouping on the right hand side of the X-axis (Eigen value: 0.601) (Figure 4.16). Both natural occurring annual and perennial grass species, such as *Tragus berteronianus* (*Tra ber*), *Chloris virgata* (*Chl vir*), *Heteropogon contortus* (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) occurred in the wide and narrow no-Roundup restoration technologies. Annual grass species, such as *Tragus berteronianus* and *Urochloa panicoides* were more positively correlated to the conventional cultivated *Digitaria eriantha* pasture restoration technologies (Figure 4.16), explaining why *Digitaria eriantha* (*Dig eriS*) did not establish in these plots.

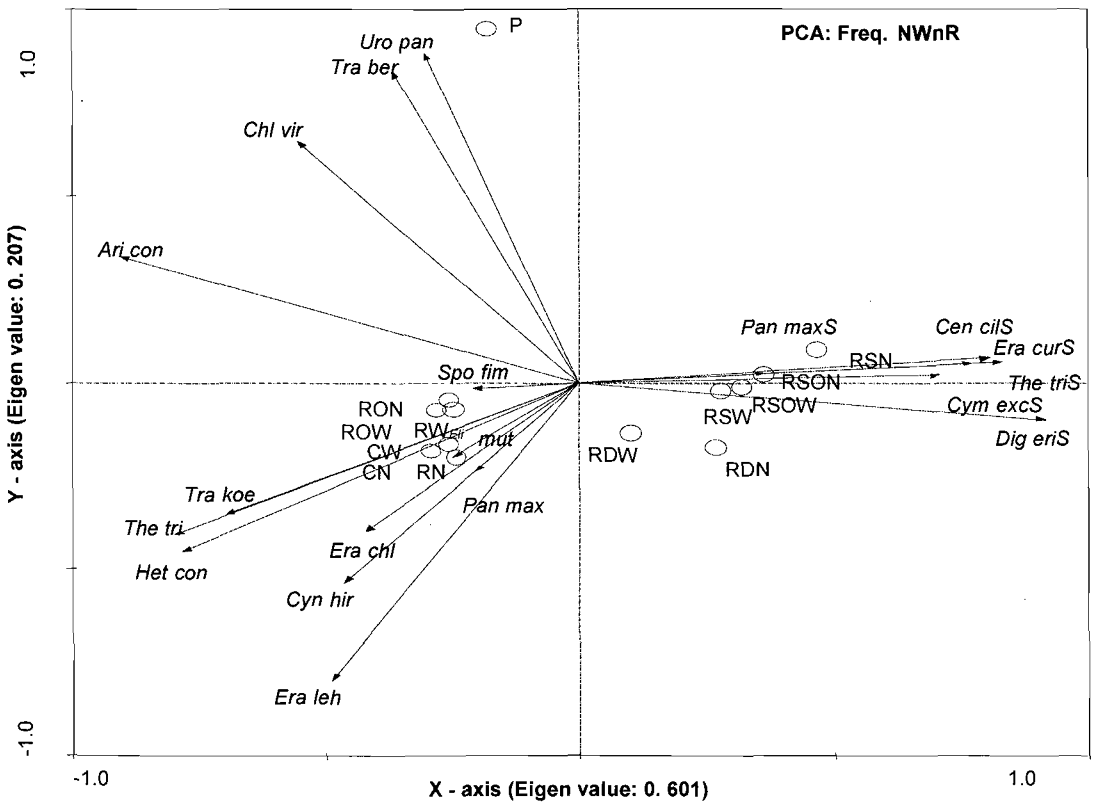

Figure 4.16 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 0.75m and the 1.5m row spacing, showing the comparison between the no-Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

8) Narrow (0.75m) and wide (1.5m) row spacing with Roundup restoration technologies

The same tendency occurred in these restoration technologies as for the no-Roundup restoration technologies. No clear distinction could be made between the narrow and wide row spacings for the re-seeded restoration applications. All the re-seeded grass species, such as *Themeda triandra* (*The triS*), *Digitaria eriantha* (*Dig eriS*) and *Eragrostis curvula* (*Era curS*) correlated positively with the restoration technologies where re-seeding was done (RSNH, RSWH, RSONH and RSOWH), as shown by the grouping on the right hand side of the X-axis (Eigen value: 0.651) (Figure 4.17). Both natural occurring annual and perennial grass species such as *Tragus berteronianus* (*Tra ber*), *Chloris virgata* (*Chl vir*), *Heteropogon contortus* (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) occurred in the wide and narrow Roundup restoration technologies. Annual grass species, such as *Tragus berteronianus* (*Tra ber*) and *Urochloa panicoides (Uro* pan) were more correlated to the conventional cultivated *Digitaria eriantha* pasture restoration technologies (PH) (Figure 4.17).

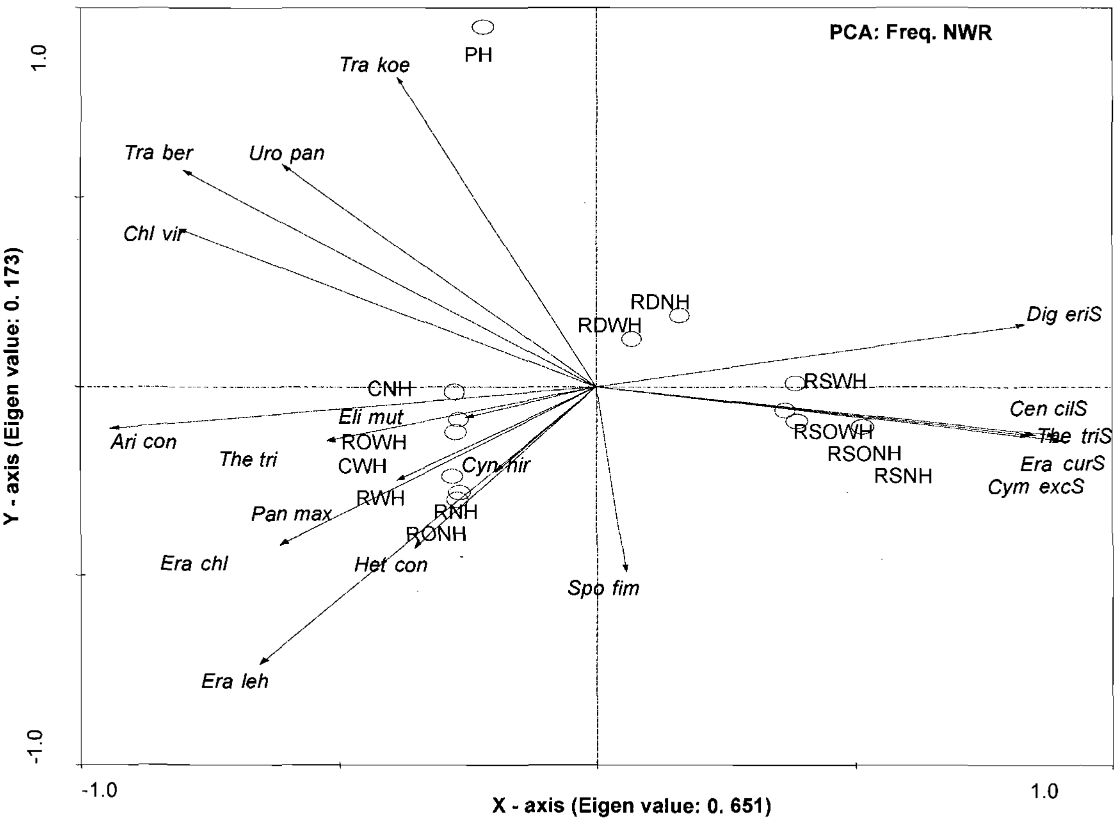

Figure 4.17 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 0.75m and the 1.5m row spacing, showing the comparison between the no-Roundup and Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

9) Narrow (0.75m) and wide (1.5m) row spacing with the no-Roundup and Roundup restoration technologies

All the re-seeded grass species, such as *Themeda triandra* (*The triS*), *Digitaria eriantha (Dig eriS)* and *Eragrostis curvula* (*Era curS*) and the respective re-seeding restoration technologies (RSN, RSW, RSNH, RSWH, RSON, RSONH, RSOW, RSOWH, RDN, RDW, RDNH and RDWH) were positive correlated with each other on the X-axis for both the narrow and wide row spacings, The naturally occurring annual and perennial grass species such as *Tragus berteronianus* (*Tra ber*), *Chloris virgata* (*Chl vir*), *Heteropogon contortus* (*Het con*), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) and the respective non-seeded restoration technologies (CN, CNH, CW, CWH, R, RH RON, ROW, ROW, RONH and ROWH) were also positively correlated to the left of the x-axis (Eigen value: 0.559) (Figure 4.18). The annual naturally occurring species, such as *Tragus berteronianus* (*Tra ber*) and *Urochloa panicoides* (*Uro koe*) were again strongly positive correlated with the conventional cultivated *Digitaria eriantha* pasture restoration technologies (P and PH). The naturally occurring perennial grass species, such as *Heteropogon contortus* (Het con), *Tragus koeleriodes* (*Tra koe*), *Eragrostis chloromelas* (*Era chl*) and *Eragrostis lehmanniana* (*Era leh*) were positively correlated with the control (CN, CNH, CW and CWH), rip (RN, RNH, RW and RWH) and rip and the application of organic material restoration (RON, RONH, ROW and ROWH) technologies (Figure 4.18).

These positive correlations between the applied restoration technologies and its corresponding grass species indicate that most of the restoration technologies were a success, except for the conventional cultivated *Digitaria eriantha* pasture restoration technologies (P and PH).

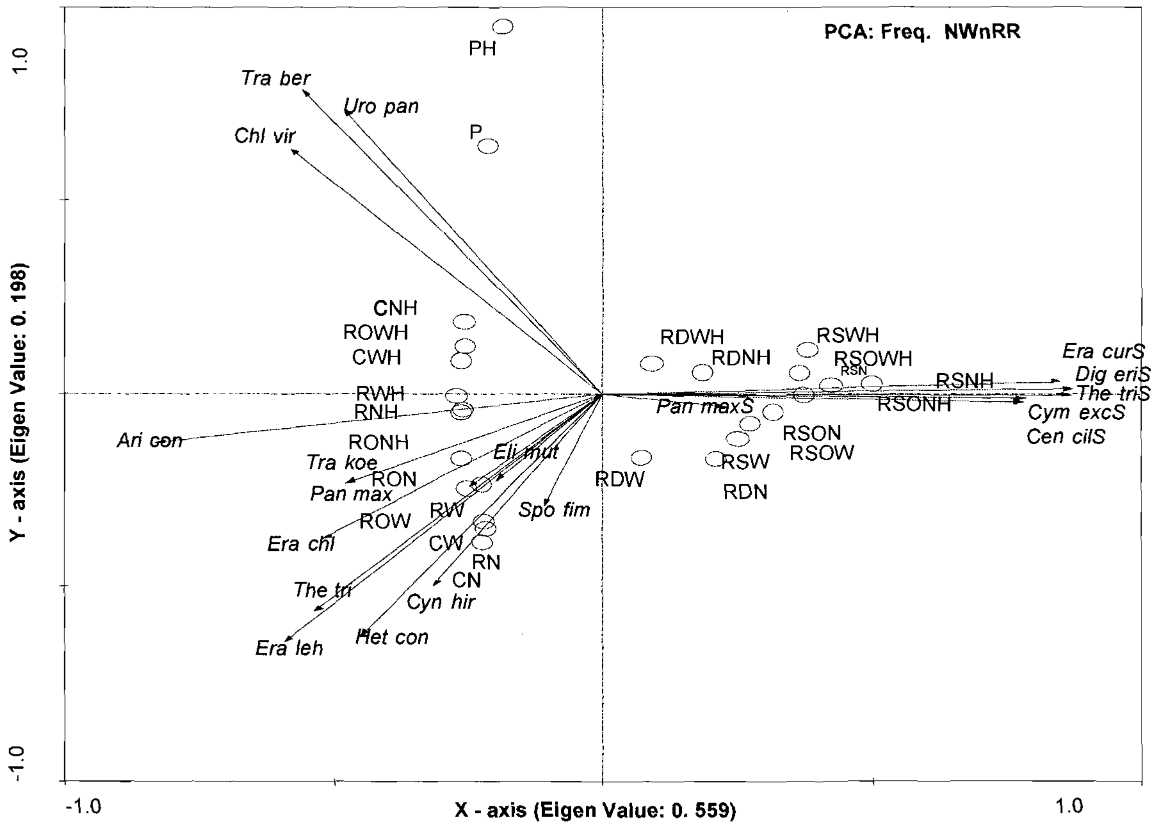

Figure 4.18 Principle Component Analyses (PCA) bi-plot of the average species frequency values for the three seasons of the natural occurring and re-seeded grass species of the 0.75m and the 1.5m row spacing, showing the comparison between the no-Roundup and Roundup restoration technologies (Appendix A for the abbreviations of the species and restoration technologies).

4.6.2 Analyses of variance (ANOVA) results

As explained in Chapter 3, Materials and Methods the trial was designed as a randomised complete block design with the following restoration technologies: the control restoration technologies (C), rip restoration technologies (R); rip and the application of organic material restoration technologies (RO); rip and the re-seeded of a seed mixture restoration technologies (RS); rip, the application of organic material and the re-seeded with a seed mixture restoration technologies (RSO); rip and the re-seeded with only *Digitaria eriantha* seed restoration technologies (RD) and the planting of conventional cultivated *Digitaria eriantha* pasture restoration technologies (P). All these restoration technologies were replicated three times and in two row spacings (0.75 and 1.5m rows), except the cultivated pasture restoration a technology which was re-seeded in 1.0m rows. The whole trial was replicated with no-Roundup and Roundup application. This gave a total of 13 restoration technologies per season and trial (no-Roundup and Roundup). Analysis of variance (ANOVA) was used to test for differences between the 13 restoration technologies per season and per restoration technology. The data was not normally distributed and with heterogeneous restoration technologies variances. Therefore the data was transformed using the square-root transformation (sqrt(x+0.5) to stabilise variances. The means of the restoration technologies were separated using Fishers' protected t-test least significant difference (LSD) at the 1% level of significance (Snedecor and Cochran, 1980), as restoration technologies variances were still heterogeneous in spite of the transformations.

It had to be emphasised that the last season of the trial (2005/06) gave a better indication of what species composition could be expected over the longer term after the application of certain restoration technologies.

1) Frequency data analyses of the re-seeded grass species for the no-Roundup restoration technologies

The different restoration technologies were group together according to the LSD of each of them. The f-probability (F prob.) value of less than 0.001 indicates the high significance of the data. The least significance value for these restoration technologies was on average 1.681, with a percentage coefficient value (CV %) of 20.233. The standard error of means for these restoration technologies was 0.425 on average over the three growing seasons (Table 4.24).

The restoration technologies where grouped according to the total value of the re-seeded grass species for the no Roundup applications, into the followings groups: group 1: RSN, group 2: RSON, RSOW and RSW, group 3: RDN, group 4: RDW and group 5: P, RN, RON, CN, RW, ROW and CW. The restoration technologies grouped together according to the combination of restoration technologies that was used in it and the row spacing, for example the rip, re-seeded and the application of organic material treatment (RSOW) and the rip and re-seeded treatments (RSW) for the wide row spacing, grouped together. There was a difference, although not significant, between narrow and wide row spacings as shown by the fact that the two row spacings were grouped together. RSN (Group 1) differed significantly from RSON, RSOW and RSW (group 2) and the two row spacings of RD (RDN and RDW) (group 3 and 4). The re-seeded restoration technologies did differ significantly from the other non-seeded technologies. The conventionally cultivated *Digitaria eriantha* pasture and the non-seeded restoration applications (P, RN, RON, CN, RW, ROW and CW) (group 5) did differ significantly from Groups 1 to 4. The reason why the conventionally cultivated *Digitaria eriantha* pasture restoration technology grouped together with the non-seeded technologies could be attributed to the fact that the germination rate and the species abundance of the re-seeded *Digitaria eriantha* were low. The species composition of this treatment was characterized by the presence of other, mainly annual grass species.

