RE-VEGETATION DYNAMICS OF LAND CLEARED OF *ACACIA MEARNSII* (BLACK WATTLE)

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Declaration of originality

I, Melanie Jane Glaum hereby declare that the research reported in this thesis is the result of my own investigations, except where acknowledged, and has not, in its entirety or in part, been submitted to any University or Institution for degree purposes.

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26/01/2005

Date

As the chairman of the research supervisory committee, I agree / ~~do not agree~~ on the behalf of the supervisory committee to the submission of this thesis for examination.

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Disclaimer

The use of trade names in this discussion is neither an endorsement nor an indictment of any named product.

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Abstract

The overall aim of the study was to investigate re-vegetation of disturbed sites, using nursery grown plugs (from seedling trays) of *Themeda triandra*, *Heteropogon contortus* and *Hyparrhenia dregeana* in order to reach practical management guidelines for re-vegetation using indigenous grass plugs. A number of field trials were set up at Kamberg Nature Reserve (29°24'S, 29°40'E) on a site that was clear felled of *A. mearnsii* in October 1997. The trials were established in January 1998 and January 1999. A total of approximately 52,000 nursery raised plugs of *T. triandra, H. contortus* and *H. dregeana* were planted into an area of approximately 7,000 m^2.

In the planting density trial, plugs of *H. dregeana* only and a combination of *T. triandra/H. contortus* were planted at 15 cm and 30 cm spacings. The *T. triandra/H. contortus* combination at 30 spacing showed the greatest survival and lateral plant growth (tiller number and basal area) and this combination is thus recommended.

In the over-sowing trials, the *H. dregeana* and *T. triandra/H. contortus* combination at both 15 cm and 30 cm spacing were over-sown with *E. curvula*. The survival and lateral growth of the *T. triandra/ H. contortus* combination at 30 cm was again greater than the other treatments. Over-sowing with *E. curvula* suppressed the survival and lateral growth of the planted plugs across all treatments compared to not over-sowing. The over-sown conditions showed a significant decrease in the diversity of the plots, both in the number of species present and the Shannon diversity index.

An area that had been cleared of *A. mearnsii* and sown to *E. curvula* 25 years previously was shown to have a lower number of species than the neighbouring veld. Nursery raised plugs of *T. triandra* were planted into the mature *E. curvula* in an attempt to improve the biodiversity of these areas. To re-introduce *T. triandra* into these *E. curvula* swards the plugs must be planted into the centre of a gap rather than around the base of an *E. curvula* plant. For improved survival of the plugs the *E. curvula* tufts must be clipped, while for best lateral growth the *E. curvula* tufts must be sprayed with a glyphosate herbicide three months prior to planting and clipping. However, the added expense of spraying and clipping is not warranted as the clipped treatments also showed good growth.

Transplant shock is common when planting nursery raised plugs out into the field, as there is a relatively small root volume in the plug compared to the above ground leaf biomass. Alleviation of moisture stress at planting using a starch based polymer with high water holding capacity (Terrasorb®) and a white, needle punched geo-fabric (Agrilen®) to provide a seven day period of artificial shade after planting did not show significant improvements over the control with regards to survival or plant growth. Thus these methods of moisture amelioration are not recommended in re-vegetation through planting of plugs at this study site.

A trial was established to investigate the biomass production of six different treatments to determine their potential to support a fire. The total biomass for the plots which were over-sown by *E. tef* and planted to only *H. dregeana* were on average sufficient for a fire, but there was a discontinuous fuel load across these plots, especially in the replications that had very low survival rates and thus these plots could not be burnt. The control and herbicide sprayed plots also showed sufficient fuel load for

a fire, but this fuel load was made up of *A. mearnsii* saplings and bramble with very little grass cover and thus a fire would not have burnt through these plots either. The *T. triandra/H. contortus* combination did not produce sufficient fuel load, due to poor survival. Thus only the plots over-sown with *E. curvula* were able to burn in this trial and as a burning trial *per sê* the trial was abandoned.

Seed bearing hay (thatch) was collected in early summer (December 1997) and late summer (April 1998). Both times of year of harvesting proved to be successful in terms of grass cover, although the early harvested thatch had a greater number of species per plot. The Shannon diversity indexes of the two treatments were not significantly different. The multi-response permutation procedure technique confirmed that there was a compositional difference between the treatments. By the end of the trial *Harpochloa falx* and *T. triandra* and *H. dregeana* were indicators for the early and the late harvested thatch respectively. Comparing the thatching trial and the planting density trial indicated that the *T. triandra/H. contortus* combination at 30 cm spacing would be recommended to maximize biodiversity.

The summer months have been shown to be the best time to plant the plugs, although the actual success will be dependant on the conditions within a particular year. The plugs should not be kept in the nursery for longer than three months and larger plugs (96 seedlings per tray) should be used.

Nursery raised plugs of *T. triandra* and *H. contortus* were planted in an equal mix in an area that was cleared of *A. mearnsii* in 1996. By June 1998 661 *H. contortus* seedlings and 14 *T. triandra* seedlings had germinated naturally. The November 1998 population consisted of 418 *H. contortus* seedlings and 18 *T. triandra* seedlings. By May 2000 the June 1998 population showed a survival of 78.4% and the November 1998 population showed a survival of 91.1%.

In the various trials, the ability of the nursery raised plugs used for re-vegetation to suppress the re-growth of *A. mearnsii* was investigated by determining the number of *A. mearnsii* seedlings per metre squared. The plant spacing and species of plugs used did not have a significant effect on the number of *A. mearnsii* seedlings per metre squared. Over-sowing with *E. curvula* did, however, significantly suppress the wattle re-growth. In the thatching trial the early harvested plots showed lower numbers of *A. mearnsii* per metre squared than the late harvest plots, as they were covered with a thick layer of thatch soon after the *A. mearnsii* was cleared which suppressed the *A. mearnsii* re-growth.

Although *E. curvula* is able to produce a high biomass and suppress the *A. mearnsii* seedlings, it has a detrimental effect on the biodiversity of the area. Therefore, in conservation areas, where biodiversity if of great importance the planted plugs (at 30 cm spacing) or seed bearing hay must be used in preference to sowing *E. curvula*, although it must be remembered that greater follow up control is likely to be needed with planted plugs or seed bearing hay. The area must be planted or thatched as soon as possible after clear felling to provide competition for the *A. mearnsii* seedlings.

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List of acronyms

ANOVA	Analysis of variance
B.P.	Before present
BRG	Bioresource Group
BRU	Bioresource Unit
Hyp	*Hyparrhenia dregeana*
KZN	KwaZulu-Natal
MRPP	Multi-Response Permutation Procedure
RGR	Relative growth rate
Them/Het	The *Themeda triandra / Heteropogon contortus* combination

1. Introduction and justification

1.1 Introduction

The KwaZulu-Natal (KZN) Drakensberg mountain range forms the main catchment area of KZN and it is therefore crucial to ensure that sound management practices are carried out to conserve the water resources of the province (Everson TM *et al.* 1988, Camp 1997). Some 243 000 ha of the KZN Drakensberg, stretching over a distance of 150 km and comprising of both the foothills and the plateau forms the uKhahlamba-Drakensberg World Heritage Site, which is under the management of Ezemvelo KwaZulu-Natal Wildlife (hereafter referred to as KZN Wildlife). The sensible management of the vegetation of these mountain catchment areas is critical for the conservation of these water resources (Everson 1985, Walker 1987, Priday 1989). Acocks (1953) described the natural vegetation of the lower slopes and foothills as Highland Sourveld (Veld type 44a); and the higher slopes and summit as *Themeda-Festuca* Alpine veld (Veld type 58). More recently, the area was described by Bredenkamp *et al* (1996) as Moist Upland Grassland (Vegetation type 42) on the lower slopes and Alti Mountain Grassland on the summit (Vegetation type 46) (Granger & Bredenkamp 1996). Camp's (1997) Bioresource groups (BRG) classify the lower slopes as Moist Highland Sourveld (BRG 8) and the summit as Montane Veld (BRG 10). The common factor amongst all three of these classifications is that grasslands are the dominant vegetation type in the area.

The study area focuses on the lower slopes of the Drakensberg, an area commonly known as the Little Berg. This area is classified as BRG 8 and occurs at an altitude between 1 400 m and 1 800 m above sea level (Camp 1997). The mean annual precipitation ranges from 800 mm to 1265 mm per annum. Mist is frequent in the area and snowfalls are common on the higher ground in winter. The mean annual temperature is 14 °C, with moderately warm summers averaging 18 °C and cold winters ranging from an average of 0 °C in the south to 6 °C in the north. Severe frosts occur during winter, with light frosts being experienced in early and late summer months (Camp 1997). The vegetation of the area is a fire maintained grassland (Everson 1985, Everson TM *et al.* 1988, Priday 1989, Camp 1997), dominated by short bunch grasses approximately 0.5 m in height (Camp 1997). The abundant grass species are *Alloteropsis semialata, Andropogon appendiculatus, Brachiaria serrata, Cymbopogon excavatus, C. validus, Digitaria tricholaenoides, Diheteropogon amplectens, Diheteropogon filifolius, Eulalia villosa, Harpochloa falx, Elionurus muticus, Eragrostis capensis, Eragrostis curvula, Eragrostis plana, Eragrostis racemosa, Heteropogon contortus, Microchloa caffra, Monocymbium ceresiiforme, Setaria nigrirostris, Sporobolus africanus, Themeda triandra, Trachypogon spicatus* and *Tristachya leucothrix*. Where fire is excluded and moisture is abundant the vegetation tends toward *Podocarpus* forest, with the initial precursors being *Cymbopogon* and *Hyparrhenia* species of grass and tree species such as *Leucosidea sericea* and *Buddleia salviifolia* (Camp 1997).

An important aspect of the natural vegetation of the Moist Highland Sourveld and Montane Veld BRGs is the diversity of the species found naturally in these areas. Biological diversity (biodiversity) can be defined at three levels, namely, genetic (within species), organismal (number of species) and ecological (community) diversity (Noss 1990, Harper & Hawksworth 1995). As the definitions of biodiversity often vary from one field of interest to another, it is important that biodiversity be defined by indicators and measurable values that will help clarify it. For example, number of species present, Shannon diversity index and indicator species that indicate a particular site, climate or change in the ecosystem can be used (Noss 1990). Ideally one should use more than one index of biodiversity to determine any changes as there may be equal numbers of species at two or more sites, but their abundance or actual composition may have changed (Noss 1990).

The stability of an ecosystem can be related to biodiversity, as there is greater resistance to the invasion of alien plants in ecosystems that are rich in species (Lovejoy 1995). Conservation efforts in the uKhahlamba-Drakensberg Park must be geared towards the maintenance of the natural biodiversity of the area. Thus, the use of indigenous species for any re-vegetation or rehabilitation work is of great importance (Campbell *et al.* 2000a). As far as possible indigenous grass species that have been collected from within the same veld type which are thus adapted to the growing conditions of the area should be used for re-vegetation (Campbell *et al.* 2000a).

One of the key alien invasive plant species threatening the natural vegetation of the KZN Drakensberg is *Acacia mearnsii* (black wattle). It is classified as a Category 2, Invaders species, in other words it was introduced into the country for its commercial value, but as it is an invasive species it can only be grown in a demarcated area for that purpose (Henderson 2001). In 1864, John van der Plank imported the first *A. mearnsii* seeds from Tasmania, to his farm in Camperdown, KZN (Bromilow 1995). It was only in 1889 that it was discovered that the bark of *A. mearnsii* secreted tannic acid, which could be used for tanning leather, and it was only after this discovery that *A. mearnsii* was planted on a large scale (Bromilow 1995). *Acacia mearnsii* is regarded as a serious problem plant in many conservation areas as it smothers the indigenous vegetation, thus reducing the biodiversity of the area (Everard 2000), creates an impenetrable jungle and reduces the water flow from catchments (Stirton 1983, Anon. 1995, Binns *et al.* 2001, Dye *et al.* 2001, Gillham & Haynes 2001). Forestry plantations will increase the evapotranspiration of an area by 80 to 90% resulting in a drop in stream flow from 20% to 10% (a 50% reduction) (Dye & Bosch 2000, Dye *et al.* 2001). The plant is highly invasive as large numbers of seed are produced, with up to 20 000 seeds m^{-2} being found in the soil below an old tree (Stirton 1983). The seeds are very persistent and have been known to remain viable for more than 50 years (Bromilow 1995). The seeds are easily spread down watercourses and their germination is stimulated by fire (Bromilow 1995). Ongoing projects have been setup through the Department of Water Affairs and Forestry and the Working for Water program to clear conservation areas of this and other exotic species (Binns *et al.* 2001, Gillham & Haynes 2001).

Long term control of *A. mearnsii* is difficult, as it coppices easily and has a high level of seed production (Bromilow 1995). Any control program must include the following three phases: initial control (drastic reduction of the existing population), follow up control (control of seedlings, root suckers and coppice re-growth) and maintenance control (ensuring that the *A. mearnsii* population remains small at a low annual cost of control) (Campbell *et al.* 2000b). A combination of chemical and mechanical techniques and sound management, including competitive cover crops are needed for effective control of *A. mearnsii* (Bromilow 1995).

Campbell *et al.* (2000b) set out guidelines for the three phases of control of alien tree species, which are summarized below. The initial control phase of *A. mearnsii* could involve the control of standing trees, or clear felling of trees (Table 1.1). The control methods for standing trees can take up to 6 to 18 months for a tree to die, depending on the size and species. As the tree dies, grasses colonize the bare soil between the dead trees. The advantage of controlling standing trees is that the soil is never exposed to erosion and in the event of a wildfire, the soil structure is not denatured by smouldering logs and brushwood. When controlling trees through felling, the removal of the trees is immediate, but careful attention must be paid to the disposal of the brushwood and to the rehabilitation of the cleared site, as the soil is exposed to erosion for a long period of time. Large stacks of brushwood must be avoided as they create a fire hazard. Burning also results in very hot temperatures which sterilize the soil and cause a breakdown in the soil structure, reduce water penetration, destroy humus and prevent grass and other plants from colonizing the area for three or more years after the burn (Campbell *et al.* 2000b).

Table 1.1: Initial control methods for controlling alien tree species (Campbell *et al.* 2000b)

Method	Description
Initial control of standing trees	
Basal bark	Apply herbicide in diesel (carrier) to the basal portion of the stem. Herbicide applied from 35 cm down to the soil surface and any exposed roots.
Strip bark	Strip bark (including cambium) from waist height down into the soil
Hand pull	Hand pull saplings or seedlings (only effective for small plants)
Frill	Use a bush knife to make downward cuts into the bark around the stem, within 30 minutes apply 1 or 2 ml herbicide mixed in water to the cuts.
Soil applied	Apply certain herbicides to the soil; herbicide is taken up by the plants through the roots.
Burning stem bases	Stack branches around the base of the stems and burn the wood.
Initial control by felling trees & controlling stumps	
Fell trees	Use chainsaws, bow saws, brush cutters or bush knives to fell trees or saplings. Stump height must be less than 15 cm.
Cut stump treatment	Apply herbicide mixed in water (with a suitable dye) to the cut surfaces of stumps, within one hour after felling. Do not spray the sides of the stumps.
Total stump treatment	Apply herbicide mixed in diesel (carrier) to the cut surface, down the sides of the stump and to any exposed roots. Can be applied several days after felling.

The follow up control phase of the alien tree seedlings and coppice growth is vitally important. If the follow up phase is ignored, the area that was cleared will soon be re-infested with a dense population of alien plants and any attempts at re-vegetation will be suppressed by the vigorous re-growth of the alien plants. Follow up methods may include chemical control, mechanical control and/or biological control agents. The particular method of follow up control used depends on the alien species in question, the level of re-infestation and the conditions of the particular site. Chemical control is usually in the form of foliar application of the correct registered herbicide, but this must be applied before the re-growth gets beyond a controllable height. If grass is present in the site a selective herbicide must be used. Mechanical control can be useful, but is time consuming and labour intensive. Soil disturbance through uprooting of seedlings and hoeing must be avoided as this will stimulate the seeds in the soil to germinate. If there is sufficient fuel load of grass below the infestation (minimum of 5 t ha^{-1} for moist areas), a hot fire may be used to kill the seedlings, but with *A. mearnsii* one must remember that a fire will also stimulate seed germination (Campbell 1993, Bromilow 1995, Campbell *et al.* 2000b). A follow up fire or herbicide application in the season following the first fire is required to eradicate the second flush of *A. mearnsii* re-growth. Through this process a large proportion of the soil seed bank can be removed. The only registered bio-control agent for *A. mearnsii* is *Melanterius maculates,* but its success in controlling *A. mearnsii* is at this stage unknown. It is important to monitor the situation two to three times during the year to ensure that re-infestation does not occur (Campbell *et al.* 2000b).

The final control phase is maintenance control, which maintains a stabilised situation at a low annual cost. A good grass cover is essential as it limits soil loss, suppresses the seedlings of the alien plants and improves the grazing capacity of the land. An annual inspection of the grass cover and alien plant re-growth is imperative to ensure that re-infestation does not occur. Maintenance control can be in the form of ensuring correct stocking rates to ensure that the grass cover is maintained. Where the seedlings of alien plants are palatable, grazing of the area will help ensure the seedlings that do germinate over time are not able to establish. Correct fire management, including frequency, intensity and timing of the burn will ensure the grass is favoured and is able to out compete any alien seedlings that germinate. Follow up control by means of mechanical or chemical control may be necessary to remove alien plants that establish in the area (Campbell *et al.* 2000b).

There are a number of herbicides are registered for the control of *A. mearnsii*. Different chemicals are suited to different tasks such as foliar spray, cut stump treatment, basal bark treatment, frill treatment or soil application (Table 1.2). The product label must be consulted when determining the use of any herbicide. The carrier (water or diesel) may also differ, depending on situation. In most cases where chemical control is used a suitable dye should be mixed with the herbicide to ensure that full coverage with the herbicide occurs (Campbell *et al.* 2000b).

Once the area has been cleared of *A. mearnsii* it must be re-vegetated to prevent soil erosion and aid in the control of re-growth. Re-vegetation is defined as the process whereby the re-appearance of the original vegetation is encouraged to reduce accelerated erosion, through plant introduction, without any ecosystem reconstruction being required (Campbell *et al.* 2000a). The site cannot be left to natural succession, as this process would start with pioneer species and over many years, slowly progress towards climax vegetation somewhat like the original vegetation (Munshower 1993). These pioneer species are generally weedy, less palatable to wildlife and offer less protection against erosion than later successional species (Munshower 1993).

Table 1.2: Registered herbicides for the control of *Acacia mearnsii* (Vermeulen *et al.* 1998)

Control required	Registered herbicides
Foliar spray	Garlon4, Roundup*, Stirrup, Tordon 101, Touchdown, Touchdown Plus, Tumbleweed
Control stumps	Access, Chopper, Fungus spores, Timbrel, Tordon 101, Tordon Super
Basal bark	Garlon 4, Tordon Super
Frill	Access, Chopper, Tordon 101
Soil applied	Bromacil WP, Bushwaker, Grazer, Hyvar X, Molopo, Savana SC, Velpar

* (or equivalent 360 g a.i./l glyphosate)

Furthermore, the *A. mearnsii* displays vigorous re-growth and being an alien invasive plant will interfere and possibly arrest the natural successional processes (Munshower 1993). It is thus advisable to re-vegetate the site with a plant community representing a more mature successional phase to ensure that undesirable weeds (Munshower 1993) and *A. mearnsii* re-growth (Bromilow 1995, Campbell *et al.* 2000b) do not colonise the site. In areas that have been covered by *A. mearnsii* for long periods of time there may also be a lack of natural grass seed to ensure sufficient regeneration of veld (Campbell *et al.* 2000a), especially in the KZN Drakensberg, where *T. triandra* and *H. contortus* generally rely on vegetative tiller production rather than flowering for propagation (Everson 1985). A number of requirements are necessary when selecting a grass species to use for re-vegetation of areas cleared of *A. mearnsii*:

- produce adequate ground cover in the first season to protect the soil from erosion;
- produce an adequate fuel load to allow a fire to be used to control the *A. mearnsii* re-growth;
- be capable of out competing the *A. mearnsii* seedlings;
- be tolerant of fire;
- be adapted to the environmental conditions of the site; and
- establish a self sustaining population of the new species and/or individuals (Dawson 1987, Campbell *et al.* 2000a & 2000b).

In the past, cleared *A. mearnsii* plantations have been re-vegetated by KZN Wildlife, using the commercially available seed of *Eragrostis curvula* var. Ermelo (hereafter referred to as *E. curvula*) (Thompson *pers. comm.* Headquarters, Ezemvelo KwaZulu-Natal Wildlife, PO Box 13053, Cascades, 3202, KwaZulu-Natal, RSA). *Eragrostis curvula* is a tufted perennial, varying in height from 0.5 m to 1.5 m, which flowers from October to December (van Oudtshoorn 1992). It is common in disturbed areas on well drained and fertile soils and is often associated with overgrazed and trampled veld in high rainfall areas (van Oudtshoorn 1992). It is highly productive, establishing easily and rapidly from seed (Gibbs Russell *et al.* 1991, van Oudtshoorn 1992), thus providing a good fuel load. Although the species *E. curvula* is indigenous to the study area, the commercially available varieties are considered to be alien ecotypes because they have been selected for their superior hay and seed production. The choice of commercial *E. curvula* seed for re-vegetation in KZN Wildlife areas, thus does not comply with their policy of using vegetative plant material that has originated from within a 50 km radius (Thompson *pers. comm.* Headquarters, Ezemvelo KwaZulu-Natal Wildlife, PO Box 13053, Cascades, 3202, KwaZulu-Natal, RSA). Furthermore, areas previously sown with *E. curvula* appear to persist as pure swards for long periods of time. The variety Ermelo produces a large amount of "top growth" which forms an impenetrable cover which prevents local species from becoming established within the sward (Dawson 1987). Thus a mono-specific stand of *A. mearnsii* is replaced with one of *E. curvula. Eragrostis curvula* has a low rate of regeneration, with few seedlings and young plants of *E. curvula* being present, resulting in a progressive deterioration of the vegetation cover over time (Dawson 1987). Poor management of areas sown to *E. curvula* result in large, elevated tufts with large areas of bare soil between the plants (Campbell *et al.* 2000a), causing an acceleration of soil erosion. The benchmark veld condition assessment for BRG 8 (Appendix A) indicates an abundance of only 1% for *E. curvula* in the Moist Highland Sourveld (Camp 1997). A mono-specific sward of *E. curvula*, although providing soil coverage and protection from erosion, does not allow the re-vegetated site to return to its natural state. An alternative re-vegetation strategy using late successional indigenous species must be investigated to ensure the area returns to a state as close to the natural veld as possible, with a good level of biodiversity in the sward.

Everson (1994) found that the poor dispersal of seed in late successional grasses limits natural re-vegetation of disturbed sites, with 94.2% of all *T. triandra* seed falling within a 0.5 m radius of the parent plant. Although *T. triandra* made up 29% of the aboveground vegetation, it only comprised <1.2% of the soil seed bank. Everson (1985) found that the ratio of vegetative to fertile tillers for *T. triandra* was 31:1 after an annual winter burn and 62:1 under biennial spring burns. This finding indicates a dependence on vegetative reproduction, through tillering, rather than flowering for the propagation of this species in the KZN Drakensberg (Everson 1985, Everson 1994). Re-vegetation with late successional grasses thus requires some form of intervention, for example, the sowing of seed, the laying of seed bearing hay over the area, or planting nursery grown seedlings (plugs).

Themeda triandra is the dominant species in the benchmark veld of the Moist Highland Sourveld (BRG 8) with an abundance of 45% (Appendix A) (Camp 1997). It is thus an ideal species to use in re-vegetation. A number of problems are, however, associated with the use of *T. triandra* seed for re-vegetation, including: long seed dormancy and poor seed viability (Baxter 1996); seed predation (Everson 1994); and the time consuming nature of seed collection, cleaning and storage (McDougall 1989). Much of the seed of *T. triandra* from montane grasslands is dormant for nine to ten months after seed drop (Baxter 1996). The main concern with the long period of seed dormancy is that the seeds may be lost from the site during this time, either through predation or rain washing them from the soil. The problem of long seed dormancy may be overcome by storing the harvested seeds in controlled environments over the winter months, thus allowing seed after ripening, while reducing their exposure to predation (Baxter 1996), but this practice increases the costs of the use of seed. The problem of poor seed viability is that only a small percentage of the sown seed will germinate (Baxter 1996).

McDougall (1989) showed that 'thatching' (the spreading of seed bearing hay over an area) was more successful than simply sowing the seed, attributed to the mulching effect of the thatch. The results from thatching are still not ideal, as one still relies on seed germination, which may be hampered by unfavourable weather, seed predation and decreased seed viability. Thus, for a species such as *T. triandra* that is known to have poor seed viability (Baxter 1996) this method of re-vegetation is unreliable in the Moist Highland Sourveld and Montane Veld areas.

Well established tufts of *T. triandra* can be excavated and transplanted into areas requiring re-vegetation (McDougall 1989). Two disadvantages are associated with this method. Firstly, it is time consuming, and secondly, the difficulty of transporting entire adult plant tufts. In addition, this method relies on destructive methods of obtaining plant material, leaving behind disturbed areas that are vulnerable to weed invasion. Finally, it has been suggested that transplanting of nursery grown seedlings may be a viable alternative (McDougall 1989, Baxter 1996), although it has not been fully explored.

Since 1996, preliminary research has been carried out at the Kamberg Nature Reserve (hereafter referred to as Kamberg) investigating the possibility of re-vegetating *A. mearnsii* plantations with nursery raised plugs[1] (Plate 1.1) of two indigenous grass species, *T. triandra* and *H. contortus* (Granger 1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA). These plugs are grown in the nursery in seedling trays and consist of a cone of planting media (pine bark) and root material (the volume of which depends on the seedling tray size used), with approximately 50 mm of leaf material above. *Hyparrhenia dregeana* has also been successfully established with this technique in the nursery, and was also available for incorporation into the research. The planting of plugs into disturbed sites removes the problems of poor seed dispersal and low germination. Transporting seedling trays is also more cost effective than transporting well established tufts as done by McDougall (1989). The most suitable planting techniques, optimal spacing of plants, optimal density for production of a sufficient fuel load and the best species mix of the three indigenous grass species *T. triandra*, *H. contortus* and *H. dregeana* is not known.

These three species were chosen as they are indigenous to the area and the seed could be harvested for all three species from the study site. *Themeda triandra* is the dominant species in good quality veld in the Moist Highland Sourveld, at 45% abundance (Appendix A) (Camp 1997) and is thus an obvious choice for study. It is a tufted perennial, 0.3 to 1.5 m tall and flowering from October to

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[1] In this document the term plugs will refer to nursery raised seedlings, whereas the term seedling will be used to refer to naturally dispersed and germinated seedlings.

July (van Oudtshoorn 1992), although in the Drakensberg it is generally low growing and flowers only in the summer months. Propagation of *T. triandra* in the KZN Drakensberg relies on vegetative growth (Everson 1985). It occurs in all veld types of southern Africa and is associated with undisturbed climax grasslands (Gibbs Russell *et al.* 1991, van Oudtshoorn 1992). This species is highly palatable and is classified as a Decreaser as its abundance decreases with over grazing (van Oudtshoorn 1992). It is resistant to fire provided that the re-growth is not persistently over grazed (van Oudtshoorn 1992). There are two recognized ecotypes of *T. triandra*, namely the Drakensberg and Zululand ecotopes (Baxter *et al.* 1993, Baxter 1996). The Drakensberg ecotope occurs in the cooler Drakensberg environment and it is characterised by its lower growing habit (about 0.5 m in height) and its reduced seed production, relying on vegetative (tiller growth) rather than sexual reproduction (seed production) as a means of propagation (Baxter *et al.* 1993, Everson 1994, Baxter 1996). The reliance on vegetative growth rather than seed production of *T. triandra* in the Drakensberg was also seen by Everson (1985). The Zululand ecotope, on the other hand, is more robust, growing up to an approximate height of 1.5 m (Baxter *et al.* 1993, Baxter 1996).

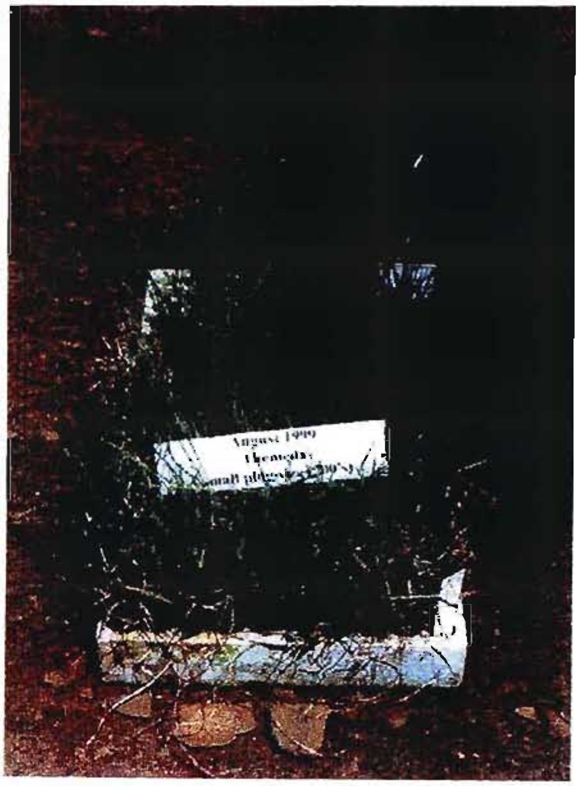


Plate 1.1: Nursery raised plugs of *Themeda triandra* (200 seedlings per tray).

Although, the percentage abundance of *H. contortus* in the benchmark for BRG 8 is only 4% (Appendix A) (Camp 1997), it was selected for further study, as seed was available at Kamberg. *Heteropogon contortus* has been successfully planted at a test site in Kamberg (Granger 1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA) and is commonly found in the veld with *T. triandra* (Gibbs Russell *et al.* 1991). *Heteropogon contortus* is a tufted perennial up to 0.7 m tall, which flowers from October to March (van Oudtshoorn 1992), although it is generally shorter in the Drakensberg. It is common in open grassland and bushveld areas, where the soils are well drained and stony (Gibbs Russell *et al.* 1991, van Oudtshoorn 1992) and has an average to high grazing value (van Oudtshoorn 1992, Camp & Smith 1998). *Heteropogon contortus* has been classified by some authors as a Decreaser species in the Highland Sourveld (Everson 1985, Tainton 1988) and as an Increase IIa species (Camp 1997, Camp & Smith 1998).

The final species selected was *H. dregeana*. It does not occur in good condition veld (as indicated by its absence from the benchmark site), but does occur in great numbers on disturbed sites, for example, road verges, in the study area. Seed was available for harvesting from these disturbed sites at Kamberg. This species is a robust, densely tufted perennial, growing to a height of 1.5 to 2 m tall (Gibbs Russell *et al.* 1991). This species flowers from November to May (Gibbs Russell *et al.* 1991).

The *T. triandra* and *H. contortus* were planted together in the plots to improve biodiversity of the revegetated plots. This combination was deemed to be valid, as both species occur in the benchmark for the veld in reasonable abundance and in practice neither species occurs as a monospecific sward in the veld. Furthermore, in the preliminary trials that were conducted at Kamberg these two species were successfully planted together (Granger 1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA). *Hyparrhenia dregeana* was planted on its own in the relevant plots as it naturally forms monospecific swards on disturbed sites, such as road verges.

Transplant shock has been recorded when planting nursery raised seedlings into the field, (for example Zandstra & Liptay 1999, Anastasiou & Brooks 2003). Transplant shock is usually as a result of high levels of evapotranspiration from the plants leaf material, while the roots (contained in the cone of root and planting medium) cannot obtain water from the soil profile. Methods of alleviating moisture stress, for example irrigation, starch based polymers and artificial shade, have been used when planting vegetable seedlings and have reduced the detrimental effects of transplant shock (Verschoor & Rethman 1992, Viero 2000). Starch based polymers have a high water holding capacity and are used in both vegetable and forestry industries at planting (Verschoor & Rethman 1992). A period of artificial shade, provided by shade cloth, at planting will also reduce the evapotranspiration of the plants at planting.

This project was designed to enhance the practical knowledge required for large scale use of nursery grown indigenous grass seedlings (plugs) for re-vegetation of disturbed sites. The main aim of the project was to develop an understanding of the re-vegetation dynamics of land cleared of *A. mearnsii* using indigenous grasses. In order to achieve this, the establishment and initial growth response of plugs must be investigated, followed by the in field survival of the plugs under different planting regimes. The ideal response for plants used in re-vegetation of old *A. mearnsii* stands would be a good survival rate, a good fuel load and a suppression of the germination and re-growth of *A. mearnsii* seedlings.

1.2 Description of the study site

The trials established for these studies were all field based as the aim of the research was to investigate the practical re-vegetation of areas cleared of *A. mearnsii.* To recreate the *in situ* soil and environmental conditions of these clear felled areas would have been impossible. The trials discussed in this research were also carried out in an extensive manner, utilising approximately 7000 m^2 of cleared land planted to the various treatments, approximately 400 m^2 previously vegetated using *T. triandra* and *H. contortus* plugs and a further 800 m^2 of mature *E. curvula* tufts was used. A total of approximately 52,000 plugs were planted in all the trials during a period of 10 days. Four teams of planters, consisting of one supervisor and four labourers were used to plant the trials.

The study site was located on a hillside with aspect and slope as uniform as possible. The main difference in the location of the individual trials was position up and down the slope and thus complete randomized block designs were used with each block located along the contour to account for change in this direction. This study site is situated on the property known as 'Game Pass', which forms part of Kamberg Nature Reserve situated in the central KZN Drakensberg (Figure 1.1). The reserve falls within the foothills of the main mountain range, an area known as the Little Berg (Killick 1990). Kamberg is one of the many reserves making up the 243 000 ha of the uKhahlamba-Drakensberg Park, under the management of KZN Wildlife. The altitude ranges from 1640 m (Stillerust) to 2243 m above sea level (Gladstone's Nose). The study site (29°22'55" S, 29°39'00" E) is located on a gentle, convex slope with an angle of 8°. In October 1997 the study site (approximately 1 ha) and surrounding area was clear felled of a dense and very old (> 70 yr) stand of *A. mearnsii*, and isolated trees of *Quercus robur* (oak), *Pinus elliottii* (pine) and *Eucalyptus* spp. (gum) (Plate 1.2).

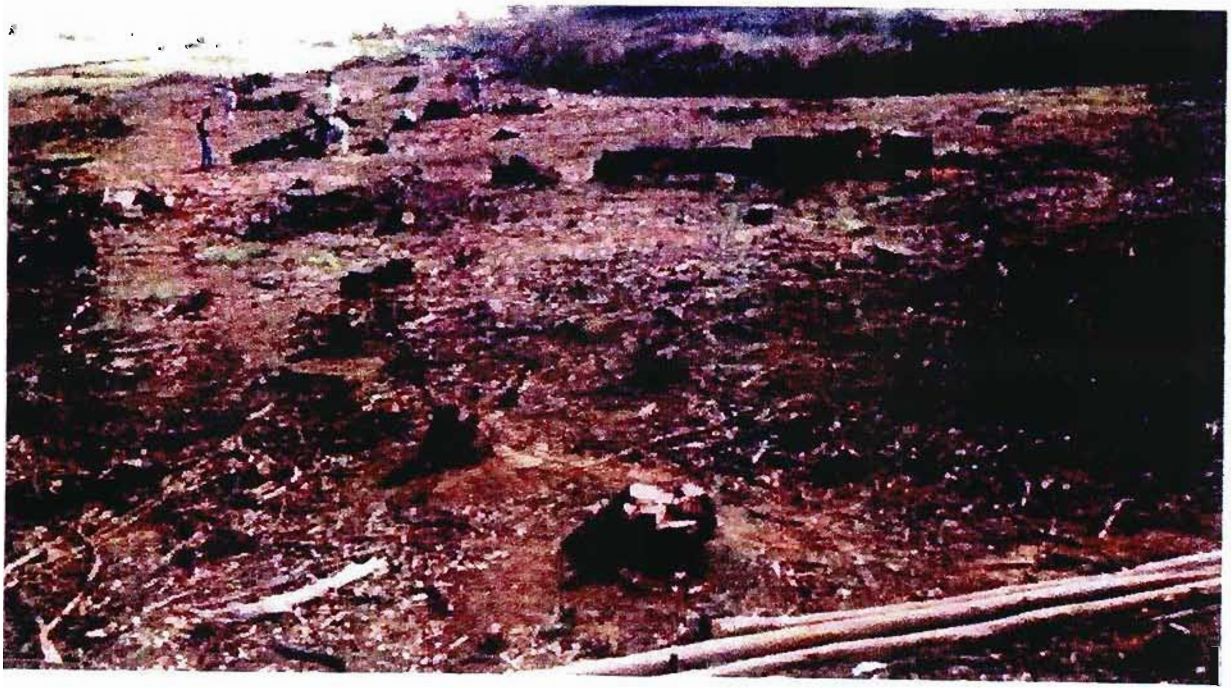


Plate 1.2: Study site cleared of *Acacia mearnsii* at Kamberg Nature Reserve in October 1998.