Table 4.24 The mean frequency value of the re-seeded grass species data over the three seasons of the no-Roundup restoration technologies (Appendix A for the abbreviations of the terms and restoration technologies).

Rest. Techn.	2003/2004			2004/2005			2005/2006		
	Mn	SD	Vr.	Mn	SD	Vr.	Mn	SD	Vr.
RSN	7.977	a	0.797	9.083	a	1.487	9.02	a	0.198
RSON	6.389	ab	3.025	7.958	ab	0.253	8.123	ab	0.775
RSOW	5.56	bc	2.380	7.895	ab	1.263	8.894	ab	0.586
RSW	6.124	ab	4.495	7.418	b	0.217	8.364	ab	0.817
RDN	5.541	bc	1.690	6.879	bc	0.776	7.435	bc	2.836
RDW	3.927	c	0.119	5.545	c	0.634	6.202	c	2.054
P	0.707	d	0.000	1.709	d	0.868	2.404	d	0.579
RN	0.707	d	0.000	0.707	d	0.000	0.707	d	0.000
RON	0.707	d	0.000	0.707	d	0.000	0.707	d	0.000
CN	0.707	d	0.000	0.707	d	0.000	0.707	d	0.000
RW	0.707	d	0.000	0.707	bc	0.000	0.707	d	0.000
ROW	0.707	d	0.000	0.707	d	0.000	0.707	d	0.000
CW	0.707	d	0.000	0.707	d	0.000	0.707	d	0.000
SEM	0.484			0.391			0.401		
F prob	<0.001			<0.001			<0.001		
LSD (1%)	1.914			1.546			1.584		
CV %	26.90			17.30			16.50		

2) Frequency data analyses of the re-seeded grass species for the Roundup restoration technologies

The same situation occurred for the Roundup applications as for the no-Roundup applications. The F prob. value of less than 0.001 indicates the high significance of the data. The LSD was 1.394, CV % was 13.90 and SEM was 0.352 (Table 4.25).

The following groups were formed: group 1: RSN and RSON, group 2: RSW and RSOW, group 3: RDN, group 4: RDW and group 5: P, RN, RON, CN, RW, ROW and CW. There was a difference, although not significant, between narrow and wide row spacings as shown by the fact that the two row spacings were grouped together. The re-seeded technologies did group together, the same as in the previous section. The re-seeding only with *Digitaria eriantha* seed grouped into two groups for the different row spacings, according to the row spacings. The conventionally cultivated *Digitaria eriantha* pasture treatment grouped together with the non-seeded restoration treatments, as discussed in the previous section (Table 4.25).

Table 4.25 The mean frequency value of the re-seeded grass species data over the three seasons of the Roundup restoration technologies (Appendix A for the abbreviations of the terms and restoration technologies).

Rest. Techn	2003/2004			2004/2005			2005/2006		
	Mn	SD	Vr.	Mn	SD	Vr.	Mn	SD	Vr.
RSN	8.844	a	0.430	10.251	a	0.127	9.324	a	0.336
RSON	7.094	bc	2.758	9.652	a	3.018	9.069	a	0.371
RSW	8.351	ab	0.131	8.626	ab	0.129	8.765	a	0.525
RSOW	6.961	bc	1.069	8.731	ab	3.367	8.943	a	1.274
RDN	5.752	cd	0.122	7.517	bc	1.982	7.296	b	0.909
RDW	4.396	d	0.263	6.198	c	0.620	6.732	b	0.279
P	1.171	e	0.193	1.725	d	0.789	2.806	c	0.941
RN	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
RON	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
CN	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
RW	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
ROW	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
CW	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
SEM	0.369			0.522			0.352		
F prob.	<0.001			<0.001			<0.001		
LSD (1%)	1.458			2.064			1.394		
CV %	17.70			20.60			13.90		

3) Frequency data analyses of the naturally occurring grass species for the no-Roundup restoration technologies

The F prob. value of less than 0.001 indicates the high significance of the data. The LSD was 1.245, CV % was 6.30 and SEM was 0.315 (Table 4.26). There was a difference, although not significant, between narrow and wide row spacings as shown by the fact that the two row spacings were grouped together. The following groups were formed: group 1: P, RN, RON, CN, RW, ROW and CW, group 2: RDW and RDN and group 3: RSOW, RSW, RSON and RSN. All the non-seeded restoration technologies grouped together, the re-seeding with *Digitaria eriantha* alone grouped together and the other re-seeded treatments grouped together. The different groups did differ significantly from each other (Table 4.26).

Table 4.26 The mean frequency value of the natural occurring grass species data over the three seasons of the no-Roundup restoration technologies (Appendix A for the abbreviations of the terms and restoration technologies).

Rest. Techn	2003/2004			2004/2005			2005/2006		
	Mn	**SD**	**Vr.**	**Mn**	**SD**	**Vr.**	**Mn**	**SD**	**Vr.**
ROW	10.205	ab	0.034	10.942	ab	0.147	10.726	a	0.175
P	10.254	ab	0.039	10.698	ab	0.086	10.388	a	0.391
CW	10.070	abc	0.154	11.106	a	0.226	10.156	a	0.023
RON	10.140	ab	0.015	10.681	ab	0.134	10.470	a	0.316
CN	10.301	a	0.085	10.634	ab	0.135	10.269	a	0.059
RN	10.121	ab	0.588	10.222	ab	0.017	10.765	a	0.418
RW	10.269	a	0.086	10.418	ab	0.936	10.336	a	0.005
RDW	9.834	abc	0.176	9.579	bc	1.122	8.486	b	1.225
RDN	8.917	bcd	0.482	8.689	cd	1.512	7.894	b	0.275
RSOW	8.757	cd	1.212	7.763	de	0.361	5.953	c	0.094
RSW	7.715	d	0.463	7.987	de	1.065	6.372	c	0.350
RSON	7.855	d	2.710	7.348	de	0.265	5.445	c	0.284
RSN	6.236	d	1.923	7.074	f	1.191	5.474	c	0.302
SEM	0.341			0.352			0.315		
F prob.	<0.001			<0.001			<0.001		
LSD (1%)	1.348			1.391			1.245		
CV %	6.40			6.40			6.30		

4) Frequency data analyses of the naturally occurring grass species for the Roundup restoration technologies

The F prob. value of less than 0.001 indicates the high significance of the data. The LSD was 1.394, CV % was 13.90 and SEM was 0.352 (Table 4.27).

The following groups were formed: group 1: RSOW, RSW, RSON and RSN, group 2: RDW and RDN and group 3: ROW, RN, P, RW, CW, RON and CN. There was a difference, although not significant, between narrow and wide row spacings as shown by the fact that the two row spacings were grouped together. All the non-seeded restoration technologies grouped together, the re-seeding with *Digitaria eriantha* alone grouped together and the other re-seeded treatments grouped together. The different groups did differ significantly from each other (Table 4.27).

Table 4.27 The mean frequency value of the natural occurring grass species data over the three seasons of the Roundup restoration technologies (Appendix A for the abbreviations of the terms and restoration technologies).

Rest. Techn	2003/2004			2004/2005			2005/2006		
	Mn	SD	Vr.	Mn	SD	Vr.	Mn	SD	Vr.
RSN	8.844	a	0.430	10.251	a	0.127	9.324	a	0.336
RSON	7.094	bc	2.758	9.652	a	3.018	9.069	a	0.371
RSW	8.351	ab	0.131	8.626	ab	0.129	8.765	a	0.525
RSOW	6.961	bc	1.069	8.731	ab	3.367	8.943	a	1.274
RDN	5.752	cd	0.122	7.517	bc	1.982	7.296	b	0.909
RDW	4.396	d	0.263	6.198	c	0.620	6.732	b	0.279
P	1.171	e	0.193	1.725	d	0.789	2.806	c	0.941
RN	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
RON	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
CN	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
RW	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
ROW	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
CW	0.707	e	0.000	0.707	d	0.000	0.707	c	0.000
SEM	0.369			0.522			0.352		
F prob.	<0.001			<0.001			<0.001		
LSD (1%)	1.458			2.064			1.394		
CV %	17.70			20.60			13.90		

4.7 Economic analyses of the different restoration application

The economical analyses of the restoration technologies applied in this study were done with the help of an Agricultural economist, Mr. T. C. Fourie[24]. The costs of each restoration technology was calculated as running and fixed cost and expressed as cost per hectare. The labour costs and the seed prices were shown in the running costs, they were only taken once into account, when the total costs were calculated. The current input costs involved in the application of each restoration technology were used in the calculation of the costs. Where no price was available, inflation related Figures were used, such as for the non commercial seeds used in the re-seeding restoration technologies, such as *Themeda triandra* and *Cymbopogon excavatus*. The seed of these two species was obtained from Eko Rehab and it was not certified seed.

[24] Carel Fourie, Department of Agriculture, Free State, Private bag X 01, Glen 9360, Tel. 051 506 1546 Fax. 051 448 4068.

The costs of the restoration technologies were described in pairs as follows: 1) the narrow (0.75m) row spacing no-Roundup restoration technology was described and discussed; 2) the wide (1.5m) row spacing no-Roundup restoration technology; 3) the narrow row spacing with Roundup restoration technology and 4) the wide row spacing with Roundup restoration technology.

The seeds of the grass species used in the re-seeding seed mixture were re-seeded in two bunches, namely coarse and fine seeds. The coarse seeds are all the seeds with chaffy and other material attached to the seeds, such as *Themeda triandra* and *Cymbopogon excavatus* seeds, while fine seeds are characterized by the *Eragrostis curvula* and *Digitaria eriantha* species.

At the end of this section the total costs (R/ha) for each of the applied restoration technologies will be compared to the current land price (R/ha) for the Glen area. It is very important to note that when the total costs for the different restorations technologies where compared to the current land price, that only the input costs were compared. The potential income increase for the farmer, by the increase in the grazing capacity (more animals) of the restored old cultivated lands was not taken into account. A basic assumption was made that the farmer did not use these old cultivated lands for grazing and it will not be used until the rangeland condition of these lands increased in such a way that the grazing capacity is more or less the same as the set norm for the farm.

As described in chapter 3 the Roundup was applied over the whole area before any restoration technologies were applied, therefore the cost of the herbicide will be the same for both row widths.

4.7.1 Cost comparison between the different restoration application

1) Control restoration technology (C)

Because this restoration technology did not require any inputs by labour, machinery, seed or herbicide, the no-Roundup control restoration technology (CN and CW) was the cheapest at zero rand (Table 4.28). The Roundup control restoration technology had the costs of Roundup, labour of the tractor driver and machinery as inputs, which was R 252.90/ha for both the 0.75m and the 1.5m row spacings control restoration technologies (CNH and CWH) (Table 4.28). The input cost for both the Roundup restoration technologies were the same, because Roundup was applied over the whole area at the same rate, as described in chapter 3 (section 3.2.6).

Table 4.28 The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup control restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Total	**(CN)**		**R 0.00**	**(CW)**		**R 0.00**
Spray	R 17.48	R 17.92	R 35.40	R 17.48	R 17.92	R 35.40
Wetter / sticker	R 19.50		R 19.50	R 19.50		R 19.50
Roundup	R 198.00		R 198.00	R 198.00		R 198.00
Total	**(CNH)**		**R 252.90**	**(CWH)**		**R 252.90**

2) Rip restoration technology (R)

The total cost involved for the no-Roundup rip restoration technology was R 606.47/ha and R 376.24/ha for the narrow and the wide row spacing respectively (RN and RW). The cost for the roundup rip restoration technologies were R 859.38/ha and R 629.15/ha for the 0.75m and 1.5m row spacings respectively (RNH and RWH). This implies that the wide row spacing was cheaper than the narrow row spacing (Table 4.29).

Table 4.29 The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction (tractor)	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Total	**(RN)**		**R 606.47**	**(RW)**		**R 376.24**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction (tractor)	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Spray	R 17.48	R 17.92	R 35.40	R 17.48	R 17.92	R 35.40
Wetter / sticker	R 19.50		R 19.50	R 19.50		R 19.50
Roundup	R 198.00		R 198.00	R 198.00		R 198.00
Total	**(RNH)**		**R 859.38**	**(RWH)**		**R 629.15**

3) Rip and the application of organic material restoration technology (RO)

The no-Roundup rip and the application of organic material restoration technology (RONH and ROWH) cost slightly more than the no-Roundup rip restoration technology (RON and ROW), costing R 984.85/ha and R 660.20/ha for the 0.75m row and the 1.5m row spacings respectively. For the Roundup rip and the application of organic material the costs were even higher, costing R 1237.75/ha and R 913.10/ha for the 0.75m and 1.5m row spacings respectively. The 1.5m row spacing rip and the application of organic material restoration technologies were cheaper than the 0.75m row spacing rip and the application of organic material restoration technologies (Table 4.30).

Table 4.30 The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip and the application of organic material restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Transport R/km**	R 131.83	R 79.08	R 210.91	R 126.49	R 73.74	R 200.23
Pick up (dung*)	R 38.62		R 38.62	R 19.31		R 19.31
Application (dung)	R 128.85		R 128.85	R 64.43		R 64.43
Total	**(RON)**		**R 984.85**	**(ROW)**		**R 660.20**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Transport R/km**	R 131.83	R 79.08	R 210.91	R 126.49	R 73.74	R 200.23
Pick up (dung*)	R 38.62		R 38.62	R 19.31		R 19.31
Application (dung)	R 128.85		R 128.85	R 64.43		R 64.43
Spray	R 17.48	R 17.92	R 35.40	R 17.48	R 17.92	R 35.40
Wetter / sticker	R 19.50		R 19.50	R 19.50		R 19.50
Roundup	R 198.00		R 198.00	R 198.00		R 198.00
Total	**(RONH)**		**R 1,237.75**	**(ROWH)**		**R 913.11**

* The time that the tractor driver had to wait for the loading of the cow dung is not included in the calculations.

** Only a half load of cow dung was needed for the 1.5 m row spacing. A full load can cover 2 ha

4) Rip and re-seeding with a seed mixture restoration technology (RS)

The no-Roundup rip and the re-seeding with a seed mixture restoration technology (RSN and RSW) cost R 2416.46/ha and R 1281.23/ha for the 0.75m and the 1.5m row spacings respectively. The same restoration technology, where Roundup was used (RSNH and RSWH) cost R 2669.36/ha and R 1534.14/ha for the narrow and the wide row spacings respectively (Table 4.31). If the total seed mixture is used for re-seeding purposes, the restoration technologies will be very expensive, but if only selected grass species are used in the re-seeding restoration technologies, the seed costs could be reduced. The wide row spacing is cheaper than the narrow row spacing.

Table 4.31 The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip and the re-seeding with a seed mixture restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Sown (chaffy)	R 28.24		R 28.24	R 14.12		R 14.12
Sown (fine)	R 28.24		R 28.24	R 14.12		R 14.12
Cen cilS (R/kg)	R 342.00		R 342.00	R 171.00		R 171.00
Chl gayS (R/kg)	R 410.40		R 410.40	R 205.20		R 205.20
Cym excS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Dig eriS (R/kg)	R 255.00		R 255.00	R 127.50		R 127.50
Era chlS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Era curS (R/kg)	R 89.10		R 89.10	R 44.55		R 44.55
Pan maxS (R/kg)	R 57.00		R 57.00	R 28.50		R 28.50
The triS (R/kg)	R 300.00		R 300.00	R 150.00		R 150.00
Total	**(RSN)**		**R 2,416.46**	**(RSW)**		**R 1,281.23**

Table 4.31 (continue) The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip and the re-seeding with a seed mixture restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Sown (chaffy seed)	R 28.24		R 28.24	R 14.12		R 14.12
Sown (fine seed)	R 28.24		R 28.24	R 14.12		R 14.12
Cen cillS (R/kg)	R 342.00		R 342.00	R 171.00		R 171.00
Chl gayS (R/kg)	R 410.40		R 410.40	R 205.20		R 205.20
Cym excS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Dig eriS (R/kg)	R 255.00		R 255.00	R 127.50		R 127.50
Era chlS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Era curS (R/kg)	R 89.10		R 89.10	R 44.55		R 44.55
Pan maxS (R/kg)	R 57.00		R 57.00	R 28.50		R 28.50
The triS (R/kg)	R 300.00		R 300.00	R 150.00		R 150.00
Wetter / sticker	R 17.48	R 17.92	R 35.40	R 17.48	R 17.92	R 35.40
Roundup	R 19.50		R 19.50	R 19.50		R 19.50
Total	**(RSNH)**		**R 2,669.36**	**(RSWH)**		**R 1,534.14**

* The time that the tractor driver had to wait for the loading of the cow dung is not included in the calculations.