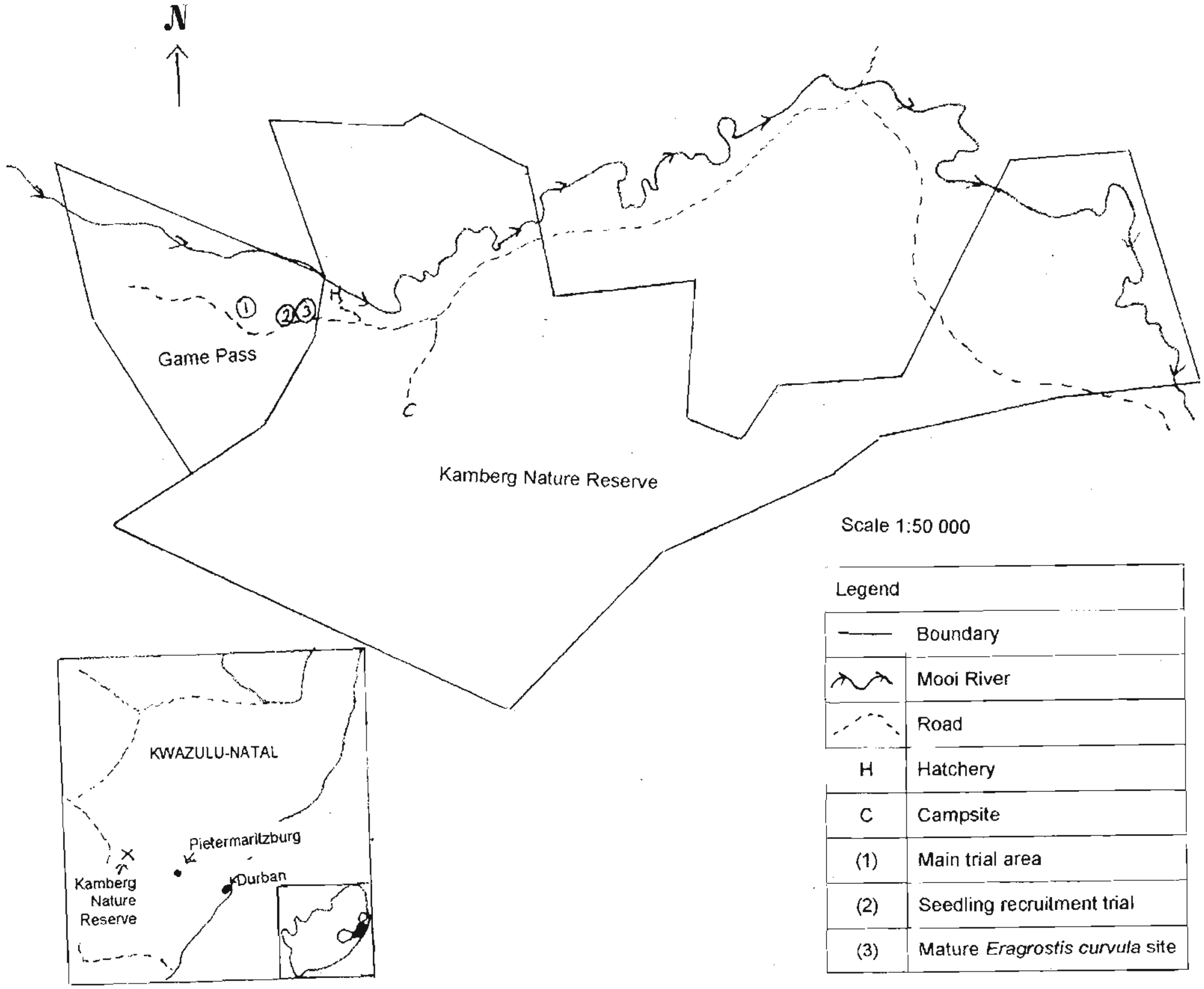


Figure 1.1: Location of Kamberg Nature Reserve within southern Africa, and location of the three trial areas of this study: (1) main trial area, (2) seedling recruitment trial, and (3) mature *Eragrostis curvula* trial site.

The geology of the KZN Drakensberg is characterized by roughly horizontal layers (dipping from < 1° to 3° mainly to the east, northeast and southeast) of rock comprised mainly of a sedimentary strata capped by igneous deposits (Eriksson 1979). Originally, layers of sandstone were deposited by water and wind, 160 million years ago, and were subsequently covered by molten lava (150 million years ago), which, on cooling, formed basalt. Except for the highland plateau of Lesotho, the majority of this basalt has been eroded. The various layers of rock that have been exposed through erosion therefore characterize the landscape at present. The spurs of the Little Berg end in conspicuous Clarens Sandstone cliffs (Killick 1990). Below the Sandstone cliffs, the Red Beds occur, which are comprised of mudstones and shales (originating 170 million years ago) and give rise to the steep grassy slopes of the Little Berg (Killick 1990). As a result of the continually changing conditions, soils show a heterogeneous pattern. In general, high iron content and acidity are characteristics of the soils of the KZN Drakensberg (Irwin & Irwin 1992). The soil depth ranges from 500 to 1000 mm, and the texture class is generally sandy clays and sandy clay loams, with slow drainage (Schulze 1997).

Kamberg is situated in Bioresource Unit Yd16 (Kamberg) which falls within the BRG 8, the Moist Highland Sourveld (Camp 1995), formerly described by Phillips (1973) as the Highland Bioclimatic Region. Mean daily maximum and minimum temperatures are 23.7 °C and 12.5 °C in midsummer (January) and 16.3 °C and 2.5 °C in midwinter (June). Between April and September the temperature often drops below 0°C, resulting in frost, with between 31 and 60 days of severe frost occurring between May and September (Schulze 1997). The mean annual precipitation, based on actual rainfall records is 1075.4 mm a^{-1} (Figure 1.2). The co-efficient of variation (CV%) for the study site is 19.5%, which is lower than the average for KwaZulu-Natal (23.0%) (Schulze 1997). The majority of the rain falls from November to March (Figure 1.3) in the form of thunderstorms (Hilliard & Burtt 1987, Killick 1990). Snow falls mainly on the summit (> 2 500 m asl), and occasionally on the lower peaks and slopes of the Little Berg, between April and September. Mid-summer snow can occur and, personal observation during the study period, recorded snow on Giant's Castle in February 1999. The evaporation is relatively high, with a mean annual evaporation of 1639 mm (Camp 1995).

The above climatic conditions determine the type of vegetation and its distribution in the landscape. The vegetation has been described as predominantly grassland with isolated areas of forest, occurring on the fire protected slopes of the Little Berg (Camp 1995). The indicator species are *Alloteropsis semialata, Festuca* spp., *Leucosidea sericea* and *Trachypogon spicatus* (Camp 1995). Other common grasses include: *Themeda triandra, Heteropogon contortus, Hyparrhenia dregeana, H. hirta, Tristachya leucothrix, Diheteropogon filifolius, Eragrostis racemosa* and *Monocymbium ceresiiforme* (Acocks 1953). The two main invasive alien species are *A. mearnsii* and *Rubus cuneifolius* (American bramble) (Killick 1990). Other alien tree species in the area, which are not excessively invasive, include *Salix babylonica* (weeping willow trees), *Quercus robur* (oak) and *Eucalyptus* spp. (gum). Primary plant production is estimated to be between 8 and 10 t ha^{-1} $season^{-1}$ (Schulze 1997). The growing season starts in September and continues through to April, with a total of between 200 and 225 days a^{-1} (Schulze 1997).

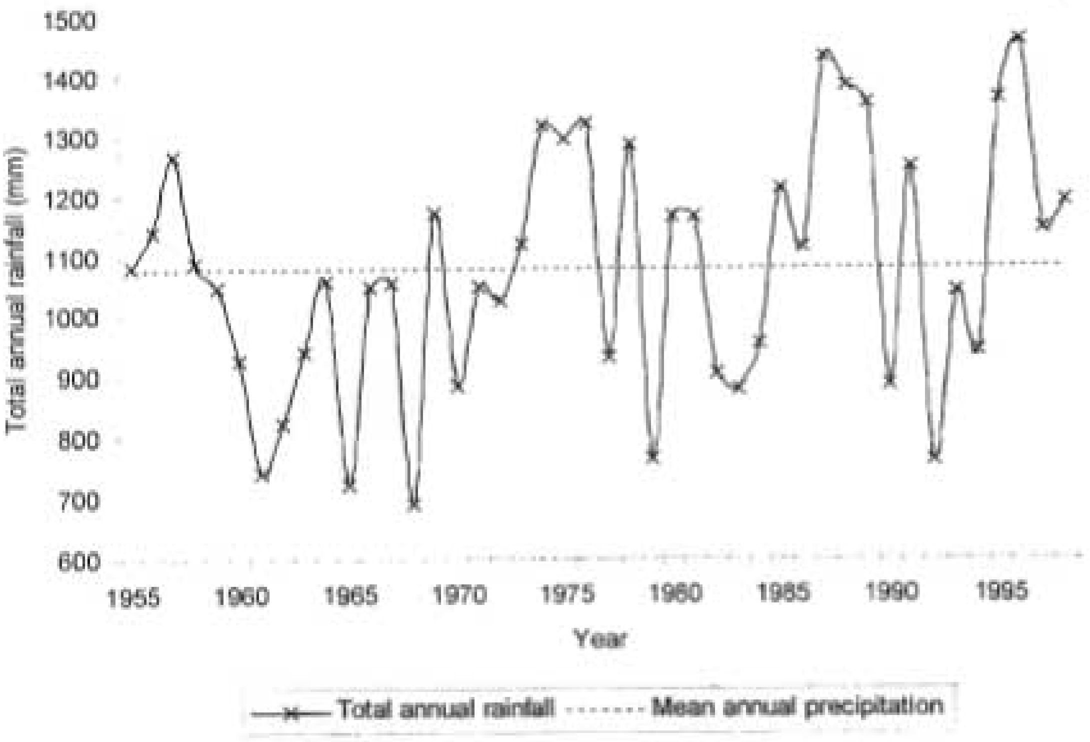


Figure 1.2: Total annual rainfall for Kamberg Nature Reserve, from 1955 to 1998. Mean annual precipitation based on 43 years of on site data.

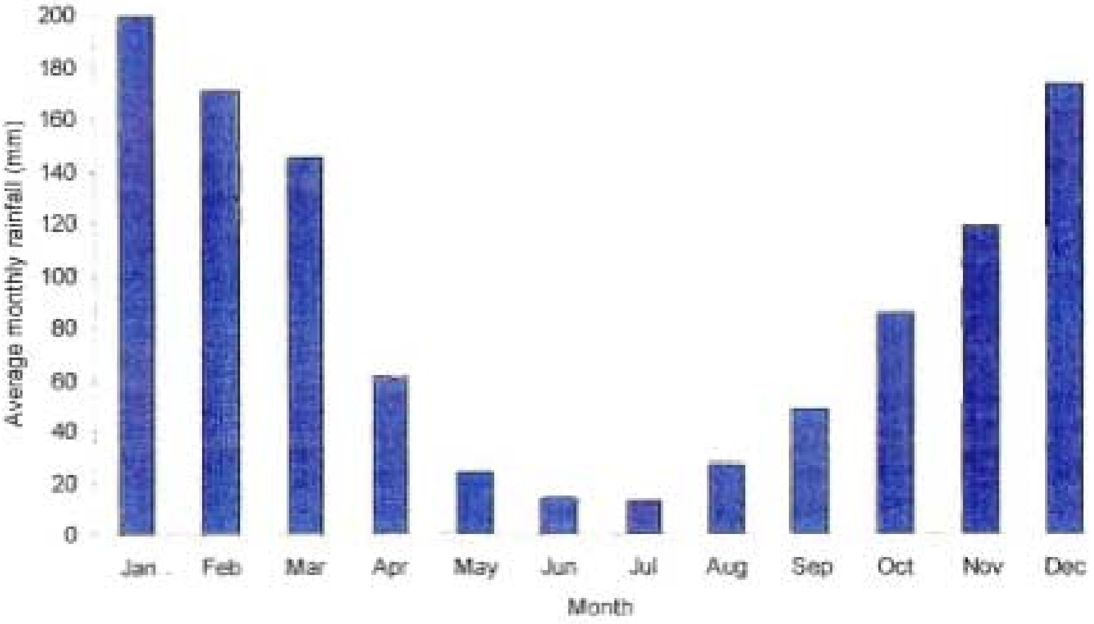


Figure 1.3: Total monthly rainfall for Kamberg Nature Reserve, from 43 years of on site data.

A number of rodent species are common to the KZN Drakensberg, namely, *Rhabdomys pumilio* (striped mouse), *Myosorex varius* (forest shrew), *Otomys irroratus* (vlei rat), *Dendromus melanotis* (grey climbing mouse), *Graphiurus murinus* (woodland dormouse), *Crocidura flavescens* (greater musk shrew), *Mus minutoides* (pygmy mouse) and *Dendromus mesomelas* (Brants's climbing mouse)

(Rowe-Rowe 1982). Except for *R. pumilio* (diurnal) and *O. irroratus* (crepuscular) all species are nocturnal. The diet of the majority of these rodents consists of vegetative material and seeds and thus could have a destructive effect on re-vegetation efforts if they occur in large enough numbers. A number of larger herbivores occur in the area. The grassland species are *Pelea capreolus* (grey rhebok), *Redunca fulvorufula* (mountain reedbuck), *Redunca arundicum* (common reedbuck), *Taurotragus oryx* (eland), *Ourebia ourebi* (oribi), *Damaliscus dorcas phillipsi* (blesbok), *Oreotragus oreotragus* (klipspringer) and *Connochaetes gnou* (black wildebeest) (Rowe-Rowe 1982). *Tragelaphus scriptus* (bushbuck) and *Sylvicapra grimmia* (grey duiker) occur in the forest and thicket areas (Rowe-Rowe 1982). Blesbok and black wildebeest tend to remain on the flatter plains of the Stillerust section of the reserve. Although the study area was grazed by a variety of animals, only eland caused significant damage to one plot through their hoof action. *Papio ursinus* (Chacma baboons) were also in the area and were regularly seen on the study site.

Fire has been a natural agent in shaping the vegetation of the KZN Drakensberg (Edwards 1984, Everson 1985, Everson TM *et al.* 1988, Priday 1989, Camp 1997), and is important in maintaining the veld condition of these grasslands (Everson 1985). A number of the KZN Drakensberg floral species have adapted to and dependant on fire. Many herbs either fail to flower or remain dormant in areas that are not burnt for a number of years (Tainton & Mentis 1984, Hilliard & Burtt 1987). Some of the fauna also shows an evolution dominated by fire, for example, Francolins (*Francolinus* spp.) are found to nest more frequently in areas that have been burnt within the past two years (Hilliard & Burtt 1987). Natural fires are started through lightning strikes and from falling boulders that strike sparks on hitting other rocks (Edwards 1984, Hall 1984). Man made fires have been a feature for thousands of years. The San were the first inhabitants of the Drakensberg and evidence of their presence dates back approximately 42,000 years B.P. (Cable *et al.* 1980, Mazel 1981). They burnt the veld to aid hunting, by attracting grazers to the newly burnt areas (Bryant 1929, Watson 1981, Edwards 1984, Hall 1984, Priday 1989, Killick 1990). Subsequent to the settlement of white farmers in the KZN Drakensberg in the 19th century, the veld was burnt to provide winter grazing for livestock (Nanni 1969, Edwards 1984, Hall 1984). The veld management adopted by the KZN Wildlife includes a variety of burning schemes. Firebreaks are burnt annually in winter to reduce the risk of the spread of uncontrolled fires. Periodic block burns of the grassland and wetlands are carried out. These block burns are carried out in August and September biennially and are applied to improve the bio-diversity, reduce the chances of devastating runaway fires and to maintain the natural vegetation in its fire-climax state (Rowe-Rowe & Lowry 1982, Everson 1985, Walker 1987, Hilliard & Burtt 1987).

1.3 Aims and objectives

1.3.1 Research aims

Re-vegetation of disturbed sites is important both to control soil erosion and to reduce subsequent weed infestation of these disturbed sites. The key focus of this research is the problems associated with the re-vegetation of cleared *A. mearnsii* areas using indigenous grass species.

The specific aim of this study was to investigate the viability and practicality of using nursery raised plugs of *T. triandra, H. contortus* and *H. dregeana* to re-vegetate old *A. mearnsii* areas. The survival and growth of the plugs were investigated to determine the success of the technique. The ultimate goal of the research was to provide practical management guidelines for re-vegetation using indigenous grass plugs.

1.3.2 Thesis structure

With the above considerations in mind, it was proposed to investigate a number of discrete questions by designing a number of field trials.

Earlier trials by Granger (1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA) determined that *T. triandra* and *H. contortus* could be grown in seedling trays in the nursery and planted out into cleared *A. mearnsii* areas. A standard plant spacing of 30 cm was used in these trials. It was felt that a closer spacing (for example 15 cm) would improve the ground cover, potentially suppressing *A. mearnsii* seedling germination and improve soil protection. A field trial, using 4 m by 4 m plots was established to investigate the effect of two plant spacings (15 cm and 30 cm) on the survival and growth of *T. triandra, H. contortus* and *H. dregeana* plants (Chapter 3, Section 3.3).

The previous practice of KZN Wildlife was to re-vegetate old *A. mearnsii* lands with commercially available *E. curvula* seed. The problem with this method was that the areas became near monospecific stands of *E. curvula.* A field trial, using 4 m by 4 m plots, was established to investigate whether over-sown *E. curvula* could be used as a nurse crop for indigenous grass plugs, as one would gain the benefits of the rapid growth and cover from the *E. curvula,* while improving the biodiversity of the sward with the *T. triandra, H. contortus* and *H. dregeana* plugs. The survival and growth of the plugs of all species were to be monitored (Chapter 3, Section 3.4).

There has been debate as to whether areas previously over-sown with *E. curvula* after clearing of *A. mearnsii*, remain as mono-specific grass swards. At Kamberg there was an area that had been cleared of *A. mearnsii* 25 years previously and sown with *E. curvula*. The species composition of these areas over-sown with *E. curvula* was compared to neighbouring veld areas (Chapter 3, Section 3.5). *Themeda triandra* plugs were planted into this mature sward to investigate if the biodiversity of these *E. curvula* swards could be improved. A number of pre-treatments were applied to the *E. curvula* tufts, namely nothing (control), clipping, spraying with herbicide and spraying and clipping, to reduce root competition and or competition for light (Chapter 3, Section 3.5) prior to the establishment of *T. triandra*.

Nursery grown seedlings are commonly used for vegetables, ornamental plants and forestry seedlings with a number of methods available to alleviate water stress at planting, for example starch based polymers and artificial shade. Two techniques, Terrasorb® (a water absorbent, starch based polymer placed into the transplant hole) and Agrilen® (a white needle punched fabric to provide artificial shade), were investigated using 4 m by 4 m plots. This trial investigated whether either method of ameliorating water stress enhanced the survival, and growth of the grass species (Chapter 4).

Fire is commonly used to control vegetation and can be used to stimulate *A. mearnsii* seeds to germinate, thus reducing the soil seed bank. The post fire flush of *A. mearnsii* seedlings can then be killed through herbicides or a second fire. A field trial, using 15 m by 15 m plots, was established to investigate whether the three indigenous grass species could provide sufficient fuel for a fire to be applied to control the *A. mearnsii* re-growth, or whether over-sowing with *E. curvula* or *E. tef* was required to build up the fuel load (Chapter 5).

Seed bearing thatch has been used in other re-vegetation work, and it was included in this field trial, using 4 m by 4 m plots, as it provides a cheaper alternative to the growing and planting out of plugs. Thatch was harvested from the surrounding veld at two times of the year (early summer and late summer) to investigate whether the time of year of harvesting of the thatch would affect the species composition (Chapter 6).

As the method of re-vegetation used in this research relies on the raising of plugs in a nursery, a number of nursery techniques were investigated. Firstly the best time of year for planting out of plugs was investigated for *T. triandra* and *H. dregeana* using two different plug volumes (98 and 200 plugs per tray) (Chapter 7, Section 7.3). A number of seedling trays with these two species and plug volumes were maintained in the nursery, to determine the length of time that the plugs can be successfully kept in the nursery (Chapter 7, Section 7.4).

An area cleared of *A. mearnsii* four years previously and planted to *T. triandra* and *H. contortus* plugs was used to determine the natural seedling recruitment from mature plants grown from plugs (Chapter 8).

In the plot based trials above, quadrat data were collected of the number of *A. mearnsii* seedlings per metre squared. These data were analysed to investigate the re-growth of *A. mearnsii* seedlings under different re-vegetation treatments (Chapter 9).

Each chapter is written as a stand alone paper, complete with introduction, materials and methods, results, discussion and conclusion. A final discussion and conclusion chapter at the end of the thesis (Chapter 10) collates the results and conclusions throughout the trials into a practical set of management guidelines and objectives for further research.

2. Materials and methods

2.1 Seed collection, seedling production and planting

Seed for all the grass species used in the trial was collected from Kamberg. This ensured that the ecotype of each species was adapted to the climate of the study site and conforms to the KZN Wildlife requirements of being sourced locally and not introducing 'foreign' germplasm. Some argument has been made that the species or ecotypes used in re-vegetation of the old *A. mearnsii* plantations should be those which are best adapted to soil conditions found in these modified sites, although this contradicts the main objective of re-vegetation which is to return the area to its natural vegetation (Campbell *et al.* 2000b). An analysis of the soil in the study area indicates that these cleared *A. mearnsii* areas were dissimilar to the natural veld areas, with natural veld having lower phosphorus, potassium, calcium and magnesium levels and being more acidic than the cleared site (50% and 3% acid saturation respectively) (Appendix B). It is therefore not necessary to use acid tolerant species. Previous studies have shown that the local ecotypes of *T. triandra* and *H. contortus* survive in the modified soil microclimates of the old *A. mearnsii* plantations (Granger 1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA).

The seeds were germinated and grown in seedling trays in nursery mist houses. The growing media used was pine bark. Ideally the plugs were planted out six to eight weeks after germination. Due to the large number of plugs required for the January 1998 planting, some plants remained in the seedling trays for 12 weeks. This proved too long a period for the *H. dregeana* and *T. triandra*, and the plugs became rank. The *H. dregeana* in particular, started to lodge within the seedling trays, resulting in the death of the plugs that were shaded. The large amount of above ground material of these older plugs also increased the transplanting stress due to high transpiration rates. The length of the leaf material caused some inconvenience in the planting out, as the plugs were easily pulled out the ground. After the problems with the rank plants at the initial planting, plants were clipped in the nursery. This did not have a negative affect the plants growth and so all plants in the nursery were subsequently maintained below 15 cm in height.

Planting templates were constructed, by welding a metal cone on to the four corners of a square metal plate so that the centre of the cones were either 30 cm or 15 cm apart to ensure the correct spacing of plants and to speed up planting (Figure 2.1). The volume of the cone matched the root volume of the seedling trays. Two metal prongs (15 cm or 30 cm long) at right angles to each other were attached at one corner to give the spacing of the next hole. The planting tools did not always create a large enough hole, especially where *A. mearnsii* sawdust, bark and root material were encountered or where the soil was very friable. A larger cone size on the planting template may alleviate this problem; or else a second person is required with a small spade to enlarge the holes. The latter option will not be cost effective when planting large areas. If the holes are not increased in size, the top of the plug is exposed at planting, which is detrimental to the plug (Granger *pers. comm.*, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA; Campbell *et al.* 2000a). Where the soil was firm and moist and the planting tool created a good hole, the plugs fitted perfectly. If the placement of a hole coincided with a stump or root that prevented a hole from being made then no plant was planted. When a large number of obstructions were encountered in one plot, the plot was rejected for planting within the trial and another plot was marked out within that particular area.

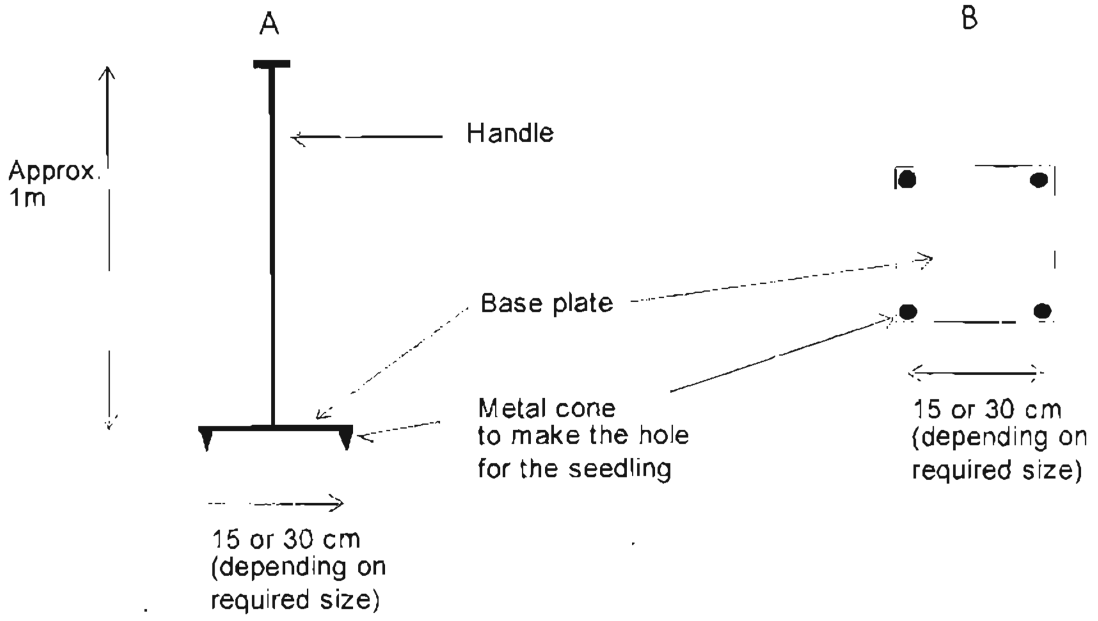


Figure 2.1: Side view (A) and view from the bottom (B) of the planting tool used to create the planting holes for the seedlings.

The local labour, sourced from a communal settlement bordering the park, were generally proficient at planting the material, but close supervision was required to ensure that the plugs were planted deep enough and that the correct species were planted in each row. To aid planting, each grass species was allocated a colour (red for *T. triandra*, yellow for *H. dregeana* and blue for *H. contortus*). Each plot was marked out by stretching ropes around three sides of the plot, and planting commenced from one corner. The planting template produced the correct spacing, while coloured ropes indicated the correct species for each row. In a field scale situation with less need for the precise, intricate patterning of species, less supervision would be required.

Once the plugs were planted there was no further intervention (except for the Agrilen® treatment, where the Agrilen® was removed seven days after planting). The plugs were not watered after planting and relied entirely on rainfall and soil moisture for all moisture requirements after planting.

2.2 General considerations for the experimental designs

For the majority of the trials a randomized complete block design was used for the experimental layout. This design accounts for environmental variation in one direction, for example, down slope (Steel & Torrie 1980). Further unwanted variation can be reduced by planting and sampling the blocks, one at a time, to accommodate changes that occur through the day or between days if measurement of each block takes a full day (Steele & Torrie 1980, Thomas & Laidlaw 1981). In the Kamberg trials, each block occurred along a contour, therefore the block effects accounted for differences down the slope. Each block represented a replicate and the treatments were randomized within each block. More detailed descriptions of the experimental design used for each trial are presented in the individual chapters.

2.3 General consideration of the plant variables recorded

Plant growth and survival were monitored for the duration of the trial. In order to determine the survival rate (as a percentage) the total number of plants planted in each plot was counted. This was not constant due to obstructions, such as stumps and roots, which prevented an equal number of plugs being planted in each plot and to allow for comparisons between plots. The numbers of surviving plants were then counted (refer to individual trials for frequency of counts). A plant was considered as being alive if there was some indication of green colouring in the leaves or young shoots were developing from the base. Survival rate was calculated as the number of plants alive in each plot divided by the total number of plants planted in the plot, expressed as a percentage.

Growth rate was determined through regular measurement of a number of plant variables for each plant. These included: number of tillers per plant, plant basal area and plant height. The number of tillers per plant provides an index of the tiller dynamics of the sward. Tiller numbers per tuft and fluxes of tiller populations are important in terms of plant persistency and survival (Davies 1981). The number of tillers was determined by counting the number of tillers per plant.

Basal area was used to monitor tuft dynamics. Plant basal area is a more reliable measure than aerial cover as it does not suffer the same seasonal fluctuations (Bonham 1989), nor is it subject to rapid changes through defoliation. The plant basal area was assumed to be an ellipse and was determined through the measurement of the long and short axes of the plant base. The long axis (D) is the first axis selected for measurement, while the short axis (d) is that which is perpendicular to the first axis (the long axis). The basal area of the ellipse was calculated as:

$$\text{Area} = \frac{\pi \, Dd}{4}$$

Finally, plant growth was indexed through mean plant height of the individual plants (Rhodes 1981). Mean plant height was measured by bunching the tuft together in one hand and measuring the mean height of the gathered plant material (Hodgson *et al.* 1971). If only one single leaf extended above the majority of the leaves its length was ignored.

The number of flowering culms was also recorded for each plant as an index of seed production and thus sexual reproduction. The grass species used in the trials flower at different times of the year with *T. triandra* and *H. contortus* both flowering from late spring to early summer and *H. dregeana* flowering in the late summer. Data were, therefore, analysed within each species to determine if the planting techniques influenced the potential seed production of these species.

A preliminary study was carried out in order to determine the required sample size (Appendix C). This study revealed that 30 plants were required per plot. The three plant variables were therefore measured on 30 tagged plants per plot. Where there were insufficient plants, all surviving plants were measured. If a tagged plant died, it was noted on the data sheet and a new plant was randomly selected from the remaining plants in the plot (if extra plants were available).

The natural grasslands of the area are characterized by a dormant period during the dry winter season. The first winter frost kills the aboveground material, resulting in the gradual death of the herbage. Everson TM *et al.* (1988) showed that after the first frost, the moisture content of the grass plants drops below 60% and the curing process is accelerated. Field measurements in Kamberg were therefore terminated after the first frost, which generally occurs in mid-May (Tyson *et al.* 1976, Schulze 1997). The final measurement of plant growth and survival was carried out in April 1999, as it took a full calendar month to collect the data for all of the field trials.

In order to determine species diversity the abundance of the plant species that colonized each plot through natural processes, along with the species that were planted or over-sown were counted using 0.5 m by 0.5 m quadrats. In the 4 m by 4 m plots, six quadrats were randomly located using random number tables (Steel & Torrie 1980). A two digit number was used with each digit falling between zero and seven. The top and left hand side of each plot was sub-divided into eight half meter sections, labelled zero through to seven. The first digit of the random number represented the location of the quadrat on the top axis and the second digit along the left hand axis. Where these two points intersected marked the top left hand corner of the quadrat. The number of each species that was rooted in the quadrat was recorded. In the 15 m by 15 m plots of the burning trial, a similar procedure was used to randomly locate the quadrats, but here, 12 quadrats were used per plot. In these plots the top and left hand axes were subdivided into 30, therefore the random numbers that were selected ranged between 0 and 29. The diversity was indexed through the Shannon Diversity Index of Ludwig & Reynolds (1988) and the number of species per plot.

2.4 Statistical analysis

Survival rates were plotted over time to determine the overall patterns of survival. Treatment effects were determined by analysing the final data set, using analysis of variance (ANOVA). All ANOVAs were carried out using Genstat® 5 Release 4.2. The three assumptions for ANOVA, namely, experimental error is normally distributed, a common variance and that treatment and environmental effects are additive, were checked in all cases and where necessary, transformation of the data were carried out to meet these assumptions (Steel & Torrie 1980). The necessary transformations are detailed in the materials and methods for the specific trials. As each treatment had only two levels the F-test within the ANOVA was sufficient to detect differences between the treatment levels (Stevens, *pers. comm.* Department of Agriculture and Environmental Affairs, Cedara. Private Bag X9059, Pietermaritzburg, 3200, KwaZulu-Natal, RSA).

The treatment effect of the different planting techniques on the number of flowering culms produced was also analysed through ANOVA. An ANOVA was carried out for each species at each time interval. Species was not used as a treatment effect as the species used in this trial were known to flower at different times of the year.

Confounding of the species effect in most trials prevented the use of ANOVA for analysing the plant growth data. This occurred because some plots were planted to a combination of *T. triandra* and *H. contortus* while others were planted to only *H. dregeana*. *Themeda triandra* and *H. contortus* were planted together as they are both dominant species in undisturbed veld in the area (Camp & Smith 1998). An initial analysis of the plant growth was carried out to determine whether or not the response of these two species differed at the 5% level (Appendix D) and if they could be considered on a whole plot basis. This investigation confirmed that these two species grew in a similar manner, as no differences ($P > 0.05$) were found between the two species. For all analyses the data from these two species were therefore pooled and a random sample of 30 plants was taken from the composite data set. Survival rates in these plots were not sub-divided into species, but were calculated for the whole plot. At each time interval an ANOVA was carried out for each plant growth variable measured, using *H. dregeana* and the *T. triandra/H. contortus* combination as the two levels of the species treatment.

Growth curves describe the relation between the measured plant variables and time (Hunt 1978). The computer program of Hunt & Parsons (1974) was used to derive the growth curves for the plant growth data. This program transforms the data onto a natural logarithmic scale to improve their homogeneity with time and to aid in distinguishing small scale changes. The data are then expressed as higher order polynomial functions of time. The program uses stepwise regression (least squares) to fit a polynomial function, up to the third order. The 95% confidence intervals are calculated for each data set. Hunt & Parsons (1974) found that fitting up to a third order polynomial provided adequate description of the plant growth, while avoiding over fitting of the data.

The resulting growth curves were plotted against time, along with their 95% confidence bands. Where the bars overlap the curves are not different ($P > 0.05$), while where there is no overlapping of the bars the two curves are different ($P \leq 0.05$). The use of these growth curves is a functional approach and the choice of mathematical function is purely incidental. The only assumption made using this approach is that the fitted growth curve adequately describes the trends in the raw data (Hunt 1978). A number of advantages are associated with this functional approach, namely: it summarises a complex process, it is an economical representation of data, it presents straightforward comparisons, it uses information from all sampling occasions, it does not require pairing of plants, harvests do not have to be large, equal replications are not necessary and it can smooth out small deviations (Hunt 1982). The purpose of curve fitting is to describe the data conveniently and to allow for statistical comparisons, which are free of the problems of repeated measures that would reduce other approaches, requiring strict assumptions of normal and independent data, to approximate tests only. There is thus, no need to present the equations, only the graphs (Danckwerts & Gordon 1989, Danckwerts 1993). As the growth curves represent the fitted values, rather than the observed values a summary of the data presented in the graphs is included in Appendix E.

The Terrasorb®-Agrilen® trial (refer to Chapter 4 for more detail) was replanted in January 1999 and had too few measurements (four) to determine growth curves (Hunt 1982). The same trial established in the mature *E. curvula* had a similar problem, in that the plant growth variables were only measured at the start and finish of the trial. The data for these trials were therefore compared using mean relative growth rates (RGR). Relative growth rates measure the rate of increase in size per unit of size (Hunt 1990). Analysis of variance is then used to determine treatment differences. The mean RGR takes into account the size differences of the plugs at the start of the trial (Hunt 1978). The mean values can be plotted as a histogram with the class interval equal to the measuring interval. The following is the general formula of Hunt (1978) was used to calculate the mean RGR (unit growth unit growth^{-1} unit time^{-1}):

$$\text{Mean RGR} = \frac{(\log_e Y_2 - \log_e Y_1)}{t_2 - t_1}$$

Where Y_1 is the dependant variable at time one (t_1) and Y_2 is the dependant variable at time two (t_2).

The data collected on species rooted in the 0.25 m^2 quadrats are analysed on the number of wattle seedlings per m^2 as an indication of the follow up management that would be required as well as on species richness, species diversity and indicator species basis. The numbers of *A. mearnsii* seedlings per meter squared were compared across treatments using ANOVA.

Species richness is a straightforward count of the number of species that are present at a particular site (Magurran 1988). The statistical differences of the number of species can be determined using one way ANOVA (for example Thysell & Carey 2001). But there is more to diversity than simply a count of the number of species. It is important to account for both the evenness (how uniform the distribution of a species is across an area) of the species as well as species richness (how many different species are present), for example the Shannon diversity index (H') (Vogel 1987, Ludwig & Reynolds 1988, Magurran 1988, Noss 1990). This index is based on the proportional abundance of the species and is a non-parametric statistic, meaning that there are no assumptions about the shape of the underlying species abundance distribution. The only two assumptions of the Shannon diversity index are that individuals are randomly sampled and that all species are represented in the sample (Peet 1974, Ludwig & Reynolds 1988, Magurran 1988). The Shannon diversity index can be calculated for a number of samples and these indices will themselves have normal distribution and can thus be tested using ANOVA (Magurran 1988).

The multi-response permutation procedure (MRPP) (Mielke & Berry 1982, Biondini *et al.* 1988) was used to test the null hypothesis of no difference in species composition between treatments (for example, Huebner & Vankat 2002, Phillips *et al.* 2003, Schowalter *et al.* 2003). The MRPP method is based on Euclidean distances and is completely data dependent and thus does not require assumptions about the underlying distribution structure or the equality of variance of the population under study, and is therefore a non-parametric technique (Mielke & Berry 1982, Biondini *et al.* 1988). The Sørenson (Bray-Curtis) dissimilarity measure was used in the MRPP to determine the compositional distance between treatments. This value is commonly used in community analysis because it retains its sensitivity to the data structure without giving undue weight to outliers (Digby & Kempton 1987, Phillips *et al.* 2003).

The indicator species method of Dufrêne & Legendre (1997) was used to detect and describe the value of different species as indicators of the two treatments (for example, Thysell & Carey 2001, Huebner & Vankat 2002, Phillips *et al.* 2003, Schowalter *et al.* 2003). The indicator species is defined as the most characteristic species of a treatment, found mostly in a single treatment and present in the majority of the replications belonging to that treatment (Dufrêne & Legendre 1997). The indicator values range from 0 (no indication) to 100 (perfect indication). This method combines the information on the concentration of species abundance in a particular treatment and the faithfulness of occurrence of a species in a particular treatment, and is thus based only on within species abundance and frequency comparisons, without any comparison among species (Dufrêne & Legendre 1997). The Monte Carlo test, using 1000 permutations, is used to test for the faithfulness of occurrence of a species within a particular group (Ludwig & Reynolds 1988, Magurran 1988). The PC-ORD, version 4.25 computer package was used to compute both the MRPP and the indicator values in this study.

The MRPP and Indicator species methods were used only for the Thatching trial (Chapter 6) as these comparisons are made within one trial. The Shannon diversity index and number of species per plot were used to compare the effect of over-sowing with *E. curvula* and to compare the diversity of the thatching trial with the use of planted plugs, as these comparisons are made between trials.

An overview of the structure of the trials is given in Figure 2.2.

Re-vegetation dynamics of land cleared of *Acacia mearnsii* (Black wattle): a research model

INTRODUCTION (Chapter 1)

- Re-vegetation after alien plant control (black wattle, *Acacia mearnsii*) at Kamberg Nature Reserve (29°24' S 29°40' E).
- Previously *Eragrostis curvula* used for re-vegetation, but results in low bio-diversity.
- Plugs[1] of *Themeda triandra* (Plate 1), *Heteropogon contortus* and *Hyparrhenia dregeana* used for re-vegetation.