** Only a half load of cow dung was needed for the 1.5 m row spacing. A full load can cover 2 ha.

5) Rip, re-seeding with a seed mixture and the application of organic material restoration technology (RSO)

The no-Roundup rip, re-seeding with a seed mixture and the application of organic material restoration technologies (RSON and RSOW) cost more than the previous restoration technologies, costing R 2794.83/ha and R 1565.20/ha for the narrow and the wide row spacings respectively. The cost for the Roundup rip, re-seeding with a seed mixture (RSONH and RSOWH) was R 3009.12 and R 1798.79/ha, for the 0.75m and the 1.5m row spacings respectively. The 1.5m row spacings were cheaper than the 0.75m row spacings, as for the previous restoration technologies (Table 4.32).

Table 4.32 The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip, the re-seeding with a seed mixture and the application of organic material restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Sown (chaffy seed)	R 28.24		R 28.24	R 14.12		R 14.12
Sown (fine seed)	R 28.24		R 28.24	R 14.12		R 14.12
Cen cillS (R/kg)	R 342.00		R 342.00	R 171.00		R 171.00
Chl gayS (R/kg)	R 410.40		R 410.40	R 205.20		R 205.20
Cym excS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Dig eriS (R/kg)	R 255.00		R 255.00	R 127.50		R 127.50
Era chlS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Era curS (R/kg)	R 89.10		R 89.10	R 44.55		R 44.55
Pan maxS (R/kg)	R 57.00		R 57.00	R 28.50		R 28.50
The triS (R/kg)	R 300.00		R 300.00	R 150.00		R 150.00
Transport (R/km**)	R 131.83	R 79.08	R 210.91	R 126.49	R 73.74	R 200.23
Pick up *	R 38.62		R 38.62	R 19.31		R 19.31
Application (dung)	R 128.85		R 128.85	R 64.43		R 64.43
Total	**(RSON)**		**R 2,794.83**	**(RSOW)**		**R 1,565.20**

Table 4.32 (continue) The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip, the re-seeding with a seed mixture and the application of organic material restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	0.75m			1.5m		
Action ↓	Total costs R / ha			Total costs R / ha		
	Running	Fixed	Total	Running	Fixed	Total
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Sown (chaffy seed)	R 28.24		R 28.24	R 14.12		R 14.12
Sown (fine seed)	R 28.24		R 28.24	R 14.12		R 14.12
Cen cilIS (R/kg)	R 342.00		R 342.00	R 171.00		R 171.00
Chl gayS (R/kg)	R 410.40		R 410.40	R 205.20		R 205.20
Cym excS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Dig eriS (R/kg)	R 255.00		R 255.00	R 127.50		R 127.50
Era chlS (R/kg)	R 150.00		R 150.00	R 75.00		R 75.00
Era curS (R/kg)	R 89.10		R 89.10	R 44.55		R 44.55
Pan maxS (R/kg)	R 57.00		R 57.00	R 28.50		R 28.50
The triS (R/kg)	R 300.00		R 300.00	R 150.00		R 150.00
Transport (R/km**)	R 131.83	R 79.08	R 210.91	R 126.49	R 73.74	R 200.23
Pick up *	R 38.62		R 38.62	R 19.31		R 19.31
Application (dung)	R 128.85		R 128.85	R 64.43		R 64.43
Spray	R 17.48	R 17.92	R 35.40	R 17.48	R 17.92	R 35.40
Wetter / sticker	R 19.50		R 19.50	R 19.50		R 19.50
Roundup	R 198.00		R 198.00	R 198.00		R 198.00
Total	**(RSONH)**		**R 3,009.12**	**(RSOWH)**		**R 1,798.79**

* The time that the tractor driver had to wait for the loading of the cow dung is not included in the calculations.

** Only a half load of cow dung was needed for the 1.5 m row spacing. A full load can cover 2 ha.

6) Rip and re-seeding with only *Digitaria eriantha* seed restoration technology (RD)

This restoration technology was more cost effective than the others, the no-Roundup rip and the *Digitaria eriantha* re-seeded restoration technologies (RDN and RDW) cost R 889.71/ha and R 517.86/ha for the 0.75m and the 1.5m row spacing respectively and for the Roundup rip and the re-seeding with *Digitaria eriantha* seed restoration technologies (RDNH and RDWH) cost R 1142.62/ha and R 770.77/ha for the 0.75m and the 1.5m row spacings respectively (Table

4.33). The *Digitaria eriantha* seed (See viability of the seed: Table 4.2 and 4.3) can however not be guaranteed, as described in the pervious results. It will depend on the quality of the seed and where it is purchased.

Table 4.33 The economical analyses of both the 0.75m and the 1.5m row spacings of the no-Roundup and the Roundup rip and the re-seeding with the *Digitaria eriantha* seed restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Row width →	**0.75m**			**1.5m**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Sown of seed	R 28.24		R 28.24	R 14.12		R 14.12
Dig eirS (R/kg)	R 255.00		R 255.00	R 127.50		R 127.50
Total	**(RDN)**		**R 889.71**	**(RDW)**		**R 517.86**
Rip	R 280.03	R 142.83	R 422.86	R 172.24	R 80.02	R 252.26
Compaction	R 99.42	R 84.19	R 183.61	R 76.81	R 47.17	R 123.98
Sown of seed	R 28.24		R 28.24	R 14.12		R 14.12
Dig eirS (R/kg)	R 255.00		R 255.00	R 127.50		R 127.50
Spray	R 17.48	R 17.92	R 35.40	R 17.48	R 17.92	R 35.40
Wetter / sticker	R 19.50		R 19.50	R 19.50		R 19.50
Roundup	R 198.00		R 198.00	R 198.00		R 198.00
Total	**(RDNH)**		**R 1,142.62**	**(RDWH)**		**R 770.77**

* The time that the tractor driver had to wait for the loading of the cow dung is not included in the calculations.

** Only a half load of cow dung was needed for the 1.5 m row spacing. A full load can cover 2 ha.

7) Conventional cultivated *Digitaria eriantha* pasture restoration technology (P)

The costs for the cultivated *Digitaria eriantha* pastures were R 1542.79/ha for the no-Roundup (P) and R 1795.69/ha for the Roundup conventional cultivated *Digitaria eriantha* pastures restoration technologies (PH) (Table 4.34). These costs included all the seedbed preparations, the re-seeding of the seeds and the compaction of the soil after it was re-seeded. The seeds were re-seeded in 1.0m rows, by hand and compacted by using a hand roller.

Table 4.34 The economical analyses of both the no-Roundup and the Roundup conventional cultivated *Digitaria eriantha* pasture restoration technologies (Appendix A for the abbreviations of the restoration technologies and the economical terms). The economical analyses of the convention planted *Digitaria eriantha* pastures.

Herbicide →	**No Roundup**			**Roundup**		
Action ↓	**Total costs R / ha**			**Total costs R / ha**		
	Running	**Fixed**	**Total**	**Running**	**Fixed**	**Total**
Rip	R 279.26	R 142.05	R 421.31	R 279.26	R 142.05	R 421.31
Plough	R 196.14	R 95.55	R 291.69	R 196.14	R 95.55	R 291.69
Disc	R 97.06	R 59.39	R 156.45	R 97.06	R 59.39	R 156.45
Harrow	R 75.78	R 57.73	R 133.50	R 75.78	R 57.73	R 133.50
Sown of seed	R 21.18		R 21.18	R 21.18		R 21.18
Making furrow	R 96.79		R 96.79	R 96.79		R 96.79
Soil compaction	R 166.88		R 166.88	R 166.88		R 166.88
Dig eirS (R/kg)	R 255.00		R 255.00	R 255.00		R 255.00
Spray				R 17.48	R 17.92	R 35.40
Wetter / sticker				R 19.50		R 19.50
Roundup				R 198.00		R 198.00
Total	**(P)**		**R 1,542.79**	**(PH)**		**R 1,795.69**

4.7.2 The comparison of the costs of each of the different restoration technologies applied in this study and the current land prices for the Glen area

To compare the current land prices and the cost of each restoration technology with each other, a land price of R 3000.00/ha was given by Mr. T. C. Fourie[25]. The comparing Figures are given in Table 4.35, in order of the cheapest to the most expensive restoration technology. It is important to consider the current land price when deciding which restoration technology to use, as it could be cheaper to buy new land as to restore the existing old cultivated lands (Table 4.35).

It is clear that the cost to implement the restoration technologies increased as the combination of restoration technologies increased. In some instances, the increase in costs were so high, such as the narrow (0.75m) row spacing, rip, re-seeding with a seed mixture and the application organic material restoration technology, with the application of Roundup (RSONH) that it become more expensive to restore, using this particular restoration technology than to buy new land, making this restoration technology uneconomical. The cost could be drastically reduced if

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only the successful established grass species were used in the re-seeding restoration technologies. Even the cost to establish conventional cultivated *Digitaria eriantha* pastures was more than half the price of new land, if purchased at R 3000.00/ha. The cheapest and most cost effective restoration technologies were the rip and rip and re-seeding with *Digitaria eriantha* seed restoration technologies. The application of Roundup only added to the cost of these restoration technologies (Table 4.33).

As the difference between the total cost and the land price decreases, in other words the restoration technology becomes more expensive the decision to and which restoration technology to use becomes more difficult (Table 4.35). If the restoration cost increased more than half the costs of new land, it becomes questionable if it will be economical to restore the old cultivated lands. This point is reached with the RSWH restoration technology, with a total cost of R 1534.14/ha. The following lists, ranked in order from the cheapest to the most expensive restoration technologies were cheaper and more expensive than RSWH, respectively: 1) Cheaper: CN, CW, CNH, CWH, RW, RDW, RN, RWH, ROW, RDWH, RNH, RDN, ROWH, RON, RDNH, RONH and RSW 2) more expensive: P, RSOW, PH, RSOWH, RSN, RSNH, RSON, and RSONH.

For example if a farmer decides to use the rip and the application of organic material restoration technology with the wide row spacing and to apply Roundup (ROWH), it will cost R 913.11/ha. At a land price of R3000.00, the farmer will save R 2086.89/ha, if the technology is applied. If the farmer decides to use the narrow row spacing of the same restoration technology, without the use of Roundup, the farmer will save R2015.15/ha, if the restoration technology is successful (RON).

Table 4.35 The comparison between the applied restoration technology's costs and the current land price in the Glen area (Appendix A for the abbreviations of the restoration technologies and the economical terms).

Restoration technology	Abbreviation	Restoration Cost (R/ha)	Difference	Decision
Control, narrow	CN	R 0.00	-R 3,000.00	Restore
Control, wide	CW	R 0.00	-R 3,000.00	
Control, narrow, with Roundup	CNH	R 252.90	-R 2,747.10	
Control, wide, with Roundup	CWH	R 252.90	-R 2,747.10	
Rip, wide	RW	R 376.24	-R 2,623.76	
Rip, *Digitaria eriantha*, wide	RDW	R 517.86	-R 2,482.14	
Rip, narrow	RN	R 606.47	-R 2,393.53	
Rip, wide, with Roundup	RWH	R 629.15	-R 2,370.85	
Rip, organic, wide	ROW	R 660.20	-R 2,339.80	
Rip, *Digitaria eriantha*, wide, with Roundup	RDWH	R 770.77	-R 2,229.23	
Rip, narrow, with Roundup	RNH	R 859.38	-R 2,140.62	
Rip, *Digitaria eriantha*, narrow	RDN	R 889.71	-R 2,110.29	
Rip, organic, wide, with Roundup	ROWH	R 913.11	-R 2,086.89	
Rip, organic, narrow	RON	R 984.85	-R 2,015.15	
Rip, *Digitaria eriantha*, narrow, with Roundup	RDNH	R 1,142.62	-R 1,857.38	
Rip, organic, narrow, with Roundup	RONH	R 1,237.75	-R 1,762.25	
Rip, re-seed, wide	RSW	R 1,281.23	-R 1,718.77	
Rip re-seed, wide, with Roundup	RSWH	R 1,534.14	-R 1,465.86	Questionable
Cultivated *Digitaria eriantha* pasture	P	R 1,542.79	-R 1,457.21	
Rip, re-seed, organic, wide	RSOW	R 1,565.20	-R 1,434.80	
Cultivated Digitaria eriantha pasture, with Roundup	PH	R 1,795.69	-R 1,204.31	
Rip, re-seed, organic, wide, with Roundup	RSOWH	R 1,798.79	-R 1,201.21	
Rip, re-seed, narrow	RSN	R 2,416.46	-R 583.54	Seriously consider to buy new land
Rip re-seed, narrow, with Roundup	RSNH	R 2,669.36	-R 330.64	
Rip, re-seed , organic, narrow	RSON	R 2,794.83	-R 205.17	
Rip, re-seed, organic, narrow, with Roundup	RSONH	R 3,009.12	R 9.12	Buy new land

- Land prices are an average for grazing veld and cultivated land prices at R 3000.00/ha,
- The difference is calculated as follows: Land price (R/ha) – Restoration cost (R/ha).

CHAPTER 5

GENERAL CONCLUSION

5.1 Introduction

Different technologies were evaluated to restore old cultivated lands, in order to better the veld condition and increase the grazing capacity. Similar restoration technologies had previously been assessed by other researchers in different environments in South Africa (Boateng, 2002; Buys, 2002; De Wet, 2001; Van den Berg, 2002 and Van der Merwe, 1997).

Specific conclusions were made, according to the different restoration technologies applied in this study and some general conclusions that were applicable to all restoration technologies were also included. Then recommendations were made on the use of the different restoration technologies to restore old cultivated lands, the shortcomings of this study and recommendations for further research of the same type, at the end of this chapter.

The specific aims of this study included, to:

- Test the viability and germination rate of the seeds that were used in the re-seeded restoration technologies;
- Evaluate different restoration technologies to restore old cultivated lands with a row width of 0.75m (narrow) and 1.5m (wide);
- Evaluate the influence of the use of herbicide in the restoration of old cultivated lands;
- Analyse the economy of the different restoration technologies that were evaluated and
- Make recommendations on the restoration of old cultivated lands.

The quantitative vegetation sampling procedures, which included frequency, basal cover and density measurements, were undertaken over a three year period (2003/04 to 2005/06). The establishment and dynamics of the re-seeded and the natural occurring species in the different restoration technology plots were described according to the vegetation survey (frequency) data. The seeds of the re-seeded species were tested *in vitro* to determine the percentage purity and the germination rate of each. Grass species used in the re-seeded trials included the following species: *Digitaria eriantha* (coated), *Chloris gayana* (coated), *Panicum maximum* (coated) *Cenchrus cilliaris* (uncoated), *Eragrostis curvula* (uncoated), *Eragrostis chloromelas* (uncoated), *Themeda triandra* (uncoated) and *Cymbopogon excavatus* (uncoated). Two rip row spacings, (narrow: 0.75m and wide: 1.5m) were evaluated, as well as the use of Roundup in the restoration of old cultivated lands. Economical analyses were carried out to compare the costs of the restoration technologies with the current average price of land if purchased.