Plate 1: *Themeda triandra* seedling (plug)

RECRUITMENT (Chapter 8)

- Can *T. triandra* and *H. contortus* plants grown from plugs produce a self-sustaing population?
  - June 1998
    All seedlings present tagged
    (June '98 population)
    (676 seedlings) (Plate 2)
    - November 1998
      - Seedligns from previous season
        - Survived (85.7%)
          - January 1999
            - Survived (82.7%)
            - Dead
        - Dead
      - New seedlings tagged (Nov '98 population) (436 seedlings)
        - January 1999
          - Survived (96.0%)
          - Dead

Plate 2. Tagged seedling of *Heteropogon contortus*

ALTERNATIVES

- Sow *E. curvula* only (results in a monospecific sward and low basal cover).
- Natural re-vegetation (very slow).
- Sow seed of indigenous grasses (high seed predation and low viability).
- Thatching of seed-bearing hay (Plate 3) (Chapter 6).

Plate 3. Seed-bearing hay (thatch) that has been laid on the ground with wattle branches placed on top to prevent loss due to wind.

RE-HABILITATION OF DISTURBED SITE

MANAGEMENT

Moisture stress (Chapter 4)

- Will alleviation of moisture stress affect the performance of *T. triandra* and *H. dregeana*
  - Soil moisture ameliorant
    - Terrasorb[8]
    - No Terrasorb
      - Atrificial shade
        - Agrilene[9]
        - No Agrilene

Nursery Techniques (Chapter 7)

- What effect does month of planting nursery age and plug size have on the survival of *T. triandra* and *H. dregeana*
  - Month of planting
  - Nursery age
    - Plug size[2]
      - Small
      - Large

Burning (Chapter 5)

- Can plugs be used to establish sufficient fuel load to control wattle regrowth?
  - Species
    - No planting
      - Herbicide spray[3]
        - Not applied
        - Applied
    - *T. triandra* & *H. contortus*
    - *H. dregeana*
    - *T. triandra*, *H. contortus* & *H. dregeana*
      - Over sowing
        - *E. teff*[4]
        - *E. curvula*[5] (Plate 4)

Plate 4. An example of a 15 m by 15 m plot that was planted to *T. triandra* and *H. dregeana* and then over-sown with *E. curvula*

Competition

- What is the competitive affect of over-sowing *E. curvula* on the performance of grass plants at Two planting densities? (Chapter 3, Section 3.4)
  - Standard sowing of *E. curvula*[6]
    - *E. curvula* only
    - Species planted
      - *T. triandra* and *H. contortus*
      - *H. dregeana*
        - Planting distance
          - 15 cm
          - 30 cm
- Does planting density and ratio of species affect their performance? (Chapter 3, Section 3.3)
  - Ratio of species
    - *T. triandra* and *H. contortus*
    - *H. dregeana*
      - Density of planting
        - 15 cm
        - 30 cm
- Can *T. triandra* be re-introduced into areas of established *E. curvula*? (Plate 5) (Chapter 3, Section 3.5)
  - Treatment of *E. curvula* plants[7]
    - Control
    - Herbicide
    - Clip
    - Herbicide and clip
      - Experimental unit
        - Four *T. triandra* plugs planted around the base of an *E. curvula* tuft
        - One *T. triandra* plug planted equidistant from surrounding *E. curvula* tufts

Plate 5. A tuft of *E. curvula* from an area that was established 25 years previously (note the low basal cover).

CONCLUSION (Chapter 10)

- Poor survival from January 1998 planting, because plugs became moribund in nursery, therefore replacement planting in January 1999.
- *H. dregeana* showed lowest survival (9%) compared to *T. triandra* (27%) and *H. contortus* (45%).
- Thatching and natrual re-vegetation showed very low basal cover.
- Self-sustaining population of *H. contortus* was achieved.
- A high degree of grazing was oserved and thus Hot Sauce animal repellent was sprayed on the plants in January 1999.

NOTES

1. Patent rights in South Africa have been applied for by JE Granger.
2. Plug sizes used: small (200 plugs per seedling tray) and large (96 plugs per seedling tray).
3. Plants that have established naturally will be sprayed with a herbicide prior to the fire.
4. *Eragrostis teff* is over-sown, at a rate of 15.6 kg seed/ha, to improve the fuel load in the first season, but being an annual it will not be persistent.
5. *E. curvula* is over-sown, at a rate of 3.9 kg seed/ha, to improve the fuel load, although it will remain in the grass sward after the fire.
6. The standard sowing rate of *E. curvula* used was 3.9 kg of seed/ha.
7. The four treatments of the *E. curvula* tufts separate four types of competition: above and below ground competition (control), above ground competition in terms of shade (tufts sprayed with Roundup), below ground competition (tufts are clipped), and no competition (tufts are sprayed and clipped).
8. Terrasorb® is a starch based polymer with an extremely high water holding capacity.
9. Agrilen® is a white, needle-punched geo-fabric which provides shade while allowing rainwater Penetration.

Figure 2.2: Diagrammatic representation of the trials.

3. Inter-specific competition

3.1 Introduction

A series of trials were set up to investigate the inter-specific competition between grass plugs. These trials investigated the effects of competition between the plugs (*T. triandra, H. contortus* and *H. dregeana*) themselves, the plugs and over-sown *E. curvula* (grown from seed) and the plugs and mature *E. curvula* tufts. In all three trials the effect of competition was evaluated through its effect on the survival and the plant growth of the plugs.

3.2 Aims and objectives

The three experiments were designed to examine the following key questions:

1. What effect does planting density of plugs have on the survival, and growth of grass plants, up to 26 months after planting?
2. What effect does the over-sowing of *E. curvula* have on the survival, and growth of grass plants, up to 26 months after planting?
3. Can *T. triandra* plugs planted out into mature swards of *E. curvula* survive?

3.3 Planting density and species mix

3.3.1 Introduction

Planting density is one of the many factors that will affect both the survival and the performance of the plants, through its influence on competition. Competition between plants occurs for the following resources: light, moisture and nutrients (Wolfson & Tainton 1999). The scope of the present study does not isolate competition for each resource, but rather focuses on the overall effects of competition for the combination these resources on the performance and growth of the plants.

Everson (1985) found that in the KZN Drakensberg, the Increaser group of grass species (species which increase in number with under or over utilization) tiller from below ground level. These species tend to dominate in fire protected sites, as they continue tillering even under high levels of shade. The Decreaser group of grasses (species present in good condition veld, that decrease in number with under or over utilization) tiller from lateral buds positioned above the soil surface, and thus require light in order to develop into tillers. The Decreaser species are therefore susceptible to removal of these lateral buds through grazing or fire, but are able to regenerate rapidly and tend to dominate in areas that are frequently burnt or grazed.

Under conditions of low light intensity, such as the shading effect that takes place under a closed canopy, the products of photosynthesis are retained by the parent shoot at the expense of the lateral tillers and the roots (Wolfson & Tainton 1999, Bartholomew 1999). Although these plants appear to be performing well, they are unlikely to survive further stresses, for example drought or defoliation, due to reduced root reserves (Everson 1985, Tainton & Hardy 1999, Wolfson & Tainton 1999). The tillers that do develop under these conditions often do not survive as they are unable to meet their own energy requirements through photosynthesis (Briske 1991, Wolfson & Tainton 1999, Bartholomew 1999). One advantage of decreased light intensity at the plant base, is that weed species, especially *A. mearnsii* seedlings could be out competed, reducing the extent of follow up treatments required (Campbell *et al.* 2000b). A balance needs to be achieved between sufficient shading (to reduce the germination of unwanted species) and sufficient light reaching the plant bases to ensure tillering.

A wider planting distance will reduce competition for resources. The reduced competition and increased light intensity at the plant bases should allow for greater survival of the plugs and increased lateral development of the grass plants (Everson 1985, Wolfson & Tainton 1999, Bartholomew 1999). The plants may show less vertical development as there is less competition for light. The *A. mearnsii* seedlings will also receive a reduced level of competition and may therefore require greater levels of control (Campbell *et al.* 2000b). Planting density will also influence the cost of the re-vegetation program. A higher planting density will result in increased costs, through an increase in the number of plants required, transporting and labour for planting.

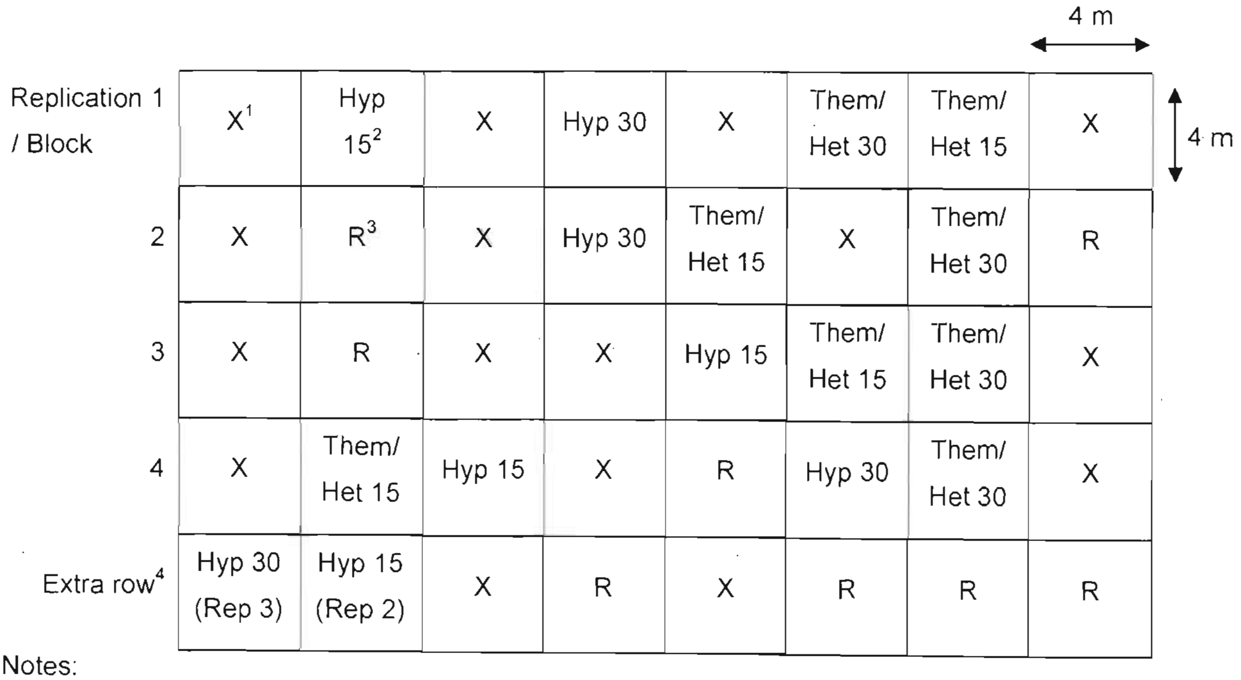
The study investigated the competitive effects of two planting densities on both plug survival and above ground plant growth of two different ratios of species. The trial specifically examined the effect of planting distance between plugs of mixed stands of *T. triandra* and *H. contortus* and pure stands of *H. dregeana* on foliage production and sexual reproductive output (measured as number of flowering culms). Inter-specific competition between *T. triandra* and *H. contortus* was not investigated within the plots, as the two species have been shown to grow in a similar manner (Appendix D - Materials and Methods).

3.3.2 Materials and methods

The trial was established at Kamberg in January 1998 (refer to Chapter 2 for a detailed description of the site). Two levels of planting density, 15 cm and 30 cm intra- and inter-row spacing were applied. The 30 cm spacing was chosen, as that was the spacing that was used in previous work where plugs were planted out into the field (Granger 1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA). The closer plant spacing (15 cm) was chosen to investigate possible advantages of establishing a closed grass canopy more rapidly to provide competition to *A. mearnsii* seedlings that might germinate in the plot.

The two mixes of species used were, an equal ratio (1:1) of *T. triandra* and *H. contortus* and, *H. dregeana* alone. Both *T. triandra* and *H. contortus* are climax grass species, occurring together in the undisturbed grassland of the area and were therefore planted together (see Chapter 1, Section 1.1 for details). In each plot the plugs were planted in three rows of each species alternating across the plot. In the veld *H. dregeana* commonly grows in dense mono-specific patches, and was therefore planted alone. All combinations of planting distance and species ratio were applied, resulting in four treatments.

Initially, this trial and the Terrasorb®-Agrilen® trial (Chapter 4) were combined, providing a total of eight treatments. This combined trial was established in a randomised complete block design, with four replications. The plot size was 4 m by 4 m. Where physical obstructions prevented plots from being planted, replacement plots were established in an extra row below, thus the randomised complete block design was compromised and the trial was analysed as a simple random design. The experimental layout is depicted in Figure 3.3.1. The Terrasorb®-Agrilen® treatments were replanted in January 1999 because of contaminated Agrilen® material. The two different ages of the populations confound the analysis and therefore they have been analysed as separate trials.



Replication 1 / Block	X[1]	Hyp 15[2]	X	Hyp 30	X	Them/ Het 30	Them/ Het 15	X
2	X	R[3]	X	Hyp 30	Them/ Het 15	X	Them/ Het 30	R
3	X	R	X	X	Hyp 15	Them/ Het 15	Them/ Het 30	X
4	X	Them/ Het 15	Hyp 15	X	R	Hyp 30	Them/ Het 30	X
Extra row[4]	Hyp 30 (Rep 3)	Hyp 15 (Rep 2)	X	R	X	R	R	R

Notes:

1 'X' designates plots that were used for the Terrasorb®-Agrilen® trial

2 The full details of the treatments are as follows:

Them/Het 15: *Themeda triandra* and *Heteropogon contortus* planted at 15 cm spacing

Them/Het 30: *T. triandra* and *H. contortus* planted at 30 cm spacing

Hyp 15: *Hyparrhenia dregeana* planted at 15 cm spacing

Hyp 30: *H. dregeana* planted at 30 cm spacing

3 'R' refers to plots that were rejected due to a large number of obstructions.

4 The extra row was created to accommodate rejected plots from previous replications.

Figure 3.3.1: The experimental design for the planting distance trial, at Kamberg, KwaZulu-Natal, 1998 to 2000.

Plug survival was recorded one month after planting (February 1998), during April 1998 (3rd month), November 1998 (10th month) (to show initial transplant survival) and March 2000 (26th month after planting) (to show long term survival of the plugs). As mentioned in Chapter 2 survival was expressed as a percentage. Survival was analysed using an analysis of variance (ANOVA) (Chapter 2, Section 2.5). An angular transformation improved the coefficients of variation (CV%), but did not change the significance level, based on the F-probability values. No transformation was therefore used for the ANOVA. In all cases where ANOVA showed either a species treatment effect or a spacing treatment effect ($P \leq 0.05$) the F-value of the ANOVA was sufficient evidence to indicate individual treatment effects, as there were only two levels within each treatment. No further tests were required to indicate individual treatment effects (Stevens *pers. comm.* Department of Agriculture and Environmental Affairs, Cedara. Private Bag X9059, Pietermaritzburg, 3200, KwaZulu-Natal, RSA).

Plant growth was measured in December 1998 and again in January, February, March and April of 1999 (11th to 15th months since planting) on a random sub-sample of 30 plants per plot as described in Chapter 2, Section 2.4. The sub-sample was selected from the plot using random number tables. Tiller number, plant basal area, plant height and number of culms per plant were analysed using the plant growth curves of Hunt & Parsons (1974) (Chapter 2, Section 2.5). An ANOVA was also carried out for each variable at each time interval. For tiller number per plant, a square root transformation reduced the CV%, but did not change the significance, thus the ANOVA was performed on the untransformed data. A log transformation was used on the plant basal area in order to satisfy the assumptions for a valid ANOVA. No transformation was required for the plant height data and flowering culms per plant data as an investigation of the residuals in the analysis showed this to be unnecessary.

The instantaneous RGR was calculated for each time interval (Hunt 1978) and plotted over time for each plant growth variable. The 95% confidence intervals were overlaid for each treatment curve. Comparisons were then made using the 95% confidence intervals to detect, by inspection, if any differences ($P \leq 0.05$) occurred.

3.3.3 Results

3.3.3.1 Survival

Throughout the trial, only a difference ($P \leq 0.05$) between species was detected (Table 3.3.1). Survival of the *T. triandra/H. contortus* combination (41.7%) was greater than for *H. dregeana* (8.0%) by March 2000. Plant spacing had no influence ($P > 0.05$) on survival, although survival rate of plants at 30 cm spacing (27.0% in March 2000) was always greater than 15 cm spacing (22.7% in March 2000), except for the *T. triandra/H. contortus* combination in February 1998 (Figure 3.3.2). The survival in all treatments decreased over time, with *H. dregeana* (declining from 47.6% to 8.0% over the duration of the trial) decreasing more rapidly than the *T. triandra/H. contortus* combination (declining from 63.7% to 41.7% over the duration of the trial).

Table 3.3.1: Summary of the F-probability values from the ANOVA of the survival rate for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination in a spacing trial at Kamberg, KwaZulu-Natal

Treatment	February 1998	April 1998	November 1998	March 2000
Plant spacing	0.276	0.252	0.349	0.356
Species	0.039	<0.001	<0.001	<0.001
Plant spacing.Species	0.176	0.476	0.579	0.638

Note: Values ≤ 0.05 are considered significantly different

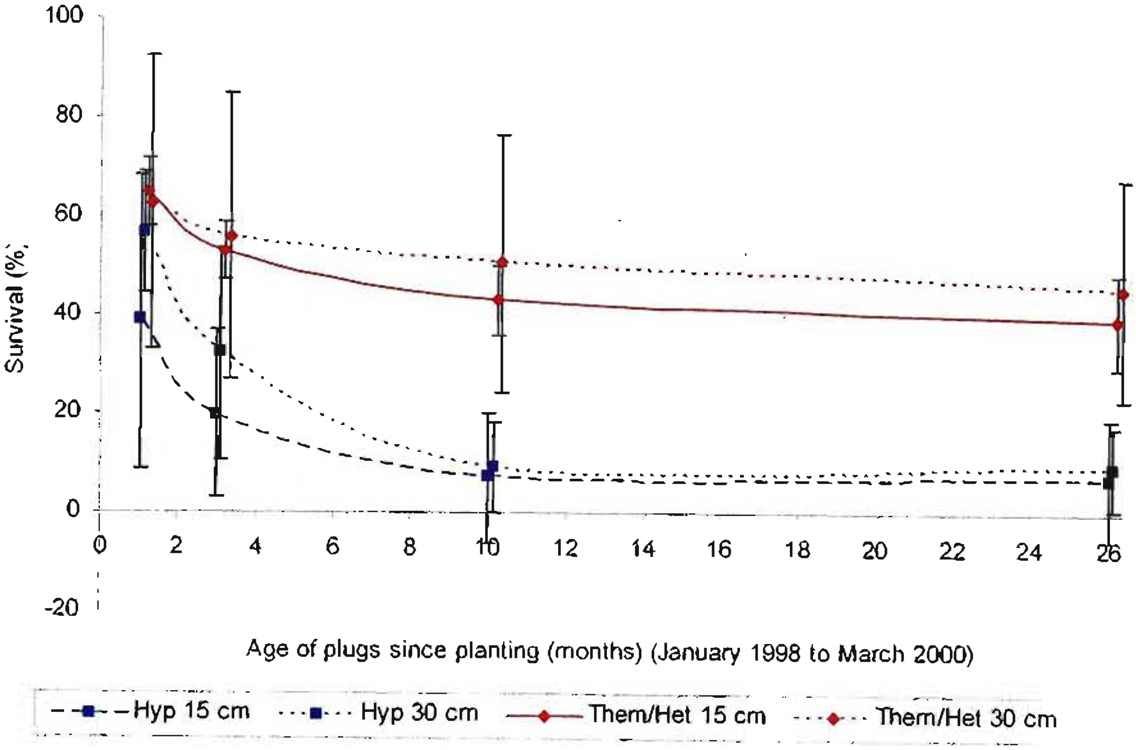


Figure 3.3.2: The survival rate (%) of *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

3.3.3.2 Plant growth

A linear growth rate over time was noted for number of tillers per plant in all four treatments (Figure 3.3.3). The gradients of the regression lines for the following treatments are parallel: *H. dregeana* at 15 cm spacing and the *T. triandra/H. contortus* combination at both spacings, although the y-intercepts differ. The increase in number of tillers per plant for *H. dregeana* at 30 cm spacing was more rapid than that for the other three treatments, and although number of tillers in this treatment were initially the lowest, by the end of the trial plants from this treatment had the largest number of tillers. The 95% confidence interval bars on the graph indicate that the growth curves for the treatments did not differ ($P > 0.05$) for the duration of the trial, except the *T. triandra/H. contortus* combination at 15 cm spacing, which produced less tillers per plant ($P \leq 0.05$) than the other three treatments (Figure 3.3.3). It was interesting to note that by the end of the trial the 30 cm spacing treatment for both species had a greater number of tillers per plant than the 15 cm spacing, indicating that more lateral growth has taken place at 30 cm spacing. Based on the diverging gradient trend seen for *H. dregeana*, it is likely that treatment differences would have become significantly greater with time.

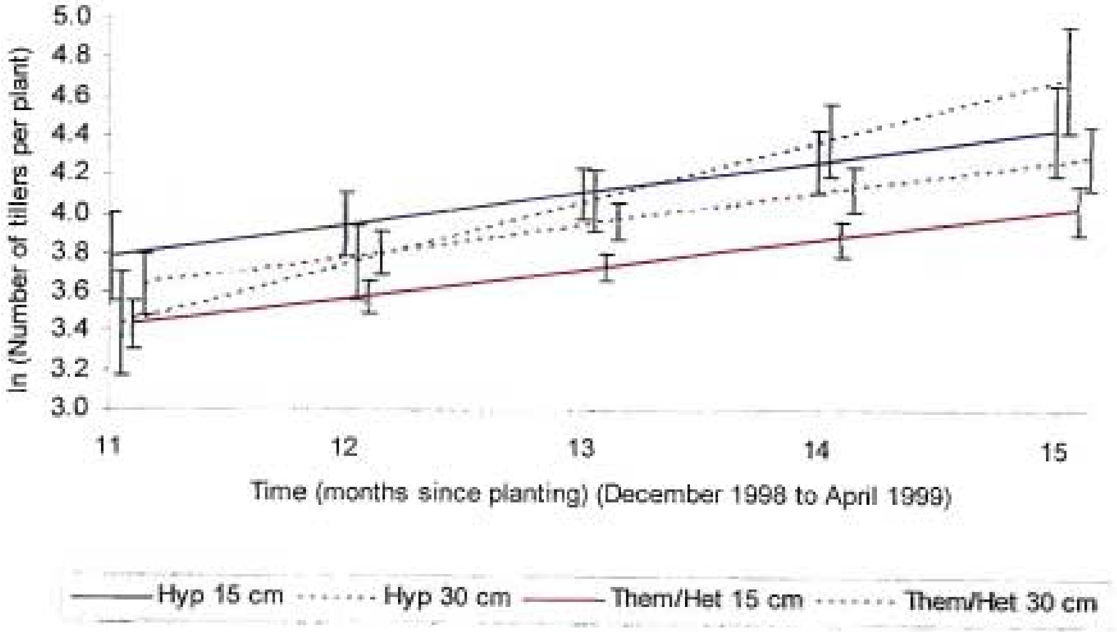


Figure 3.3.3: The growth curves of the natural log of tiller numbers per plant for *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

The ANOVA showed that for the 11th and 12th months after planting (December 1998 and January 1999) there were no significant differences ($P > 0.05$) between the treatments (Table 3.3.2). In February 1999 (13th month) a difference ($P \leq 0.05$) was apparent for the species treatment. The *H. dregeana* plants had a larger number of tillers per plant compared with the *T. triandra/H. contortus* combination. In March and April of 1999, both treatments differed ($P \leq 0.05$), although no interactions took place. By March and April the *H. dregeana* plants had greater ($P \leq 0.05$) numbers of tillers than the *T. triandra/H. contortus* combination. A spacing effect became evident towards the end of the trial; with the 30 cm spacing producing a greater number of tillers per plant (for all species) compared to the 15 cm treatments.

Table 3.3.2: Summary of the F-probability values from the ANOVA of the number of tillers per plant for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination in a spacing trial at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Plant spacing	0.679	0.918	0.285	0.024	0.016
Species	0.516	0.245	0.030	0.003	0.002
Plant spacing.Species	0.217	0.212	0.248	0.685	0.750

Note: Values ≤ 0.05 are considered significantly different

The instantaneous RGR of the number of tillers per plant, showed that growth rate remained constant for the duration of the trial (as expected) due to the linear growth rate of the plants (Figure 3.3.4). From this graph it is obvious that the growth rate for *H. dregeana* at 30 cm is greater ($P \leq 0.05$) than that for the remaining three treatments, which, according to the 95% confidence intervals do not differ from each other.

As might be expected, the growth pattern for basal area was very similar to tiller number, as an increase in tiller number per plant results in an increase in the lateral development of the plant (i.e. an increase in plant basal area) (Figure 3.3.5). There were no differences ($P > 0.05$) between the growth curves for the four treatments. The increase in plant basal area of *H. dregeana* at 30 cm spacing was more rapid (steeper gradient) than the remaining treatments. There was a slight difference in the gradient of the two levels of plant spacing for the *T. triandra/H. contortus* combination, with the 30 cm spacing treatment growing faster than the 15 cm spacing. The 30 cm spacing treatments had larger plant basal areas than their counterparts at 15 cm spacing.

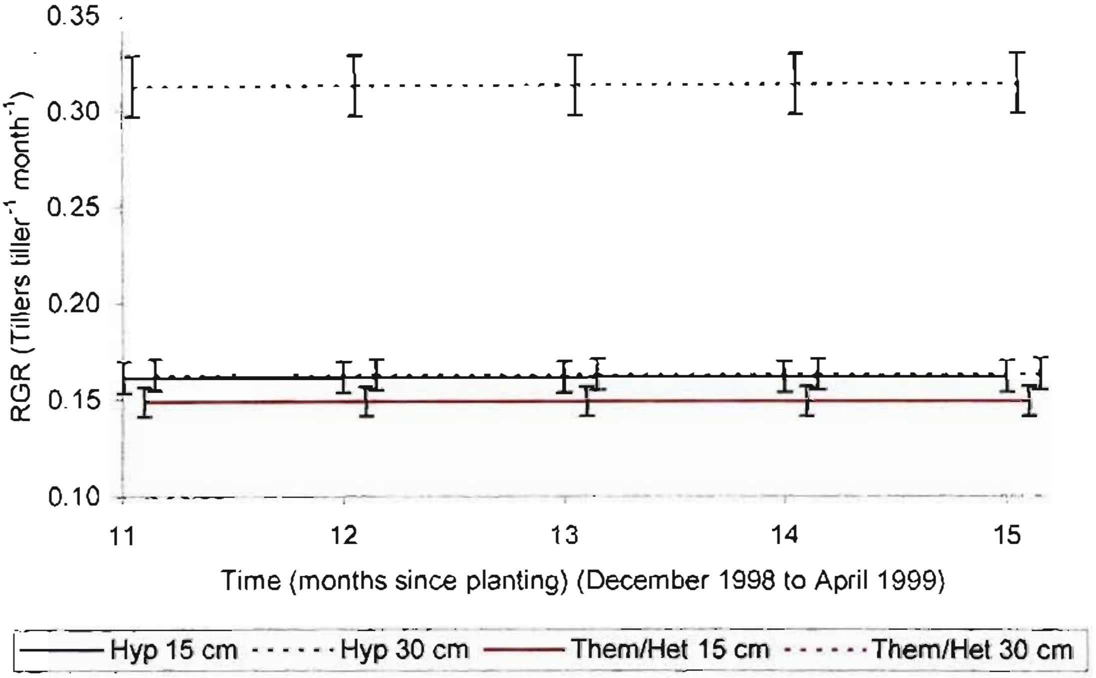


Figure 3.3.4: The relative growth rate of tiller per plant (tillers tiller^{-1} month^{-1}) of *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

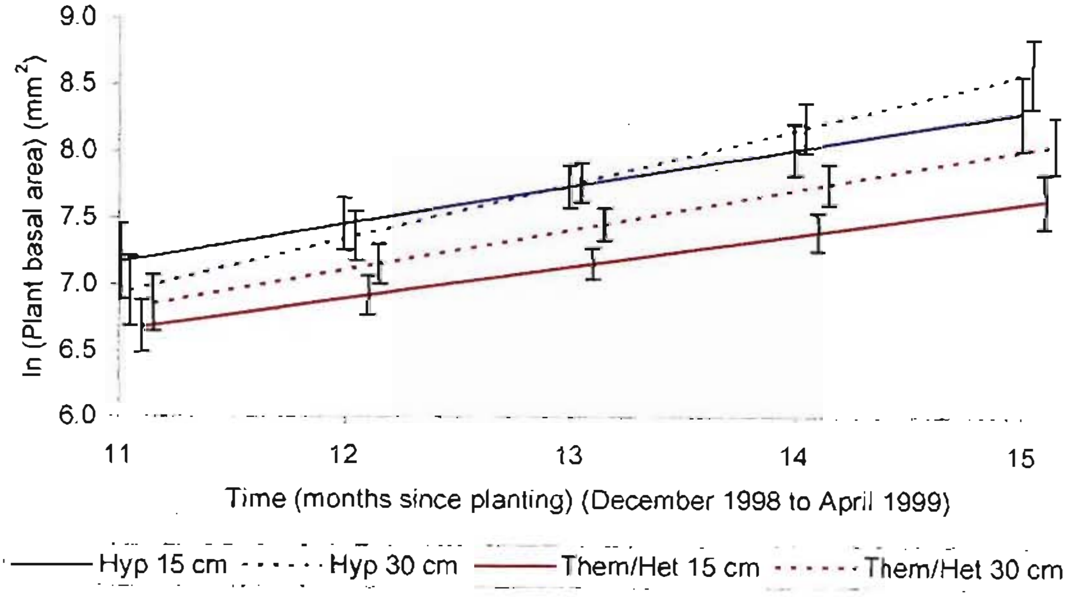


Figure 3.3.5: The growth curves of the natural log of plant basal area of *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

No differences ($P > 0.05$) in basal area between the treatments were evident from the ANOVA analysis for both December 1998 and January 1999 (Table 3.3.3). In February 1999 differences ($P \leq 0.05$) in the growth of each species were evident and by March and April there was a difference ($P \leq 0.05$) across species and spacing. In the months where species effect became significant, the plant basal area of the *H. dregeana* plants was greater than that of the *T. triandra/H. contortus* combination. By the end of the study period, plants in the 30 cm spacing plots had greater lateral growth ($P \leq 0.05$) than those in the closer (15 cm) spacing (especially noticeable for *H. dregeana*). It was evident that in the *T. triandra/H. contortus* combination treatments the relative differences ($P \leq 0.05$) were smaller. These patterns match the patterns for tiller number per plant, as an increase in tiller number will increase plant basal area.

Table 3.3.3: Summary of the F-probability values from the ANOVA of the log transformation of the plant basal area for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination in a spacing trial at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Plant spacing	0.895	0.863	0.398	0.007	0.012
Species	0.915	0.130	0.045	0.012	0.022
Plant spacing.Species	0.497	0.489	0.503	0.964	0.707

Note: Values ≤ 0.05 are considered significant.

The RGR of the basal area was constant for all treatments (Figure 3.3.6). The growth rate for *H. dregeana* plants at 30 cm spacing was greater ($P \leq 0.05$) than the *T. triandra/H. contortus* combination at 30 cm spacing and *H. dregeana* plants at 15 cm, which in turn are greater ($P \leq 0.05$) than the *T. triandra/H. contortus* combination at 15 cm spacing. As mentioned earlier, the 15 cm spacing had a lower growth rate than the 30 cm spacing, showing that lower planting densities allow for more lateral development in the plants.

The height data have a slightly different growth curve compared to the other variables, as the growth functions are mostly quadratic, with a cubic function for *T. triandra/ H. contortus* at 15 cm spacing (Figure 3.3.7). This cubic relation was evident as this treatment reached a plateau over the last two months (March and April 1999) of the trial, while the remaining treatments reached a peak plant height and then decreased in the last two months. This decrease in plant height was due to increased grazing pressure on the trial plots, as the Eland and Reedbuck moved down from their summer grazing areas on the plateau of the Drakensberg to the foothills of the Little Berg. An analysis of the growth curves and the ANOVA for each month showed that *H. dregeana* had a much taller growth form than either *T. triandra* or *H. contortus* ($P \leq 0.05$) throughout the trial (Table 3.3.4). This was expected, as these two species are known to have different growth forms (van Oudtshoorn 1992). In contrast to basal area there was no difference ($P > 0.05$) in plant height between the two row spacings, however, the plants in the 15 cm spacing are generally taller.

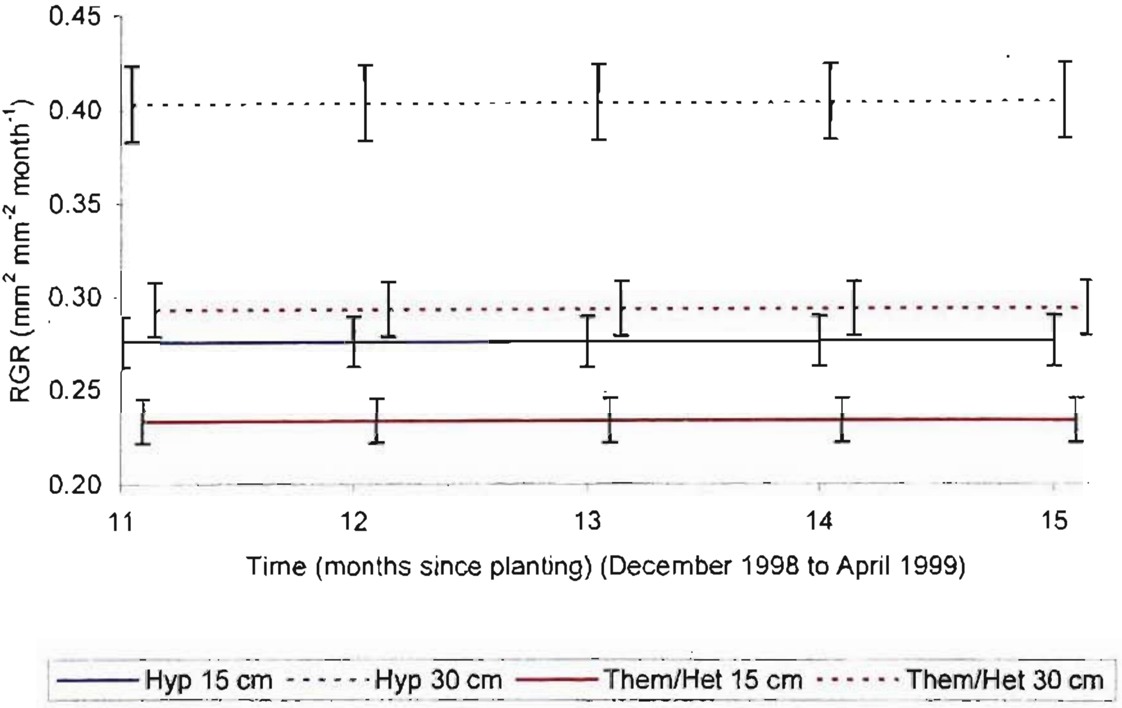


Figure 3.3.6: The relative growth rate of plant basal area (mm^2 mm^{-2} month^{-1}) of *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

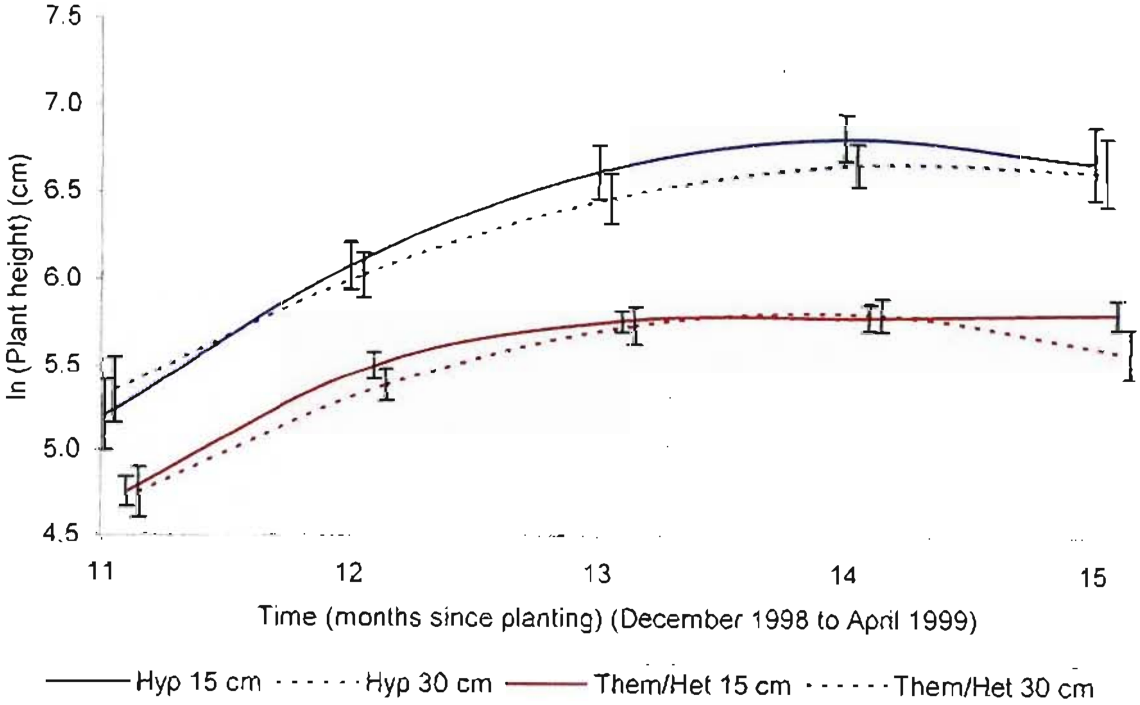


Figure 3.3.7: The growth curves of the natural log of plant height of *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

Table 3.3.4: Summary of the F-probability values from the ANOVA of the plant height data for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination in a spacing trial at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Plant spacing	0.671	0.752	0.271	0.063	0.408
Species	<0.001	0.001	<0.001	<0.001	<0.001
Plant spacing.Species	0.511	0.893	0.328	0.147	0.282

Note: Values ≤ 0.05 are considered significant.

Due to the quadratic nature of the growth curves the RGR are negative as the increase in plant height was at a decreasing rate (Figure 3.3.8). The cubic function for the *T. triandra/H. contortus* combination at 15 cm shows a quadratic relationship for RGR as the decrease in the RGR reaches a minimum at 14 months (March 1999) and increases slightly, when actual plant heights reached a plateau. The decrease in the RGR of height was greater for the two 15 cm spacing than the 30 cm spacing.

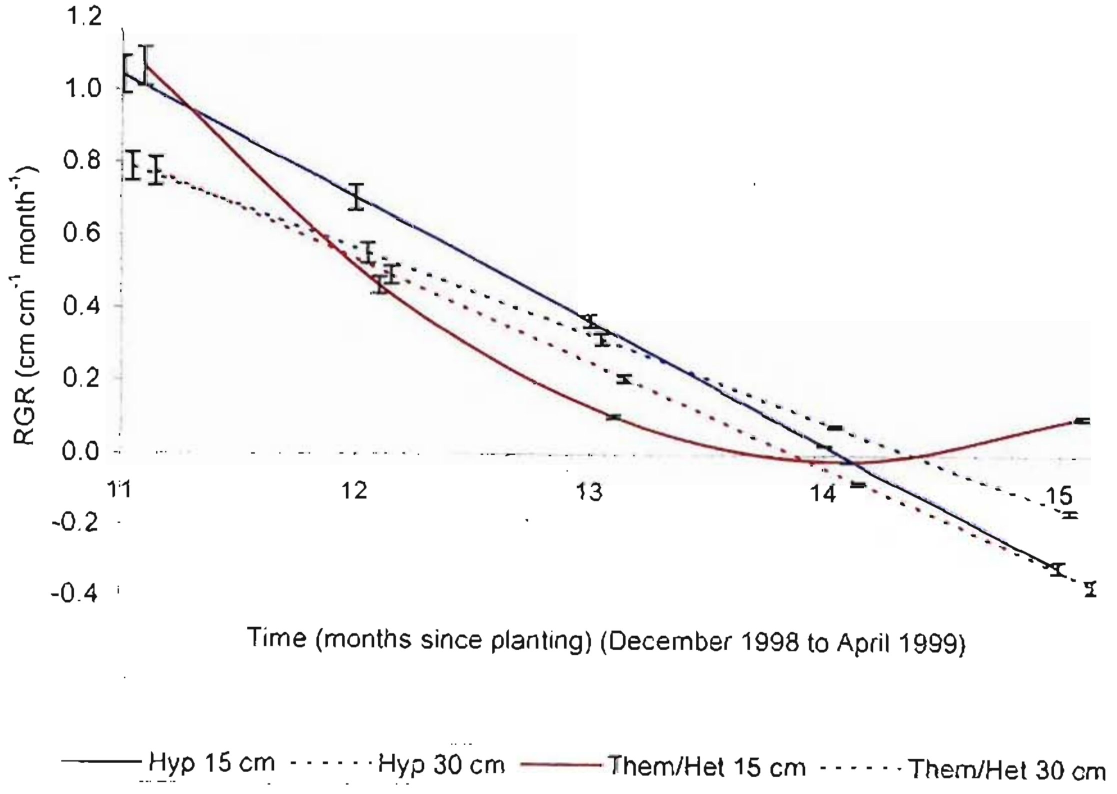


Figure 3.3.8: The relative growth rate of plant height (cm cm^{-1} month^{-1}) for *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings in a planting density trial at a rehabilitated *Acacia mearnsii* site in Kamberg, KwaZulu-Natal.

The two species flowered at different times of the year and thus were analysed separately. In mid-summer (December/January) the *T. triandra/H. contortus* combination flowered. An ANOVA showed no differences (P > 0.05) for the spacing treatment, during these months (Table 3.3.5).

Table 3.3.5: Summary of the F-probability values from the ANOVA of the number of flowering culms for the *Themeda triandra/Heteropogon contortus* combination in a spacing trial at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999
Plant spacing	0.118	0.204

Note: Values ≤ 0.05 are considered significant.

The *H. dregeana* plants flowered in the late summer, starting in February and continuing until April. The ANOVA for February, March and April of 1999 showed no differences (P > 0.05) for the spacing treatment (Table 3.3.6).

Table 3.3.6: Summary of the F-probability values from the ANOVA of the number of flowering culms for *Hyparrhenia dregeana* in a spacing trial at Kamberg, KwaZulu-Natal

Treatment	February 1998	March 1999	April 1999
Plant spacing	0.310	0.452	0.333

Note: Values ≤ 0.05 are considered significant.

3.3.4 Discussion and conclusions

The results showed differences (P ≤ 0.05) between species, especially by the end of the trial. This was expected due to the different growth strategies of the species under investigation. *Hyparrhenia dregeana* is a very tall growing, Increaser I species. It is characteristic of veld that has been under utilized and is also common in disturbed sites such as road verges. It commonly forms dense, near mono-specific stands (Gibbs Russell *et al.* 1991, van Oudtshoorn 1992). *Themeda triandra* and *H. contortus* are both abundant in well managed veld. *Themeda triandra* is a Decreaser species and thus decreases in abundance due to both over and under utilization of the vegetation, while *H. contortus* is an Increaser IIa species, which is present in veld in good condition, but increases in abundance with moderate overgrazing. These species generally have a lower growth habit than H. *dregeana* (Gibbs Russell *et al.* 1991, van Oudtshoorn 1992, Camp & Smith 1998).

The results of this trial suggest that *H. dregeana* is less adapted to being established as plugs (survival rate 8% compared to 41.5% for *T. triandra/H. contortus*). This low survival rate may have been exacerbated by the height that plugs were allowed to reach in the seedling trays before being transplanted. The *H. dregeana* plugs had grown too tall in the seedling trays, causing lodging and shading out of smaller plugs. After January 1998, all plugs kept in the nursery were clipped to prevent accumulation of leaf material. The Terrasorb®-Agrilen® trial may show a truer reflection of the potential for *H. dregeana* plugs for re-vegetation, as younger material was planted out in this trial (see Chapter 4).

Generally the plants that survived the first winter after planting formed a relatively stable population, with the survival rate not changing substantially after November 1998. From these data it was apparent that the first 11 months were the critical period that determined the long term survival of the plugs. It is possible that if plugs are watered for the first few days after planting survival might be improved.

For all three plant variables, the *H. dregeana* plants showed a greater ($P \leq 0.05$) increase in tiller number per plant, plant basal area and plant height compared to the *T. triandra/H. contortus* combination. This is principally due to the difference in plant growth habits. Although no research has been done comparing the tillering dynamics of these two species, it is known that species do differ in their tiller demography (Bartholomew 1999, Wolfson & Tainton 1999). Given that there was no difference ($P > 0.05$) in the number of tillers per plant or basal area at the start of the trial, and that this treatment effect only manifested itself later on, *H. dregeana* must have a higher overall growth rate compared to the *T. triandra/H. contortus* combination. This would mean that *H. dregeana* forms a closed canopy sooner and thus was better able to protect disturbed sites from soil erosion, although the lower survival rate of *H. dregeana* meant that the remaining plants received a lower level of competition than in the *T. triandra/H. contortus* plots (where survival was greater).

Plant spacing generally had less of an effect than species. Differences ($P \leq 0.05$) were only seen in March and April of 1999, for the number of tillers per plant and plant basal area. During these months the 30 cm spacing showed a greater ($P \leq 0.05$) number of tillers per plant and plant basal area compared to the 15 cm spacing. This suggested that the closer plant spacing formed a closed canopy sooner, thereby increasing the inter-plant competition for light as shading increased. The shading would have decreased the light intensity at the base of the plants, thus reducing the rate of tillering (Langer *et al.* 1964, Everson 1985, Briske 1991, Wolfson & Tainton 1999, Bartholomew 1999). It was expected that as the number of tillers increased per plant, so plant basal area would increase, due to the lateral plant growth taking place. In rehabilitation, one must select a species that produces new tillers rapidly to ensure a good basal cover in a short space of time.

Although plant height data did not show a difference ($P > 0.05$) with respect to spacing, the general trends showed that the 15 cm spacing yielded a consistently greater plant height. This suggests that the competition for light intensity is expressed through an increase in the plant height, in an attempt for the plants at the closer spacing to reach through the canopy towards the sunlight. As the plant dedicates more photosynthates towards increased vertical growth, fewer nutrients are available for lateral tiller development (Wolfson & Tainton 1999, Bartholomew 1999). Plant height was also adversely affected by grazing. This effect was uncontrolled and makes these data more variable than if grazing could have been excluded. Grazing possibly had a greater affect on the *H. dregeana* plants in the late summer, as it was observed that animals grazed only the inflorescence of these plants and did not reduce the leaf volume. This could account for the greater RGR of *H. dregeana,* as the photosynthetically active leaf area was not reduced as much as the more palatable *T. triandra/ H. contortus* combination.

Canopy cover was not directly measured in the trial, although this would be useful to monitor from a rehabilitation perspective. As the sooner the canopy closes the better the soil protection from erosion through reducing rain drop impact and the more likely that *A. mearnsii* seedlings will be out competed, thus reducing the follow up control methods required. Through observation all treatments achieved closed canopy cover by the end of the trial. *H. dregeana* plugs in the 15 cm spacing were starting to grow into each other by the end of the trial, though there was reduced survival with the 15 cm spacing. The loss of individual plants resulted in a delay in the canopy cover developing. A fine balance exists between a closer plant spacing to increase basal cover and a larger plant spacing (with less competition for resources) to improve survival.

The number of flowering culms showed no treatment differences, apart from when each species was flowering. This difference was due to the phenological differences of the species and not a treatment difference. The lack of response in the number of flowering culms may be directly related to the reliance on vegetative propagation and not seed production of the climax grass species in the KZN Drakensberg was found by Everson (1985) at Cathedral Peak.

In conclusion, it is recommended that a plant spacing of 30 cm be used in rehabilitation of cleared *A. mearnsii* sites. This spacing is cheaper (due to the reduced number of plants required). In addition, these plants showed a greater survival and grew more rapidly at 30 cm spacing than at 15 cm. Further research is required to determine the length of time taken for the canopy to close.

3.3.5 Summary

In January 1998 a planting density trial was established at Kamberg to investigate the effect of plant spacing on the survival and growth of nursery raised plugs planted into a site cleared of *A. mearnsii.* Plugs of only *H. dregeana* and a combination of *T. triandra/H. contortus* were planted at 15 cm and 30 cm spacings. By the end of the trial the *T. triandra/H. contortus* combination showed a greater survival ($P \leq 0.05$) than *H. dregeana.* Although not statistically significant, the 30 cm spacings of both species showed a greater survival than the 15 cm spaced plugs. The number of tillers per plant for all treatments increased linearly over time, with *H. dregeana* showing the most rapid tiller development. The 30 cm spacings consistently produced greater number of tillers than the 15 cm spacing, although the differences were not significant ($P > 0.05$). Plant basal area showed a similar response to tiller number with *H. dregeana* showing a greater basal area than the *T. triandra/H. contortus* combination, and the 30 cm spacing being greater than the 15 cm spacing, although none of these differences were significant at the 5% level. Plant height only showed a species effect, as expected as

H. dregeana is a taller growing plant than either *T. triandra* or *H. contortus*. There was no spacing effect ($P > 0.05$) on plant height, although the plugs at 15 cm spacing showed a greater plant height than the plugs at 30 cm spacing. There was no spacing effect ($P > 0.05$) for number of flowering culms per plant, only a species difference in the season that the species flowered, with the *T. triandra/H. contortus* combination flowering in the late spring and early summer and *H. dregeana* flowering in the late summer. From the above results it is clear that the recommended species for re-vegetation of this *A. mearnsii* site is the *T. triandra/H. contortus* combination at 30 cm spacing.

3.4 Competitive effect of over-sowing with *Eragrostis curvula*

3.4.1 Introduction

Traditionally KZN Wildlife have re-vegetated areas cleared of *A. mearnsii* by over-sowing the area with *E. curvula* (Thompson *pers. comm.* Headquarters, Ezemvelo KwaZulu-Natal Wildlife, PO Box 13053, Cascades, 3202, KwaZulu-Natal, RSA). This provided a quick aerial cover and good biomass within one or two seasons. Once a good fuel load was established, fire could be used as a management tool to control *A. mearnsii* re-growth, by stimulating the *A. mearnsii* seeds to germinate. A follow up treatment of herbicide or fire then kills the *A. mearnsii* seedlings removing a large amount of *A. mearnsii* seed from the seed bank (Campbell *et al.* 2000a & 2000b). Areas that were over-sown up to 25 years ago have remained almost pure swards of *E. curvula,* negatively impacting on the bio-diversity of the area. Due to these mono-specific swards of *E. curvula* forming, alternative methods of re-vegetating these areas need to be investigated.

Granger (1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA) showed that nursery grown plugs of *T. triandra* and *H. contortus* could be used to re-vegetate sites cleared of *A. mearnsii.* In this trial the plugs of *T. triandra, H. contortus* and *H. dregeana*, were planted and over-sown with *E. curvula*. The advantages of using *E. curvula* for re-vegetation will be achieved, such as high fuel loads and rapid canopy cover, with the long term benefit of other indigenous species preventing a mono-specific stand.

With the over-sowing of *E. curvula* competition for resources between the plants will be increased, especially light, moisture and nutrients (Wolfson & Tainton 1999). Under conditions of low light intensity, e.g. shading under a closed canopy, the products of photosynthesis will be retained by the parent shoot at the expense of the lateral tillers and the roots (Wolfson & Tainton 1999, Bartholomew 1999), and an increase in plant height will occur as the plants compete for light. Tillers that do develop under intense shading will often not survive, as they are unable to supply their own energy requirements through photosynthesis (Briske 1991, Wolfson & Tainton 1999, Bartholomew 1999). One advantage of the decreased light intensity at the plant base is that weed species, especially *A. mearnsii* seedlings, tend to be out competed, reducing the extent of follow up treatments required to control the *A. mearnsii* re-growth.

The aim of the trial was to investigate whether over-sowing with *E. curvula* had an impact on vegetative and sexual reproductive production of the planted plugs, or whether it would act as a nurse crop and enhance their growth and development. Two different species with very different growth forms were used, firstly *H. dregeana* which is a tall growing Increaser I species. Secondly, *T. triandra* and *H. contortus* (treated as one "species") as they are both short growing species, abundant in the undisturbed veld (van Oudtshoorn 1992, Camp & Smith 1998) and were shown to develop in a similar manner (Appendix D). Plant spacings between plugs of 15 cm and 30 cm were used.

3.4.2 Materials and methods

The trial was established at Kamberg in January 1998 (refer to Chapter 2 for details of the study site and planting methods). The species mixes that were used were *T. triandra* and *H. contortus* (planted in a 1:1 ratio and *H. dregeana* planted alone. Both species were planted at two planting densities, 15 cm and 30 cm apart, thus creating four treatments planted to plugs. All four treatments were over-sown with *E. curvula* seed, plus a control plot, which had no plugs planted and was over-sown with *E. curvula*.

Commercially available *E. curvula* var. Ermelo seed was used. The recommended broadcast sowing rate of 3.9 kg ha $^{-1}$ as defined by Bartholomew (2000) was used. The seed was mixed with pine bark to bulk it up and was hand broadcast across each plot. The total seed/pine bark mix for each plot was divided in half and broadcast across the entire plot from opposing directions to achieve an even spread of seed across the plot.

In order to compare plugs that were not over-sown with *E. curvula,* with those that were over-sown, the data from this trial were compared to the earlier planting density trial (Chapter 3, Section 3.3). This comparison was possible as the two trials were located adjacent to each other along the contour and were planted at the same time and measurements of plant growth and survival took place at the same time. The two species at the two plant spacings were compared both with and without over-sowing of *E. curvula*. The combination of these two trials for analysis was done to avoid the duplication of similar treatments across the trial area, while still being able to investigate a wide range of treatments.

A plot size of 4 m by 4 m, with five treatments and four replications was used, in a randomised complete block design. Where obstructions prevented plots from being planted, that particular treatment was moved along the contour and a blank plot was left (Figure 3.4.1).

The survival of the plugs was recorded one month after planting during February 1998 and again in April 1998 and November 1998 (3rd and 10th months after planting respectively). The survival of plugs in the plots that were over-sown with *E. curvula* was not recorded after November 1998, due to the dense aerial cover of *E. curvula*, which obscured the planted plugs. As mentioned in Chapter 2 survival was expressed as a percentage. The survival of the plants was investigated using ANOVA.

The assumptions for a valid ANOVA test where investigated. An angular transformation was found to improve the coefficients of variation (CV%), but did not change the significance; therefore no transformation was used for the ANOVA. In all cases where ANOVA showed either a spacing treatment effect or a species treatment effect ($P \leq 0.05$), the F-value of the ANOVA was sufficient to indicate the individual treatment effects, as there were only two levels within each treatment. No further tests were required to indicate individual treatment effects (Stevens *pers. comm.* Department of Agriculture and Environmental Affairs, Cedara. Private Bag X9059, Pietermaritzburg. 3200, KwaZulu-Natal, RSA).

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4 m

4 m

Replication/Block	1	E.curv[1]	Them/ Het 30	Hyp 30	Hyp 15	Them/ Het 15	R[2]
	2	E.curv	Hyp 15	Hyp 30	Them/ Het 30	Them/ Het 15	R
	3	Hyp 15	Hyp 30	E.curv	R	Them/ Het 30	Them/ Het 15
	4	R	Them/ Het 15	Hyp 30	Hyp 15	Them/ Het 30	E.curv

Notes:	1	E.curv	*Eragrostis curvula* only
		Them/Het 15	*Themeda triandra* & *Heteropogon contortus* spaced at 15 cm intervals plus *E. curvula*
		Them/Het 30	*Themeda triandra* & *Heteropogon contortus* spaced at 30 cm intervals plus *E. curvula*
		Hyp 15	*Hyparrhenia dregeana* spaced at 15 cm intervals plus *E. curvula*
		Hyp 30	*Hyparrhenia dregeana* spaced at 30 cm intervals plus *E. curvula*
	2		'R' refers to plots that were rejected due to a large number of obstructions

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Figure 3.4.1: The experimental design for the over-sowing trial, at Kamberg, KwaZulu-Natal, 1998 to 2000.

In order to monitor plant growth, a total of five sets of readings were taken on a sub-sample of 30 plants in each plot, including both the planted plugs and the over-sown *E. curvula* tufts (Chapter 2, Section 2.4). These measurements commenced in December 1998 and were taken again in January, February, March and April of 1999 (11 to 15 months after planting). Tiller number, plant basal area and plant height were analysed using the plant growth curves of Hunt & Parsons (1974) as described in Chapter 2, Section 2.5. An ANOVA was also carried out for each variable at each time interval, as well as for the number of flowering culms per plant. For the tiller numbers per plant, it was found that a square root transformation reduced the CV%, but did not change the significance and therefore the ANOVA was performed on the untransformed data. A log transformation was used on the plant basal area in order to satisfy the assumptions for a valid ANOVA. No transformation was required for the plant height data and flowering culms per plant data as an investigation of the residuals in the analysis showed this to be unnecessary.

The instantaneous RGR was calculated for each time interval and results plotted over time. The 95% confidence intervals were plotted for each treatment. Comparisons were made using the 95% confidence intervals to detect, by inspection, if any differences ($P \leq 0.05$) occurred.

The effect of over-sowing with *E. curvula* on the biodiversity of the plots was investigated by comparing the number of species per plot and the Shannon diversity index of the over-sown trial with that of the planting density trial (as discussed in Chapter 2, Section 2.5).

3.4.3 Results

3.4.3.1 Survival

For the duration of the trial the only treatment that consistently showed a difference ($P \leq 0.05$) was the species treatment, although in May 1998, the plant spacing treatment showed a difference at the 5% level (Table 3.4.1). The survival of the *T. triandra/H. contortus* combination (42.8% by the end of the trial) was greater than that of *H. dregeana* (6.9% by the end of the trial) ($P \leq 0.001$). Although plant spacing was not significantly different, the 30 cm spacing (28.4% by the end of the trial) had a higher survival rate than the 15 cm spacing (21.3% by the end of the trial), except for the *T. triandra/ H. contortus* combination plugs in February 1998, and in November 1998 the *H. dregeana* plugs over-sown with *E. curvula* (Figure 3.4.2). The over-sowing of *E. curvula* had no effect ($P > 0.05$) on the survival of the plugs, it was noted that the over-sown treatments showed a lower survival (22.4% by the end of the trial) compared to the plugs that had not been over-sown with *E. curvula* (27.3% by the end of the trial), except for the *T. triandra/H. contortus* combination planted at 30 cm (Figure 3.4.2). The survival of all plugs decreased over time, although the drop in survival was most obvious in the first three months after planting. The survival of *H. dregeana* dropped more rapidly (from 40.8% to 6.9%) than that of the *T. triandra/H. contortus* combination (62.1% to 42.8%).

3.4.3.2 Plant growth

The number of tillers produced per plant differed greatly between species in the over-sowing trial. The *E. curvula* tufts, both on their own and over-sown over plugs, produced more tillers and grew more rapidly ($P \leq 0.05$) than either of the other two species (Figure 3.4.3). The *E. curvula* only treatment was consistently higher in number of tillers per plant compared to the *E. curvula* tufts that were sown over planted plugs, although not always significant at the 5% level. The *T. triandra/*

Table 3.4.1: Summary of the F-probability values from the ANOVA of the survival rate for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination over-sown with *Eragrostis curvula*, at 15 cm and 30 cm plant spacings at Kamberg, KwaZulu-Natal

Treatment	February 1998	May 1998	November 1998
E. curvula	0.108	0.090	0.220
Plant spacing	0.064	0.050	0.071
Species	<0.001	<0.001	<0.001
E. curvula.Space	0.756	0.737	0.541
E. curvula.Species	0.291	0.906	0.516
Space.Species	0.535	0.922	0.104
E. curvula.Space.Species	0.161	0.255	0.353

Note: Values ≤ 0.05 are considered significantly different

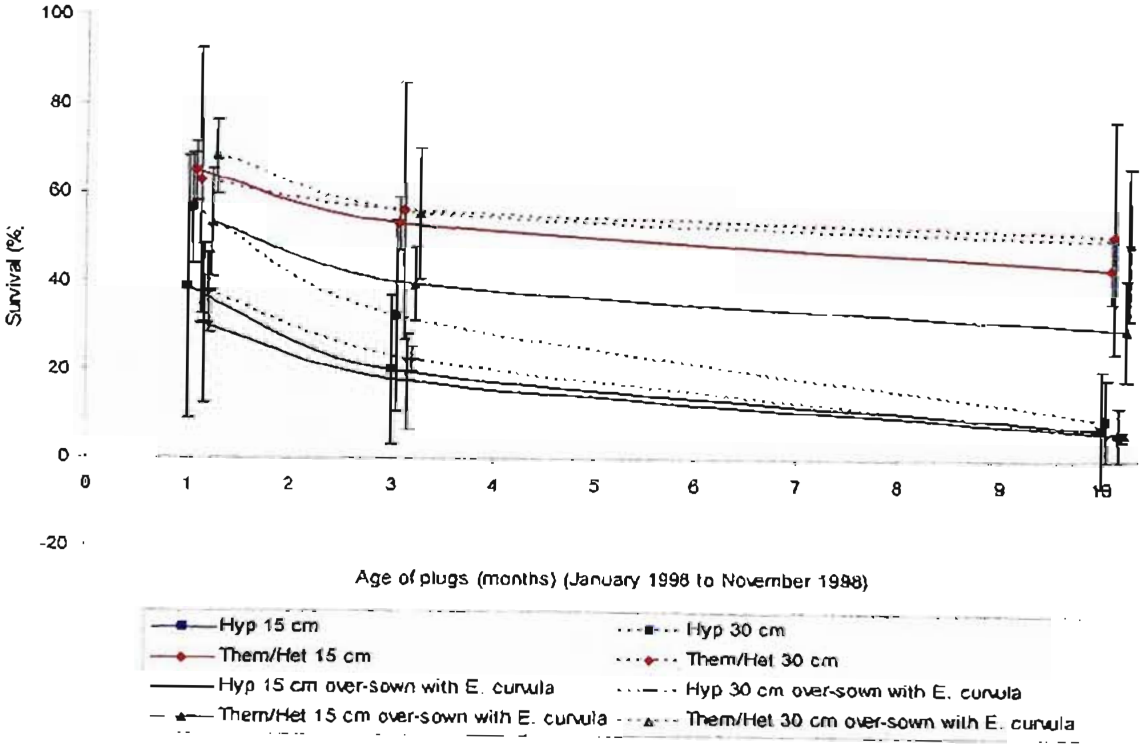


Figure 3.4.2: The survival rate (%) of *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het) planted at 15 and 30 cm plant spacings, with or without being over-sown with *Eragrostis curvula* at a rehabilitated *Acacia mearnsii* plantation site in Kamberg, KwaZulu-Natal.

H. contortus combination showed a similar growth pattern to the *E. curvula* tufts, although they produced less tillers per plant (P ≤ 0.05). The 30 cm spacing for the *T. triandra/H. contortus* combination showed consistently higher numbers of tillers per plant than the 15 cm spacing, but this difference was only significant (P ≤ 0.05) after the 12th month from planting (January 1999). The *H. dregeana* plugs showed no change in the number of tillers per plant for the duration of the measurements, indicating new tiller development took place in the first 11 months after planting only. The spacing of plants was different (P ≤ 0.05) for *H. dregeana* with the 15 cm spacing being greater (P ≤ 0.05) than the 30 cm spacing.

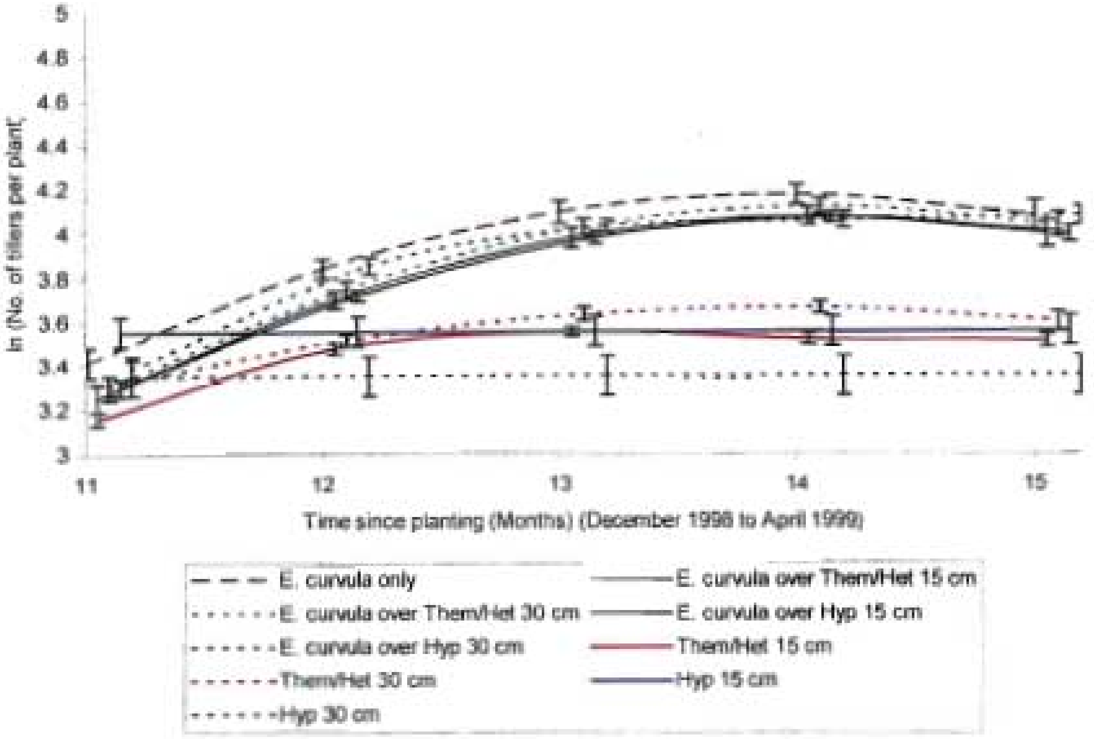


Figure 3.4.3: The growth curves of the natural log of number of tillers per plant for *Eragrostis curvula*, *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart in an over-sowing with *Eragrostis curvula* trial, at Kamberg, KwaZulu-Natal.

The data from the planting density trial (Chapter 3, Section 3.3) were used with the data from the current trial in order to determine the effect of over-sowing with *E. curvula* on the development of tillers. For both species and spacings of planted plugs, the number of tillers per plant were lower (P ≤ 0.05) with over-sowing of *E. curvula*, this effect was greatest for *H. dregeana* at 30 cm spacing (Figure 3.4.4).

The ANOVA indicates that for the duration of the trial there were no treatment or interaction effects (P > 0.05) for the number of tillers per plant for the planted plugs (Table 3.4.2) or the *E. curvula* tufts (Table 3.4.3). Over-sowing with *E. curvula* reduced the number of tillers per plant for the planted plugs (P ≤ 0.05) (Table 3.4.4). A species effect (P ≤ 0.05) was seen by the third month (February 1999). An interaction effect between species and over-sowing was evident by the end of the study.

The RGR for tiller per plant (Figure 3.4.5) indicate that for all treatments the *E. curvula* tufts developed new tillers at the same rate (P > 0.05) except for the *E. curvula* tufts sown over *H. dregeana* at 30 cm spacing. Over time, the growth rate of new tillers progressively decreased for *E. curvula*. The *T. triandra/H. contortus* combination plugs at 30 cm showed a constant decrease in the rate of tiller development, while at 15 cm spacing the rate of tiller development initially declined rapidly before levelling off towards the end of the trial, when the RGR became positive. Due to the *H. dregeana* plugs showing no change in tiller number per plant over the duration of the trial they had a zero RGR, and thus do not appear on Figure 3.4.5.

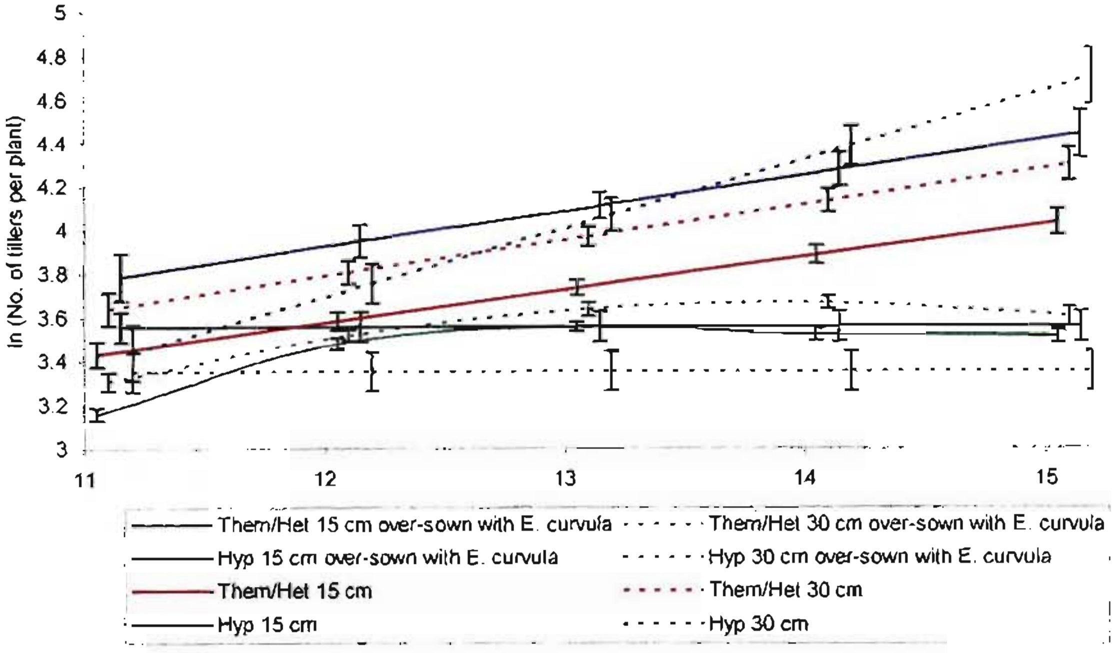


Figure 3.4.4: A comparison of the growth curves of the natural log of number of tillers per plant for *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart, with and without over-sowing of *Eragrostis curvula*, at Kamberg, KwaZulu-Natal.

Table 3.4.2: Summary of the F-probability values from the ANOVA of the tiller numbers per plant for the planted plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination over-sown with *Eragrostis curvula*, at 15 cm and 30 cm plant spacings at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	Feb 1999	March 1999	April 1999
Space	0.539	0.479	0.775	0.940	0.991
Species	0.940	0.925	0.198	0.683	0.620
Space.Species	0.151	0.206	0.329	0.306	0.368
Note: Values ≤ 0.05 are considered significantly different					

Table 3.4.3: Summary of the F-probability values from the ANOVA of the tiller numbers per plant for the *Eragrostis curvula* tufts sown over plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Control (*E. curvula* only)	0.158	0.130	0.066	0.147	0.175
Control.Species	0.307	0.576	0.923	0.792	0.867
Control.Space	0.314	0.206	0.359	0.384	0.359
Control.Species.Space	0.734	0.565	0.981	0.969	0.967

Note: Values ≤ 0.05 are considered significantly different

Table 3.4.4: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the tiller numbers per plant for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
E. curvula	0.010	< 0.001	< 0.001	< 0.001	< 0.001
Space	0.561	0.654	0.471	0.060	0.053
Species	0.600	0.385	0.014	0.008	0.007
E. curvula.Space	0.905	0.773	0.327	0.052	0.051
E. curvula.Species	0.562	0.335	0.167	0.003	0.002
Space.Species	0.112	0.105	0.143	0.787	0.653
E. curvula.Space.Species	0.612	0.748	0.568	0.447	0.547

Note: Values ≤ 0.05 are considered significantly different

Although the planted plugs initially had a larger basal area than the *E. curvula* tufts, the *E. curvula* soon grew larger. There were no treatment effects (P > 0.05) within the *E. curvula* tufts, but again *E. curvula* on its own developed larger basal areas, than in plots in which *E. curvula* was sown over plugs (Figure 3.4.6). This is to be expected as the plant basal area will increase as the tiller numbers per plant increase. The two *H. dregeana* treatments showed a constant plant basal area for the duration of the trial, with the 15 cm spacing having a greater (P ≤ 0.05) basal area than the 30 cm spacing. The *T. triandra/H. contortus* combination showed a slow increase in basal area during the trial with the 30 cm spacing treatment increasing basal area, although only significant at the end of the trial (P ≤ 0.05).

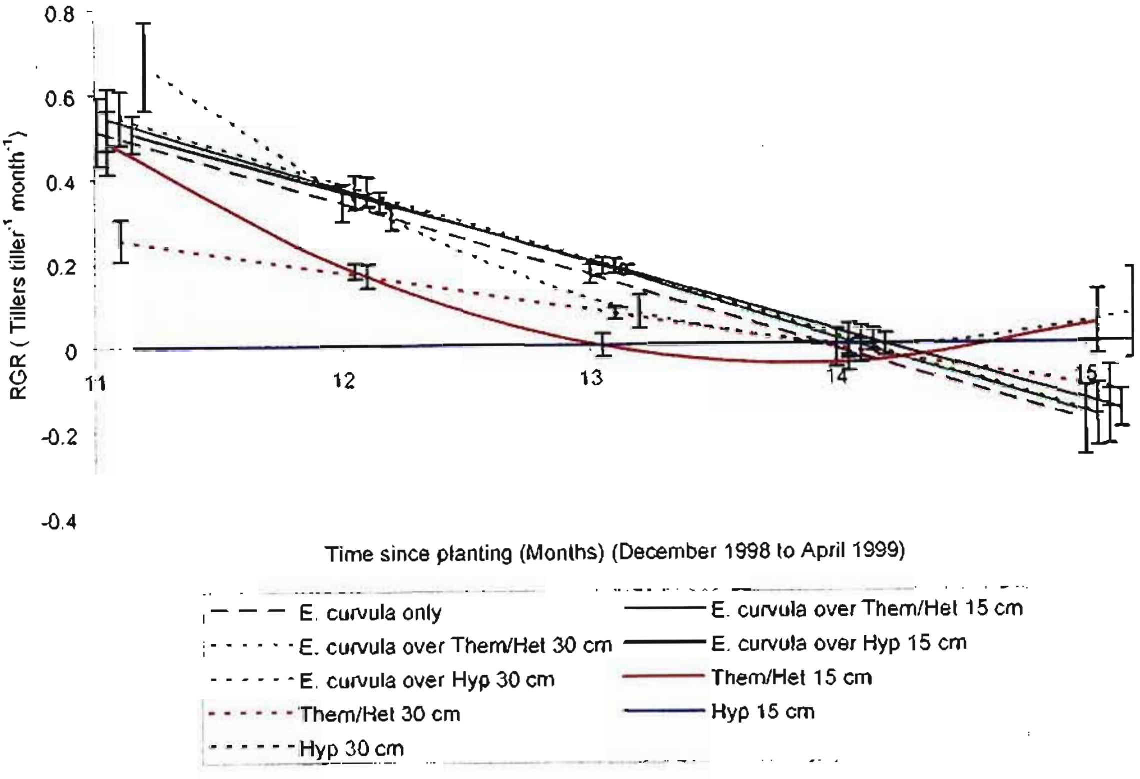


Figure 3.4.5: The relative growth rate of tillers per plant (tillers tiller^{-1} month^{-1}) for *Eragrostis curvula, Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart in an over-sowing with *Eragrostis curvula* trial, at Kamberg, KwaZulu-Natal.

Within each treatment, the over-sowing of *E. curvula* caused a decrease ($P \leq 0.05$) in the basal area of planted species (Figure 3.4.7). The over-sown *H. dregeana* treatments maintained a constant plant size in comparison to plants not over-sown (which increased in size). The growth curves for over-sown versus not over-sown treatments are divergent; indicating that as the plants mature the negative effect of the *E. curvula* becomes increasingly apparent.