5.2 Conclusions

5.2.1 Seed viability

The purity of the coated grass species were ranked, in order of purity as follows: *Digitaria eriantha* (96%), *Chloris gayana* (85.6%) and *Panicum maximum* (84.3%). The uncoated species ranked as follows: *Cenchrus cilliaris* (97.9%), *Eragrostis curvula* (95.4%), *Eragrostis chloromelas* (91.3%), *Themeda triandra* (72.5%) and *Cymbopogon excavatus* (44.7%). Only three of these species (*Digitaria eriantha*, *Themeda triandra* and *Eragrostis curvula*) established reasonable well in the re-seeded application restoration treatments. *Eragrostis curvula* (86%) and *Themeda triandra* (76%) had the highest germination rates which explained the good establishment of these species under natural conditions. Although *Digitaria eriantha* had a low germination rate of only 19%, it did perform well in the re-seeding applications, due to its high purity value of 96.0%.

According to studies done by other authors (De Wet, 2001 and Van den Berg, 2002) and from the results of this study the coated seeds' germination rate were lower than that of the uncoated seeds in the laboratory tests. Only one of the coated grass species (*Digitaria eriantha*), used in the re-seeded restoration technologies established well during this study and it was therefore concluded that uncoated seeds could be used successfully in the restoration of old cultivated lands.

5.2.2 Vegetation before restoration technologies were applied

The initial species composition of the old cultivated lands was characterized by high species abundance values of annual, as well as perennial grass species, such as *Aristida congesta* and *Eragrostis lehmanniana*. The reason for the high species abundance of the initial vegetation is that these old cultivated lands did lay fallow for some time (about ten years) before the application of the restoration technologies. Other perennial species (such as *Themeda triandra* and *Cynodon hirsutus*) also occurred in patches in the trial sites (Appendix B: table B 13 and B 14). The basal cover of these old cultivated lands was low: 3.8% and 7.86% for the no-Roundup treated and the Roundup treated trials areas (camps), respectively. The species composition of the study area did not reflect the typical vegetation of the Bloemfontein dry grassland (Gh 8) as classified by Mucina and Rutherford (2006), which indicated that the vegetation of these old cultivated lands were still disturbed, even after such a long resting period.

It was therefore decided that these old cultivated lands needed to be restored, in order to better its species composition, dry matter production and grazing capacity, by re-seeding with more palatable grass species. Its grazing capacity would increase and subsequently the income of the farmer would be increased, due to an increase in animal numbers.

5.2.3 Evaluation of the restoration technologies

The restoration technologies evaluated in this study were described according to the following: the rip application, re-seeded species, natural occurring species, herbicide application, the two row spacings and the restoration costs involved in the executing of the different restoration technologies.

1) The rip application

The rip restoration technology did have a positive affect on the growth and establishment of new and existing perennial species, especially in the re-seeded restoration technologies and those where organic material was applied. This therefore seems to be a good technology to restore old cultivated lands.

2) The re-seeded species

Digitaria eriantha, *Themeda triandra* and *Eragrostis curvula* established successfully and increased in species abundance in all the re-seeded applications over the three seasons. The PCA ordinations showed that a strong positive correlation between the re-seeded grass species and all the re-seeding restoration technologies existed. These three species could therefore be used in the re-seeding of old cultivated lands.

The reaction of *Digitaria eriantha* in the conventional cultivated pasture restoration technology was poor and the mixed results made it impossible to make any conclusion of its success or failure.

3) The natural occurring species

According to the PCA ordination there was a strong positive correlation between the restoration technologies where no re-seeding was done and the natural occurring species, such as *Eragrostis lehmanniana*, *Heteropogon contortus*, *Themeda triandra, Cynodon hirsutus*, *Tragus berteronianus*, *Aristida congesta* and *Eragrostis chloromelas*.

There was a more positive correlation between the application of organic material and natural occurring annual and perennial grass species, such as *Themeda triandra*, *Heteropogon contortus*, *Eragrostis chloromelas* and *Tragus berteronianus*, over the three year period. *Eragrostis curvula* decreased in species abundance as *Digitaria eriantha* and *Themeda triandra* increased in abundance.

4) The application of organic material

The application of organic material did have a greater positive correlation with regard to the perennial species in plots, where a narrow row spacing (0.75m) was applied. The wide row spacing (1.5m) did favour the species abundance of *Eragrostis lehmanniana* where no Roundup was applied.

The application of organic material did help with the initial establishment of the re-seeded species, especially in the treatments where Roundup was applied, but this affect was gradually minimised over the three seasons. This was in contrast with what other authors find in their studies (Boateng, 2002; Van den Berg, 2002 and Van der Merwe, 1997), where the application of organic material had a positive effect on the re-seeded grass species. The reason for the poor performance of the organic material could be due to the fact that it was collected from a dairy. The nutrients of this cow dung could have been washed out in the diary. Another contributing factor towards this could be due to the fact that the organic material content of the soil was already high due to the plant cover of the soil and that the addition of any organic material had little to no effect.

5) The herbicide application

With the application of Roundup herbicide, the species abundance of the annual species, such as *Tragus berteronianus* did increase immediately in the first season, as well as over the three seasons the study was carried out. The perennial species, such as *Themeda triandra* only increased gradually, over time. The application of Roundup could have helped to reduce the inter-species competition for moisture, especially in the re-seeded restoration technologies. The application of Roundup did have a negative influence on the occurrence of existing perennial species, such as *Themeda triandra*, but the application of herbicide did enhance the initial establishment of the seedlings of the re-seeded species. The effect of the application of herbicide in this study was mainly negative due to the fact that species abundance of the existing palatable grass species declined and that of the more unpalatable species, such as *Eragrostis lehmanniana* and *Tragus berteronianus* increased.

6) The two row spacings

The species abundance value of re-seeded species was higher in the narrow row spacing (0.75m). The wide row spacing did favour the perennial species, of especially the natural occurring species, such as *Themeda triandra*.

7) The restoration costs

The input costs for the different restoration technologies drastically increased as the number of input actions in the different combination of the restoration technologies increased. The control, where no actions were applied, for example, cost nothing. On the other hand the rip, re-seeding with a seed mixture and the application of organic material in 0.75m (narrow) rip rows (RSONH) that was the most expensive at a cost of R3009.12/ha.

All the wide row restoration technologies were considerably cheaper than the narrow row applications, due to the lesser number of rows that were spread over the hectare, the lower running costs for the tractor and less seed that was used in the re-seeded applications. On the other hand, the narrow row spacing did benefit *Digitaria eriantha*, *Themeda triandra* and *Eragrostis curvula*. The increase in grazing capacity must be weighed against the input costs in the decision making process of which restoration technology to apply.

5.3 Recommendations to restore old cultivated lands

The success of the re-seeded restoration technologies depended on the quality of the seeds used in these restoration technologies. Poor seed can lead to poor restoration results in the natural environment leading to unnecessary high input costs (Boateng, 2002; Van den Berg, 2002 and Van der Merwe, 1997). Seed viability and germination tests should be carried out first to establish the quality of the seed, especially if non-certified seed is bought or if the seeds of natural occurring species, such as *Themeda triandra* is harvested in the rangeland, as this will influence the success of the restoration technologies applied. If the viability non-certified seeds have to be tested before the restoration, it can increase the costs, which could be higher than using certified seed in the first place. Normally the seed purity of uncertified seed is low, because the cleaning of it is considered to be too costly and it may contain lots of stones, soil, other plant material and even weed seeds. It is therefore recommended to buy only certified seed, from a recognised seed merchant, as they are by law forced to keep the certified seeds to a certain prescribed standard.

The already existing abundance and composition of species the old cultivated land that is to be restored is an other important factor to consider, as this will determine the type of restoration technologies, especially when combined with re-seeding, is to be used. For example if the species abundance of good palatable perennial grass species is already high, such as *Themeda triandra*, then it is recommended that no herbicide be applied as the application of herbicide has a negative impact on these species and that this species is not included in the seed mixture when re-seeding. On the other hand, if the plant community of the old cultivated land is characterized by high species abundance of annual low grazing valued grass species then the application of herbicide is advised to eliminate the competition factor of the existing vegetation with that of the newly established seedlings of the re-seeded species.

If a natural occurring highly palatable perennial grass species, such as *Themeda triandra*, is to be used in a re-seeding application, the seed should be harvested in the rangeland near the site where the old cultivated land is to be restored, to ensure that the correct ecotype of the same species is used. Ecotypes are the product of genetic response of a population of the same species to a specific habitat (Barbour *et al*., 1987). The specific ecotype is adapted to the specific habitat it occur in and it may not necessary survive in any other habitat. This could lead to failure of a re-seeded restoration technology, because the ecotype from another habitat was not adapted to the new habitat of the old cultivated land that was restored.

As the application of restoration technologies to restore old cultivated lands can be very costly and the costs increase as the number of actions increase, it is very important to consider the most economical implications of each restoration technology that will be applied. The most important factor that will influence the decision, of which restoration technology is to be used, would rest on the available budget of the farmer.

Input costs can be lowered when only a single species, such as *Digitaria eriantha* is used, in re-seeding restoration technologies. If the species composition is to be increased and the old cultivated land be managed as a natural rangeland, then a more expensive option should be considered, such as: rip and the re-seeding with a seed mixture (e.g. the three recommended species: *Digitaria eriantha*, *Themeda triandra* and *Eragrostis curvula*). Organic material must only be used if it is available in large quantities, relatively near the old cultivated land due to the high labour and transport costs involved.

5.4 Shortcomings of this study and recommendations for further studies of the same type

During and after the completion of this study the following shortcomings and recommendations for further research in this field were identified:

- During the planning phase of this study the soil seed bank analyses was included in the study. Unfortunately the infrastructure (glasshouse) available to the researcher for the germination was not to standard and had to be shared with another researcher involved in the germination of vegetable plants. The result of the soil seed bank samples could therefore not be used in this study. It is recommended that in-depth soil seed bank studies be carried out before any restoration technologies with the necessary infrastructure.

- Due to a lack of proper marking and poor communication between the researcher and the technician, the biomass data collected from the study site could not be used. The sample plots were marked incorrectly and did not correlate with the frequency and other data collected at the study site. It is therefore recommended that good weather- and fire proof markings should be used to mark each plot clearly, for future identification and that proper communication between all stakeholders involved in the research trial exists.

- If the biomass data is collected, it is recommended that it should be done at more regular intervals, approximately every four weeks, to determine the influence of defoliation (grazing) on the grass species and to identify the growing cycle of the grass species in the particular study site.

- Except for the rainfall. other environmental factors that could influence the germination and establishment of both the re-seeded and the seeds in the soil seed bank were not sampled in this trial. It is recommended that more environmental data be collected, such as the minimum and maximum temperature, soil nutrient content changes in each plot and soil temperatures, over time for each season. This is necessary to explain certain trends in the vegetation data, for example if the environmental data was available, it could have helped in the explanation of the poor performance of *Digitaria eriantha* in the conventional pasture technology and why the same seed performed well in the other re-seeded restoration technologies.

- If the restoration technologies are implemented successfully and the grazing capacity of these restored areas increased, accordingly, then the farmer's income should also increase. This possible increase in income should be added in the economical analyses of the different restoration technologies, when the economical viability of the different restoration technologies is calculated. The ratio between the input costs and the possible increase in income could be large enough to soften the higher input costs of restoration.

- Soil sampling and analyses of nutrients, before and during the restoration of old cultivated lands will aid in the decision making process. For example if the soil nutrient content is high, no organic material will be necessary and costs will be reduced.

- The occurrence and influence of soil micro-organisms to help with the availability of the plant nutrients and to better the soil structure should also be researched, because some soil organisms aid in the availability of soil nutrients, or vice versa. For example: *Nitrosomonas, Nitrosolobus* and *Nitrosospira* is a group of autotrophic bacteria that are able to covert ammonia to nitrites, thus making nitrogen available to the plants, while other organisms, such as *Nitrobacter*, are responsible for the oxidation of nitrates and therefore the fixation of nitrogen, making nitrogen unavailable to the plants (Brady, 1984).

- When old cultivated land lay fallow for an extended period, the abundance and composition of existing species should be determined as well as the veld condition, first, before applying certain restoration technologies. This could reduce the costs of restoration technologies.

- If the veld condition is to be determined for the calculation of the grazing capacity, then the vegetation surveys should be carried out over the total area that is restored and not only on the rip-furrows, as this may lead to an overestimation of the veld condition.

  If the success of the restoration and especially the establishment od re-seeded species be evaluated alone, then the vegetation sapling can be carried out only on the rip-furrows.

- The large circumference of the wheel point apparatus (3.0m), used in this study was a disadvantage because the vegetation was only recorded at 1.5m intervals which could have resulted that some of the indicator or important species were missed in the small research trial plots. Smaller and finer samplings are recommended when sampling the old cultivated lands.

- The influence of grazing on the restored area should be investigated in order to determine if the applied restoration technology or combination of technologies has a positive or negative influence on the applied restoration technologies. Both the short and long term effect of grazing should be determined, as this will have an affect on the sustainability of the new restored ecosystem.

- A survey technique should be investigated to distinguish between the re-seeded and naturally occurring (already in the plant community present) individual grass tufts of the same species in the old cultivated restored plots. This will determine the differences in success between the re-seeded and non-seeded plants .This would only be applicable when the old cultivated lands to be restored were laying fallow for a period and the grass species to be used in the re-seeding restoration technology did already established itself in the plant community.

Chapter 6

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6.1 Literature

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Appendix A

Abbreviations

1. Rainfall data

R days	=	Average number of rain days
Tmax	=	Average maximum temperature
Tmin	=	Average minimum temperature
Ave	=	Average value over 80.33 years
Long	=	Long term average rainfall;
Std	=	Standard deviation;
Std Max	=	Maximum standard deviation rainfall;
Std Min	=	Minimum standard deviation rainfall.

2. Grass species mixture

Ratio	=	Seeding rate in kg/ha;
%	=	Percentage of each species of the total seed mixture;
Treated	=	The seed was treated with a enhancing chemical.

3. Vegetation data

Freq.	=	Frequency value (%);
Basal.	=	Basal cover value (%);
Dens.	=	Density value (%);
Import.	=	Calculated importance value;
Rank.	=	Ranking of importance value (High to low).

4. Restoration technologies

R	=	Rip;
S	=	Re-seeding with the seed mixture;
D	=	*Digitaria eriantha* seed;
N	=	0.75m (narrow) row spacing;
W	=	1.5m row (wide) spacing;
H	=	with Roundup application.

5. Combination of restoration technologies applied

CN	=	no-Roundup, control, 0.75 m row spacing, without Roundup;
CW	=	no-Roundup control, 1.5 m row spacing, without Roundup;
RN	=	no-Roundup, rip, 0.75m row spacing;
RW	=	no-Roundup, rip, 1.5 m row spacing;
RON	=	no-Roundup, rip, organic material, 0.75m row spacing;
ROW	=	no-Roundup, rip, Organic material 1.5 m row spacing;
RSN	=	no-Roundup, rip, seed mixture, 0.75 m row spacing;
RSW	=	no-Roundup, rip, seed mixture, 1.5 m row spacing;
RSON	=	no-Roundup, rip, seed mixture, organic material, 0.75 m row spacing;
RSOW	=	no-Roundup, rip, seed mixture, organic material, 1.5 m row spacing;
RDN	=	no-Roundup, rip, *Digitaria eriantha* seed, 0.75 m row spacing;
RDW	=	no-Roundup, rip, *Digitaria eriantha* seed, 1.5 m row spacing;
P	=	no-Roundup, conventional cultivated *Digitaria eriantha* pasture;
CNH	=	Roundup, control, 0.75 m row spacing, with Roundup;
CWH	=	Roundup, control, 1.5 m row spacing, with Roundup;
RNH	=	Roundup, rip, 0.75m row spacing;
RWH	=	Roundup, rip, 1.5 m row spacing;
RONH	=	Roundup, rip, organic material, 0.75m row spacing;
ROWH	=	Roundup, rip, Organic material 1.5 m row spacing;
RSNH	=	Roundup, rip, seed mixture, 0.75 m row spacing;
RSWH	=	Roundup, rip, seed mixture, 1.5 m row spacing;
RSONH	=	Roundup, rip, seed mixture, organic material, 0.75 m row spacing;
RSOWH	=	Roundup, rip, seed mixture, organic material, 1.5 m row spacing;
RDNH	=	Roundup, rip, *Digitaria eriantha* seed, 0.75 m row spacing;
RDWH	=	Roundup, rip, *Digitaria eriantha* seed, 1.5 m row spacing;
PH	=	Roundup, conventional cultivated *Digitaria eriantha* pasture and
1, 2 or 3	=	Replication 1, 2 or 3.