The plant basal area was log transformed to fit the assumption for ANOVA (Steel & Torrie 1980). The ANOVA identified no treatment effects ($P > 0.05$) for the plant basal area of the plugs (Table 3.4.5) or the *E. curvula* (Table 3.4.6). On analysis of the effect of over-sowing of *E. curvula* it was evident that the *E. curvula* suppressed ($P \leq 0.05$) the development of the plant basal area after January 1999 (Table 3.4.7). The results for February 1999 (13th month since planting) showed a species effect, with *H. dregeana* having a greater ($P \leq 0.05$) plant basal area than the *T. triandra/H. contortus* combination, this was also seen in the number of tillers per plant, where *H. dregeana* had a greater number of tillers per plant than the *T. triandra/H. contortus* combination. An interaction between over-sowing and species became apparent at the end of the trial (Table 3.4.7).

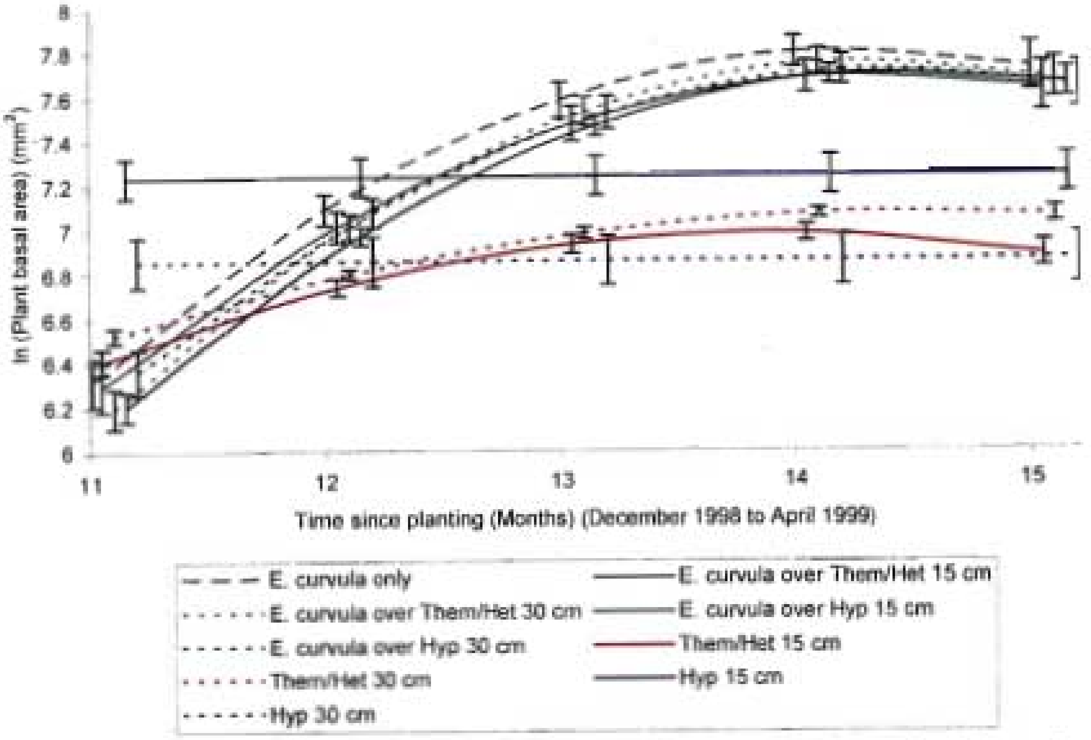


Figure 3.4.6: The growth curves of the natural log of plant basal area for *Eragrostis curvula*, *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart in an over-sowing with *Eragrostis curvula* trial, at Kamberg, KwaZulu-Natal.

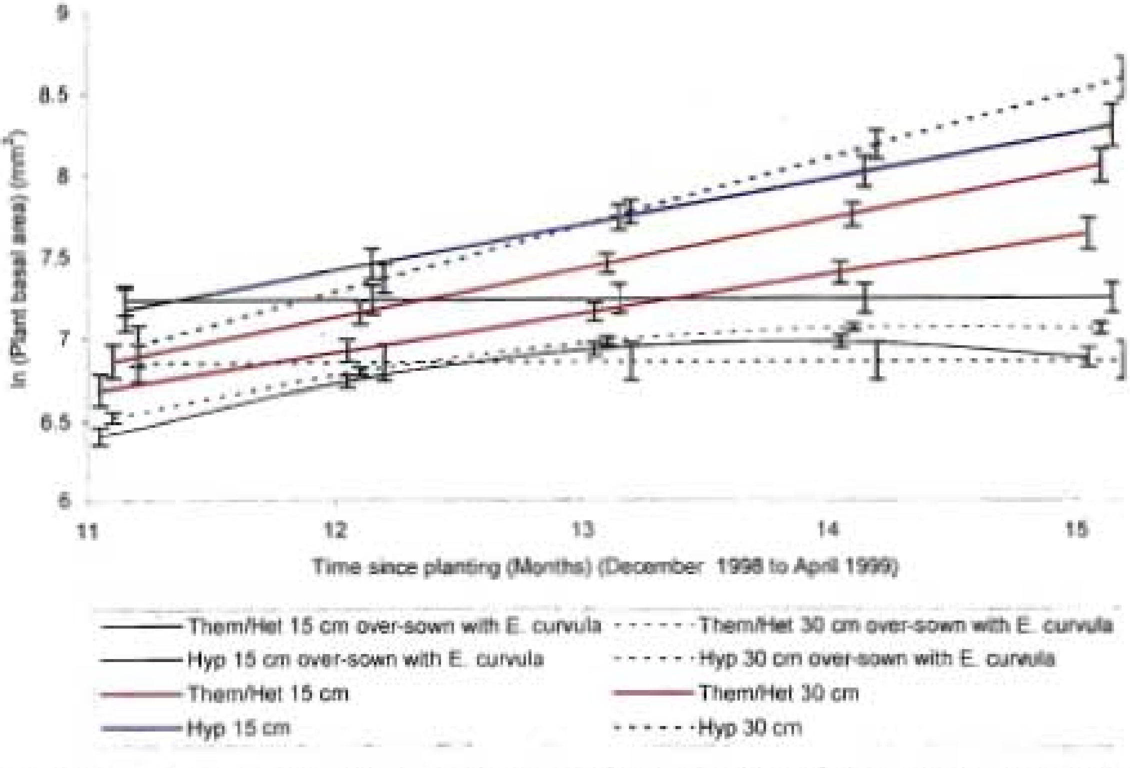


Figure 3.4.7: A comparison of the growth curves of the natural log of plant basal area per plant for *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart, with and without over-sowing of *Eragrostis curvula*, at Kamberg, KwaZulu-Natal.

Table 3.4.5: Summary of the F-probability values from the ANOVA of the plant basal area for the planted plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination over-sown with *Eragrostis curvula*, at 15 cm and 30 cm plant spacings at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	Feb 1999	March 1999	April 1999
Space	0.931	0.533	0.613	0.976	0.912
Species	0.811	0.907	0.256	0.969	0.624
Space.Species	0.450	0.242	0.262	0.318	0.386

Note: Values ≤ 0.05 are considered significantly different

Table 3.4.6: Summary of the F-probability values from the ANOVA of the plant basal area for the *Eragrostis* curvula tufts sown over plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Control (*E. curvula* only)	0.484	0.643	0.346	0.527	0.532
Control.Species	0.844	0.896	0.813	0.891	0.903
Control.Space	0.909	0.364	0.705	0.737	0.754
Control.Species.Space	0.460	0.313	0.890	0.939	0.993

Note: Values ≤ 0.05 are considered significantly different

Table 3.4.7: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the plant basal area for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
E. curvula	0.387	0.019	0.003	< 0.001	< 0.001
Space	0.967	0.685	0.913	0.111	0.159
Species	0.803	0.278	0.013	0.059	0.087
E. curvula.Space	0.871	0.534	0.396	0.122	0.225
E. curvula.Species	0.933	0.368	0.331	0.052	0.013
Space.Species	0.294	0.162	0.135	0.225	0.260
E. curvula.Space.Species	0.997	0.581	0.869	0.552	0.604

Note: Values ≤ 0.05 are considered significantly different

The RGR of plant basal area (Figure 3.4.8) shows no difference (P > 0.05) between the *E. curvula* tufts and similar growth rates (P > 0.05) among the two plant spacings of the *T. triandra/H. contortus* combination. There was, however, a difference between species (P ≤ 0.05), with *E. curvula* in all situations showing greater rate of change in basal area than the *T. triandra/H. contortus* combination.

The two *H. dregeana* treatments both showed a zero RGR with plant basal area remaining constant for the duration of the trial.

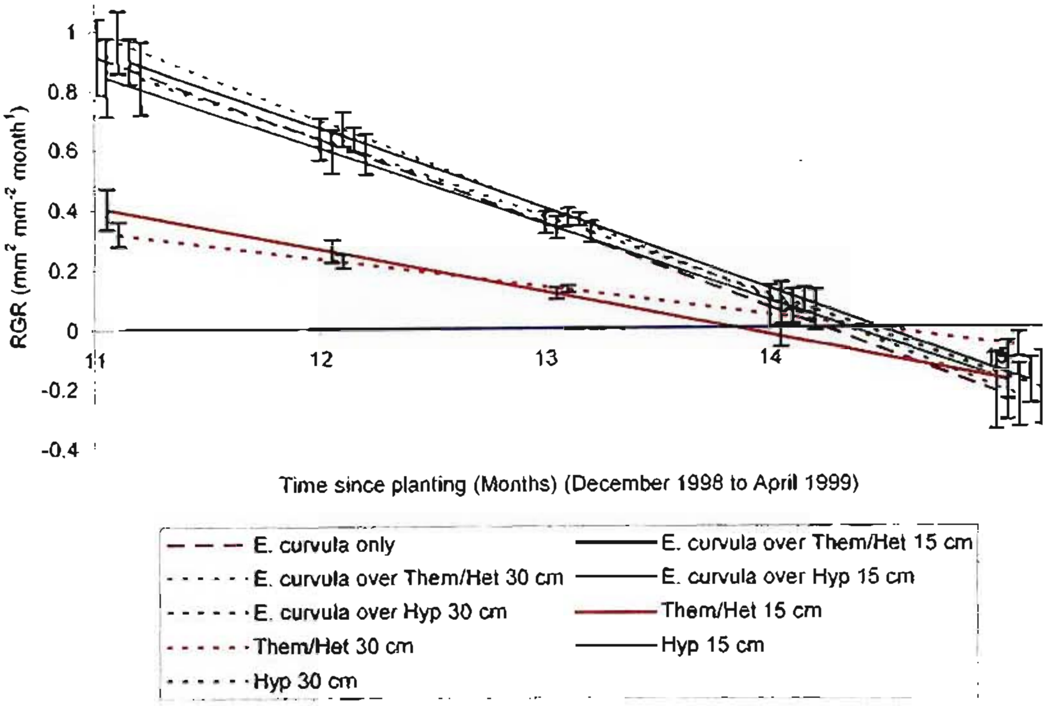


Figure 3.4.8: The relative growth rate of plant basal area (mm^2 mm^{-2} month^{-2}) for *Eragrostis curvula, Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart in an over-sowing with *Eragrostis curvula* trial, at Kamberg, KwaZulu-Natal.

At 11 months after planting (December 1998), plant heights were greater ($P \leq 0.05$) for *E. curvula* planted on its own ($P \leq 0.05$) than sown over plugs. By the 13th month (February 1999), the other *E. curvula* tufts had reached the same height ($P > 0.05$) and there were no differences between *E. curvula* tufts (Figure 3.4.9). The *H. dregeana* plugs increased in height rapidly from the 11th month (December 1998) to the end of the trial, 4 months later (April 1999) and were not different ($P > 0.05$) to the *E. curvula* tufts by the 13th month (February 1999). Towards the end of the study period, *H. dregeana,* planted at 15 cm, showed a greater ($P \leq 0.05$) plant height than *H. dregeana* at 30 cm. The two *T. triandra/H. contortus* combination treatments were of a similar height to the *H. dregeana* plants at 11 months after planting (December 1998), but did not grow so rapidly and by the 12th month (January 1999) were less ($P \leq 0.05$) than the *H. dregeana* plants at both plant spacings.

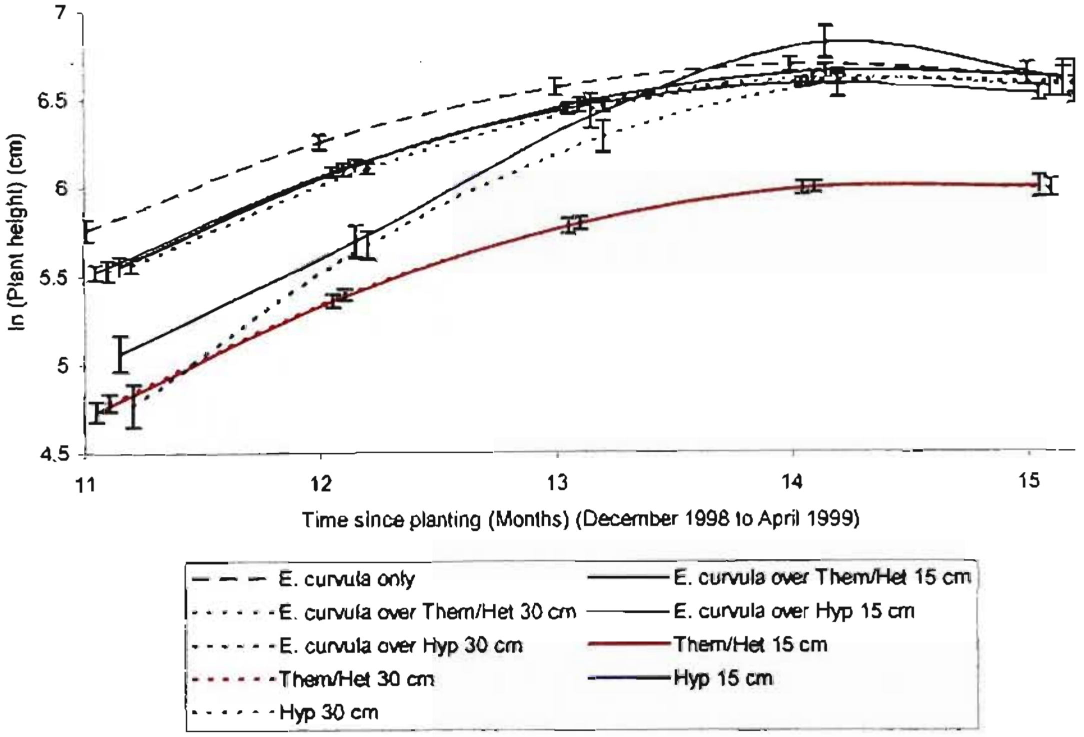


Figure 3.4.9: The growth curves of the natural log of plant height for *Eragrostis curvula, Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart in an over-sowing with *Eragrostis curvula* trial, at Kamberg, KwaZulu-Natal.

Over-sowing with *E. curvula* had a negative impact on the height of *H. dregeana* plugs, although this difference was only significant ($P \leq 0.05$) up until the 13th month after planting (February 1999) (Figure 3.4.10). The *T. triandra/H. contortus* combination showed the opposite effect with the over-sown treatments showing a greater ($P \leq 0.05$) plant height by the end of the trial for both spacing levels. The apparent increase in the plant height of the *T. triandra/H. contortus* combination with over-sowing may have been due to the canopy of *E. curvula* protecting the planted plugs from grazing, as the plants not over-sown with *E. curvula* experienced grazing pressure from eland, reedbuck and duiker.

The ANOVA of plant height for the plugs showed a species effect ($P \leq 0.05$) throughout the trial, with *H. dregeana* showing a greater ($P \leq 0.05$) plant height compared to the *T. triandra/H. contortus* combination (Table 3.4.8). In December 1998 there was an interaction effect ($P \leq 0.05$) between spacing and species, but this was not maintained for the remainder of the trial.

In the *E. curvula* the only differences ($P \leq 0.05$) were for the control (*E. curvula* only) versus planting of plugs. This difference was only significant ($P \leq 0.05$) for December 1998, January 1999 and February 1999 (11th to 13th months since planting) (Table 3.4.9).

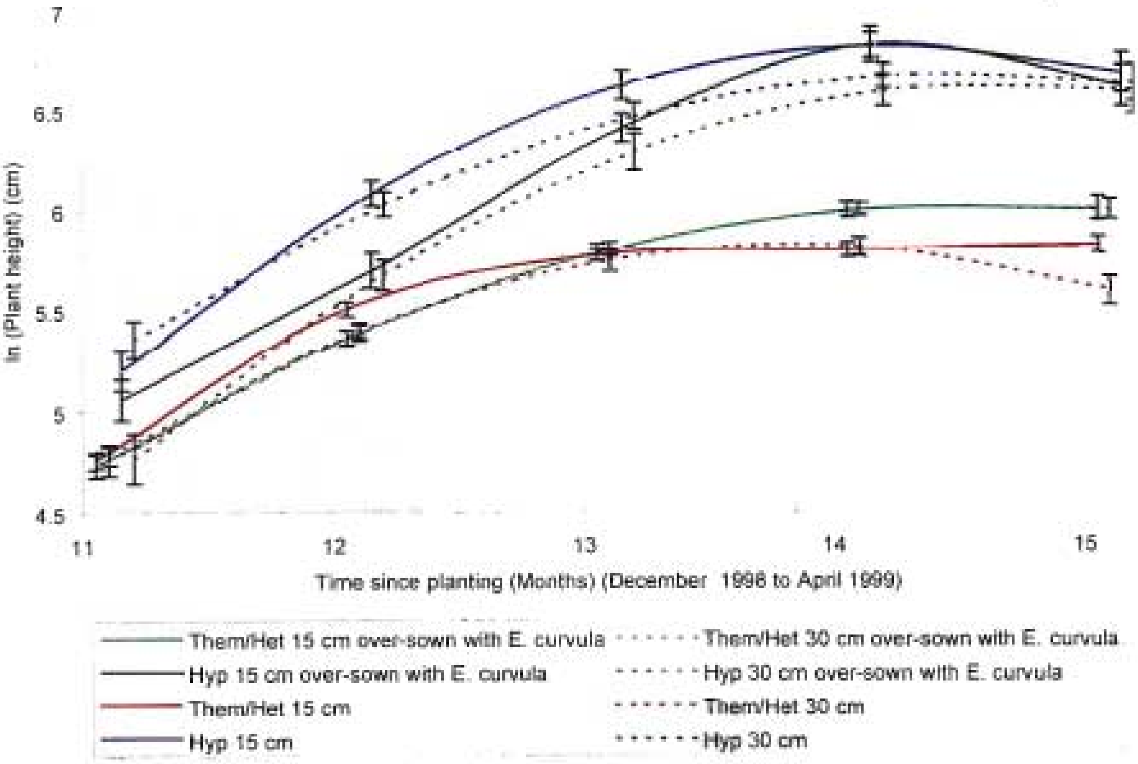


Figure 3.4.10: A comparison of the growth curves of the natural log of plant height for *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart, with or without being over-sown with *Eragrostis curvula*, at Kamberg, KwaZulu-Natal.

Table 3.4.8: Summary of the F-probability values from the ANOVA of the plant height for the planted plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination over-sown with *Eragrostis curvula*, at 15 cm and 30 cm plant spacings at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Space	0.083	0.270	0.268	0.448	0.430
Species	0.005	0.005	< 0.001	< 0.001	< 0.001
Space.Species	0.023	0.103	0.227	0.457	0.457

Note: Values ≤ 0.05 are considered significantly different

Comparing the effect of over-sowing with *E. curvula*, the only treatment effect ($P \leq 0.05$) throughout the trial was species effect (Table 3.4.10), with *H. dregeana* plants being taller ($P \leq 0.05$) than the *T. triandra/H. contortus* combination by the end of the trial. The other treatment that showed a difference was the over-sowing treatment in January 1999 (12^{th} month), where all combinations of treatments were significantly smaller ($P \leq 0.05$) when over-sown with *E. curvula* compared to plants not over-sown. There was a spacing effect ($P \leq 0.05$) in March 1999 (14^{th} month since planting), with 15 cm spacing showing greater plant height than 30 cm spacing (Table 3.4.10). An interaction effect

($P \leq 0.05$) was also apparent between over-sowing and species treatments in December 1998, January 1999 and April 1999 (Table 3.4.10).

Table 3.4.9: Summary of the F-probability values from the ANOVA of the plant height for the *Eragrostis* curvula tufts sown over plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
Control (*E. curvula* only)	0.002	0.005	0.013	0.074	0.068
Control.Species	0.514	0.729	0.698	0.248	0.237
Control.Space	0.970	0.945	0.550	0.894	0.913
Control.Species.Space	0.874	0.893	0.246	0.241	0.224

Note: Values ≤ 0.05 are considered significantly different

Table 3.4.10: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the plant height for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
E. curvula	0.127	0.006	0.943	0.189	0.382
Space	0.800	0.491	0.067	0.042	0.159
Species	<0.001	< 0.001	< 0.001	< 0.001	< 0.001
E. curvula.Space	0.275	0.995	0.807	0.313	0.852
E. curvula.Species	0.007	0.003	0.081	0.067	0.007
Space.Species	0.772	0.495	0.071	0.084	0.773
E. curvula.Space.Species	0.117	0.694	0.965	0.497	0.373

Note: Values ≤ 0.05 are considered significantly different

The only differences ($P \leq 0.05$) with RGR of plant heights were for *H. dregeana* at both 15 and 30 cm spacing (Figure 3.4.11). These two treatments have a greater RGR compared to all the other treatments, except *H. dregeana* at 15 cm. All treatments showed a decrease in RGR over time.

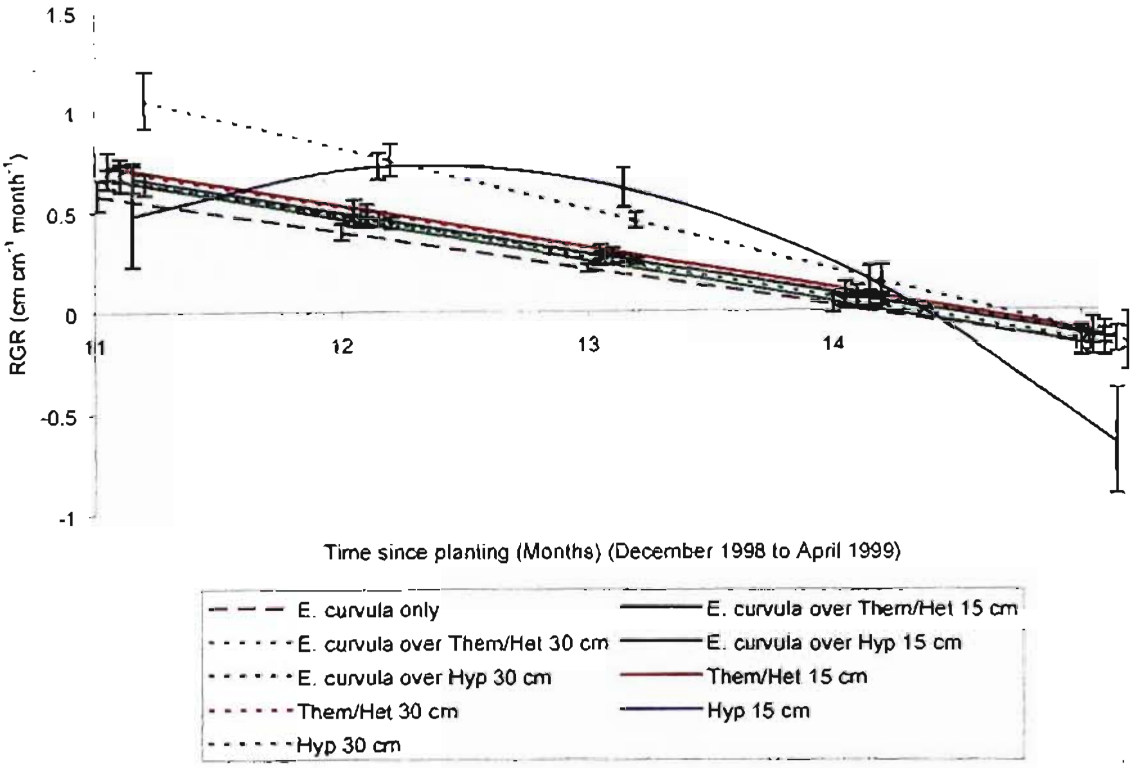


Figure 3.4.11: The relative growth rate of plant height (cm cm^{-1} month^{-1}) for *Eragrostis curvula*, *Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), planted 15 cm and 30 cm apart in an over-sowing with *Eragrostis curvula* trial, at Kamberg, KwaZulu-Natal.

The ANOVA for the number of flowering culms per plant for the planted plugs was only analysed for the effect of spacing, as the species flowered at different times of the year. The ANOVA showed no spacing treatment effect (P > 0.05) for the number of flowering culms per plant for the plugs (Table 3.4.11).

Table 3.4.11: Summary of the F-probability values from the ANOVA of the number of culms per plant for the planted plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination over-sown with *Eragrostis curvula*, at 15 cm and 30 cm plant spacings at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	Feb 1999	March 1999	April 1999
Space	0.821	0.536	0.206	0.279	0.399

Note: Values ≤ 0.05 are considered significantly different

The ANOVA for the *E. curvula* tufts was analysed for number of culms per plant in December 1998 and January 1999 as these were the months that flowering occurred. There were no treatment effects (P > 0.05) for the number of flowering culms per *E. curvula* plant (Table 3.4.12).

Table 3.4.12: Summary of the F-probability values from the ANOVA of the number of flowering culms per plant for the *Eragrostis* curvula tufts sown over plugs of *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999
Control (*E. curvula* only)	0.175	0.065
Control.Species	0.769	1.000
Control.Space	0.552	0.519
Control.Species.Space	0.755	0.674

Note: Values ≤ 0.05 are considered significantly different

The ANOVA of number of flowering culms per plant comparing the effects of over-sowing with *E. curvula* was analysed without considering species. The ANOVA showed only one treatment effect (P ≤ 0.05) for over-sowing in April 1999 (Table 3.4.13), where *H. dregeana* at 15 cm spacing had a greater number of flowering culms per plant than the 30 cm spacing.

Table 3.4.13: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the number of flowering culms per plant for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	December 1998	January 1999	February 1999	March 1999	April 1999
E. curvula	0.066	0.139	0.827	0.225	< 0.001
Space	0.332	0.668	0.137	0.110	0.887
E. curvula.Space	0.231	0.193	0.750	0.833	0.289

Note: Values ≤ 0.05 are considered significantly different

3.4.3.3 Biodiversity

The number of species per plot did not show any treatment effects (P > 0.05) at the early stages of the trial (November 1998), but by March 1999 the over-sowing treatment, species treatment and over-sowing by species interaction were different (P ≤ 0.05). In March 2000 only the over-sowing treatment was different (P ≤ 0.05) (Table 3.4.14). In both March 1999 and 2000 the over-sown plots showed a reduced number of species per plot (4.5 and 3.5 respectively) compared to the plots that were not over-sown with *E. curvula* (6.0 and 7.56 respectively). The interaction effect in March 1999 was a consequence of a reduction in the number of species per plot under the over-sown treatments was greater for the plots planted to *H. dregeana* than those planted to the *T. triandra/H. contortus* combination. *Hyparrhenia dregeana* that was not over-sown had 6.25 species per plot and 3.50 species per plot when over-sown, compared to the *T. triandra/H. contortus* plot which showed 5.75 and 5.50 species per plot respectively. Using a least significant differences test it was found that the number of species per plot for *H. dregeana* over-sown with *E. curvula* was less than the other three combinations (P ≤ 0.05).

Table 3.4.14: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the number of species that occurred per plot for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	November 1998	March 1999	March 2000
Over-sown	0.261	0.002	< 0.001
Spacing	0.067	0.260	0.886
Species	0.899	0.096	0.072
Over-sown.Spacing	0.067	0.569	0.886
Over-sown.Species	0.067	0.008	0.668
Spacing.Species	0.899	1.000	0.668
Over-sown.Spacing.Species	0.704	0.569	0.668

Note: Values ≤ 0.05 are considered significantly different

In November 1998 the Shannon diversity index showed a difference for the following treatment effects (P ≤ 0.05): over-sowing, spacing and species (Table 3.4.15). The Shannon diversity index for the plots over-sown with *E. curvula* in November 1998 was lower than those plots not over-sown with *E. curvula* (0.730 and 1.022 respectively (Appendix E)). The 30 cm spacing showed a lower Shannon diversity index than the 15 cm spacing in November 1998 (0.752 versus 1.000 (Appendix E)). The *H. dregeana* plots in November 1998 had a lower diversity index (0.709) than the *T. triandra/ H. contortus* combination (1.043) (Appendix E). In March 1999 the over-sowing treatment was again lower (P ≤ 0.05) than the not over-sown treatments (Table 3.4.15) (0.590 and 1.401 respectively (Appendix E)) with no other treatment effects being of significance.

Table 3.4.15: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the Shannon diversity index for *Hyparrhenia dregeana* and the *Themeda triandra/Heteropogon contortus* combination, at 15 cm and 30 cm plant spacings, at Kamberg, KwaZulu-Natal

Treatment	November 1998	March 1999
Over-sown	0.006	< 0.001
Spacing	0.019	0.290
Species	0.002	0.148
Over-sown.Spacing	0.192	0.422
Over-sown.Species	0.692	0.818
Spacing.Species	0.641	0.164
Over-sown.Spacing.Species	0.556	0.593

Note: Values ≤ 0.05 are considered significantly different

3.4.4 Discussion and conclusions

Overall, the results of the over-sowing trial showed a similar trend to that seen in the planting density trial (Chapter 3, Section 3.3), with the greatest survival and plant growth differences occurring between species, rather than plant spacing. As a general trend, over-sowing with *E. curvula* tended to depress tiller growth and basal area in the plugs. In some cases the plants in the over-sown treatments were taller than those not over-sown. This was attributed to competition for light, with plants putting all their growth effort into attaining height at the expense of tiller development, thus restricting development of the plant basal area. The increase in plant height under the over-sown conditions could also be through *E. curvula* tufts protecting the planted plugs from grazing.

The main statistical difference in plug survival was between species, with *H. dregeana* having a consistently lower survival rate. Plant spacing at 15 cm had a consistently lower survival rate per species than those planted at 30 cm spacing. Over-sowing of *E. curvula* in all cases resulted in a decrease in the survival of the planted plugs as the *E. curvula* germinated and grew rapidly, soon reaching a height greater than the plugs. An increase in competition for resources resulted in the *E. curvula* tufts out competing the plugs. As mentioned in Chapter 2, Section 2.3, *H. dregeana* plugs were over grown in the nursery and the large size and leaf area at planting would have increased the transplanting stress of these plants, resulting in an increased mortality of the plugs. Furthermore, the previous vegetation was *A. mearnsii*, which is a legume, thus resulting in elevated soil nitrogen levels. Veld fertilization trials have shown that the climax grass species, such as *T. triandra* are replaced by nitrophilous species, especially *E. curvula* under nitrogen fertilization treatments (Edwards & Nel 1973, le Roux & Mentis 1986, Barnes *et al.* 1987). The dominance of *E. curvula* in these trials thus may be due to its tolerance of the elevated nitrogen levels that are created by legume species.

Over-sowing with *E. curvula* decreased the number of tillers produced per plant for all treatments. This difference was significant at the 5% level, indicating that the *E. curvula* tufts were competing for resources with the planted plugs and limiting vegetative growth. The lack of new tiller development in the over-sown treatments may be a result of a lack of light reaching the growing points of the planted plugs, along with an increase in competition for water and nutrients (Everson 1985, Briske 1991, Wolfson & Tainton 1999, Bartholomew 1999). *Hyparrhenia dregeana* produced a greater number of tillers per plant for the 15 cm spacing compared to the 30 cm spacing, which is likely to be due to the fact that Increaser I species develop tillers from below ground and are thus able to continue tillering even under high shade intensities (Everson 1985, Everson CS *et al.* 1988). The *T. triandra/ H. contortus* combination plugs showed a response that would be expected for the low light conditions experienced under close planting combined with over-sowing as the 15 cm spacing had a lower number of tillers per plant than the 30 cm spacing. This could be due to the competition for sunlight created by the closer spacing and the deep shading effect of the *E. curvula* canopy which prevented light from reaching the growing points of the tillers, thus reducing the rate of tillering (Everson 1985, Briske 1991, Wolfson & Tainton 1999, Bartholomew 1999). This lack of light to stimulate tiller development is compounded by the plant dedicating more photosynthates towards increased vertical growth due to the competition for light, and limiting the nutrients available for lateral tiller development (Wolfson & Tainton 1999, Bartholomew 1999).

The species planted as plugs showed different tillering dynamics, with the *T. triandra/H. contortus* combination showing an increase in tillers per plant from the 11th to 15th months after planting and *H. dregeana* maintaining a constant number of tillers per plant over this period. These two species had different growth forms and are classified in different ecological groups. It would thus appear that the number of tillers per plant for *H. dregeana*, (Increaser I), did not increase after 11 months from planting, while the *T. triandra/H. contortus* combination continued to show an increase in the number of tillers per plant. No previous research has compared the tillering dynamics of these two species, but it is known that species differ in their tiller demography (Bartholomew 1999, Wolfson & Tainton 1999).

The basal area was also reduced in the over-sown treatments and follows a similar trend to that seen with the number of tillers per plant where *H. dregeana* plugs maintained a constant plant basal area, while the *T. triandra/H. contortus* combination showed an increase in plant basal area. This was not surprising as the production of new tillers was suppressed by competition for light and other resources, thereby reducing the basal area of the plants.

The height of the *H. dregeana* plugs was suppressed by over-sowing with *E. curvula*, due to competition for resources. The plant spacing effect was significant at 15 cm because of increased competition for light. The *T. triandra/H. contortus* combination showed the opposite effect, with over-sowing of *E. curvula* resulting in the plugs increasing their height in an attempt to reach the sunlight. This difference in response is likely to be due to the different growth habits of these two species, as the *T. triandra/H. contortus* combination plugs were shorter than the *E. curvula* tufts, whereas *H. dregeana* plugs were a similar height to the *E. curvula* tufts and thus could compete for sunlight.

The significant effect of number of flowering culms was due to the species having seasonal differences in the time of flowering. The *E. curvula* and the *T. triandra/H. contortus* combination flowered in early summer, while *H. dregeana* flowered in late summer. The only effects of over-sowing were within the *H. dregeana* species where over-sowing significantly decreased the number of flowering culms per plant ($P \leq 0.05$). This was due to competition for sunlight forcing these plants to direct their resources into increasing the height of the plants leaves in the sward, rather than utilizing the available resources for sexual reproductive growth. The *T. triandra/H. contortus* combination did not show any affects of over-sowing with *E. curvula* on the number of flowering culms per plant, these two species have been shown to not rely on seeding for their propagation in the KZN Drakensberg (Baxter *et al.* 1993, Everson 1994, Baxter 1996).

Over-sowing had a negative effect on both the number of species present and the diversity (as measured by the Shannon diversity index). At the start of the trial both the 30 cm spacing and the *H. dregeana* appeared to suppress the Shannon diversity index compared to the 15 cm spacing and the *T. triandra/H. contortus* combination, but by March 1999 these two treatment effects were no longer significant. These differences could have been brought about by the fact that in the *H. dregeana* only one species was planted compared to the two species of the *T. triandra/ H. contortus* species and the 15 cm would have shown a greater evenness of spread of the species than the 30 cm spacing.

In conclusion, it is evident that over-sowing *E. curvula* was detrimental to the survival and growth of the plugs and the diversity of the plots. It is thus not recommended to over-sow planted plugs of the species investigated in this trial with *E. curvula*. Studies over a longer time period are required to determine whether or not these planted plugs have the ability to survive and produce seedlings over a five to ten year period. Further investigation into biomass production must be carried out to determine whether the drop in survival and growth of the planted plugs is more beneficial than the increase in biomass and production of fuel load gained with the over-sowing of *E. curvula*. With regard to plant spacing, it is recommended that a plant spacing of 30 cm be used as this improves the survival and development of the plugs. The negative effect of the 30 cm spacing over the 15 cm spacing was only evident at the start of the trial. In terms of choice of species the *T. triandra/H. contortus* combination showed a better survival than *H. dregeana*.

3.4.5 Summary

The effect of over-sowing planted plugs of the *T. triandra/H. contortus* combination and *H. dregeana* with *E. curvula* was investigated. The two species combinations were planted at both 15 cm and 30 cm spacing and then over-sown with *E. curvula*. A control treatment of pure *E. curvula* was also included. The results from this over-sowing trial were compared to that of the planting density trial in order to investigate the effect of over-sowing on the survival and growth of plugs. By March 2000 the survival of the *T. triandra/H. contortus* combination was greater than the survival of the *H. dregeana*. Although the difference was not significant, over-sowing with *E. curvula* suppressed the survival of the planted plugs across all treatments. *E. curvula* on its own grew more rapidly than when sown over plugs, with greater tiller numbers, basal area and height (expect for *H. dregeana* at 15 cm spacing). Both planted species, showed suppressed tillering and plant basal growth under over-sown conditions. The *T. triandra/H. contortus* combination showed an increase in plant height when over-sown with *E. curvula*, while *H. dregeana* showed a decrease in plant height. The spacing effect for the *T. triandra/H. contortus* combination showed greater tillers numbers and plant basal area with the 30 cm planting distance compared to the 15 cm spacing, while the plant height was equal at both spacings. The *H. dregeana*, on the other hand, showed greater tiller numbers, basal area and plant height at the 15 cm spacing rather than the 30 cm spacing. The over-sown conditions showed a significant decrease in the diversity of the plots, both in the number of species present and the Shannon diversity index. Under over-sown conditions the *T. triandra/H. contortus* combination showed better survival and are recommended as species for re-vegetating these sites when planted at 30 cm spacing. If *H. dregeana* is to be planted and over-sown with *E. curvula* it should be planted at the 15 cm spacing as this improved the growth of this species. Overall, over-sowing the planted plugs with *E. curvula* is not recommended as it has a detrimental effect on plug survival, lateral growth of the plugs and the diversity of the site.

3.5. Introduction of *Themeda triandra* into an established sward of *Eragrostis curvula*

3.5.1 Introduction

At Kamberg, an area was cleared of *A. mearnsii* and re-vegetated using *E. curvula* seed 25 years ago. This area has remained an almost pure sward of *E. curvula* with few other forbs or grass species in the area. The re-vegetated areas thus do not match the ideal veld condition benchmark for the site (Appendix A). Furthermore, observation of this site showed the basal cover to be poor (Plate 3.5.1) under these mature *E. curvula* swards, despite a good aerial cover, thus soil erosion will occur between the plants, especially after the area is burnt. Dawson (1987) also showed poor basal cover and degradation over time of swards of the Ermelo variety of *E. curvula* used for re-vegetation of road verges.