6. Plant surveys

Freq.	=	Plant frequency value as %;
Basal.	=	Basal cover value for each species as %;
Dens.	=	Density value for each species as %;
I. V.	=	Importance value for each species (the sum of the abovementioned);
Rank.	=	Ranking of the species according to their importance value.

7. Plant species

Ari con	=	*Aristida congesta*;
Chl vir	=	*Chloris virgata*;
Cyn hir	=	*Cynodon hirsutus*;
Eli mut	=	*Elionurus muticus*;
Era chl	=	*Eragrostis chloromelas*;
Era leh	=	*Eragrostis lehmanniana*;
Het con	=	*Heteropogon contortus*;
Pan max	=	*Panicum maximum*;
Spo fim	=	*Sporobolus fimbriatus*;
The tri	=	*Themeda triandra*;
Tra ber	=	*Tragus berteronianus*;
Tra koe	=	*Tragus koeleriodes*;
Uro pan	=	*Urochloa panicoides*;
Cen cilS	=	*Cenchrus cilliaris* (re-seeded);
Cym excS	=	*Cymbopogon excavatus* (re-seeded);
Dig eriS	=	*Digitaria eriantha* (re-seeded);
Era curS	=	*Eragrostis curvula* (re-seeded);
Pan maxS	=	*Panicum maximum* (re-seeded);
The tri S	=	*Themeda triandra* (re-seeded).

8. PCA ordination analyses

Restoration technology abbreviations = same as in point 4 and 5 of this chapter;

nR	=	no Roundup applied;
R	=	Roundup applied.

9. Annova analyses

Mn	=	Mean value;
SD	=	Standard deviation;
Vr.	=	Variance;
SEM	=	Standard error means;
F Pop	=	F probability value;
LSD	=	Least significant difference;
CV %	=	Percentage coefficient value.

10. Economical analyses

Action	=	Actions applied in the combination of restoration technologies;
Running	=	Running costs;
Fixed	=	Fixed costs;
Compaction (meg)	=	Mechanical compaction of the soil;
Coarse seed	=	Chaffy seeds, with awns, etc;
Fine seeds	=	Small smooth seeds.

Ap

R

Table B 1 Frequency data: Three years and Average: No Herbicide: 0.75 m Rows (Appendix A for abb

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-0
	Restoration technologies →	RN	RN	RN	RN	RSN	RSN	RSN	RSN	RON	RON	RON	RON	RSON
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.33	1.27	2.10	1.23	0.00	0.00	0.00	0.00	0.3
	Cym excS	0.00	0.00	0.00	0.00	0.33	0.49	0.00	0.27	0.00	0.00	0.00	0.00	0.0
	Dig eriS	0.00	0.00	0.00	0.00	19.39	25.26	35.04	26.56	0.00	0.00	0.00	0.00	12.9
	Era cur S	0.00	0.00	0.00	0.00	22.94	8.45	7.30	12.90	0.00	0.00	0.00	0.00	16.1
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.3
	The tri S	0.00	0.00	0.00	0.00	18.79	26.89	28.70	24.80	0.00	0.00	0.00	0.00	10.4
Natural occurring	Ari con	21.33	21.65	13.21	18.73	11.41	9.07	1.80	7.43	16.59	22.31	17.00	18.63	14.7
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Chl vir	1.61	1.57	0.93	1.37	0.33	0.00	0.00	0.11	1.65	2.47	2.29	2.13	0.9
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Cyn hir	8.52	13.84	14.50	12.29	2.18	0.87	2.35	1.80	3.28	4.23	4.53	4.01	0.9
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.09	0.0
	Eli mut	0.00	0.97	0.31	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Era cur	5.16	1.87	4.49	3.84	0.00	0.00	0.00	0.00	0.66	0.83	0.66	0.72	0.0
	Era leh	22.60	39.27	39.77	33.88	5.23	20.34	20.86	15.48	27.38	38.36	42.90	36.21	10.8
	Het con	0.28	2.89	8.58	3.92	0.33	0.00	0.31	0.21	2.00	4.51	7.46	4.65	1.5
	Pan max	0.84	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Spo fim	0.00	0.00	0.25	0.08	0.00	0.00	0.31	0.10	0.00	0.00	0.00	0.00	0.0
	The tri	4.53	13.42	16.02	11.32	0.00	0.00	0.00	0.00	5.51	11.06	14.79	10.45	0.0
	Tra ber	12.87	3.90	0.62	5.80	11.38	7.35	0.30	6.35	28.87	14.26	9.41	17.51	14.
	Tra koe	2.55	0.31	1.32	1.40	0.00	0.00	0.91	0.30	0.95	0.84	0.64	0.81	0.6
	Uro pan	19.71	0.31	0.00	6.68	7.36	0.00	0.00	2.45	13.10	0.85	0.33	4.76	15.
	Total	100	100	100	100	100	100	100	100	100	100	100	100	10

endix B

w data

viations).

04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSON	RSON	RSON	RDN	RDN	RDN	RDN	CN	CN	CN	CN	P	P	P	P
0.30	0.62	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.88	0.31	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28.34	34.75	25.36	28.10	39.00	46.19	37.76	0.00	0.00	0.00	0.00	0.00	2.55	5.07	2.54
4.03	7.72	9.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.45	25.77	18.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.13	3.82	9.23	11.22	13.84	5.53	10.20	20.71	29.32	21.38	23.80	3.77	28.83	49.10	27.23
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.30	0.63	0.62	1.22	0.00	0.30	0.51	3.65	4.06	1.30	3.00	0.32	7.57	8.36	5.42
0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.85	0.31	0.71	3.64	1.81	3.28	2.91	5.27	6.44	7.39	6.37	0.00	1.21	0.61	0.61
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	3.06	0.82	0.30	1.39	0.98	0.00	0.00	0.33	0.00	0.27	0.00	0.09
30.32	24.82	21.99	12.60	30.83	30.39	24.61	23.00	31.34	29.30	27.88	0.61	7.47	11.12	6.40
1.39	1.26	1.40	3.67	2.81	2.97	3.15	4.02	6.32	8.01	6.12	0.00	0.55	2.77	1.11
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.10	0.00	0.00	0.31	0.10
0.00	0.00	0.00	6.38	8.61	10.12	8.37	16.77	19.34	31.39	22.50	0.97	2.22	6.98	3.39
4.01	0.00	6.19	17.12	2.28	0.62	6.67	11.27	1.17	0.32	4.25	26.90	45.63	14.05	28.86
0.00	0.00	0.21	0.00	0.00	0.00	0.00	2.70	1.73	0.91	1.78	0.32	0.28	0.00	0.20
0.00	0.00	5.19	12.98	0.00	0.00	4.33	11.62	0.00	0.00	3.87	67.11	3.42	1.63	24.05
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 2 Frequency data: Three years and Average: Herbicide: 0.75 m Rows (Appendix A for abbrevia

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04
	Restoration technologies →	RNH	RNH	RNH	RNH	RSNH	RSNH	RSNH	RSNH	RONH	RONH	RONH	RONH	RSONH
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.00	1.53	0.51	0.00	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.23	0.92	0.38	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	12.52	25.62	32.22	23.45	0.00	0.00	0.00	0.00	12.13
	Era cur S	0.00	0.00	0.00	0.00	29.74	9.82	7.01	15.53	0.00	0.00	0.00	0.00	20.96
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	24.73	39.05	37.63	33.80	0.00	0.00	0.00	0.00	15.07
Natural occurring	Ari con	10.13	11.83	22.23	14.73	8.07	2.12	0.95	3.72	9.75	13.59	23.00	15.45	8.03
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	3.59	6.60	6.43	5.54	0.55	0.47	0.31	0.44	4.33	7.81	10.03	7.39	3.34
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	4.54	1.56	2.06	2.72	0.00	0.00	0.92	0.31	0.91	0.64	4.40	1.98	13.93
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	2.00	0.91	8.45	3.79	0.00	0.00	0.00	0.00	1.05	0.72	0.62	0.80	0.00
	Era leh	27.43	42.56	44.91	38.30	9.46	18.94	14.69	14.37	27.55	45.07	45.43	39.35	6.43
	Het con	0.00	1.69	2.88	1.53	0.25	0.24	0.32	0.27	0.00	0.00	1.85	0.62	0.00
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.00	0.32	0.11	0.00	0.00	0.29	0.10	0.00	0.00	0.31	0.10	0.00
	The tri	1.34	4.85	5.44	3.88	0.00	0.00	0.00	0.00	2.21	2.30	7.10	3.87	0.00
	Tra ber	24.73	27.58	6.65	19.65	7.57	3.51	3.20	4.76	16.37	27.72	6.65	16.91	12.50
	Tra koe	0.33	0.00	0.62	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.10	0.50
	Uro pan	25.90	2.43	0.00	9.44	7.11	0.00	0.00	2.37	37.83	2.15	0.31	13.43	7.11
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100

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05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
	RSONH	RSONH	RDNH	RDNH	RDNH	RDNH	CNH	CNH	CNH	CNH	PH	PH	PH	PH
1	1.85	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1.16	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	26.42	20.55	27.01	38.61	44.42	36.68	0.00	0.00	0.00	0.00	0.87	2.41	7.37	3.55
52	7.52	14.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	29.72	23.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	1.68	4.07	8.83	6.59	6.73	7.38	8.76	12.44	17.28	12.82	1.47	6.16	27.22	11.62
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	1.35	2.59	3.20	1.01	2.27	6.02	11.54	16.76	11.44	1.99	9.00	26.07	12.36
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	8.21	10.04	0.26	0.72	2.82	1.27	4.09	4.63	7.41	5.38	1.71	0.72	2.42	1.62
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.26	0.52	2.58	1.12	0.00	0.00	2.46	0.82	0.00	0.00	0.00	0.00
14	21.45	15.68	14.53	23.02	27.45	21.67	12.86	38.94	42.83	31.54	0.90	6.19	4.05	3.71
1	0.28	0.16	1.77	0.43	0.63	0.95	0.32	0.31	0.93	0.52	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.29	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.10	0.00	0.00	0.00	0.00
0	0.00	0.00	2.07	7.59	13.12	7.59	3.09	0.85	5.24	3.06	0.30	0.82	1.88	1.00
9	1.40	6.13	29.88	17.50	1.24	16.21	46.42	30.64	6.48	27.85	36.07	65.71	23.94	41.91
0	0.00	0.17	0.00	1.18	0.00	0.39	0.00	0.00	0.31	0.10	0.00	0.00	4.60	1.53
1	0.00	2.44	12.81	0.63	0.00	4.48	18.45	0.64	0.00	6.36	56.68	8.99	2.44	22.71
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 3 Frequency data: Three years and Average: No Herbicide: 1.5 m Rows (Appendix A for abl

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03
	Restoration technologies →	RW	RW	RW	RW	RSW	RSW	RSW	RSW	ROW	ROW	ROW	ROW	RSOW
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.99	0.55	0.86	0.80	0.00	0.00	0.00	0.00	0
	Cym excS	0.00	0.00	0.00	0.00	0.30	0.31	1.51	0.70	0.00	0.00	0.00	0.00	0
	Dig eriS	0.00	0.00	0.00	0.00	14.89	13.22	25.00	17.70	0.00	0.00	0.00	0.00	11
	Era cur S	0.00	0.00	0.00	0.00	13.61	7.94	9.07	10.21	0.00	0.00	0.00	0.00	7
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	The tri S	0.00	0.00	0.00	0.00	8.57	24.51	26.58	19.89	0.00	0.00	0.00	0.00	9
Natural occurring	Ari con	16.83	21.88	17.29	20.27	13.45	15.37	5.08	11.30	17.44	27.24	20.78	21.82	10
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Chl vir	2.21	0.33	2.83	1.58	4.37	0.00	0.33	1.57	0.33	1.39	1.67	1.13	4
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Cyn hir	9.05	7.11	10.56	10.50	7.92	5.03	4.79	5.91	2.93	1.21	3.42	2.52	2
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Eli mut	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Era cur	2.74	1.98	2.83	2.23	0.00	0.00	0.00	0.00	1.89	1.40	2.11	1.80	0
	Era leh	18.80	36.49	38.27	38.01	15.51	27.65	25.34	22.83	21.83	38.49	36.94	32.42	21
	Het con	1.25	5.67	4.70	4.42	0.40	2.07	0.60	1.02	1.59	4.06	6.13	3.92	0
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Spo fim	0.33	0.00	0.94	0.31	0.00	0.00	0.28	0.09	0.00	0.00	0.62	0.21	0
	The tri	4.47	14.83	19.73	15.99	0.00	0.00	0.00	0.00	7.96	19.31	24.44	17.24	0
	Tra ber	18.88	7.33	0.95	4.06	10.74	3.35	0.30	4.80	29.28	5.56	2.42	12.42	15
	Tra koe	0.30	1.35	1.90	1.19	0.69	0.00	0.28	0.32	0.31	1.34	1.48	1.04	0
	Uro pan	0.30	1.35	1.90	1.19	0.69	0.00	0.28	0.32	0.31	1.34	1.48	1.04	15
	Total	100	100	100	100	100	100	100	100	100	100	100	100	1

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04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSOW	RSOW	RSOW	RDW	RDW	RDW	RDW	CW	CW	CW	CW	RW	RW	RW	RW
0.99	2.33	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.79	0.30	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.99	30.44	21.79	13.54	25.32	35.42	24.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.34	5.60	5.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23.47	30.34	21.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.95	5.03	8.72	9.59	12.41	7.27	9.76	13.30	27.68	23.71	21.56	16.83	21.88	17.29	20.27
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.18	2.01	1.15	1.04	0.30	0.83	1.57	2.42	5.60	3.20	2.21	0.33	2.83	1.58
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.92	3.19	2.95	7.66	6.91	11.76	8.77	8.49	8.63	12.30	9.81	9.05	7.11	10.56	10.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.10	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32
0.00	0.00	0.00	4.97	0.54	3.20	2.90	1.72	0.51	0.31	0.85	2.74	1.98	2.83	2.23
31.35	20.76	24.40	14.98	31.84	27.52	24.78	29.15	36.51	27.93	31.20	18.80	36.49	38.27	38.01
0.48	0.00	0.36	1.99	2.73	1.47	2.06	4.50	4.77	11.00	6.76	1.25	5.67	4.70	4.42
0.00	0.00	0.00	0.30	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.82	0.27	0.30	0.00	0.00	0.10	0.00	0.26	0.00	0.09	0.33	0.00	0.94	0.31
0.00	0.00	0.00	7.38	14.01	12.18	11.19	10.64	13.15	15.88	13.22	4.47	14.83	19.73	15.99
3.47	0.00	6.25	19.07	4.89	0.60	8.19	17.66	2.46	0.00	6.71	18.88	7.33	0.95	4.06
0.24	0.00	0.18	0.00	0.00	0.29	0.10	2.61	2.58	3.26	2.82	0.30	1.35	1.90	1.19
0.00	0.00	5.19	19.08	0.31	0.00	6.46	10.06	1.04	0.00	3.70	0.30	1.35	1.90	1.19
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 4 Frequency data: Three years and Average: Herbicide: 1.5 m Rows (Appendix A for abbrevia