Plate 3.5.1: *Eragrostis curvula* tuft after the fire in September 1998, indicating the poor basal cover of this site, Kamberg, KwaZulu-Natal (penknife is 8.5 cm long).

A number of factors may be preventing the natural grasses from establishing in these *E. curvula* swards, for example, poor seed dispersal (Everson 1994); inability of the seeds to penetrate the *E. curvula* swards (Dawson 1987); long dormancy, poor germination and viability of the seed (Baxter 1996); and seed predation. Refer to Chapter 1 for a detailed discussion of the problems associated with using indigenous grass species for re-vegetation. Other factors that could potentially be adversely affecting the germination and growth of the indigenous grasses include competition and/or an allelopathic effect from the mature *E. curvula*.

Of the climax grass species, *T. triandra* is the most well known, due to its high grazing value and as an indicator of good veld condition (Tainton *et al.* 1976, van Oudtshoorn 1992). Plugs of this species could be successfully grown in the nursery and transplanted into the field (Granger 1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA). Plugs of *T. triandra* were planted into a mature *E. curvula* sward to establish how *T. triandra* plugs survive and grow in a mature *E. curvula* sward. If these plugs were able to survive then one can conclude that allelopathic effects did not inhibit the growth of seedlings, though further research into seed dispersal and germination would be required to determine whether competition and/or allelopathic compounds were inhibiting seed germination *per sê*.

3.5.2 Materials and methods

The trial was established at Kamberg on a site cleared of *A. mearnsii* (using the method of clear felling) approximately 25 years prior to the trial. After clearing the *A. mearnsii*, the area was re-vegetated using *E. curvula*. At the time of commencing the trial, the site was typical of many long established swards of *E. curvula* in the KZN Drakensberg, with low species richness in comparison to the adjourning indigenous grassland. Plugs of *T. triandra* were planted into the mature *E. curvula* sward following a number of treatments of the mature plants.

In order to investigate the species richness of the experimental area in comparison to the neighbouring veld, the nested sub-quadrat method as described by Morrison *et al.* (1995) was used. A square quadrat with eight nested sub-quadrats with cumulative areas of: 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0 and 20.0 m^2 were used. Four quadrats were analysed in both the mature *E. curvula* sward and the adjoining indigenous grassland. The importance score, the score associated with the smallest sub-quadrat in which the species is first encountered (8 being the score for the smallest sub-quadrat and one for the largest) was determined. Importance scores were standardized as a fraction of the total number of sub-quadrats sampled in the quadrat and averaged for all four replications. As the scores for the sub-quadrats are reversed, they provide an inverse estimate of the area occupied by the species (in other words, a density estimate) (Morrison *et al.* 1995, Whalley & Hardy 2000). The frequency score was also measured; this is a measure of the total number of sub-quadrats in which the species is found. Again the frequency score is standardized as a fraction of the total number of sub-quadrats sampled and averaged for the four replications. The frequency score has a logarithmic relation to density, thus making it equivalent to the traditional frequency estimates (Morrison *et al.* 1995, Whalley & Hardy 2000).

Within the *E. curvula* sward two treatments, each at two levels were applied to randomly selected *E. curvula* tufts. Firstly a clipping treatment, where plants were or were not clipped to a height of 50 mm two weeks prior to planting to remove competition for sunlight. Secondly, a spray treatment was applied, where plants were sprayed with a glyphosate herbicide three months prior to planting in order to kill the *E. curvula* tufts. The objective of killing the *E. curvula* was to remove competition for nutrients and water. Again plants were either sprayed or not sprayed. A total of four permutations of these treatments were therefore possible: control (no treatment, plugs receiving full competition), sprayed only (competition for sunlight), clipped only (root competition only), and sprayed and clipped (zero competition). Where plants were sprayed and clipped, the clipping was obviously only required at the start of the trial as the plants had been killed using herbicides. For the clip only treatment the clipping treatment was maintained every second week for the first four months of the trial (i.e. until April 1999).

Two planting methods were investigated. Firstly, four *T. triandra* plugs were planted around the base of an *E. curvula* tuft. These plugs therefore received maximum competition levels. Secondly, one *T. triandra* plug was planted in the centre of a gap between *E. curvula* tufts. Thirty replications of each treatment and each planting method were established, therefore totalling 240 experimental units and 600 plugs.

After burning the area in September 1998, the trial was planted during the last week of December 1998. The spray only treatments were established in a separate area that had not been burnt, as a full canopy was required to provide maximum shade.

Plug survival was assessed as a percentage of live plants surviving at the time of measurement. Survival was recorded in February, March and April of 1999 and again in March and May of 2000 in order to establish any trends in the survival of *T. triandra*. Survival over time was plotted with 95% confidence intervals, where significant differences could be identified through observation. The final survival measurement at the termination of the trial in May 2000 was analysed using analysis of variance (ANOVA) to identify treatment differences. Where a treatment affect showed a significant difference, least significant differences were used to test individual treatment differences (Steel & Torrie 1980).

Initial plug growth was studied by counting the number of tillers, measuring the plant basal area and plant height (refer to Chapter 2 for a detailed description of the measurements taken). These measurements were taken at planting and again four months later in April 1999. The RGR over these initial four months was calculated for each variable (refer to Chapter 2 for an explanation of the formula used.) The RGR measures the rate of increase in size per unit of size (Hunt 1990). The mean RGR takes into account the size differences of the plugs at the start of the trial (Hunt 1978). Analysis of variance was then used to determine the presence of treatment differences. Least significant differences were used to test the differences between individual treatments (Steel & Torrie 1980).

3.5.3 *Results*

3.5.3.1 Species richness of *Eragrostis curvula* swards and surrounding veld

The list of species for each site showed significant differences in the species composition of the two sites. The 25 year old *Eragrostis* site comprised of two grass species, *A. mearnsii* seedlings, *Rubus cuneifolius* (American Bramble), one sedge species and a total of 10 broad leaved forbs, see Table 3.5.1 for full details. The two grass species were *E. curvula* and *H. dregeana*, with frequency scores of 1.00 and 0.46 respectively, indicating that *E. curvula* was found in all the sub-quadrats, while *H. dregeana* was found in just under half the sub-quadrats. The importance score of *E. curvula* was 1.00, indicating that it was first found in the smallest sub-quadrat. The majority of the broad leaved forb species had low frequency scores and low importance scores, indicating that these species were not very common within the study site.

The neighbouring pristine veld consisted of 16 grass species, *A. mearnsii* seedlings, one sedge (different to the one found in the *Eragrostis* site) and 16 broad leaved forbs (Table 3.5.1). The absence of *R. cuneifolius* is important, as this species is an invasive alien. The large number of species of grasses and forbs present in the veld are an indication of the high species richness of the veld in comparison to the *Eragrostis* site. *Eragrostis curvula* is present, but with a frequency score of 0.41 (present in less than half the sub-quadrats) and an importance score of 0.66 (first located in the third or fourth concentric sub-quadrat). The diversity of the area is further indicated by the lack of any one species dominating all sub-quadrats, as the highest frequency score was 0.94 for *T. triandra* and *Oxalis obliquifolia* jointly.

From the above results it can be seen that the study site was typical of many old *E. curvula* swards that have been observed (Granger *pers. comm.*, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA). The species richness of the area is low, especially when comparing grass species richness. The perception that sowing *E. curvula* can form a monospecific sward is correct, especially when looking at the distribution of *H. dregeana*, which tends to be restricted to small clustered populations around mother plants.

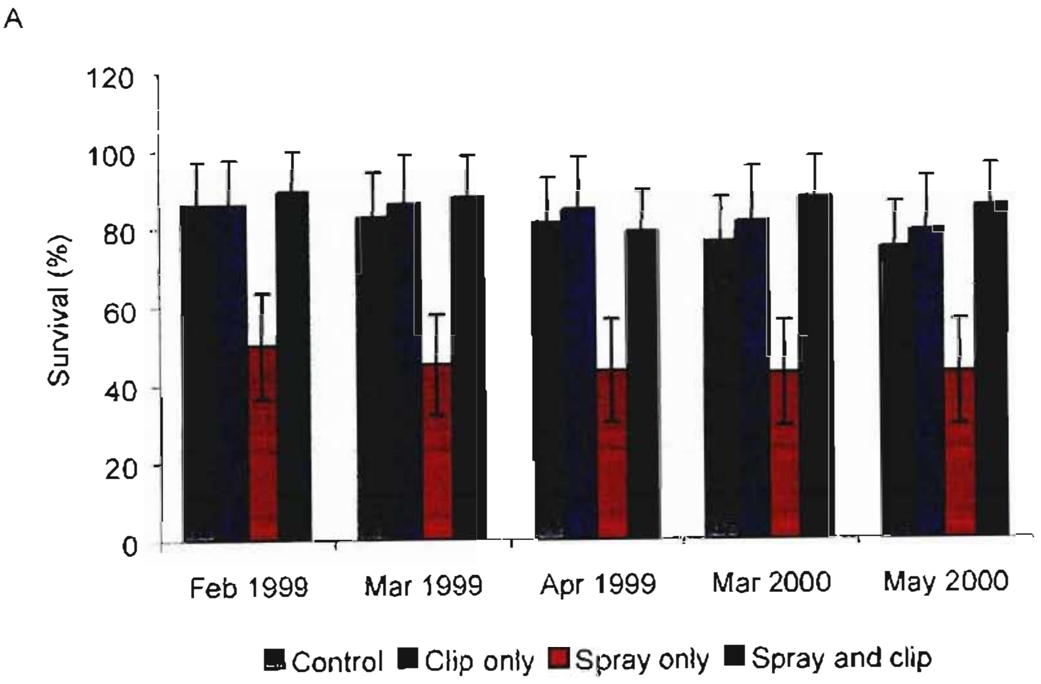
3.5.3.2 Survival

The survival of *T. triandra* in all treatments showed little variation over the duration of the trial (Figure 3.5.1), although there was a slight decrease over time. This indicates that the first two months after planting is critical for establishment of plugs, with little change in survival levels after February 1999. Where *T. triandra* plugs were planted into gaps, survival was greater than when planted at the base of an *E. curvula* plant. The plugs thus performed better, with lower levels of competition.

Table 3.5.1: Average frequency and importance scores of species recorded in the 25 year old *Eragrostis curvula* site and the neighbouring veld, at Kamberg, KwaZulu-Natal, January 1998

Species	Frequency score		Importance score	
	Eragrostis	Veld	Eragrostis	Veld
Eragrostis curvula	1.00	0.41	1.00	0.66
Hyparrhenia dregeana	0.46	0.75	0.50	0.75
Rhodohypoxis baurii var. *platypetala*	0.66	0.44	0.84	0.50
Berkheya multijuga	0.59	0.13	0.66	0.38
Acacia mearnsii	0.25	0.13	0.46	0.13
Cyperus obtusiflorus var. *flavissimus*	0.13		0.13	
Indigofera cuneifolia	0.38		0.75	
Helichrysum tenax var. *tenax*	0.25		0.75	
Rubus cuneifolius	0.13		0.13	
Helichrysum miconiifolium	0.13	0.31	0.38	0.31
Artemisia afra	0.13		0.13	
Oxalis obliquifolia	0.38	0.94	0.38	0.97
Leonotus leonurus	0.13		0.13	
Ajuga ophrydis	0.56		0.13	
Themeda triandra		0.94		0.94
Heteropogon contortus		0.75		0.91
Trachypogon spicatus		0.81		0.84
Monocymbium ceresiiforme		0.69		0.72
Melinis nerviglumus		0.63		0.69
Diheteropogon filifolius		0.66		1.00
Tristachya leucothrix		0.84		0.94
Panicum aquinerve		0.25		0.38
Loudetia simplex		0.66		0.75
Sopubia cana		0.91		0.94
Sandersonia aurantiaca		0.42		0.67
Aristida junciformis		0.84		0.97
Dietes iridioides		0.59		0.75
Pentanisia prunelloides		0.31		0.38
Panicum natalense		0.38		0.59
Alloteropsis semialata		0.81		0.97
Scirpus falsus		0.75		0.92
Oenothera rosea		0.25		0.50
Eulophia leontoglossa		0.25		0.38
Kohautia amatymbica		0.50		0.56
Buddleia salviifolia		0.63		0.67
Ledebouria cooperi		0.29		0.46
Helichrysum aureonitens		0.50		0.75
Eragrostis racemosa		0.38		0.38
Diheteropogon amplectens		0.50		0.63
Scilla nervosa		0.38		0.63
Sebaea thodeana		0.13		0.25

Nomenclature: Hilliard & Burtt 1987, Killick (1990)



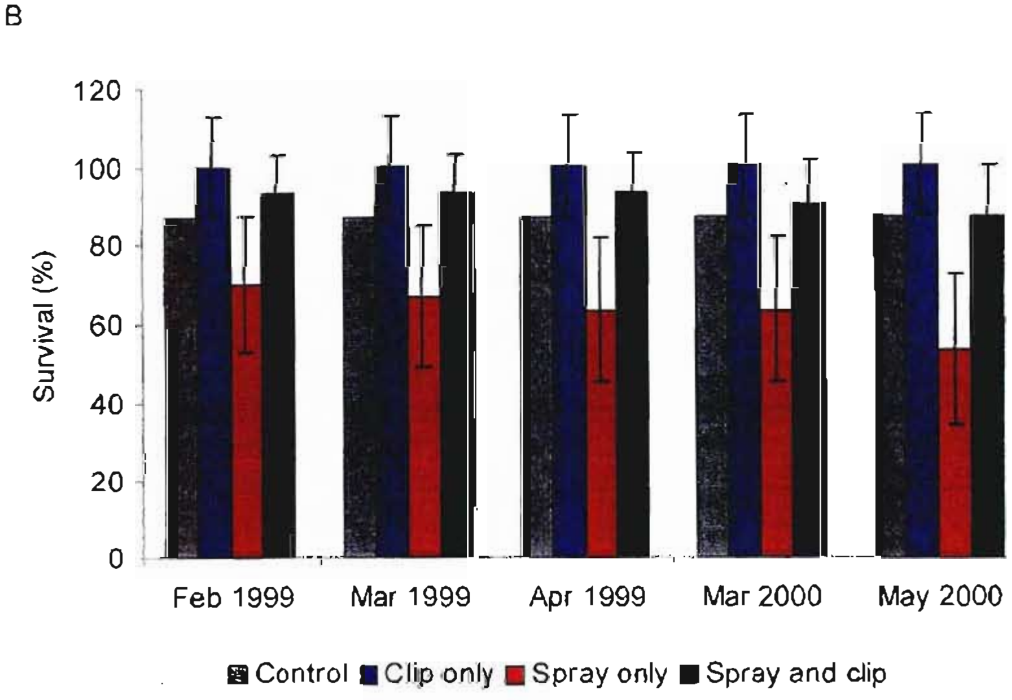


Figure 3.5.1: Survival of *Themeda triandra* plugs over time, where the *Themeda triandra* plugs were planted A) around the base of an *Eragrostis curvula* plant and B) in the centre of a gap between well established *Eragrostis curvula* tufts, at Kamberg, KwaZulu-Natal (in diagram B the control treatment showed the same survival across all replications, thus confidence levels can not be shown).

The ANOVA revealed that there were both treatment ($P \leq 0.05$) and planting method ($P \leq 0.05$) differences, although there was no interaction effect ($P > 0.05$). On average, across all treatments, the survival of plugs planted around the base of *E. curvula* tufts showed a lower survival (69.8%) than those planted into gaps (81.7%) ($P \leq 0.05$) (Table 3.5.2). By the end of the study period the spray only treatment had lower survival (47.9%) when compared to the remaining three treatments ($P \leq 0.05$). From Table 3.5.2 the clip only treatment with plugs planted into gaps had the highest survival, though this was only different ($P \leq 0.05$) from the spray only treatments, the clip only and control treatments for the plugs planted around the base of a mature plant.

Table 3.5.2: Percentage survival of *Themeda triandra* plugs, in May 2000 following planting around the base of an *Eragrostis curvula* tuft (plant base) and in the centre of a gap (centre) in December 1998, Kamberg, KwaZulu-Natal (different letters indicate a difference at the 5% level using least significant differences)

Treatment of the *Eragrostis curvula* tufts	Planting method		Average
	Plant base	Centre	
Clip only	78.3 b	100 a	89.2 a
Control	74.2 b	86.7 a b	80.4 a
Spray only	42.5 c	53.3 c	47.9 b
Spray and clip	84.2 a b	86.7 a b	85.4 a
Average	69.8	81.7	75.7

3.5.3.3 Relative growth rate

An analysis of variance of the RGR of tillers, showed that the planting method had an effect ($P \leq 0.05$, Table 3.5.3). Plugs planted into a gap (0.2578 tillers tiller^{-1}) showed a greater relative increase in tiller numbers compared to those plugs planted around the base of a plant (0.1755 tillers tiller^{-1}). There was also a treatment effect (Table 3.5.3), with the spray and clip treatments showing a greater increase in tiller numbers (0.2729 tillers tiller^{-1}) compared to the remaining three treatments ($P \leq 0.05$). There was no interaction effect between planting method and treatment. The spray and clip treatments, where plugs were planted into the centre of the gap, had the greatest relative increase in tiller numbers (Table 3.5.4), though only significantly ($P \leq 0.05$) greater than the control, the clip only and the spray only with plugs planted around the base of the *E. curvula* plant. The plugs generally showed a greater increase in tiller numbers per plant under low competition levels (spray and clip treatments).

Table 3.5.3: Analysis of variance of relative growth rate of tillers per plant for *Themeda triandra* plugs planted into a mature *Eragrostis curvula* sward, Kamberg, KwaZulu-Natal

Source of variance	d.f.	S.S.	M.S.	V.R.	F prob
Planting method	1	0.407	0.407	19.94	<0.001
Treatment	3	0.268	0.089	4.38	0.005
Planting method.Treatment	3	0.032	0.011	0.52	0.667
Residual	199 (33)	4.062	0.020		
Total	206 (33)	4.669			

Note: Values ≤ 0.05 are considered significantly different

Table 3.5.4: Relative growth rate of the numbers of tillers per plant (from January 1999 to April 1999) and the final number of tillers per plant (April 1999), of *Themeda triandra* plugs planted around the base of an *Eragrostis curvula* plant (plant base) and plugs planted in the centre of a gap between *E. curvula* tufts (centre), Kamberg, KwaZulu-Natal (different letters indicate a difference at the 5% level using least significant differences)

Planting method	Treatment	RGR (tillers tiller^{-1})		No. of tillers per plant
Plant base	Control	0.1683	b c	19.09
	Clip only	0.1587	c	21.52
	Spray only	0.1276	c	9.93
	Spray and clip	0.2473	a	28.34
Centre	Control	0.2452	a	23.9
	Clip only	0.2440	a b	36.33
	Spray only	0.2436	a b	16.2
	Spray and clip	0.2986	a	36.73

The RGR of plant basal area showed both a planting method and a treatment effect ($P \leq 0.05$, Table 3.5.5). The RGR of plant basal area showed a similar pattern to the RGR of the tiller numbers. This was expected because tiller number increases so plant basal area would be expected to increase. The plants planted into a gap (0.605 mm^2 mm^{-2}) developed greater basal areas than those planted at the base of an *E. curvula* plant (0.440 mm^2 mm^{-2}) ($P \leq 0.05$). The spray and clip treatments (0.685 mm^2 mm^{-2} and 0.613 mm^2 mm^{-2} for plugs planted into gaps and around the base of a plant respectively) had a greater increase ($P \leq 0.05$) in plant basal area compared to the other treatments (Table 3.5.6).

A slightly different pattern was noticed when investigating the RGR of plant height with a difference only in treatment effect ($P \leq 0.05$, Table 3.5.7). The highest growth rate for plant height was the control (0.3827 mm mm^{-1}), followed by the spray and clip treatment (0.3508 mm mm^{-1}), which were greater ($P \leq 0.05$) than the clip only (0.288 mm mm^{-1}), and in turn greater ($P \leq 0.05$) than the spray only treatment (0.175 mm mm^{-1}) (Table 3.5.8). Although the planting method did not show a difference ($P > 0.05$), it was interesting to note that the pattern had reversed compared to growth rates for tiller numbers and basal area. The plugs planted around the base of an *E. curvula* plant (0.309 mm mm^{-1}) showed the greatest RGR for plant height compared to those planted into gaps (0.289 mm mm^{-1}) (Table 3.5.8). This suggests that under conditions of increased competition for sunlight the growth of the plugs was concentrated into an increase in height, at the expense of tiller initiation and basal area growth.

Table 3.5.5: Analysis of variance of relative growth rate of plant basal area for *Themeda triandra* plugs planted into a mature *Eragrostis curvula* sward, Kamberg, KwaZulu-Natal

Source of variance	d.f.	S.S.	M.S.	V.R.	F prob
Planting method	1	1.636	1.636	22.77	<0.001
Treatment	3	1.449	0.483	6.72	<0.001
Planting method.Treatment	3	0.178	0.059	0.82	0.482
Residual	199 (33)	14.298	0.072		
Total	206 (33)	17.124			

Note: Values ≤ 0.05 are considered significantly different

Table 3.5.6: Relative growth rate of the plant basal area (January 1999 to April 1999) and the final plant basal area (April 1999) of *Themeda triandra* plugs planted around the base of an *Eragrostis curvula* plant (plant base) and plugs planted in the centre of a gap between *E. curvula* tufts (centre), Kamberg, KwaZulu-Natal (different letters indicate a difference at the 5% level using least significant differences)

Planting method	Treatment	RGR (mm^2 mm^{-2})		Plant basal area (mm^2)
Plant base	Control	0.395	c	236
	Clip only	0.419	c	281
	Spray only	0.333	c	111
	Spray and clip	0.613	a b	495
Centre	Control	0.587	a b	435
	Clip only	0.605	a b	678
	Spray only	0.544	b	335
	Spray and clip	0.685	a	781

Table 3.5.7: Analysis of variance of relative growth rate of plant height for *Themeda triandra* plugs planted into a mature *Eragrostis curvula* sward, Kamberg, KwaZulu-Natal

Source of variance	d.f.	S.S.	M.S.	V.R.	F prob
Planting method	1	0.022	0.022	2.19	0.140
Treatment	3	1.514	0.505	49.61	<0.001
Planting method.Treatment	3	0.073	0.024	2.39	0.070
Residual	199 (33)	2.025	0.010		
Total	206 (33)	3.285			

Note: Values ≤ 0.05 are considered significantly different

Table 3.5.8: Relative growth rate of plant height (January 1999 to April 1999) and final plant height (April 1999) of *Themeda triandra* plugs planted around the base of an *Eragrostis curvula* plant (plant base) and plugs planted in the centre of a gap between *E. curvula* tufts (centre), Kamberg, KwaZulu-Natal (different letters indicate a difference at the 5% level using least significant differences)

Planting method	Treatment	RGR (mm mm^{-1})	Plant height (mm)
Plant base	Control	0.3946 a	343.2
	Clip only	0.3243 b	283.3
	Spray only	0.1647 d	81.7
	Spray and clip	0.3510 a b	313.4
Centre	Control	0.3708 a b	316.9
	Clip only	0.2510 c	249.5
	Spray only	0.1850 d	116.5
	Spray and clip	0.3507 a b	318.1

The spray and clip treatments also showed a surprisingly large increase in plant height, despite showing the highest RGR for tiller number and basal area. This treatment appears to provide the best conditions for growth, as there is no competition for light or soil resources. The survival of these plugs was also good (85.4%), suggesting that this treatment yields the highest probability of success in survival and growth. This was to be expected as it presents the amount of competition to the developing plugs.

3.5.4 Discussion and conclusions

The above results indicate that it is possible to successfully introduce *T. triandra* plugs into a mature *E. curvula* sward (100% survival for some treatments). As the lowest survival (42.7%) was found in the spray only treatment, it would appear that competition for light has an important effect on the survival and growth of the plugs. Had the area remained un-burnt in the previous spring, it is likely that differences between the control and the clip only would have been greater, due to the greater amounts of moribund material present in an un-burnt sward. Due to the relatively high level of survival in the control treatment (average of 80.4%), it is unlikely that allelopathic affects prevent seedlings of *T. triandra* from developing, but rather a lack of viable seed material.

In terms of plant growth, an increase in lateral development (tiller number and plant basal area) would be of greater preference than plant height in terms of plant establishment, vegetative growth and subsequently good basal cover and reduced erosion. This is especially true in the Drakensberg environment, where species such as *T. triandra* are reliant on vegetative tillering and not seed production as a means of propagation (Everson 1985, Baxter 1996). Planting method generally had a greater effect than treatment on the measured growth variables. The greatest success was achieved when plugs were planted into gaps, allowing greater lateral plant growth. The clip only and the spray and clip treatments also aided lateral plant growth, due to reduced competition for sunlight in both treatments and reduced competition for nutrients and soil moisture with the spray and clip treatment. This is supported by Everson (1985) where the tillering of *T. triandra* and *H. contortus* was suppressed by shading by other plants.

The spray only treatment showed the poorest survival and plant growth. This, however, does not explain the very poor growth observed for the spray only treatments. The spray only treatments were located further up the slope than the other treatments in an area that had not been burnt the previous September and thus had a full canopy. The survival and growth of these plugs was very low, suggesting that the full canopy cover of this treatment at the start of the trial had a detrimental effect on the plugs. As mentioned above, this treatment was located further up the slope in an un-burnt area, to be able to ensure a full canopy cover, simulating conditions typical of an old, moribund *E. curvula* sward. The presence of a number of seasons of moribund material appeared to have had a significant detrimental affect on the plugs in the spray and clip treatment, and had the control also been planted in an un-burnt area, poorer survival and growth may have been recorded, due to increased competition levels. A residue effect of the herbicide is also possible, but should not have been the cause of the low survival rate due to the plants being sprayed three months prior to the commencement of the trial. It is generally accepted that glyphosate is adsorbed onto the soil particles and thus is rendered inactive on contact with the soil (Sprankle *et al.* 1975a, Carlisle & Trevors 1988). It has been found that phosphorus occupies the same adsorption sites as the glyphosate and thus if high levels of phosphorus are present the adsorption can be reversed, reactivating the glyphosate (Sprankle *et al.* 1975a, Sprankle *et al.* 1975b, Carlisle & Trevors 1988).

A number of recommendations are made following this trial as described below. To improve the species richness of a mature sward of *E. curvula,* burn the area three months prior to planting. To ensure reduced competition for sunlight and good survival and lateral growth of plugs, mow the re-growth before planting plugs of desired species. To reduce costs, plugs could be planted into the sward without first mowing, as adequate survival can be achieved. *Themeda triandra* plugs should then be planted into the gaps between the *E. curvula* tufts. Spraying the *E. curvula* with a glyphosate herbicide and then mowing can enhance the growth of the plugs, but would increase the costs.

Since these plugs survived and grew successfully, it can be concluded that once *T. triandra* seedlings have germinated allelopathic effects do not inhibit growth, rather competition for resources. Further investigation is required to determine the long term success of this method. Monitoring the flowering and seeding of the planted plugs along with seedling establishment would determine if the plugs are permanently established and able to maintain the *T. triandra* population in the area. Periodic botanical analyses would indicate how the biodiversity may have changed over time. Other species that have successfully been grown in the nursery could also be tested on these sites. These species include *Heteropogon contortus* and *Hyparrhenia dregeana.*

To fully investigate why the natural grasses are not moving into the area, a number of other factors would require investigation. Examination of soil seed bank levels in different age *E. curvula* swards and at increasing distances into a mature sward would determine the numbers of seed of various species in the soil. Seed dispersal experiments in full canopy areas and in mown areas, would establish whether mowing *E. curvula* tufts would aid seed dispersal from neighbouring natural grassland areas. To investigate seed predation levels, seed restaurant trials would be required. Finally seed germination trials under the conditions experienced in a mature *E. curvula* sward would determine whether these mature swards suppress seed germination.

3.5.5 Summary

An area cleared of *A. mearnsii* and sown to *E. curvula* 25 years previously was compared to the neighbouring veld. The neighbouring veld was found to have greater species richness than the *E. curvula* sites, with 16 grass species, *A. mearnsii* seedlings, one sedge and 16 broad leaved forbs species, compared to two grass species, *A. mearnsii* seedlings, *R. cuneifolius*, one sedge species and 10 broad leaved forbs species found in the mature *E. curvula* site. Nursery raised plugs of *T. triandra* were planted into the mature *E. curvula* in an attempt to improve the biodiversity of these areas. Two treatments with four permeations were used to pre-treat the *E. curvula*, no treatment (control with full competition), clip only (competition for moisture and nutrients), sprayed with a glyphosate herbicide only (competition for light) and spray and clip (no competition). The two planting methods (replicated 30 times for each treatment) were either four plugs planted around the base of the *E. curvula* plant (maximum competition) or one plug planted into the centre of a gap between surrounding *E. curvula* tufts (minimum competition). The survival and the lateral growth of the plugs (tiller development and basal area) were greatest for plugs planted into gaps. The pre-treatment with the greatest survival was the clip only treatment. The greatest lateral growth was recorded for the spray and clip treatment, where competition levels were minimal. Greatest plant height was found with the control treatment, in full competition with plugs planted around the base of a mature *E. curvula* plant. High survival levels and greater lateral growth of the plugs are the factors that ensure good basal cover and thus protect the area from soil erosion. It is therefore, suggested that to re-introduce *T. triandra* into these mature *E. curvula* swards one must burn the veld three months before planting, re-growth must then be mown before planting and the plugs must be planted into the centre of gaps. If the area cannot be mown, the plugs can be planted directly into post burnt area to ensure good survival and growth.

4. Alleviation of moisture stress at planting

4.1 Introduction

The establishment of *T. triandra* and *H. contortus* using plugs has been successful at Kamberg (Granger 1998 unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA). A number of questions relating to the most efficient and successful method of establishment remain. One possible factor that could result in a low plug survival, especially, in warm climates and drought years, is water stress. Anastasiou & Brooks (2003) found that poor plug survival after planting *Spartina patens* (Salt meadow cord grass) was related to transplant shock, and lasted up to 30 days after planting. The plugs have a small cone of root material relative to the above ground biomass. With the high transpiration rates at planting, the roots are not well established and can only draw soil moisture from a very small area. Plants with larger root volumes have been found to suffer less from 'transplant shock' (Zandstra & Liptay 1999). Irrigating the plugs for the first few days is common practice in the vegetable and forestry industries, but is expensive (Viero 2000). In many areas of re-vegetation it is also not possible to irrigate the plugs due the location of the site and the lack of equipment or a water source. Other methods of reducing moisture stress need to be investigated.

There are a number of ways to alleviate moisture stress at planting, for example artificial shade (e.g. shade cloth), time of year of planting, time of day of planting (cooler times of the day incur less moisture stress) and soil moisture ameliorants. Two commonly used methods for vegetable and forestry plugs are artificial shade and soil moisture ameliorant (Verschoor & Rethman 1992, Viero 2000). These methods were investigated in this trial to attempt to improve the survival and growth of the grass plugs.

A soil moisture ameliorant, (Terrasorb®), was used to increase the water holding capacity of the soil surrounding the plug. Terrasorb® is a starch based polymer with a high water holding capacity, and can absorb up to 200 times its own mass in water (Verschoor & Rethman 1992). The use of super absorbent polymers, in other trials have resulted in an increase in above and below ground biomass, especially under water stressed conditions (Banko 1984, Pill 1988, Latimer *et al.* 1990, Verschoor & Rethman 1992, Munshower 1993, Viero 2000). Verschoor & Rethman (1992) found that Terrasorb® increased the field capacity of sandy and clay soils by 250% and 138% respectively. They also found that Terrasorb® halves the irrigation frequency for both soil types. With the sandy soils the irrigation frequency was 2.7 days without Terrasorb® and 5.0 days with Terrasorb®. The irrigation frequency of the clay soil was 2.4 days and 5.0 days without and with Terrasorb® respectively.

Agrilen®, a white, needle punched, geo-fabric was used to provide the artificial shade. This material reduces moisture stress by reducing evapotranspiration and evaporation from the soil surface, while not preventing the exchange of gases or the entry of precipitation. Artificial shade was applied for seven days, to reduce evapotranspiration in the first week after planting, and reduce transplant shock.

This trial was established to identify whether a soil moisture ameliorant (Terrasorb®) and/or a period of artificial shade (Agrilen®) would increase the survival and growth of plugs of *Themeda triandra*, *Hyparrhenia dregeana* and *Heteropogon contortus*.

4.2 Materials and methods

The experiment was sited at Kamberg (refer to Chapter 2 for a detailed description of the study site). The treatments were planted into 4 m by 4 m plots, with four replications, using a randomised complete block design (Figure 4.1). Where physical obstructions prevented plots from being planted, replacement plots were established in an extra row below, thus the randomised complete block design was compromised and the trial was analysed as a simple random design. The *T. triandra* and *H. dregeana* plugs were planted at 30 cm spacing with all possible combinations of the soil moisture ameliorant (Terrasorb®) and artificial shade (Agrilen®) as follows:

1. *Hyparrhenia dregeana* and *Themeda triandra* only (control);
2. *Hyparrhenia dregeana* and *Themeda triandra* with a soil moisture ameliorant (Terrasorb®) applied at planting;
3. *Hyparrhenia dregeana* and *Themeda triandra* a soil moisture ameliorant (Terrasorb®) applied at planting and with a seven day period of artificial shade provided by Agrilen®; and
4. *Hyparrhenia dregeana* and *Themeda triandra* with a seven day period of artificial shade provided by Agrilen®.

Treatments were combined with those of the planting density trial (investigating the species mix and planting densities) to improve randomization. But as the Agrilen® had been contaminated prior to planting in January 1998, the trial was replanted in the first week of January 1999 using new Agrilen® and thus the Terrasorb®-Agrilen® trial had to be statistically analyzed separately.

In January 1999, when the trial was replanted, only *T. triandra* and *H. dregeana* plugs were available for planting. At planting, Terrasorb® was applied to the plots by mixing the Terrasorb® flakes with water, as per the product label. The flakes became swollen as they absorbed the water and 50 ml of the resultant jelly like mix was spooned into the planting holes, before planting the plugs. On the Agrilen® treatments, once planting was completed Agrilen® was suspended 0.2 m above the experimental plots. Agrilen® remained over the plots for seven days.

Plug survival was determined in February 1999 and again in March 2000 and May 2000 (up to 16 months after planting). Survival was expressed as a percentage (refer to Chapter 2). Plant growth was measured by tiller number, basal area (mm^2) and mean plant height (mm) (see Chapter 2 for details on the sampling method). The first measurement of plant growth was taken in the last week of January 1999 (3 weeks after the plugs were planted) and subsequent measurements were taken before the onset of the first frost (February, March and April of 1999), up to four months after planting.

4 m

4 m

Replication/ Block 1	Agrilen[1]	X[2]	Agrilen/ Terrasorb	X	Terrasorb	X	X	Control
2	Control	R[3]	Agrilen	X	X	Agrilen/ Terrasorb	X	R
3	Agrilen	R	Control	Terrasorb	X	X	X	Agrilen/ Terrasorb
4	Agrilen/ Terrasorb	X	X	Control	R	X	X	Terrasorb
Extra row[4]	X	X	Agrilen (Rep 4)	R	Terrasorb (Rep 2)	R	R	R

Notes:

1 Full description of the treatments applied to each plot:

Control: *Themeda triandra* and *Hyparrhenia dregeana* only

Terrasorb: *T. triandra* and *H. dregeana* plus Terrasorb®

Agrilen/Terrasorb: *T. triandra* and *H. dregeana* plus Terrasorb® and Agrilen®

Agrilen: *T. triandra* and H. *dregeana* plus Agrilen®

2 'X' designates plots that were used for the planting density trial

3 'R' refers to plots that were rejected due to a large number of obstructions.

4 The extra row was created to accommodate rejected plots from previous replications.

Figure 4.1: The experimental design for the Terrasorb®-Agrilen® trial, at Kamberg, KwaZulu-Natal, January 1999 to April 1999.

Plug survival was plotted over time with a 95% confidence interval. Significant differences could then be identified by observation. Survival data were further analyzed using ANOVA to identify the presence of treatment effects. An ANOVA was carried out for each species individually over time to avoid confounding of the ANOVA.

An ANOVA with respect to tiller number, basal area and mean plant height was carried out for each time period. The log transformed plant basal area data were used for the ANOVA to satisfy the assumptions for ANOVA. The tiller number per plant, basal area and mean plant height were each plotted over time with the 95% confidence intervals. Where confidence levels overlapped the treatments were deemed to not be different at the 95% level.

Hunt & Parsons (1974) growth curve analysis approach could not be used for the plant growth data as only four readings over time were taken and the minimum required for this method to successfully determine growth curves is five consecutive readings (Hunt 1982). Instead RGR, across each time period, was plotted on a bar graph with 95% confidence levels to examine treatment differences (refer to materials and method (Chapter 2) for the formula used to calculate RGR). RGR was plotted using a bar graph as an average RGR between two sets of measurements (Hunt 1978, 1990), in this case between months. Where confidence levels overlapped, treatments were not different (P > 0.05).

4.3 Results

4.3.1 Survival

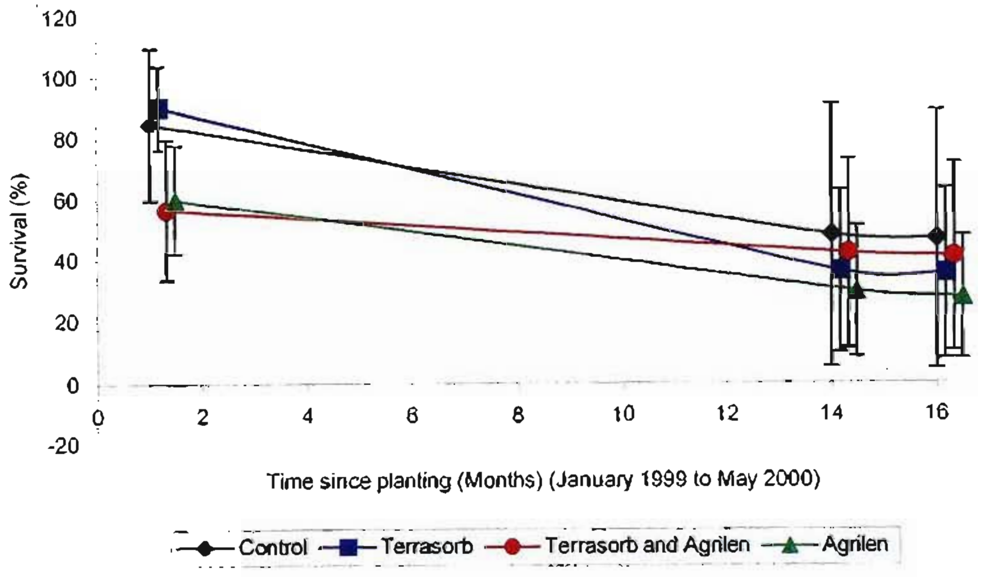
The survival of the plugs was initially high (averaging 72.8% for *H. dregeana* and 42.3% for *T. triandra*), but decreased over the duration of the trial to 37.3% and 29.2% for *H. dregeana* and *T. triandra* respectively, although these levels were not different (P > 0.05) (Figure 4.2). Therefore, Terrasorb® had no effect (P > 0.05) on the survival of either *H. dregeana* or *T. triandra*. By the end of the trial, the control (no Terrasorb®) had a greater survival than those planted with Terrasorb®. Agrilen® had a negative effect (P ≤ 0.05) on the survival of *H. dregeana* only in February 1999 (Table 4.1), where the plugs with no Agrilen® showed a survival of 87.4% and those with Agrilen® were 58.2%. For *T. triandra* this effect was significant (P ≤ 0.05) throughout the trial, with a survival of 40.8% and 17.6% in May 2000 for no Agrilen® and with Agrilen® respectively (Table 4.1).

Table 4.1: Summary of F-probability values for the ANOVA of survival of *Hyparrhenia dregeana* and *Themeda triandra* planted with or without Agrilen® to provided artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal

		February 1999	March 2000	May 2000
H. dregeana	Agrilen®	< 0.001	0.385	0.376
	Terrasorb®	0.788	0.951	0.895
	Agrilen®.Terrasorb®	0.262	0.137	0.124
T. triandra	Agrilen®	0.047	0.048	0.032
	Terrasorb®	0.851	0.374	0.343
	Agrilen®.Terrasorb®	0.401	0.751	0.781

Note: Values ≤ 0.05 are considered significantly different

A



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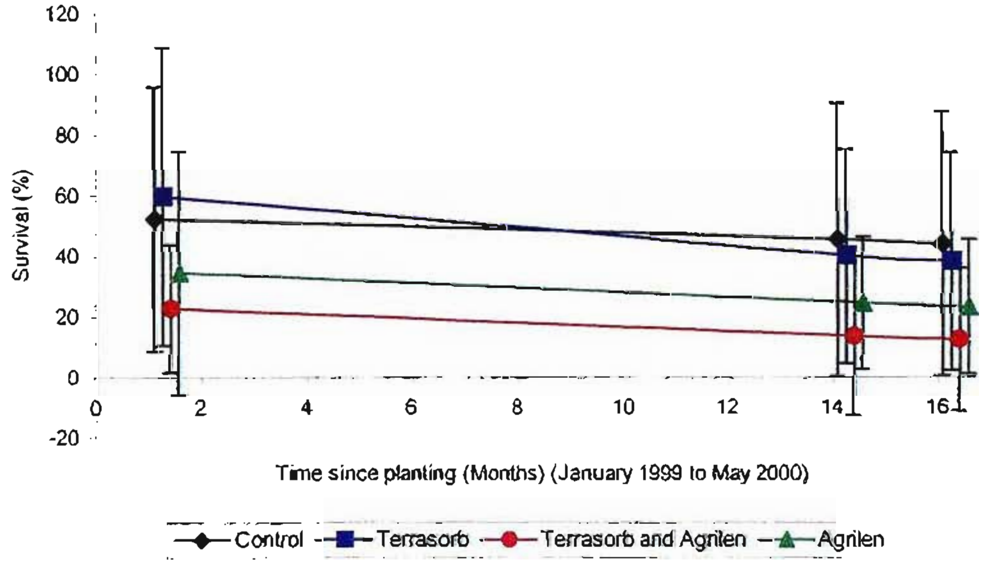


Figure 4.2: Survival of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provide artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

4.3.2 Plant growth

The ANOVA (Table 4.2) and plot of tiller numbers per plant (Figure 4.3) showed that three weeks after planting (January 1999), the number of tillers per plant was similar, but Terrasorb® ($P \leq 0.05$) and species ($P \leq 0.05$) along with an interaction of Agrilen® and species ($P \leq 0.05$) had significant effects. Initially Terrasorb® suppressed number of tillers per plant (7.7 and 6.5 tillers per plant for no Terrasorb® and Terrasorb® respectively). The *T. triandra* plugs initially had a greater number of tillers per plant than *H. dregeana*: 7.66 and 6.55 tillers per plant respectively. The interaction effect of Agrilen® and species was due to an increase in the number of tillers per plant for *H. dregeana* under Agrilen® (5.93 to 7.16), while the opposite occurred for *T. triandra* with the number of tillers per plant under Agrilen® decreasing from 8.22 to 7.10. All treatments showed a classical sigmoidal type of growth, increasing in tiller numbers per plant rapidly initially, and slowing down towards the end of the trial. By the end of the study period the treatments showed different growth patterns for tillers per plant, with the control treatment for both species, Terrasorb® for *T. triandra* and Terrasorb®.Agrilen® for *H. dregeana* being greater than ($P \leq 0.05$) the remaining four treatments (Figure 4.3), although the ANOVA did not show any treatment effects ($P > 0.05$) (Table 4.2).

Table 4.2: Summary of F-probability values for the ANOVA of tillers per plant of *Hyparrhenia dregeana* and *Themeda triandra* planted with or without Agrilen® to provided artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal

	January 1999	February 1999	March 1999	April 1999
Terrasorb®	0.041	0.612	0.742	0.706
Agrilen®	0.992	0.075	0.212	0.237
Species	0.009	0.901	0.056	0.951
Terrasorb®.Agrilen®	0.199	0.916	0.237	0.272
Terrasorb®.Species	0.809	0.984	0.603	0.705
Agrilen®.Species	0.001	0.285	0.174	0.203
Terrasorb®.Agrilen®.Species	0.646	0.617	0.455	0.548

Note: Values ≤ 0.05 are considered significantly different

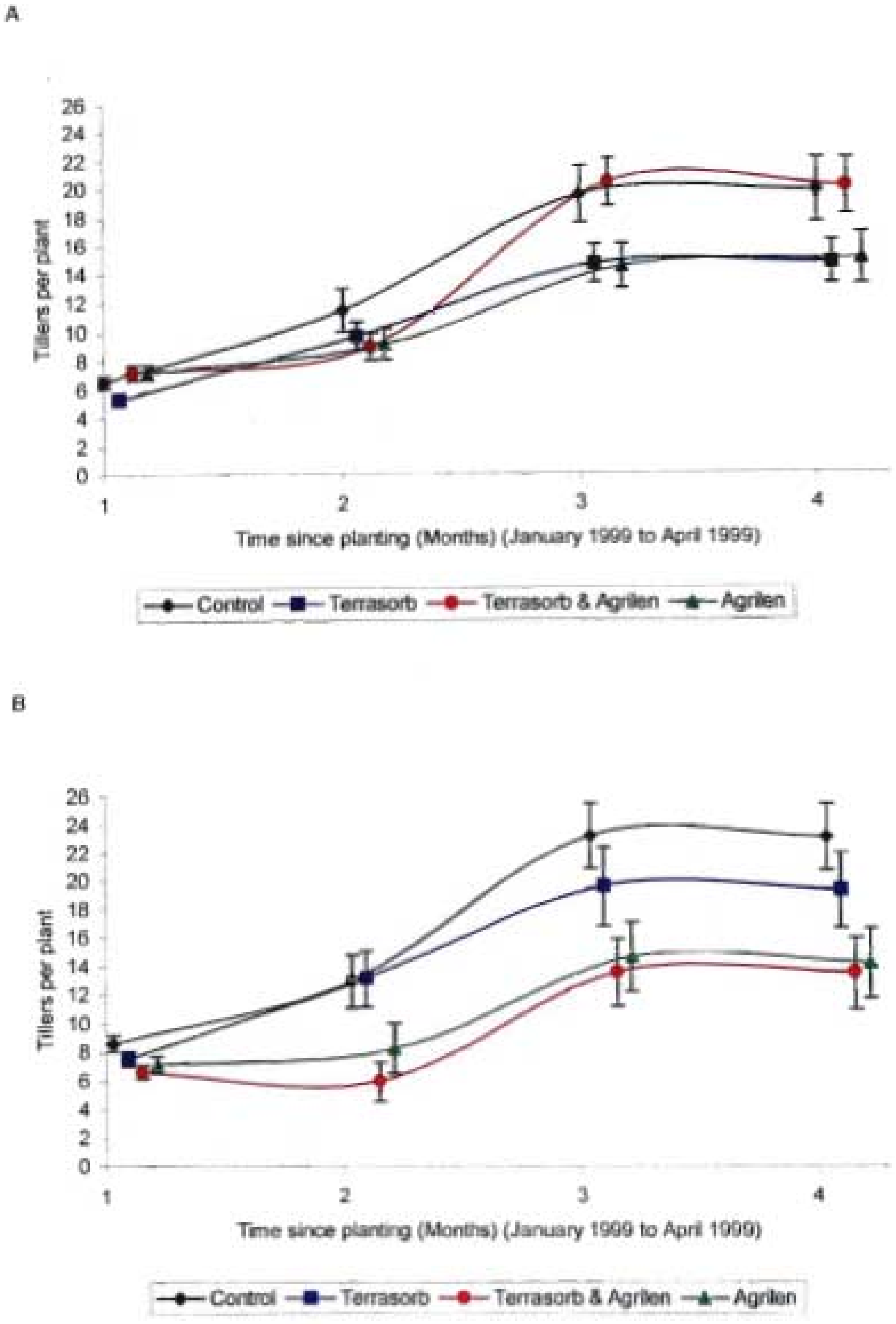


Figure 4.3: Number of tillers per plant of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provide artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

Basal area followed a very similar pattern to the number of tillers per plant, as new tillers develop so the plant basal area will increase. Initially all plants showed a small basal area (Figure 4.4), although the ANOVA of logged data showed a Terrasorb®, Species and Agrilen®.Species effect ($P \leq 0.05$) at the start of the trial (Table 4.3). Terrasorb® initially suppressed the plant basal area (65.9 mm^2

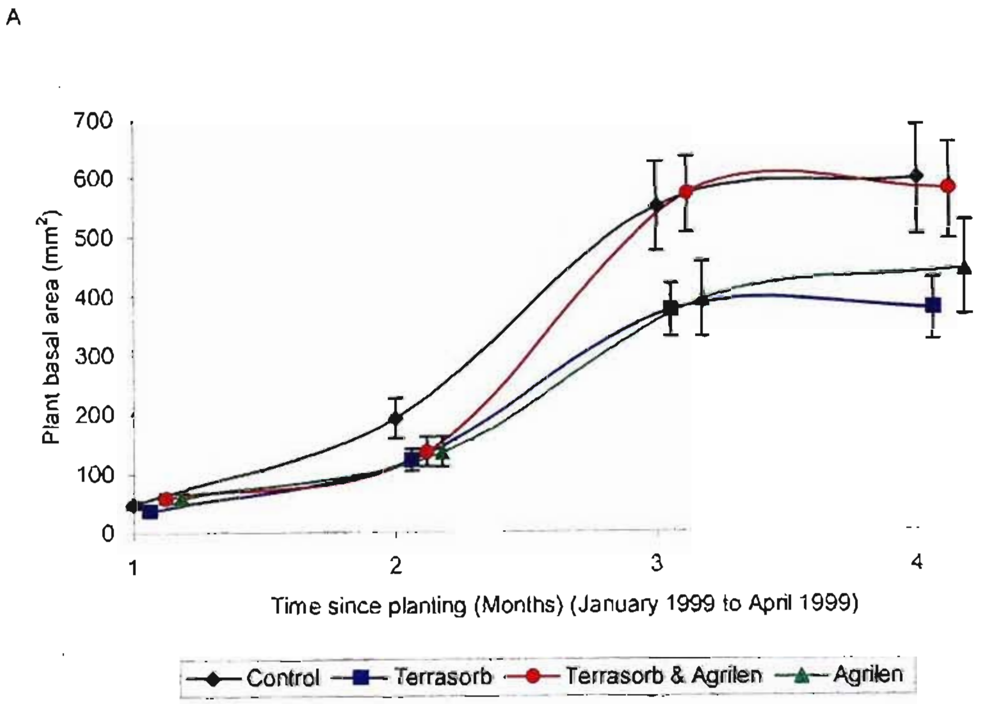
versus 53.6 mm^2), with *T. triandra* having a greater basal area than *H. dregeana* (68.6 mm^2 versus 51.0 mm^2). Again the interaction is due to the artificial shade, created by Agrilen®, increasing the plant basal area of *H. dregeana* from 42.6 to 59.3 mm^2, while decreasing the basal area of *T. triandra* from 74.3 to 62.8 mm^2. The ANOVA showed a Terrasorb®.Agrilen® interaction ($P \leq 0.05$) in March 1999 (14th month since planting). This was due to Terrasorb® suppressing the basal area when no Agrilen® was present (from 510 mm^2 to 391 mm^2). When Agrilen® was used together with Terrasorb®, basal area increased from 365 mm^2 to 449 mm^2, although the ANOVA did not show any differences ($P > 0.05$) at the end of the trial. The plot of plant basal area over time indicates that plant basal area for the control treatment of both species (Terrasorb® for *T. triandra* and Terrasorb®.Agrilen® for *H. dregeana)* is greater than the remaining four treatments ($P \leq 0.05$) (Figure 4.4).

Table 4.3: Summary of F-probability values for the ANOVA of the plant basal area of *Hyparrhenia dregeana* and *Themeda triandra* planted with or without Agrilen® to provided artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal

	January 1999	February 1999	March 1999	April 1999
Terrasorb®	0.137	0.440	0.819	0.638
Agrilen®	0.995	0.110	0.269	0.423
Species	0.001	0.375	0.067	0.126
Terrasorb®.Agrilen®	0.216	0.723	0.042	0.283
Terrasorb®.Species	0.895	0.682	0.805	0.962
Agrilen®.Species	< 0.001	0.362	0.173	0.277
Terrasorb®.Agrilen®.Species	0.888	0.408	0.255	0.318

Note: Values ≤ 0.05 are considered significantly different

Plant height was consistent for species ($P \leq 0.05$) throughout the trial (Figure 4.5 and Table 4.4), with *H. dregeana* (195.4 mm in April 1999) having a greater plant height than *T. triandra* (132.1 mm in April 1999) due to their very different growth forms. Initially there was an Agrilen®.Species interaction ($P \leq 0.05$) (Table 4.4), where Agrilen® suppressed the plant height of *H. dregeana* (from 193.4 mm to 153.9 mm) while increasing the plant height of *T. triandra* (from 109.1 mm to 158.4 mm) (Figure 4.5). By the end of the study period the only differences where species, with no differences ($P > 0.05$) within each species, apart from *T. triandra* where the control (133.8 mm) was taller than the Terrasorb®.Agrilen® treatment (124.8 mm) ($P \leq 0.05$) (Figure 4.5).



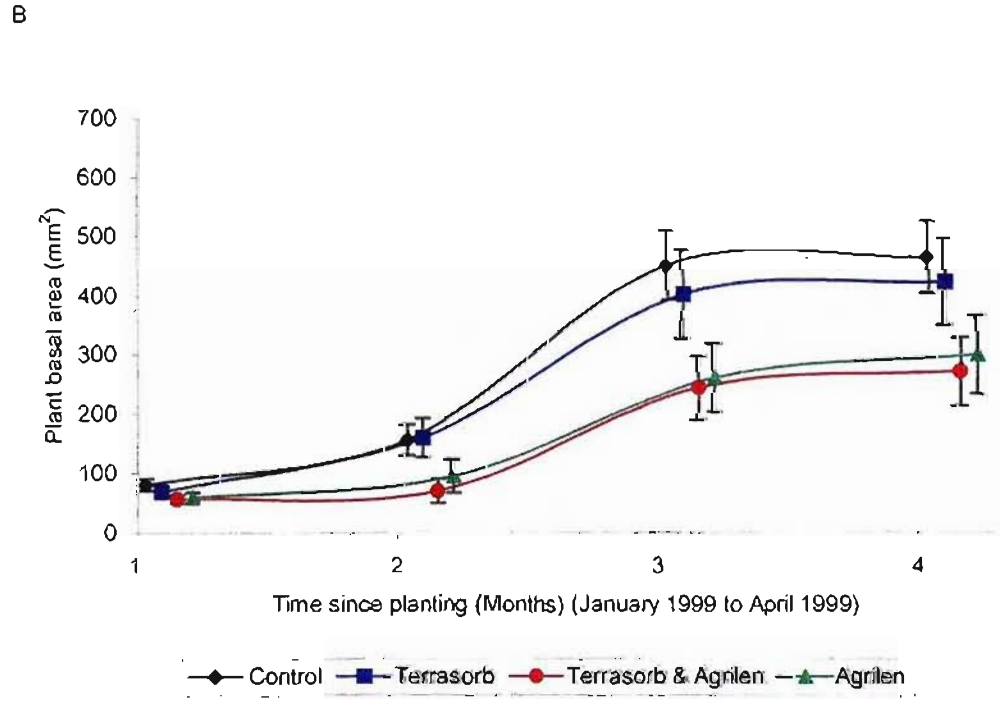
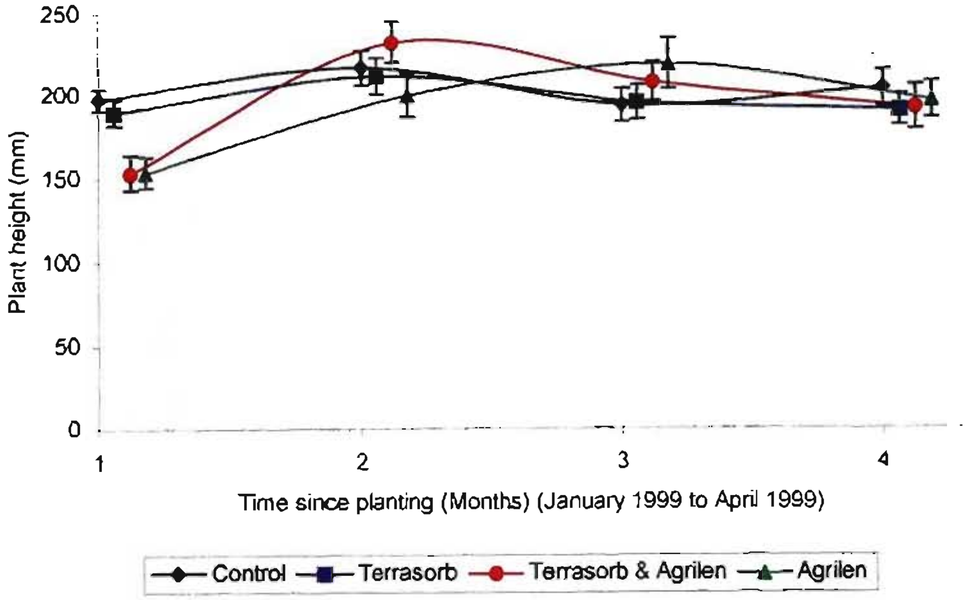


Figure 4.4: Plant basal area of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provide artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

A



B

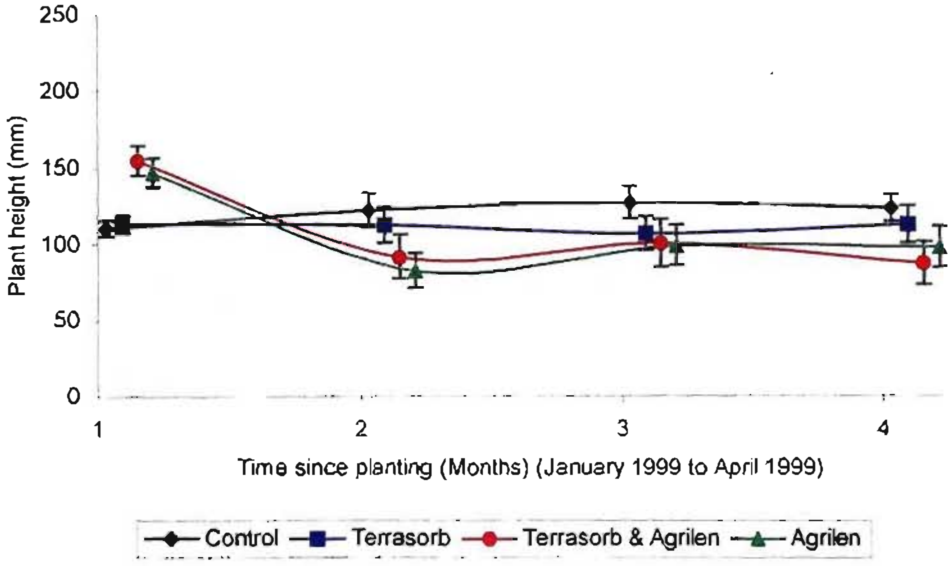


Figure 4.5: Plant height of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provide artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

Table 4.4: Summary of F-probability values for the ANOVA of the plant height of *Hyparrhenia dregeana* and *Themeda triandra* planted with or without Agrilen® to provided artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal

	January 1999	February 1999	March 1999	April 1999
Terrasorb®	0.897	0.682	0.654	0.510
Agrilen®	1.000	0.390	0.968	0.334
Species	<0.001	<0.001	<0.001	<0.001
Terrasorb®.Agrilen®	0.543	0.390	0.886	0.884
Terrasorb®.Species	0.348	0.669	0.872	0.944
Agrilen®.Species	<0.001	0.324	0.251	0.438
Terrasorb®.Agrilen®.Species	0.897	0.777	0.581	0.888

Note: Values ≤ 0.05 are considered significantly different

The RGR of tillers per plant (tillers tiller^{-1} month^{-1}) showed no treatment effects ($P > 0.05$), except for *H. dregeana* where Terrasorb®.Agrilen® was greater than Agrilen® alone in the period February to March ($P \leq 0.05$) (Figure 4.6). Although there were no differences ($P > 0.05$) in the RGR over time, it was noted that from January to February (the first two months after planting) tiller growth was slow. Between February and March there was an increase in the RGR of tillers per tiller. From March to April there was very little growth of new tillers and in fact a negative RGR occurred, indicating tiller mortality. In the 1999 season all new tiller development ceased after March.

The RGR of the plant basal area, showed the same patterns as tiller numbers per plant (Figure 4.7). There were no differences ($P > 0.05$) between treatments for the development of the plant basal area. Again the RGR increased from January through to March where it peaked before declining drastically in the March to April period.

Plant height showed no treatment effects ($P > 0.05$) for RGR (Figure 4.8). Plant height increased very little (a low RGR) from month to month. This slow growth was a result of the grazing pressure by small antelope, eland and horses.

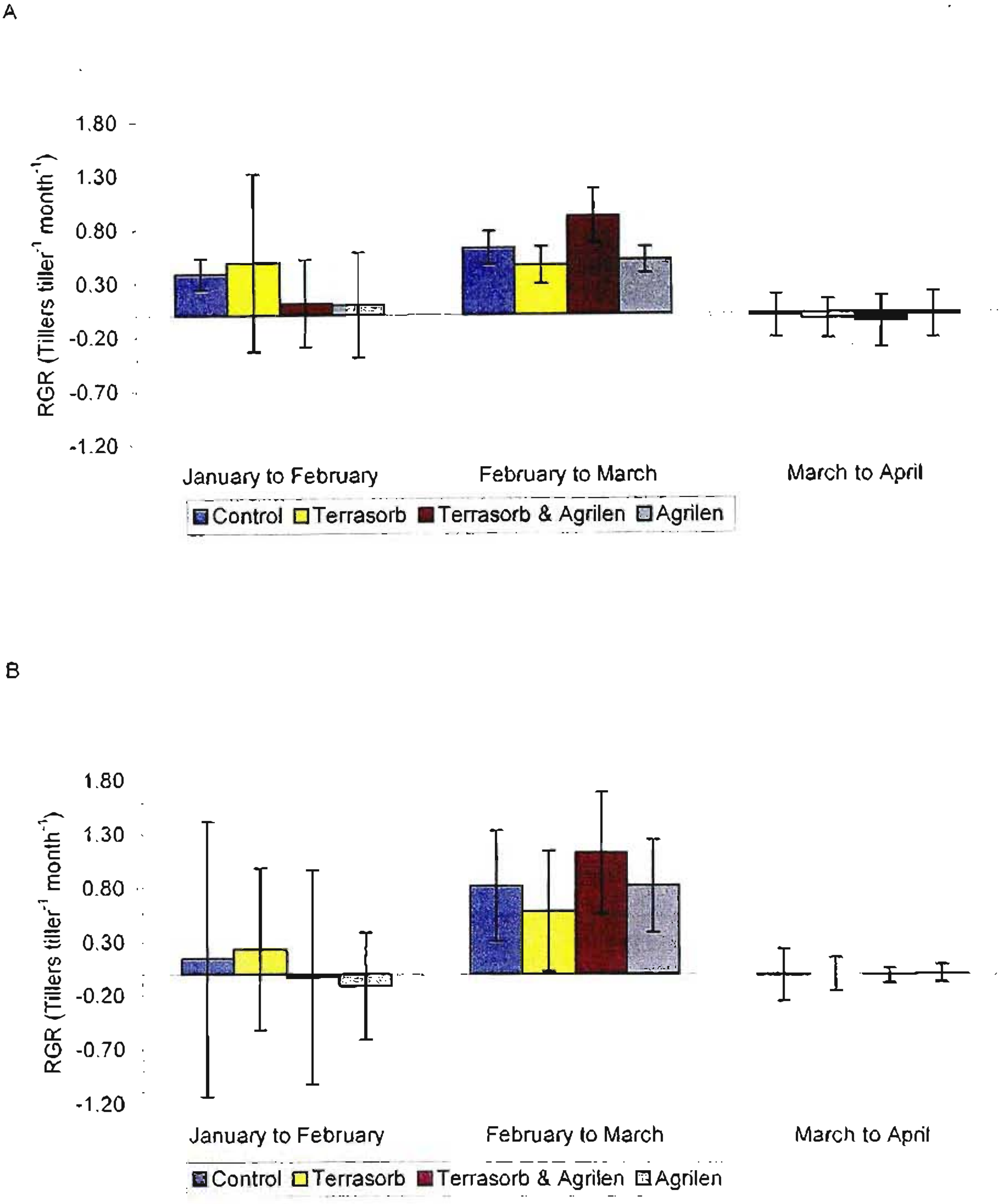


Figure 4.6: Relative growth rate of tillers per plant (tillers tiller^{-1} month^{-1}) of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provide artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

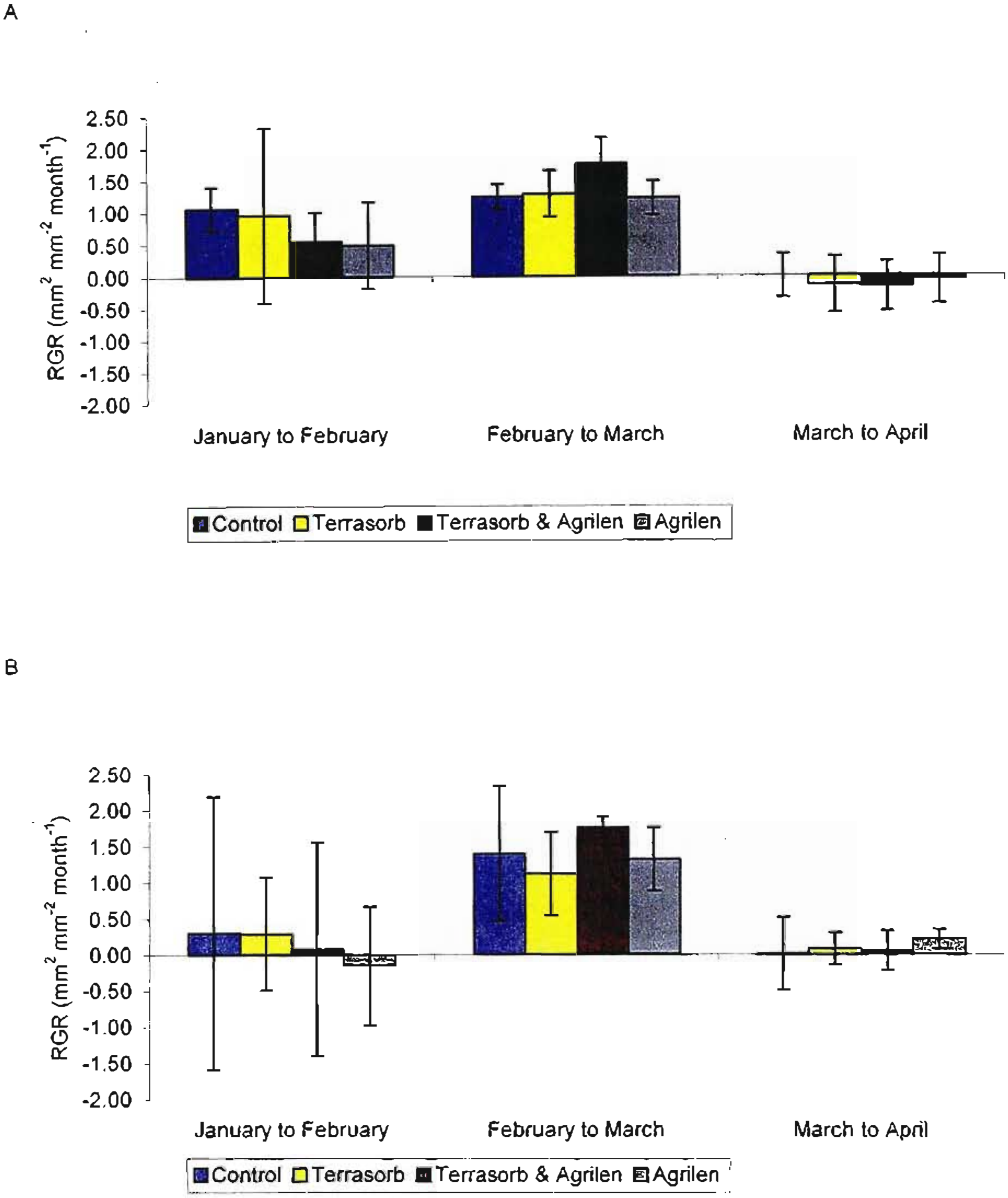


Figure 4.7: Relative growth rate of plant basal area (mm^2 mm^{-2} $month^{-1}$) of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provided artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

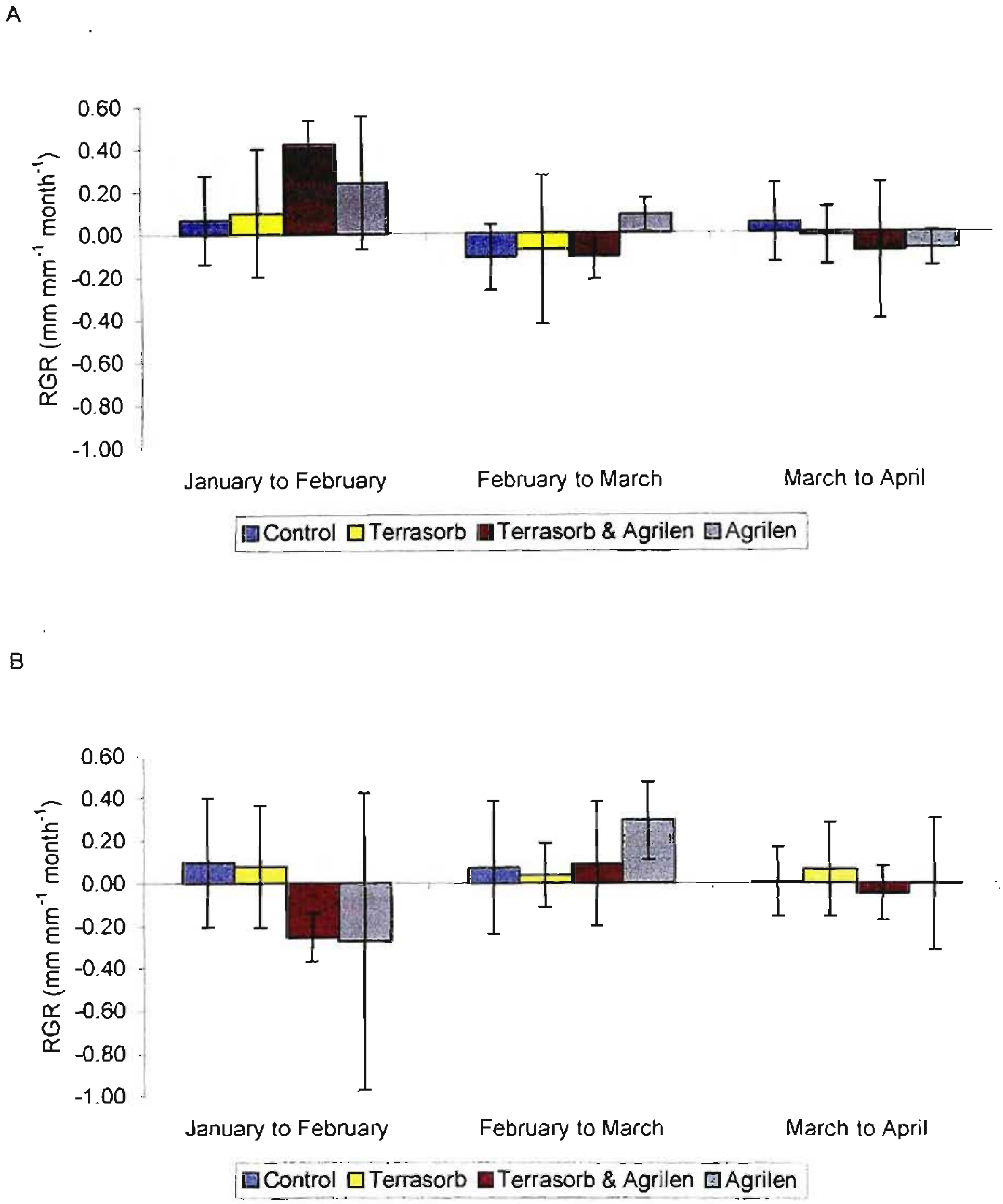


Figure 4.8: Relative growth rate of plant height (mm mm^{-1} month^{-1}) of *Hyparrhenia dregeana* (A) and *Themeda triandra* (B) planted with or without Agrilen® to provided artificial shade for the first seven days and with or without Terrasorb® applied at planting in a trial at Kamberg, KwaZulu-Natal.

4.4 Discussion and conclusions

In this trial, the *H. dregeana* plugs had a higher survival rate than *T. triandra*, whereas the planting density trial and the over-sowing trials both showed the reverse. As the control for each species had a greater survival than those species in the planting density trial and no differences (P > 0.05) were found between the moisture amelioration treatments, it can be concluded that the increase in survival in this trial could have been due to younger planting material, rather than a treatment effect. This trial was planted in 1999, and all plugs used were young and had not had a chance to grow tall or moribund in the seedling trays. The other two trials (planted in 1998) had very poor survival of *H. dregeana*. The first planting material used in these trials had remained in seedling trays too long, with plugs growing too tall and lodging in the trays which resulted in shading of other plants in the trays. This moribund material (when planted) had a large leaf area to support and thus high levels of transpiration, resulting in moisture stress for these plants and increased 'transplant shock'. The younger material would have had none of these problems and with a consequent reduction in 'transplant shock' and hence higher survival levels.

Contrary to the results of Banko (1984), Pill (1988) and Verschoor & Rethman (1992), Terrasorb® did not improve the survival or growth of the plugs. The rainfall for the months of this trial was below the long term monthly average expected from January to April (Table 4.5). Under these conditions of below average rainfall it was expected that the Terrasorb® would have had a greater effect, but this was not the case. It is possible that other factors influenced the effectiveness of the Terrasorb®. Verschoor & Rethman (1992) found that response to Terrasorb® appears to be greater on sandy soils as opposed to clay soils, where clay soils only show an increase in biomass under water stressed conditions. The soil analysis of the study site showed a high clay percent (>35% clay), which may have reduced the effectiveness of the Terrasorb. The pH of the soil in the study site was 4.23 (Appendix B) which could have reduced the effectiveness of the Terrasorb® as its absorption of water is inhibited at pH's below 6 (Verschoor & Rethman 1992).

Table 4.5: Comparison of the long term mean monthly rainfall and the actual rainfall for 1999 for the January to April period

Month	Average monthly rainfall	1999 season
January	199.1	134.1
February	171.0	141.0
March	145.4	110.3
April	61.0	18.6
Total	576.5	404.0

There was a lack of response of survival of plugs under Agrilen®. This could be the result of the Agrilen® sagging onto the plants during the seven days (due to rain and storm winds).

The tiller numbers per plant and plant basal area showed similar growth and development which is understandable as the plant basal area will expand as new daughter tillers develop and grow. For *H. dregeana* the control and the Terrasorb®.Agrilen® treatments had greater tiller numbers per plant than Agrilen® and Terrasorb® on their own. For *T. triandra,* the control and Terrasorb® showed the greatest number of tillers per plant. The RGR of tillers per plant showed a marked decrease from February/March to March/April. In March/April the RGR of tillers became negative indicating that tiller mortality occurred from March onwards. The plants started going into winter dormancy as the conditions were no longer conducive to development of new tillers in these young plugs. From the BRU (Yd16 – Kamberg) information, in March and April the mean daily temperature drops from 16.8 °C to 14.4 °C and the mean minimum temperatures are 11.2 °C and 8.1 °C respectively while there are no Utah-7 chill units in March, but 15 chill units in April (Camp 1995). Everson TM *et al.* (1988) found that in the Highland Sourveld in the Natal Drakensberg the grass sward started curing (drying out) at the end of April, supporting the evidence that plant growth slowed down after March. The curing process can only be initiated once the plant's growth slows down as it goes into winter dormancy.

By the end of the study period the only difference for plant height was a species difference, which is understandable, given the difference in the growth patterns of the two species (van Oudtshoorn 1992). The RGR of plant height showed very little change over the duration of the trial for both species. In many cases there was a negative RGR, which can be attributed to grazing by small antelope, eland and horses.