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-0
	Restoration technologies →	RWH	RWH	RWH	RWH	RSWH	RSWH	RSWH	RSWH	ROWH	ROWH	ROWH	ROWH	RSOWH
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.51	1.27	0.60	0.00	0.00	0.00	0.00	0.0
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.78	0.66	0.48	0.00	0.00	0.00	0.00	0.0
	Dig eriS	0.00	0.00	0.00	0.00	13.98	21.48	30.59	22.02	0.00	0.00	0.00	0.00	17.3
	Era cur S	0.00	0.00	0.00	0.00	29.97	10.17	10.34	16.83	0.00	0.00	0.00	0.00	20.8
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	The tri S	0.00	0.00	0.00	0.00	16.46	23.12	30.20	23.26	0.00	0.00	0.00	0.00	11.7
Natural occurring	Ari con	12.15	13.53	18.72	14.80	5.47	2.60	5.18	4.42	12.73	11.14	20.34	14.74	5.6
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Chl vir	0.66	4.13	7.77	4.19	0.86	4.08	2.86	2.60	3.59	7.97	10.43	7.33	2.81
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Cyn hir	4.77	1.67	4.19	3.54	0.29	0.23	0.61	0.38	2.72	3.33	9.18	5.08	0.2
	Dig eriS	0.00	0.29	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.10	0.0
	Era cur	1.36	0.83	2.29	1.50	0.00	0.00	0.00	0.00	2.08	1.26	1.25	1.53	0.0
	Era leh	24.45	41.55	47.64	37.88	9.54	25.22	10.95	15.24	21.29	42.39	35.38	33.02	10.6
	Het con	0.00	0.00	1.73	0.58	0.00	0.00	0.64	0.21	0.00	0.52	2.99	1.17	0.7
	Pan max	0.00	0.00	0.31	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Spo fim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	The tri	1.56	4.51	11.24	5.77	0.00	0.00	0.00	0.00	0.00	1.61	4.31	1.97	0.0
	Tra ber	32.62	32.03	5.16	23.27	10.02	11.54	6.69	9.42	28.75	27.03	15.20	23.66	17.5
	Tra koe	0.00	0.00	0.64	0.21	0.00	0.00	0.00	0.00	0.00	0.85	0.31	0.39	0.0
	Uro pan	25.90	2.43	0.00	9.44	7.11	0.00	0.00	2.37	37.83	2.15	0.31	13.43	12.4
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100

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-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSOWH	RSOWH	RSOWH	RDWH	RDWH	RDWH	RDWH	CWH	CWH	CWH	CWH	RWH	RWH	RWH	RWH
27	2.38	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.60	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.93	28.66	23.31	17.45	30.63	41.08	29.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	7.09	11.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.17	33.08	24.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	2.66	3.70	11.86	14.31	15.42	13.87	13.93	10.61	23.94	16.16	12.15	13.53	18.72	14.80
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.58	1.13	3.70	7.04	3.04	4.59	7.23	9.56	7.18	7.99	0.66	4.13	7.77	4.19
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	1.48	0.81	0.29	0.00	0.88	0.39	4.97	3.48	5.92	4.79	4.77	1.67	4.19	3.54
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.10
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	0.00	4.21	1.79	1.36	0.83	2.29	1.50
.99	20.79	19.15	11.09	31.20	29.46	23.92	14.78	43.29	42.16	33.41	24.45	41.55	47.64	37.88
35	1.22	1.11	0.33	1.03	1.82	1.06	0.29	1.33	2.44	1.35	0.00	0.00	1.73	0.58
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.10	0.00	0.00	0.31	0.10
00	0.29	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.11	0.00	0.00	0.00	0.00
00	0.00	0.00	2.15	2.14	7.07	3.79	1.77	2.78	6.20	3.58	1.56	4.51	11.24	5.77
.65	1.17	9.80	36.19	12.82	1.21	16.74	43.20	27.69	5.87	25.59	32.62	32.03	5.16	23.27
22	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	1.14	0.38	0.00	0.00	0.64	0.21
00	0.00	4.14	16.94	0.84	0.00	5.93	12.65	1.27	0.32	4.75	25.90	2.43	0.00	9.44
00	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 5 Basal Cover: Three years and Average: No Herbicide: 0.75 m Rows (Appendix A for abbreviat

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04
	Restoration technologies →	RN	RN	RN	RN	RSN	RSN	RSN	RSN	RON	RON	RON	RON	RSON
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.10	0.00	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	2.27	5.24	8.11	5.21	0.00	0.00	0.00	0.00	2.21
	Era cur S	0.00	0.00	0.00	0.00	0.99	0.00	0.94	0.64	0.00	0.00	0.00	0.00	0.32
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	1.90	2.77	4.82	3.16	0.00	0.00	0.00	0.00	0.32
Natural occurring	Ari con	0.61	1.59	1.43	1.21	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.09	0.00
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	0.00	1.25	3.41	1.55	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.09	0.00
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	0.28	0.62	0.62	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era leh	0.00	0.33	2.14	0.82	0.33	1.43	0.00	0.59	0.63	0.56	0.33	0.51	0.00
	Het con	0.00	0.65	1.37	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.11	0.62
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri	0.00	0.98	1.81	0.93	0.00	0.00	0.00	0.00	0.00	0.00	1.65	0.55	0.00
	Tra ber	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.28	0.00
	Tra koe	0.00	0.00	0.56	0.19	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.11	0.00
	Uro pan	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
	Total	0.89	5.41	11.35	5.88	5.80	9.44	14.16	9.80	0.95	1.94	2.31	1.74	3.47

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5	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
	RSON	RSON	RDN	RDN	RDN	RDN	CN	CN	CN	CN	P	P	P	P
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	11.64	6.87	2.10	7.49	14.86	8.15	0.00	0.00	0.00	0.00	0.00	0.58	1.92	0.83
7	0.93	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	4.80	2.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.25	0.00	0.08	0.91	1.22	0.65	0.93	0.00	0.55	0.26	0.27
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.10	0.00	0.56	0.87	0.48
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.91	0.30	0.30	1.73	0.30	0.78	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.31	0.59	0.31	1.27	2.58	1.39	0.65	1.81	0.62	1.03	0.00	0.28	0.52	0.27
0	0.00	0.21	0.00	0.25	0.30	0.18	1.57	1.74	0.61	1.30	0.00	0.00	0.31	0.10
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.31	0.25	1.76	0.77	1.29	1.18	2.48	1.65	0.00	0.56	0.63	0.40
0	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.28	0.00	0.31	0.96	0.58	0.52	0.69
0	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.11	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.11	1.89	0.00	0.00	0.63
2	17.68	11.02	2.71	9.51	20.41	10.88	5.98	8.25	4.66	6.30	2.85	3.11	5.04	3.67

Table B 6 Basal Cover: Three years and Average: Herbicide: 0.75 m Rows (Appendix A for abbrevia

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
	Restoration technologies →	RNH	RNH	RNH	RNH	RSNH	RSNH	RSNH	RSNH	RONH	RONH	RONH	RONH
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.11	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	0.55	5.15	11.37	5.69	0.00	0.00	0.00	0.00
	Era cur S	0.00	0.00	0.00	0.00	2.15	0.00	1.53	1.23	0.00	0.00	0.00	0.00
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	0.90	4.00	9.70	4.87	0.00	0.00	0.00	0.00
Natural occurring	Ari con	0.51	0.28	1.25	0.68	0.00	0.23	0.00	0.08	0.79	0.62	0.32	0.58
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	0.70	0.00	0.98	0.56	0.00	0.00	0.00	0.00	0.26	0.00	0.32	0.20
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	0.33	0.00	0.98	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era leh	1.34	2.00	3.93	2.43	0.25	0.47	1.23	0.65	0.79	0.62	0.97	0.80
	Het con	0.00	0.28	0.32	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.00	0.32	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri	0.00	0.31	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Tra ber	0.23	0.31	0.00	0.18	0.00	0.00	0.00	0.00	0.26	0.62	0.32	0.40
	Tra koe	0.00	0.00	0.31	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Uro pan	1.44	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.09
	Total	4.57	3.19	8.09	5.28	3.86	9.83	24.15	12.61	2.38	1.87	1.94	2.06

04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSONH	RSONH	RSONH	RDNH	RDNH	RDNH	RDNH	CNH	CNH	CNH	CNH	PH	PH	PH	PH
0.20	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.29	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.36	7.46	4.46	2.98	8.18	17.70	9.62	0.00	0.00	0.00	0.00	0.00	0.77	1.50	0.76
0.52	0.57	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.86	5.15	3.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.31	0.00	0.19	0.26	0.00	0.32	0.19	0.32	0.00	0.61	0.31	0.00	0.00	0.61	0.20
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.26	0.00	0.00	0.09	0.00	0.28	1.24	0.51	0.00	0.29	0.89	0.39
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.24	0.25	0.00	0.00	0.00	0.00	0.57	1.13	0.93	0.88	0.28	0.00	0.00	0.09
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.56	0.19	0.00	0.00	0.92	0.31	0.00	0.00	0.00	0.00
0.51	1.24	0.75	0.29	1.18	1.04	0.84	0.62	2.33	2.47	1.81	0.00	0.24	0.00	0.08
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.99	1.54	0.84	0.60	0.56	0.62	0.59	0.00	0.24	0.00	0.08
0.20	0.00	0.07	0.28	0.24	0.00	0.17	0.85	0.60	0.00	0.48	1.16	2.58	0.61	1.45
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.30	0.00	0.28	0.00	0.09
1.97	14.96	10.50	4.07	10.59	21.16	11.94	3.87	4.91	6.79	5.19	1.44	4.40	3.90	3.25

Table B 7 Basal Cover: Three years and Average: No Herbicide: 1.5 m Rows (Appendix A for abbreviati

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04
	Restoration technologies →	RW	RW	RW	RW	RSW	RSW	RSW	RSW	ROW	ROW	ROW	ROW	RSOW
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.09	0.00	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.20	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	1.39	1.70	7.13	3.41	0.00	0.00	0.00	0.00	1.22
	Era cur S	0.00	0.00	0.00	0.00	0.60	0.00	2.31	0.97	0.00	0.00	0.00	0.00	0.31
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	1.19	2.49	5.28	2.98	0.00	0.00	0.00	0.00	1.52
Natural occurring	Ari con	0.00	0.69	0.63	0.97	0.00	0.30	0.28	0.19	0.33	2.16	0.80	1.10	0.31
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	0.00	0.00	0.32	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.28	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	1.19	1.26	2.47	1.66	0.79	1.09	0.33	0.74	0.64	0.00	0.53	0.39	0.30
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	0.30	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.30	0.00
	Era leh	0.00	1.01	3.15	1.50	0.00	0.30	1.88	0.73	0.94	2.79	1.52	1.75	0.30
	Het con	0.00	1.63	1.26	1.18	0.00	0.30	0.00	0.10	0.93	0.80	0.00	0.58	0.00
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.10	0.00
	The tri	0.00	1.83	1.25	1.35	0.00	0.00	0.00	0.00	0.97	3.29	1.44	1.90	0.00
	Tra ber	0.30	0.36	0.32	0.23	0.00	0.30	0.00	0.10	1.27	0.30	0.00	0.53	0.00
	Tra koe	0.00	0.00	0.63	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.19	0.00
	Uro pan	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.11	0.60
	Total	2.12	6.78	10.02	7.40	3.97	6.49	18.10	9.52	5.41	9.34	6.91	7.22	4.56

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-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSOW	RSOW	RSOW	RDW	RDW	RDW	RDW	CW	CW	CW	CW	RW	RW	RW	RW
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
82	8.25	4.10	1.80	3.93	11.14	5.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.82	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	4.60	3.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.56	1.28	0.61	0.00	0.69	0.63	0.97
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.11	0.00	0.00	0.32	0.11
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.32	0.21	0.00	1.74	0.89	0.88	0.63	3.13	3.32	2.36	1.19	1.26	2.47	1.66
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.30	0.00	0.29	0.20	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.21
24	1.25	0.60	0.58	0.91	0.89	0.79	1.67	1.67	0.64	1.33	0.00	1.01	3.15	1.50
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.21	0.00	1.63	1.26	1.18
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.89	0.62	1.17	0.90	0.63	1.63	1.96	1.41	0.00	1.83	1.25	1.35
31	0.00	0.10	0.28	0.31	0.00	0.20	0.31	0.00	0.00	0.10	0.30	0.36	0.32	0.23
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.65	0.39	0.00	0.00	0.63	0.21
.00	0.00	0.20	0.58	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
60	15.24	8.80	4.43	7.50	14.38	8.77	3.24	7.49	8.83	6.52	2.12	6.78	10.02	7.40

Table B 8 Basal Cover: Three years and Average: Herbicide: 1.5 m Rows (Appendix A for abbreviations

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04
	Restoration technologies →	RWH	RWH	RWH	RWH	RSWH	RSWH	RSWH	RSWH	ROWH	ROWH	ROWH	ROWH	RSOWH
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.26	0.32	0.19	0.00	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	0.56	4.24	9.25	4.68	0.00	0.00	0.00	0.00	0.00
	Era cur S	0.00	0.00	0.00	0.00	2.35	1.54	0.99	1.63	0.00	0.00	0.00	0.00	0.00
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	0.87	3.73	7.83	4.14	0.00	0.00	0.00	0.00	0.00
Natural occurring	Ari con	0.00	0.27	0.95	0.41	0.00	0.00	0.00	0.00	0.55	0.31	0.91	0.59	0.00
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	0.00	0.00	0.32	0.11	0.00	0.27	0.00	0.09	0.00	0.27	0.00	0.09	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	0.00	0.00	0.32	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era leh	2.32	3.08	1.52	2.30	0.58	0.27	1.61	0.82	0.94	2.14	1.53	1.54	2.32
	Het con	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.20	0.00
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri	0.00	0.00	0.63	0.21	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.09	0.00
	Tra ber	0.94	0.92	0.00	0.62	0.28	0.51	0.61	0.47	0.30	1.11	0.00	0.47	0.94
	Tra koe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Uro pan	0.68	0.00	0.00	0.23	0.00	0.00	0.00	0.00	1.84	0.31	0.00	0.72	0.68
	Total	3.94	4.27	3.73	3.98	4.64	10.82	20.60	12.02	3.63	4.42	3.04	3.70	3.94

-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
	RSOWH	RSOWH	RDWH	RDWH	RDWH	RDWH	CWH	CWH	CWH	CWH	RWH	RWH	RWH	RWH
00	0.00	0.00	0.00	0.26	0.32	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.56	4.24	9.25	4.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	2.35	1.54	0.99	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.87	3.73	7.83	4.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.95	0.41	0.00	0.00	0.00	0.00	0.55	0.31	0.91	0.59	0.00	0.27	0.95	0.41
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.32	0.11	0.00	0.27	0.00	0.09	0.00	0.27	0.00	0.09	0.00	0.00	0.32	0.11
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.32	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.11
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08	1.52	2.30	0.58	0.27	1.61	0.82	0.94	2.14	1.53	1.54	2.32	3.08	1.52	2.30
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.20	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.63	0.21	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.09	0.00	0.00	0.63	0.21
92	0.00	0.62	0.28	0.51	0.61	0.47	0.30	1.11	0.00	0.47	0.94	0.92	0.00	0.62
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.23	0.00	0.00	0.00	0.00	1.84	0.31	0.00	0.72	0.68	0.00	0.00	0.23
27	3.73	3.98	4.64	10.82	20.60	12.02	3.63	4.42	3.04	3.70	3.94	4.27	3.73	3.98

Table B 9 Density data: Three years and Average: No Herbicide: 0.75 m Rows (Appendix A for abbrev

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-0
	Restoration technologies →	RN	RN	RN	RN	RSN	RSN	RSN	RSN	RON	RON	RON	RON	RSON
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
	Cym excS	0.00	0.00	0.00	0.00	0.11	0.00	0.49	0.20	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	4.17	6.62	11.15	7.31	0.00	0.00	0.00	0.00	5.29
	Era cur S	0.00	0.00	0.00	0.00	8.26	14.49	6.14	9.63	0.00	0.00	0.00	0.00	16.8
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
	The tri S	0.00	0.00	0.00	0.00	16.08	16.66	18.71	17.15	0.00	0.00	0.00	0.00	10.6
Natural occurring	Ari con	26.20	30.37	26.43	27.67	18.48	16.29	12.20	15.66	40.13	24.27	15.92	26.77	23.4
	Cen cil	0.47	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	0.20	0.17	0.32	0.23	0.47	0.19	0.00	0.22	0.70	1.78	0.30	0.93	1.69
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	10.90	21.87	24.90	19.22	3.70	3.16	6.16	4.34	1.35	9.45	11.21	7.34	4.00
	Dig eriS	0.67	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.08	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.08	0.00	0.00	0.00	0.00	0.00
	Era cur	3.76	1.93	3.35	3.01	0.00	0.00	0.00	0.00	1.94	0.62	0.79	1.12	0.00
	Era leh	18.59	32.22	24.94	25.25	22.54	30.94	33.46	28.98	15.57	31.52	47.85	31.65	8.90
	Het con	0.23	1.60	2.31	1.38	0.58	1.10	2.99	1.56	0.75	3.02	3.65	2.47	1.01
	Pan max	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.37	0.00	0.12	0.18	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
	The tri	3.15	4.61	9.84	5.87	0.00	0.00	0.00	0.00	3.15	6.24	8.32	5.90	0.00
	Tra ber	12.53	0.98	1.51	5.01	9.52	6.52	3.17	6.40	22.52	18.41	8.39	16.44	13.8
	Tra koe	4.81	4.98	6.28	5.35	0.33	3.33	5.29	2.98	1.71	2.22	3.57	2.50	0.44
	Uro pan	18.50	0.90	0.00	6.47	15.10	0.71	0.00	5.27	11.96	2.46	0.00	4.81	13.7
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100

ons).

04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSON	RSON	RSON	RDN	RDN	RDN	RDN	CN	CN	CN	CN	RN	RN	RN	RN
.14	0.75	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.00	0.45	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.31	11.14	7.58	7.34	12.30	16.87	12.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.87	8.48	12.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.20	19.09	15.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.83	8.24	18.18	23.69	23.59	5.58	17.62	21.72	44.83	17.87	28.14	26.20	30.37	26.43	27.67
.00	0.00	0.00	0.00	0.60	0.00	0.20	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.16
.14	0.53	0.78	1.37	0.00	0.00	0.46	4.51	2.55	1.75	2.94	0.20	0.17	0.32	0.23
.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.28	8.39	4.89	4.36	4.49	11.63	6.83	5.42	5.37	18.70	9.83	10.90	21.87	24.90	19.22
.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	0.00	0.00	0.51	0.67	0.00	0.00	0.22
.00	0.00	0.00	0.00	0.00	0.61	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.00	0.00	0.00	2.32	2.25	3.18	2.58	2.00	0.48	0.46	0.98	3.76	1.93	3.35	3.01
9.54	41.09	26.51	17.08	40.80	51.96	36.61	17.98	22.28	40.04	26.77	18.59	32.22	24.94	25.25
.96	1.85	1.27	1.25	3.23	3.33	2.60	1.20	3.60	3.39	2.73	0.23	1.60	2.31	1.38
.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.04
.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.12
.00	0.00	0.00	2.70	6.48	5.96	5.05	8.11	11.29	14.52	11.31	3.15	4.61	9.84	5.87
9.72	0.00	7.87	17.41	5.28	0.88	7.86	19.57	3.90	0.68	8.05	12.53	0.98	1.51	5.01
.00	0.00	0.15	0.00	0.39	0.00	0.13	5.81	5.06	2.37	4.41	4.81	4.98	6.28	5.35
.03	0.00	4.93	22.48	0.60	0.00	7.69	12.13	0.63	0.23	4.33	18.50	0.90	0.00	6.47
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 10 Density data: Three years and Average: Herbicide: 0.75 m Rows (Appendix A for abbreviation

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04
	Restoration technologies →	RNH	RNH	RNH	RNH	RSNH	RSNH	RSNH	RSNH	RONH	RONH	RONH	RONH	RSONH
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.11	0.15	1.42	0.56	0.00	0.00	0.00	0.00	0.24
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.32	0.81	0.38	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	3.36	6.09	18.08	9.18	0.00	0.00	0.00	0.00	9.82
	Era cur S	0.00	0.00	0.00	0.00	18.21	15.34	13.76	15.77	0.00	0.00	0.00	0.00	11.03
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	14.00	19.01	24.04	19.02	0.00	0.00	0.00	0.00	8.41
Natural occurring	Ari con	11.08	15.53	15.02	13.88	8.84	5.33	2.24	5.47	13.20	13.55	27.64	18.13	9.98
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	2.54	7.54	4.59	4.89	0.23	0.15	0.00	0.13	2.62	6.55	5.39	4.85	3.55
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	5.41	2.94	8.76	5.70	1.15	1.40	3.62	2.06	3.53	2.36	7.04	4.31	15.14
	Dig eriS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	2.78	4.06	5.99	4.28	0.00	0.00	0.00	0.00	0.52	0.19	0.49	0.40	0.00
	Era leh	21.16	31.43	52.67	35.08	18.02	34.89	30.46	27.79	20.51	27.13	39.27	28.97	14.58
	Het con	0.00	0.21	1.10	0.44	0.14	0.64	1.59	0.79	0.26	0.24	1.77	0.76	0.00
	Pan max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.11	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.05	0.00
	The tri	2.11	3.82	2.69	2.87	0.00	0.00	0.00	0.00	1.66	1.33	1.20	1.40	0.00
	Tra ber	19.04	32.25	8.87	20.05	12.40	16.68	2.40	10.49	14.92	44.11	16.49	25.17	13.14
	Tra koe	0.00	0.36	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.04	0.00
	Uro pan	35.88	1.75	0.32	12.65	23.52	0.00	1.59	8.37	42.78	4.54	0.44	15.92	14.11
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100

-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
[illegible]	RSONH	RSONH	RDNH	RDNH	RDNH	RDNH	CNH	CNH	CNH	CNH	RNH	RNH	RNH	RNH
42	0.64	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.40	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03	11.35	8.73	9.35	9.16	16.82	11.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.69	21.12	14.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.20	12.22	12.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	1.36	5.34	12.74	9.23	10.77	10.91	11.01	15.61	14.98	13.87	11.08	15.53	15.02	13.88
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	0.00	1.83	5.41	3.74	0.00	3.05	6.51	11.31	12.52	10.11	2.54	7.54	4.59	4.89
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.91	20.94	16.99	0.74	2.46	6.05	3.09	6.95	8.00	14.46	9.80	5.41	2.94	8.76	5.70
00	0.00	0.00	0.00	0.00	0.00	0.00	8.70	0.00	0.00	2.90	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.37	3.61	8.76	4.25	0.08	1.22	2.71	1.34	2.78	4.06	5.99	4.28
.98	24.36	20.31	11.77	15.97	38.09	21.94	9.78	23.57	35.21	22.85	21.16	31.43	52.67	35.08
00	0.00	0.00	2.55	0.39	1.41	1.45	0.00	0.13	0.41	0.18	0.00	0.21	1.10	0.44
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.04
00	0.00	0.00	5.37	7.41	14.82	9.20	0.41	0.56	2.34	1.11	2.11	3.82	2.69	2.87
.41	7.37	13.98	24.74	46.95	3.28	24.99	40.09	38.35	17.15	31.86	19.04	32.25	8.87	20.05
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.20	0.00	0.36	0.00	0.12
47	0.25	4.95	26.94	1.08	0.00	9.34	16.47	0.62	0.22	5.77	35.88	1.75	0.32	12.65
)0	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 11 Density data: Three years and Average: No Herbicide: 1.5 m Rows (Appendix A for abbrevi

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-0
	Restoration technologies →	RW	RW	RW	RW	RSW	RSW	RSW	RSW	ROW	ROW	ROW	ROW	RSOW
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.22	0.00	0.00	0.00	0.00	0.5
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.44	0.23	0.22	0.00	0.00	0.00	0.00	0.0
	Dig eriS	0.00	0.00	0.00	0.00	5.58	6.73	8.82	7.04	0.00	0.00	0.00	0.00	3.5
	Era cur S	0.00	0.00	0.00	0.00	5.89	7.79	4.52	6.06	0.00	0.00	0.00	0.00	12.6
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	The tri S	0.00	0.00	0.00	0.00	5.65	10.17	12.81	9.55	0.00	0.00	0.00	0.00	7.6
Natural occurring	Ari con	24.15	25.55	12.99	22.97	28.00	16.63	17.31	20.65	26.91	28.83	27.82	27.85	25.3
	Cen cil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Chl vir	1.76	0.38	0.00	0.18	3.87	0.57	0.42	1.62	2.20	2.94	1.75	2.30	5.0
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Cyn hir	10.15	11.09	22.10	18.35	3.33	11.44	11.50	8.76	0.49	4.16	3.67	2.77	1.0
	Dig eriS	0.00	0.13	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Era cur	4.15	3.45	1.42	2.27	0.00	0.00	0.00	0.00	7.11	1.43	2.45	3.66	0.0
	Era leh	14.01	31.84	44.05	36.04	19.02	33.48	40.79	31.10	10.31	32.09	44.87	29.09	13.6
	Het con	1.13	0.67	1.49	1.26	0.62	0.22	1.78	0.87	0.58	1.84	3.36	1.93	0.2
	Pan max	0.05	0.12	1.45	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Spo fim	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.07	0.0
	The tri	3.98	7.23	12.04	7.96	0.00	0.00	0.00	0.00	3.64	7.24	12.12	7.67	0.0
	Tra ber	9.92	11.36	1.94	4.76	10.29	5.65	0.69	5.55	33.76	14.32	0.83	16.30	11.0
	Tra koe	11.29	4.61	2.31	3.97	0.99	6.65	0.46	2.70	0.00	5.61	2.58	2.73	0.3
	Uro pan	19.40	3.56	0.21	1.56	16.76	0.22	0.00	5.66	15.00	1.54	0.35	5.63	18.9
	Total	100	100	100	100	100	100	100	100	100	100	100	100	10

s).

04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
RSOW	RSOW	RSOW	RDW	RDW	RDW	RDW	CW	CW	CW	CW	RW	RW	RW	RW
0.33	1.76	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.21	0.29	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.90	9.60	6.36	3.88	8.46	9.33	7.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.08	4.35	7.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.13	18.33	13.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23.96	11.47	20.27	25.32	21.01	15.51	20.61	35.05	28.79	24.85	29.57	24.15	25.55	12.99	22.97
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.59	0.21	1.93	2.81	0.65	0.40	1.29	2.52	2.77	0.40	1.89	1.76	0.38	0.00	0.18
0.00	0.00	0.00	0.72	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.98	5.83	4.61	10.37	7.18	26.93	14.83	6.12	15.27	20.73	14.04	10.15	11.09	22.10	18.35
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.04
0.00	0.45	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.62	2.80	3.17	2.53	0.47	1.05	1.04	0.85	4.15	3.45	1.42	2.27
33.28	44.13	30.34	15.15	41.39	36.22	30.92	16.81	26.01	30.64	24.48	14.01	31.84	44.05	36.04
0.88	1.34	0.82	0.50	1.81	1.33	1.21	2.27	3.85	5.47	3.87	1.13	0.67	1.49	1.26
0.00	0.00	0.00	0.05	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.12	1.45	0.52
0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	2.68	0.89	0.00	0.00	0.00	0.12
0.00	0.00	0.00	3.69	8.82	6.85	6.45	3.87	4.83	3.53	4.08	3.98	7.23	12.04	7.96
5.47	1.12	5.88	19.83	6.11	0.26	8.73	18.96	6.02	0.82	8.60	9.92	11.36	1.94	4.76
3.48	0.89	1.57	0.00	1.49	0.00	0.50	0.64	10.41	9.83	6.96	11.29	4.61	2.31	3.97
0.70	0.22	6.61	16.04	0.27	0.00	5.44	13.30	1.00	0.00	4.77	19.40	3.56	0.21	1.56
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 12 Density data: Three years and Average: Herbicide: 1.5 m Rows (Appendix A for abbreviations).

←Species	Year	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04
	Restoration technologies →	RWH	RWH	RWH	RWH	RSWH	RSWH	RSWH	RSWH	ROWH	ROWH	ROWH	ROWH	RSOWH
Re-seeded	Cen cil S	0.00	0.00	0.00	0.00	0.00	0.00	2.31	0.77	0.00	0.00	0.00	0.00	0.16
	Cym excS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dig eriS	0.00	0.00	0.00	0.00	4.00	5.43	15.96	8.46	0.00	0.00	0.00	0.00	5.70
	Era cur S	0.00	0.00	0.00	0.00	14.97	7.91	10.23	11.04	0.00	0.00	0.00	0.00	15.44
	Pan max S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	The tri S	0.00	0.00	0.00	0.00	10.55	10.96	22.73	14.75	0.00	0.00	0.00	0.00	11.31
Natural occurring	Ari con	10.11	9.67	18.73	12.84	8.02	9.19	5.42	7.54	10.01	8.26	16.65	11.64	8.24
	Cen cil	0.00	1.11	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chl vir	0.52	4.54	4.82	3.29	0.37	1.30	0.29	0.65	3.90	4.71	9.74	6.12	3.28
	Cym excS	0.00	0.16	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cyn hir	2.47	2.84	7.27	4.19	3.01	1.63	1.14	1.93	3.63	11.71	13.36	9.57	1.68
	Dig eriS	0.10	2.86	0.00	0.98	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.09	0.00
	Eli mut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Era cur	1.47	3.38	1.90	2.25	0.00	0.00	0.00	0.00	0.70	0.30	0.50	0.50	0.00
	Era leh	21.33	26.38	50.73	32.81	19.91	33.40	39.04	30.78	25.33	29.92	30.76	28.67	19.98
	Het con	0.00	0.16	0.24	0.13	0.12	0.15	0.00	0.09	0.00	0.10	0.19	0.09	0.58
	Pan max	0.00	0.15	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spo fim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
	The tri	2.47	7.61	3.60	4.56	0.00	0.00	0.00	0.00	1.13	1.68	0.45	1.09	0.00
	Tra ber	24.46	39.11	11.70	25.09	11.82	29.33	2.88	14.68	22.82	37.35	26.81	28.99	12.93
	Tra koe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	2.38	0.00	0.85	0.62
	Uro pan	37.08	2.04	1.01	13.37	27.23	0.71	0.00	9.31	32.05	3.60	1.54	12.40	19.92
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100

05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave	03-04	04-05	05-06	Ave
	RSOWH	RSOWH	RDWH	RDWH	RDWH	RDWH	CWH	CWH	CWH	CWH	RWH	RWH	RWH	RWH
8	1.32	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.38	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	11.67	8.77	7.98	6.67	17.15	10.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	8.16	11.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	17.43	14.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	9.22	8.22	16.05	18.51	21.67	18.75	16.29	14.22	19.43	16.65	10.11	9.67	18.73	12.84
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.37
3	0.70	1.64	3.03	3.69	2.78	3.17	4.71	6.65	7.38	6.25	0.52	4.54	4.82	3.29
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.05
0	2.98	1.55	0.22	1.10	2.33	1.22	1.45	9.82	10.48	7.25	2.47	2.84	7.27	4.19
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	2.86	0.00	0.98
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.44	2.45	0.00	0.96	1.31	0.00	3.05	1.45	1.47	3.38	1.90	2.25
52	34.81	29.10	11.52	21.21	40.55	24.43	15.51	22.84	33.19	23.85	21.33	26.38	50.73	32.81
6	1.87	0.87	0.00	1.23	1.23	0.82	0.00	0.00	1.16	0.39	0.00	0.16	0.24	0.13
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.05
0	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	2.15	4.97	4.48	3.86	2.43	1.44	4.35	2.74	2.47	7.61	3.60	4.56
55	8.54	13.01	28.59	38.64	9.81	25.68	44.33	44.10	19.26	35.90	24.46	39.11	11.70	25.09
0	2.68	1.10	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.05	0.00	0.00	0.00	0.00
8	0.23	8.41	30.01	1.53	0.00	10.51	13.83	0.93	1.70	5.49	37.08	2.04	1.01	13.37
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table B 13 Initial species distribution in study area for the restoration technologies without the application

RN1		RW1		RSN1		RSW1		CN1		CW1		RSON2	
Ari con	17.00	Ari con	22.77	Cen cilS	0.99	Cen cilS	1.79	Ari con	16.00	Ari con	16.30	Dig eriS	1
Chl vir	2.00	Chl vir	2.97	Cym excS	0.99	Cym excS	0.89	Cyn hir	2.00	Era chl	3.26	Era curS	
Cyn hir	18.00	Cyn hir	2.97	Dig eriS	25.74	Dig eriS	17.86	Era chl	2.00	Era leh	47.83	The triS	
Era leh	41.00	Era leh	20.79	Era curS	27.72	Era curS	17.86	Era leh	28.00	Het con	2.17	Ari con	1
The tri	4.00	Spo fim	0.99	The triS	23.76	The triS	17.86	Het con	1.00	The tri	13.04	Era leh	1
Tra ber	6.00	The tri	4.95	Ari con	8.91	Ari con	10.71	The tri	29.00	Tra ber	1.09	Het con	
Uro pan	12.00	Tra ber	10.89	Era leh	0.99	Cyn hir	1.79	Tra ber	11.00	Tra koe	2.17	Tra ber	1
		Uro pan	33.66	Tra ber	10.89	Era leh	2.68	Uro pan	11.00	Uro pan	14.13	Uro pan	2
						Tra ber	9.82						
						Tra koe	0.89						
						Uro pan	17.86						

RON1		ROW1		RDN1		RDW1		RN2		RW2		RDN2	
Ari con	3.92	Ari con	6.86	Dig eriS	42.11	Dig eriS	16.35	Ari con	15.91	Ari con	20.59	Dig eriS	1
Cyn hir	3.92	Cyn hir	5.88	Ari con	6.14	Ari con	4.81	Chl vir	1.14	Chl vir	0.98	Ari con	2
Era chl	0.98	Era chl	0.00	Cyn hir	1.75	Cyn hir	0.96	Era chl	4.55	Cyn hir	0.98	Chl vir	
Era leh	50.00	Era leh	35.29	Era chl	0.00	Era chl	8.65	Era leh	12.50	Era chl	1.96	Era chl	
The tri	1.96	The tri	3.92	Era leh	15.79	Era leh	14.42	The tri	4.55	Era leh	8.82	Era leh	
Tra ber	23.53	Tra ber	34.31	The tri	2.63	The tri	3.85	Tra ber	28.41	Het con	1.96	Het con	
Uro pan	15.69	Uro pan	13.73	Tra ber	20.18	Tra ber	33.65	Tra koe	6.82	The tri	4.90	The tri	1
				Uro pan	11.40	Uro pan	17.31	Uro pan	26.14	Tra ber	32.35	Tra ber	2
										Uro pan	27.45	Tra koe	
												Uro pan	1

RSON1		RSOW1		P1		RSN2		RSW2		RON2	
Dig eriS	17.14	Cen cilS	0.92	Ari con	0.99	Dig eriS	13.73	Dig eriS	13.73	Ari con	2
Era curS	34.29	Dig eriS	15.60	The tri	0.99	Era curS	19.61	Era curS	20.59	Chl vir	
The triS	15.24	Era curS	21.10	Tra ber	24.75	The triS	17.65	The triS	7.84	Cyn hir	
Ari con	3.81	The triS	11.01	Tra koe	0.00	Ari con	1.96	Ari con	11.76	Era chl	
Cyn hir	2.86	Ari con	1.83	Uro pan	73.27	Chl vir	0.98	Cyn hir	2.94	Era leh	1
Era leh	7.62	Cyn hir	0.92			Era leh	14.71	Era leh	17.65	Het con	
Tra ber	14.29	Era leh	27.52			Het con	0.98	Tra ber	17.65	The tri	
Uro pan	4.76	Tra ber	14.68			Tra ber	17.65	Uro pan	7.84	Tra ber	2
		Uro pan	6.42			Uro pan	12.75			Uro pan	1

Roundup (1st year % frequency) (Appendix A for abbreviations).

RSOW2		P2		RSN3		RSW3		RN3		RW3	
Dig eriS	9.35	Ari con	5.50	Cen cilS	0.93	Dig eriS	10.81	Ari con	31.09	Ari con	7.14
Era curS	0.93	Era leh	1.83	Dig eriS	11.11	The triS	6.31	Chl vir	1.68	Chl vir	2.68
The triS	12.15	Tra ber	16.51	Era curS	5.56	Ari con	6.31	Cyn hir	7.56	Cyn hir	23.21
Ari con	22.43	Uro pan	76.15	Pan maxS	0.93	Chl vir	11.71	Era chl	10.92	Era chl	6.25
Chl vir	2.80			The triS	8.33	Cyn hir	5.41	Era leh	14.29	Era leh	26.79
Cyn hir	1.87			Ari con	26.85	Era leh	18.02	Het con	0.84	Het con	1.79
Era leh	17.76			Chl vir	2.78	Het con	0.90	Pan max	2.52	The tri	3.57
Het con	0.93			Era leh	6.48	Tra ber	18.02	The tri	5.04	Tra ber	13.39
Tra ber	13.08			Het con	3.70	Uro pan	22.52	Tra ber	4.20	Tra koe	0.89
Tra koe	0.93			Tra ber	14.81			Tra koe	0.84	Uro pan	14.29
Uro pan	17.76			Tra koe	1.85			Uro pan	21.01		
				Uro pan	16.67						

RDW2		CN2		CW2		RSON3		RSOW3		RDN3		RDW3	
Dig eriS	13.56	Ari con	23.81	Ari con	20.75	Cen cilS	0.93	Dig eriS	10.81	Dig eriS	24.77	Dig eriS	10.71
Ari con	19.49	Chl vir	3.81	Chl vir	1.89	Dig eriS	11.11	The triS	6.31	Ari con	7.34	Ari con	4.46
Chl vir	2.54	Cyn hir	6.67	Cyn hir	0.94	Era curS	5.56	Ari con	6.31	Chl vir	1.83	Chl vir	0.89
Cyn hir	5.93	Era chl	0.95	Era chl	1.89	Pan maxS	0.93	Chl vir	11.71	Cyn hir	9.17	Cyn hir	16.07
Era leh	13.56	Era leh	27.62	Era leh	13.21	The triS	8.33	Cyn hir	5.41	Era chl	4.59	Era chl	6.25
Het con	5.08	Het con	5.71	Het con	9.43	Ari con	26.85	Era leh	18.02	Era leh	14.68	Era leh	16.96
The tri	8.47	The tri	12.38	The tri	8.49	Chl vir	2.78	Het con	0.90	Het con	7.34	Het con	0.89
Tra ber	10.17	Tra ber	7.62	Tra ber	29.25	Era leh	6.48	Tra ber	18.02	The tri	6.42	Pan max	0.89
Uro pan	21.19	Tra koe	0.95	Tra koe	4.72	Het con	3.70	Uro pan	22.52	Tra ber	9.17	Spo fim	0.89
		Uro pan	10.48	Uro pan	9.43	Tra ber	14.81			Uro pan	14.68	The tri	9.82
						Tra koe	1.85					Tra ber	13.39
						Uro pan	16.67					Uro pan	18.75

ROW2		RON3		ROW3		P3		CN3		CW3	
Ari con	15.74	Ari con	22.86	Ari con	29.70	Ari con	4.81	Ari con	22.32	Ari con	2.86
Cyn hir	0.93	Chl vir	0.95	Chl vir	0.99	Chl vir	0.96	Chl vir	7.14	Chl vir	2.86
Era chl	3.70	Cyn hir	1.90	Cyn hir	1.98	The tri	1.92	Cyn hir	7.14	Cyn hir	24.76
Era leh	21.30	Era leh	17.14	Era chl	1.98	Tra ber	39.42	Era leh	13.39	Era leh	26.67
Het con	2.78	The tri	8.57	Era leh	8.91	Tra koe	0.96	Het con	5.36	Het con	1.90
The tri	12.04	Tra ber	38.10	Het con	1.98	Uro pan	51.92	The tri	8.93	The tri	10.48
Tra ber	27.78	Tra koe	2.86	The tri	7.92			Tra ber	15.18	Tra ber	22.86
Tra koe	0.93	Uro pan	7.62	Tra ber	25.74			Tra koe	7.14	Tra koe	0.95
Uro pan	14.81			Uro pan	20.79			Uro pan	13.39	Uro pan	6.67

Table B 14 Initial species distribution in study area for the restoration technologies with the application o

RNH1		RWH1		RSNH1		RSWH1		CNH1		CWH1		RSONH	
Ari con	9.35	Ari con	4.35	Dig eriS	32.61	Cen cilS	1.54	Ari con	9.43	Ari con	11.11	Cen cilS	
Chl vir	3.74	Chl vir	0.87	Era curS	10.14	Cym excS	1.54	Chl vir	2.83	Chl vir	3.03	Cym excS	
Cyn hir	4.67	Cyn hir	1.74	The triS	39.13	Dig eriS	21.54	Cyn hir	0.94	Cyn hir	1.01	Dig eriS	
Era chl	1.87	Era chl	0.87	Ari con	1.45	Era curS	4.62	Era leh	33.96	Era leh	34.34	Era curS	
Era leh	53.27	Era leh	60.00	Era leh	15.94	The triS	23.85	Het con	0.94	Het con	3.03	The triS	
The tri	1.87	The tri	2.61	Het con	0.72	Ari con	3.08	Tra ber	50.94	The tri	4.04	Ari con	
Tra ber	19.63	Tra ber	26.09			Chl vir	5.38	Uro pan	0.94	Tra ber	41.41	Chl vir	
Uro pan	5.61	Uro pan	3.48			Era leh	26.92			Uro pan	2.02	Era leh	
						Tra ber	10.77					Tra ber	
						Uro pan	0.77						

RONH1		ROWH1		RDNH1		RDWH1		RNH2		RWH2		RDNH	
Ari con	19.35	Ari con	15.09	Dig eriS	49.40	Dig eriS	27.27	Ari con	15.13	Ari con	17.43	Dig eriS	
Chl vir	7.53	Chl vir	5.66	Ari con	4.17	Ari con	13.22	Chl vir	5.04	Chl vir	8.26	Ari con	
Cyn hir	1.08	Cyn hir	2.83	Chl vir	0.60	Chl vir	7.44	Era leh	21.01	Era leh	19.27	Chl vir	
Era chl	2.15	Eli mut	0.94	Cyn hir	0.60	Era leh	30.58	The tri	5.04	The tri	2.75	Era leh	
Era leh	61.29	Era chl	3.77	Era leh	22.62	Tra ber	19.83	Tra ber	52.10	Tra ber	51.38	Het con	
The tri	1.08	Era leh	33.02	Het con	0.60	Uro pan	1.65	Uro pan	1.68	Uro pan	0.92	The tri	
Tra ber	7.53	Tra ber	30.19	The tri	4.17							Tra ber	
		Tra koe	0.94	Tra ber	16.67							Tra koe	
		Uro pan	7.55	Uro pan	1.19							Uro pan	

RSONH1		RSOWH1		PH1		RSNH2		RSWH2		RONH	
Cen cilS	1.80	Dig eriS	29.61	Ari con	5.93	Dig eriS	19.26	Dig eriS	15.49	Ari con	
Dig eriS	29.34	Era curS	9.87	Chl vir	5.08	Era curS	4.44	Era curS	10.56	Chl vir	
Era curS	7.78	The triS	28.95	Era leh	0.85	The triS	49.63	The triS	30.99	Cyn hir	
The triS	16.77	Ari con	3.29	Tra ber	73.73	Ari con	2.22	Ari con	0.70	Era leh	
Chl vir	0.60	Cyn hir	1.97	Uro pan	14.41	Chl vir	0.74	Chl vir	2.82	The tri	
Cyn hir	23.95	Era leh	9.21			Era leh	19.26	Cyn hir	0.70	Tra ber	
Era leh	13.77	Het con	0.66			Tra ber	4.44	Era leh	19.72	Uro pan	
Tra ber	5.99	Tra ber	15.79					Tra ber	19.01		
		Tra koe	0.66								

ndup (1st year % frequency) (Appendix A for abbreviations).

	RSOWH2		PH2		RSNH3		RSWH3		RNH3		RWH3	
3	Cen cilS	0.81	Cen cilS	0.81	Dig eriS	25.00	Dig eriS	22.03	Ari con	11.02	Ari con	18.85
7	Cym excS	0.81	Cym excS	0.81	Era curS	18.13	The triS	15.25	Chl vir	11.02	Chl vir	3.28
5	Dig eriS	20.16	Dig eriS	20.16	The triS	37.50	Ari con	4.24	Era chl	0.85	Cyn hir	3.28
5	Era curS	7.26	Era curS	7.26	Ari con	3.75	Era leh	54.24	Era leh	53.39	Era chl	1.64
3	The triS	40.32	The triS	40.32	Chl vir	0.63	Het con	3.39	Het con	5.08	Era leh	45.90
4	Ari con	0.81	Ari con	0.81	Era leh	13.75	.	0.85	The tri	7.63	The tri	8.20
3	Era leh	14.52	Era leh	14.52	Het con	0.63			Tra ber	11.02	Tra ber	18.85
1	Tra ber	15.32	Tra ber	15.32	Uro pan	0.63						
8												

	RDWH2		CNH2		CWH2		RSONH3		RSOWH3		RDNH3		RDWH3	
0	Dig eriS	27.59	Ari con	19.42	Ari con	11.54	Dig eriS	25.00	Dig eriS	22.03	Dig eriS	35.94	Dig eriS	37.04
0	Ari con	16.38	Chl vir	23.30	Chl vir	17.31	Era curS	18.13	The triS	15.25	Ari con	7.81	Ari con	13.33
5	Chl vir	12.93	Cyn hir	1.94	Cyn hir	1.92	The triS	37.50	Ari con	4.24	Chl vir	5.47	Chl vir	0.74
6	Era leh	26.72	Era leh	25.24	Era leh	41.35	Ari con	3.75	Era leh	54.24	Cyn hir	1.56	Era leh	36.30
1	Het con	0.86	Tra ber	29.13	Het con	0.96	Chl vir	0.63	Het con	3.39	Era chl	1.56	Het con	2.22
2	The tri	3.45	Uro pan	0.97	The tri	0.96	Era leh	13.75	Tra ber	0.85	Era leh	34.38	The tri	2.96
1	Tra ber	11.21			Tra ber	25.00	Het con	0.63			The tri	9.38	Tra ber	7.41
5	Uro pan	0.86			Uro pan	0.96	Uro pan	0.63			Tra ber	3.91		
1														

	ROWH2		RONH3		ROWH3		PH3		CNH3		CWH3	
3	Ari con	8.87	Ari con	13.08	Ari con	9.45	Dig eriS	2.88	Ari con	8.47	Ari con	9.17
)	Chl vir	6.45	Chl vir	8.41	Chl vir	11.81	Ari con	6.47	Chl vir	8.47	Chl vir	8.33
3	Cyn hir	3.23	Era leh	43.93	Cyn hir	3.94	Chl vir	15.83	Cyn hir	11.02	Cyn hir	7.50
)	Era leh	52.42	Tra ber	28.97	Era leh	41.73	Cyn hir	2.16	Era leh	57.63	Era leh	54.17
3	The tri	4.84	Uro pan	5.61	Het con	1.57	Era leh	15.11	The tri	2.54	The tri	3.33
7	Tra ber	20.97			Tra ber	29.92	The tri	0.72	Tra ber	11.86	Tra ber	16.67
3	Tra koe	1.61			Uro pan	1.57	Tra ber	50.36			Uro pan	0.83
	Uro pan	1.61					Uro pan	6.47				