During the trial period (a slightly below average rainfall season; 172.5 mm below average from January to April) there were no benefit from using either Terrasorb® or Agrilen® to alleviate moisture stress and 'transplant shock' of the grass plugs. It would not be recommended to use either treatment in a normal year, as they are both expensive and time consuming. Terrasorb® could be considered in sandy soils, drier climates or when drought years are forecast.

4.5 Summary

Transplant shock is common when planting nursery raised seedlings, as there is a relatively small root volume in the plug compared to the above ground leaf biomass. Attempts to alleviate moisture stress at planting through the use of either a starch based polymer with high water holding capacity (Terrasorb®) or a white, needle punched geo-fabric (Agrilen®) to provide a seven day period of artificial shade after planting. These two treatments were applied at two levels in the following combination; control (no Terrasorb® or Agrilen®), Terrasorb® only, Terrasorb® and Agrilen® together and finally Agrilen® only. Plugs of *T. triandra* and *H. dregeana* were planted in each treatment at a 30 cm plant spacing. The survival of *H. dregeana* plugs was greater than *T. triandra*, but there were no significant treatment effects. For both species the control showed the greatest survival (although this was not significantly different from the other treatments). The number of tillers per plant and the basal area for *H. dregeana* showed that Terrasorb® with Agrilen® and the control were greater than the

Terrasorb® only and the Agrilen® only treatments. For *T. triandra* the control and Terrasorb® only treatments had a greater number of tillers and basal area than the Agrilen® only and the Terrasorb® with Agrilen®. The only differences for plant height were that the *H. dregeana* plants were taller than the *T. triandra* plants, with no treatment effect within the each species. The RGR showed no treatment effects for any of the growth variables measured. The RGR for tiller numbers per plant and basal area increased in the first two months and then decreased, becoming negative in the March to April time period, showing that new tiller development ceased as temperature dropped. Terrasorb® and Agrilen® did not show significant improvements over the control with regards to survival or plant growth. These methods of moisture amelioration are not recommended in re-vegetation through planting of plugs at this study site. Further research is needed in drier climates and drought years before conclusive recommendations are made.

5. Burning trial

5.1 Introduction

After the manual clearing of an *A. mearnsii* thicket, fire can stimulate the germination of *A. mearnsii* seeds (Campbell 1993, Bromilow 1995, Campbell *et al.* 2000b). Once the seedlings emerge they can be sprayed with a triclopyr herbicide (Vermeulen *et al.* 1998), or burnt again the following year and killed by fire if there is sufficient fuel load to burn. A minimum of fuel load of 5 t ha^{-1} (0.5 kg m^{-2}) for moist areas is required to ensure a hot enough fire to control the *A. mearnsii* seedlings (Campbell *et al.* 2000b). Thus fire can effectively reduce the *A. mearnsii* seed bank within two to three seasons. It is important to eliminate the *A. mearnsii* seed bank as quickly as possible, as the *A. mearnsii* seed remains viable for more than 50 years (Bromilow 1995).

In the past, *E. curvula* was used to re-vegetate sites after clearing of *A. mearnsii*. This species not only provided good ground cover rapidly, but also a good fuel load within one to two seasons. The problem with *E. curvula* is that it creates a near monospecific sward with very low biodiversity. The use of indigenous grass plugs for re-vegetating has been considered, but one of the key questions is whether or not these plugs can provide an adequate fuel load to burn within a year of establishment.

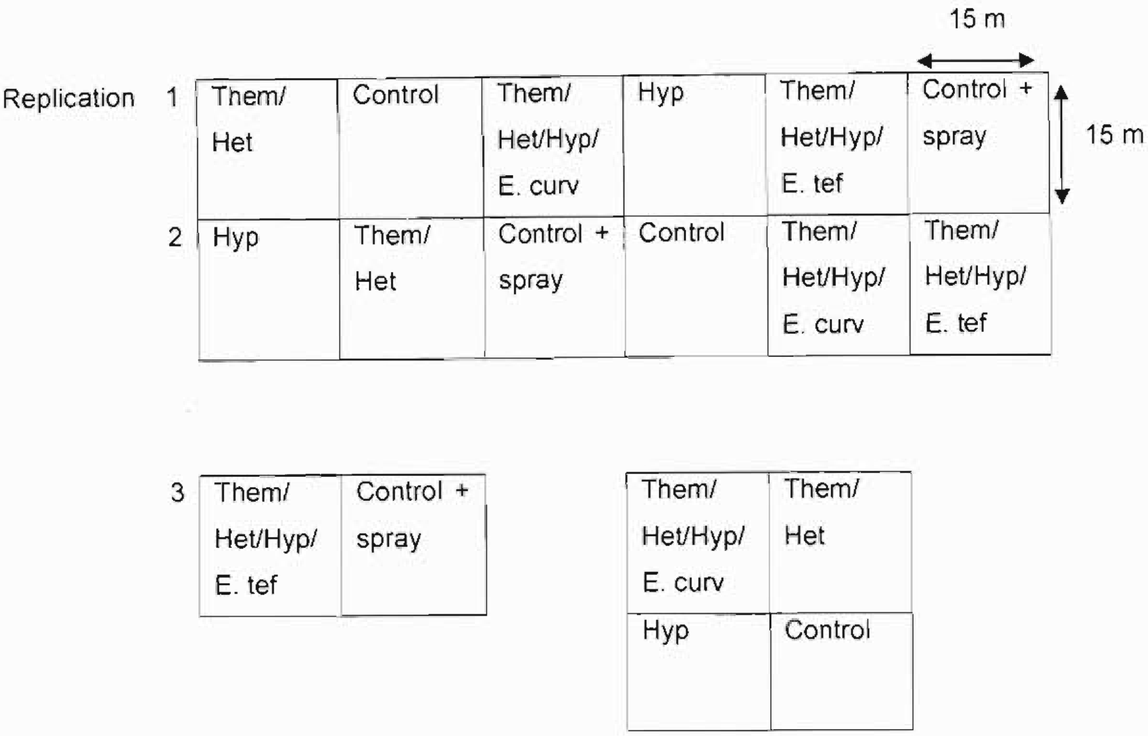
5.2 Materials and methods

The burning trial was established at Kamberg, on a site that had recently been cleared of *A. mearnsii*. Eighteen plots of 15 m by 15 m (six treatments by three replications) were used to provide an area to burn. Grass plugs were planted with 30 cm spacing. Three replications were made, in a randomized block design (Figure 5.1). The first two replications were placed one below each other along the slope, but the third block had to be fitted in and this block runs around the corner of the slope and covers a slightly different aspect although on a similar contour. Only the north-south aspect has been shown to be important in the KZN Drakensberg, where *T. triandra, H. contortus, Alloteropsis semialata, Diheteropogon filifolius, Rendlia altera* and *Monocimbium ceresiiforme* dominating the warmer north facing slopes and *Festuca costata* var. *costata* and *Andropogon appendiculatus* are dominant on the south facing aspects (Walker 1987). It was therefore felt that the aspect effect of this last replication would be minimal. Further problems were found in the randomization of treatments within each plot. Two of the six treatments did not require planting of grass material (control and spray treatments), therefore these two treatments were selectively placed into the 'worst' plots (those plots that encompassed a large number of stumps or felled tree trunks). Care was taken to ensure that the allocation of these treatments were within blocks, therefore the complete randomized block design was maintained and the four planted treatments were randomly allocated to the remaining plots. The treatments used in this trial are as follows:

1. control (natural re-vegetation);
2. control and spray (natural re-vegetation sprayed with a herbicide before burning);
3. *T. triandra* and *H. contortus;*

4. *H. dregeana;*
5. *T. triandra, H. contortus* and *H. dregeana* over-sown with *E. tef (*SA Brown) (15.6 kg seed ha^{-1}); and
6. *T. triandra, H. contortus* and *H. dregeana* over-sown with *E. curvula* (Ermelo) (3.9 kg seed ha^{-1}).

The recommended sowing rate for broadcast seed was used for both *E. tef* and *E. curvula* as defined by Bartholomew (2000).



Replication						
1	Them/ Het	Control	Them/ Het/Hyp/ E. curv	Hyp	Them/ Het/Hyp/ E. tef	Control + spray
2	Hyp	Them/ Het	Control + spray	Control	Them/ Het/Hyp/ E. curv	Them/ Het/Hyp/ E. tef

3	Them/ Het/Hyp/ E. tef	Control + spray

Them/ Het/Hyp/ E. curv	Them/ Het
Hyp	Control

Notes: Control: no treatment

Control + spray: no planting, re-growth sprayed with herbicide before burning

Them/Het: *Themeda triandra* and *Heteropogon contortus* (1:1)

Hyp: *Hyparrhenia dregeana*

Them/Het/Hyp/Eragrostis tef: *Themeda triandra*, *Heteropogon contortus* and *Hyparrhenia dregeana*, over-sown with *Eragrostis tef*

Them/Het/Hyp/E. curvula: *T. triandra, H. contortus* and *H. dregeana*, over-sown with *E. curvula*

Figure 5.1: Experimental design for the burning trial at Kamberg, KwaZulu-Natal, 1998 to 1999.

Survival (see Chapter 2) of the planted plugs was determined in February 1998 and again in April 1998 and November 1998. The plots over-sown with *E. curvula* were not assessed in November 1998 due to the dense aerial cover. Survival data were plotted with the 95% confidence interval, where the confidence intervals overlap the treatments are not significantly different ($P > 0.05$). An ANOVA was used to investigate the treatment and species effects on survival in February and April of

1998, an ANOVA could not be carried out for November 1998, as survival was not measured for one treatment. The survival was very low in the first year and spot planting was done in January 1999 to boost the fuel load.

The comparative yield method of Haydock & Shaw (1975) was used in August 1999 to measure the biomass of the plots in a non-destructive method. A set of five reference quadrates were established at the start of sampling and the biomass of these were ranked on a scale of one (lowest biomass) to five (highest biomass). Twelve quadrats were then randomly sampled across each plot and the biomass was assigned a score based on the initial reference quadrats. Half scores and scores greater than five were assigned where necessary. Finally, five reference quadrats and ten other quadrats were clipped and the grass material dried and weighed to get actual biomass. The biomass from these clipped quadrats was used to create a calibration curve, through linear regression. The results form these measurements were plotted with the 95% confidence intervals and differences were identified visually. The control and control and spray treatments both had very little grass material making up their biomass, as these two treatments were dominated by *A. mearnsii* and *Rubus cuneifolius*. Thus, these two treatments could not be included in this assessment as the comparative yield method was developed for determining the biomass of the grass layer only (Haydock & Shaw 1975).

5.3 Results

5.3.1 Survival

The initial survival was low (Figure 5.2) with a mean of 32.4% in February 1998, one month after planting. From Figure 5.2 and Table 5.1, there were no differences (P > 0.05) in survival for any of the treatments. A great variation in the survival of all treatments was attributed to the very poor survival of the third replication in comparison to the other two replications (Table 5.2). This difference may have been due to the fact that this was the last replication to be planted of all the trials at Kamberg, and thus the plant material used in this replication was older and thus may have been stressed prior to planting. The conditions were also very hot towards the end of the planting time, which could also have played a role in the poor survival of the third replication.

Table 5.1: Summary of the F-probability values from the ANOVA of the survival of *Themeda triandra*, *Heteropogon contortus* and *Hyparrhenia dregeana* planted alone and with over-sowing of *Eragrostis curvula* and *Eragrostis tef*, in a burning trial at Kamberg, KwaZulu-Natal

	February 1998	April 1998
Treatment	0.640	0.848
T. triandra/H. contortus vs. *H. dregeana*	0.237	0.309
Over-sowing with *E. curvula* vs. *E. tef*	0.318	0.562

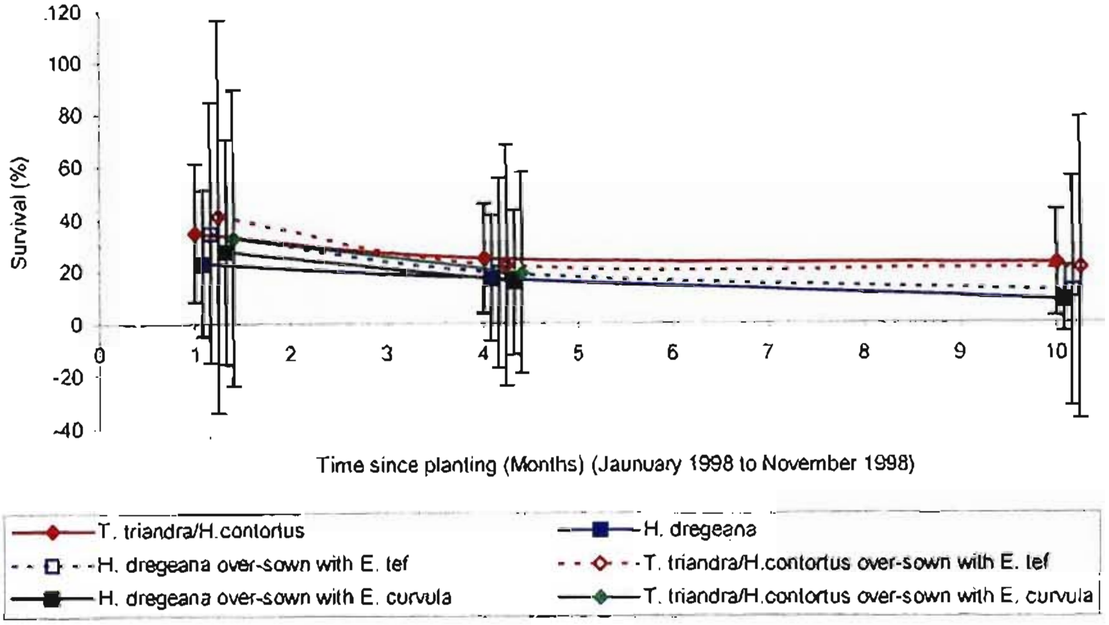


Figure 5.2: Survival of the *Themeda triandra/Heteropogon contortus* combination and *Hyparrhenia dregeana* planted alone and *T. triandra, H. contortus* and *H. dregeana* over-sown with *Eragrostis curvula* or *Eragrostis tef*, in a burning trial at Kamberg, KwaZulu-Natal, 1998.

Table 5.2: Summary of the survival (%) of *Themeda triandra, Heteropogon contortus* and *Hyparrhenia dregeana* planted alone and with over-sowing of *Eragrostis curvula* and *Eragrostis tef*, for each replication, in April 1998, in a burning trial at Kamberg, KwaZulu-Natal

Treatment	Species (where necessary)	Replications		
		1	2	3
T. triandra/H. contortus		32.57	26.33	15.84
H. dregeana		17.99	26.40	7.00
Over-sowing with *E. tef*	*H. dregeana*	9.00	36.04	12.89
	T. triandra/H. contortus	11.64	43.44	11.32
Over-sowing with *E. curvula*	*H. dregeana*	20.52	23.62	3.02
	T. triandra/H. contortus	33.65	21.17	2.93
AVERAGE		20.90	29.50	8.83

5.3.2 *Comparative yield method*

The regression equation for biomass was calculated from the clipped samples in g per quadrat (0.25 m^2) and was then converted to kg m^{-2}. The equation was as follows:

Biomass (g per 0.25 m^2) = 0 + (78.947 * rank)

The comparative yield method of estimating biomass in the plots showed a number of differences between treatments. The *T. triandra/H. contortus* combination treatment showed the lowest biomass (0.377 kg m^{-2}) ($P \leq 0.05$) (Figure 5.3). The *H. dregeana* (0.702 kg m^{-2}) and over-sowing with *E. tef* (0.706 kg m^{-2}) treatments were not different from each other ($P > 0.05$). The treatments over-sown with *E. curvula* showed the greatest biomass (1.158 kg m^{-2}) ($P \leq 0.05$).

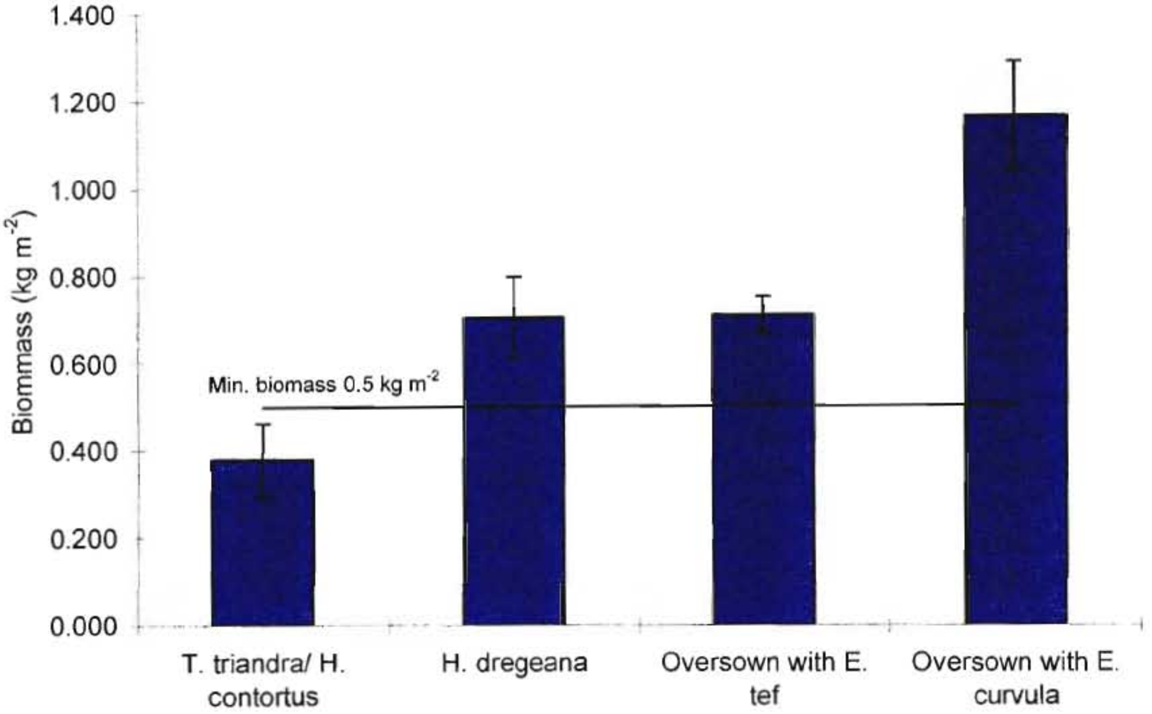


Figure 5.3: Biomass as determined using the comparative yield method for the burning trial, at Kamberg, KwaZulu-Natal, 1998 to 1999. Note the biomass of the control and the spray were made up of principally of *Rubus cuneifolius* and *Acacia mearnsii* saplings.

Through these results and through visual inspection of the plots in the field, the only treatment that had both the required biomass of 0.5 kg m^{-2} of grass material (Campbell *et al.* 2000b) and a continuous fuel cover required to carry a fire across the plot (Trollope 1984), in all three replications was the treatment over-sown with *E. curvula*. The *T. triandra/H. contortus* combination plots had an insufficient fuel load to carry a fire across the plot with only 0.377 kg m^{-2}. The *H. dregeana* plots and the plots over-sown with *E. tef* also had a fuel load greater than 0.5 kg m^{-2} but these plots did not have a continuous fuel load across the plot in all three replications and thus a fire could not have burnt all the way across the plots in all three replications. Further investigation into burning and response to burning could not be carried out and the trial was abandoned as a burning trial in terms of the original objectives.

5.4 Discussion and conclusions

In general the survival of this trial was very poor, with the third replication having a particularly poor survival. It has been speculated that as this replication was the last to be planted and the last of the plant material was used for planting this replication thus the quality of these plugs was not high.

A biomass of 0.5 kg m^{-2} is recommended for the control of wattle seedlings in moist areas (Campbell *et al.* 2000b). The biomass estimates and visual inspection of the plots showed that only the *E. curvula* over-sowing treatment gave a sufficient, continuous biomass. The lack of continuity in fuel load can be attributed to poor plug survival. The results of estimated biomass indicate that if adequate and even survival across the re-vegetated site had occurred, then there would be sufficient fuel load for a fire. Although the actual estimated fuel loads, give the impression that the plots could have been burnt, these do not account for the patchy distribution of this biomass. In some cases (especially with *H. dregeana)* the biomass is high due to the size of the mature plants, but the low survival has meant that there is a discontinuous cover over the plot which would not enable a fire to move across the plots (Trollope 1984).

Although this study appears to indicate that indigenous plugs do not meet the requirements of providing sufficient fuel load, this is mostly due to the poor survival of the plugs. If a good plug survival rate could be ensured it is likely that these plugs would provide the required fuel load to carry a fire. A number of factors affected plug survival, for example moribund planting material, and a number of solutions have arisen, for example, keeping the plugs mown in the nursery and only using young, vigorous planting material. Future trials investigating the fuel load production are therefore required when taking into account the overall conclusion of this study (Chapter 10).

5.5 Summary

The seeds of *A. mearnsii* have been shown to remain viable for up to 50 years and it is important to reduce the soil seed bank as quickly as possible after clearing *A. mearnsii*. Fire stimulates seed germination and thus can be used to reduce the soil seed bank. The re-growth of *A. mearnsii* can then be killed through use of herbicides or a second fire if there is sufficient fuel load. A trial was established to investigate the biomass production of six different treatments, namely; control (left to natural re-vegetation), natural re-vegetation sprayed with a herbicide (control and spray), *T. triandra* and *H. contortus* plugs, *H. dregeana* plugs, *T. triandra, H. contortus* and *H. dregeana* plugs over-sown with *E. tef* and finally *H. dregeana* plugs, *T. triandra, H. contortus* and *H. dregeana* plugs over-sown with *E. curvula*. There were no treatment differences in the survival of the planted plugs by the end of the trial. In general, the survival of the plugs planted in this trial was very poor compared to the other trials planted at the same time. There was also a great variation in the survival of plugs between the three replications. The comparative yield method was used to measure the biomass of material produced in the six treatments. The plots over-sown with *E. curvula* showed a significantly greater biomass, than the plots which were over-sown by *E. tef*, planted to *H. dregeana*, the control, and the natural re-vegetation sprayed with a herbicide (control and spray), which were significantly greater than the *T. triandra* and *H. contortus* plots. Although the total biomass for the plots which were over-sown by *E. tef* and planted to *H. dregeana* only were on average sufficient for a fire, there was a discontinuous fuel load across these plots, especially in the replications that had very low survival rates and thus these plots could not be burnt. The control and control and spray plots were colonized by mostly *A. mearnsii* saplings and bramble with very little grass cover and thus the comparative yield method was not used to estimate biomass for these. Thus only the plots over-sown with *E. curvula* were able to be burnt in this trial and as a burning trial *per sê* the trial was abandoned.

Further research is required into improving the survival of the planted plugs in order to be able to create a continuous fuel load.

6. Thatching trial

6.1 Introduction

Thatching is a method of re-vegetating by spreading seed bearing hay over an area (McDougall 1989). Thatching has been used successfully in a number of re-vegetation programs; although for *T. triandra* in the Moist Highland Sourveld it is not always successful, due to the long dormancy and low viability of the seed (Baxter 1996). Despite these drawbacks, as a revegetation method it requires less labour and less facilities than producing plugs. Furthermore the seed bearing thatch can be harvested to include all species that are flowering in the veld at the time of harvest and thus the diversity of these revegetated sites is improved.

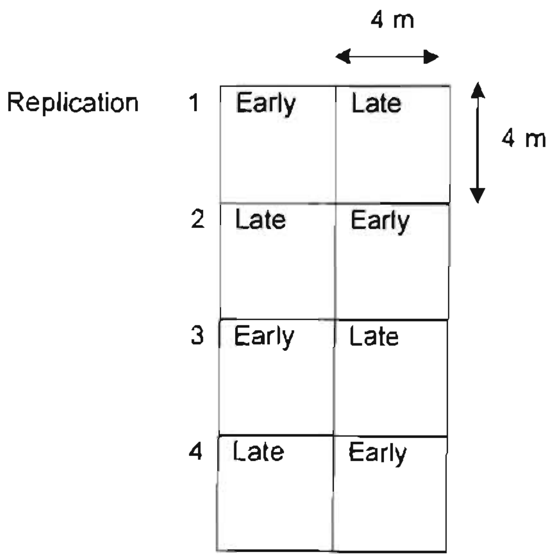
Seed bearing hay is commonly spread out immediately after harvest, thus no storage facilities are required. McDougall (1989) showed that *T. triandra* could be established by spreading *T. triandra* thatch immediately after harvest. A short period of up to two weeks of storage is useful in humid environments to prevent fungi developing on the seeds, while not being long enough for seed shatter (seeds dropping off the stalks) to occur. If seed shatter occurs one has to sow the seed separately from the stalk material, although the stalk material may be spread over the sown seeds as mulch and is thus no longer seed bearing hay in the strict sense of the term.

This method was included as a cheaper alternative to the more expensive and time consuming method of planting nursery grown plugs. The aim of the trial was to determine whether or not indigenous grass and forb species could be established through thatching of seed bearing hay, and whether the time of year of harvesting the thatch would influence the species that germinated.

6.2 Materials and methods

Two treatments were included in this trial, firstly seed bearing hay harvested in early summer (December 1997) and secondly seed bearing hay collected in late summer (April 1998) as a different set of species were observed to be flowering later in the season. The seed bearing hay was collected from the surrounding, undisturbed vegetation. A range of both grass species and forb species flowering at that time of the year were harvested from indigenous grasslands in average to good condition (determined by visual observation). The thatch material was spread out to air dry for two weeks after harvesting to prevent fungi developing on the seed material, but not long enough to result in seed shatter. After two weeks of drying the material was spread over plots of 4 m by 4 m. Four replications of the two treatments were included in the trial in a randomised complete block design (Figure 6.1). After the thatching material was spread out on the plots, *A. mearnsii* brush (left over after clearing) was spread over the plots to prevent the thatch from being blown away (Plate 6.1). This brush would also have added to the mulching effect of the thatch material and helped to prevent antelope from grazing the newly germinated seedlings.

In November 1998, March 1999 and March 2000 the species that had germinated in the plots were counted in 0.5 m by 0.5 m (0.25 m^2) quadrates. Six quadrats were randomly placed in each plot using random number tables (Steel & Torrie 1980). The abundance of each species was recorded by counting the number of rooted individuals per species in each quadrat. The average number of each species for the six quadrats was calculated for each plot.



Note: Early: Early summer seeds and thatch
Late: Late summer seeds and thatch

Figure 6.1: Experimental layout of the thatching trial at Kamberg, KwaZulu-Natal, 1998 to 2000.

Plate 6.1: Thatched grass material spread over a 4 m by 4 m plot and covered with wattle brushwood (February 1998).

The number of species present and Shannon diversity index of each were used to compare the species diversity of the treatments across the four replications (as described in Chapter 2). The statistical significance of both these measures was tested using ANOVA. Where the ANOVA showed a significant treatment effect, no post ANOVA test was required as there were only two levels (Stevens *pers. comm.* Department of Agriculture and Environmental Affairs, Cedara. Private Bag X9059, Pietermaritzburg, 3200, KwaZulu-Natal, RSA).

The MRPP technique was used to compare the compositional differences between the treatments, by testing the null hypothesis of no difference. The Sørenson (Bray-Curtis) dissimilarity measure was used in the MRPP to determine the compositional distance between treatments (refer to Chapter 2 for further details of the method).

Finally, the indicator species method of Dufrêne & Legendre (1997) was used to detect and describe the value of different species as indicators of the two treatments. An indicator value of zero shows that the species in question is not an indication of the treatment, while a value of 100 is a perfect indication of the treatment. The Monte Carlo test, using 1000 permutations, was used to test for the faithfulness of occurrence of a species within a particular group (Ludwig & Reynolds 1988, Magurran 1988).

As the thatching trial and the planting density trial were established in close proximity to each other, along the same contour of cleared *A. mearnsii*. The species diversity of the thatching and planting density trials were compared using the number of species present and Shannon diversity index to investigate which method provided the best diversity for re-vegetation (as described in Chapter 2). The statistical significance of both measures was tested using ANOVA. Where the ANOVA showed a significant treatment effect, the least significant differences were calculated to test the individual treatment differences.

6.3 Results

6.3.1 Early versus late harvested thatch

Over the duration of the trial and across both treatments a total of 29 different species were observed (Table 6.1). Of these, 17 were grass species, 11 were forb species and *A. mearnsii*. The most abundant species across the trial was *A. mearnsii*, followed by *Loudetia simplex* in the early harvested thatch and *Arundinella nepalensis* in the late harvested thatch in November 1998. In March 1999 and March 2000 *Harpochloa falx* was the most abundant species in the early harvested thatch and *Hyparrhenia dregeana* in the late harvested thatch.

The number of species per plot was greater in the early harvested treatment (8.5 species - November 1998) (P = 0.027) compared to the late harvested treatment (4.3 species) (Table 6.2). In March 1999 there were no differences in the number of species recorded per treatment (P > 0.05) (Table 6.2). By

March 2000 the number of species present in the early harvested treatment (10.0 species) was again greater than the late harvested treatment (6.5 species) (P = 0.04) (Table 6.2).

Table 6.1: Average of species abundances per 0.25 m^2 for each treatment over time

Scientific name	Nov 1998		March 1999		March 2000	
	Early	Late	Early	Late	Early	Late
Acacia mearnsii	18.17	46.67	38.50	55.00	27.50	15.83
Alloteropsis semialata	0.50		2.17	0.17	2.00	0.50
Andropogon schirensis			0.33	1.83		
Aristida junciformis	2.33		0.50		0.67	
Arundinella nepalensis		3.83			0.50	1.33
Bidens pilosa					0.33	1.33
Bromus catharticus					0.33	
Brunsvigia natalensis	0.33		0.17	0.17		
Buddleia salviifolia			1.50			
Commelina africana	0.67	0.17		0.17		
Elionurus muticus	3.33					
Eragrostis curvula	0.33		1.67	3.67	2.00	3.83
Eragrostis racemosa		1.33	0.33	4.00		
Harpochloa falx	1.67		10.17		9.83	
Helichrysum tenax var. *tenax*	0.83	0.50	0.33	0.33	0.67	0.33
Heteropogon contortus	0.17		1.83		1.17	
Hyparrhenia dregeana				12.00		11.00
Hyparrhenia hirta				1.50		
Lasiosiphon capitatus	0.67		0.33			
Leonotus leonurus					0.67	
Loudetia simplex	5.50					
Melinis nerviglumus			1.83	1.67	3.00	2.00
Panicum natalense			0.33	1.33	1.00	
Phytolacca dodecandra			0.33		1.00	0.17
Rubus cuneifolius		0.33	0.17		0.17	
Senecio spp.		0.17		0.33		
Themeda triandra	0.33		0.50		0.83	
Tristachya leucothrix	1.67					

Table 6.2: One way analysis of variance of the number of species present per treatment for thatch harvested in early and in late summer in November 1998, March 1999 and March 2000

Date	Source of variation	SS	d.f.	MS	F	P-value	F-critical value
November 1998	Between groups	36.125	1	36.125	8.417	0.027	5.987
	Within groups	25.75	6	4.292			
	Total	61.875	7				
March 1999	Between groups	4.500	1	4.500	1.000	0.356	5.987
	Within groups	27.00	6	4.500			
	Total	31.500	7				
March 2000	Between groups	24.500	1	24.500	21.000	0.004	5.987
	Within groups	7.00	6	1.167			
	Total	31.500	7				

The Shannon diversity index showed a difference only in November 1998 (P = 0.014) (Table 6.3), with the diversity of the early harvested treatment greater than the late harvested treatment (Shannon diversity index of 1.50 and 0.52 respectively). In March 1999 and March 2000 the diversity index was not different (P > 0.05), although the early harvested treatment now showed a lower diversity index than the late harvested treatment, 1.19 and 1.25 in March 1999 and 1.41 and 1.46 in March 2000 respectively.

Table 6.3: Analysis of variance of the Shannon diversity index for the early and late harvested thatch in November 1998, March 1999 and March 2000

Date	Source of variation	SS	d.f.	MS	F	P-value	F-critical value
November 1998	Between groups	1.933	1	1.933	11.559	0.014	5.987
	Within groups	1.003	6	0.167			
	Total	2.936	7				
March 1999	Between groups	0.008	1	0.008	0.034	0.860	5.987
	Within groups	1.356	6	0.226			
	Total	1.364	7				
March 2000	Between groups	0.005	1	0.005	0.047	0.835	5.987
	Within groups	0.669	6	0.111			
	Total	0.674	7				

The MRPP showed a significantly different species composition for all three time periods (P ≤ 0.05) (Table 6.4). The early harvested thatch consistently had a greater distance measure compared to the late harvested thatch (Table 6.4).

Table 6.4: Multi-response permutation procedure of early and late harvested thatch for November 1998, March 1999 and March 2000, using the Sørenson (Bray-Curtis) distance measure

Date	Average distance measure		Probability
	Early harvested thatch	Late harvested thatch	
November 1998	0.462	0.128	0.013
March 1999	0.398	0.283	0.011
March 2000	0.409	0.354	0.008

The indicator species method of Dufrêne & Legendre (1997) uses relative abundance and relative frequency to calculate indicator values. Two species will be used as examples of how to interpret the relative abundance, relative frequency and indicator values from Tables 6.5, 6.6 and 6.7. Thereafter, only significant species from the Monte Carlo test will be discussed as indicator species. The relative abundance is calculated on a percentage basis with for example, the relative abundance of *A. mearnsii* in November 1998 showing an abundance of 35% in the early harvested treatment and 65% in the late harvested treatment (Table 6.5), thus indicating that it is present in greater numbers in the late harvested treatment. The relative frequency of *A. mearnsii* is 100 for both treatments, indicating that it was present in both treatments and in all plots. The relative frequency of *Commelina africana* is 50 and 25 in the early and late harvested treatments respectively, indicating that it is more frequent in the early harvested plots, but not present in all four replications of this treatment. The indicator values give an indication of how well a particular species is an indication of a particular treatment. The lower the value the less of an indicator the species is, while values tending toward 100 are a clear indicator of a particular treatment. The Monte Carlo test, however, tests the significance and faithfulness of the species as an indicator. In November 1998 three species were significant indicators (P = 0.052), *A. mearnsii* which is present in greater numbers in the late harvested treatment, *Elionurus muticus* and *Loudetia simplex* which both only occurred in the early harvested treatment and thus are clear indicators of this treatment (Table 6.5).

In March 1999 four species were significant indicators, *Alloteropsis semialata* (P = 0.051), *Buddleia salviifolia* (P = 0.026), *Harpochloa falx* (P = 0.026) and *Hyparrhenia dregeana* (P = 0.026) (Table 6.6). The first three of these species are all indicators of the early harvested treatment, while *H. dregeana* is an indicator of the late harvested treatment.

In March 2000 three species were significant indicators, *Harpochloa falx* (P = 0.026) and *Themeda triandra* (P = 0.06) which were both indicators of the early harvested treatment and *Hyparrhenia dregeana* (P = 0.026), which was an indication of the late harvested treatment (Table 6.7).

Table 6.5: Relative abundance, relative frequency, indicator value and Monte Carlo test probability of the indicator values for each species in the early and late harvested treatments in November 1998 (0 indicates than this species was not found in any of the replications, while 100 indicates that this species was found in all of the replications)

Scientific name	Relative Abundance		Relative frequency		Indicator values		Monte Carlo
	Early	Late	Early	Late	Early	Late	Probability
Acacia mearnsii	35	65	100	100	35	65	0.052
Alloteropsis semialata	100	0	75	0	75	0	0.164
Aristida junciformis	100	0	75	0	75	0	0.164
Arundinella nepalensis	0	100	0	75	0	75	0.172
Brunsvigia natalensis	100	0	25	0	25	0	1.000
Commelina africana	87	13	50	25	43	3	0.442
Elionurus muticus	100	0	100	0	100	0	0.052
Eragrostis curvula	100	0	25	0	25	0	1.000
Eragrostis racemosa	0	100	0	75	0	75	0.160
Harpochloa falx	100	0	50	0	50	0	0.445
Helichrysum tenax var. *tenax*	78	22	50	50	39	11	0.565
Heteropogon contortus	100	0	25	0	25	0	1.000
Lasiosiphon capitatus	100	0	50	0	50	0	0.458
Loudetia simplex	100	0	100	0	100	0	0.052
Rubus cuneifolius	0	100	0	50	0	50	0.441
Senecio spp.	0	100	0	25	0	25	1.000
Themeda triandra	100	0	50	0	50	0	0.458
Tristachya leucothrix	100	0	75	0	75	0	0.167
Wahlenbergia undulata	0	100	0	25	0	25	1.000

Table 6.6: Relative abundance, relative frequency, indicator value and Monte Carlo test probability of the indicator values for each species in the early and late harvested treatments in March 1999 (0 indicates than this species was not found in any of the replications, while 100 indicates that this species was found in all of the replications)

Scientific name	Relative Abundance		Relative frequency		Indicator values		Monte Carlo Probability
	Early	Late	Early	Late	Early	Late	
Acacia mearnsii	50	50	100	100	50	50	0.960
Alloteropsis semialata	93	7	100	25	93	2	0.051
Andropogon schirensis	25	75	50	50	13	37	0.653
Aristida junciformis	100	0	25	0	25	0	1.000
Brunsvigia natalensis	60	40	25	25	15	10	1.000
Buddleia salviifolia	100	0	100	0	100	0	0.026
Commelina africana	0	100	0	25	0	25	1.000
Eragrostis curvula	45	55	75	100	34	55	0.592
Eragrostis racemosa	11	89	50	100	5	89	0.078
Harpochloa falx	100	0	100	0	100	0	0.026
Helichrysum tenax var. *tenax*	56	44	50	50	28	22	0.847
Heteropogon contortus	100	0	75	0	75	0	0.132
Hyparrhenia dregeana	0	100	0	100	0	100	0.026
Hyparrhenia hirta	0	100	0	50	0	50	0.444
Lasiosiphon capitatus	100	0	50	0	50	0	0.412
Melinis nerviglumis	62	38	50	100	31	38	1.000
Panicum natalense	24	76	25	50	6	38	0.426
Phytolacea dodecandra	100	0	50	0	50	0	0.463
Rubus cuneifolius	100	0	25	0	25	0	1.000
Senecio spp.	0	100	0	25	0	25	1.000
Themeda triandra	100	0	50	0	50	0	0.393
Wahlenbergia undulata	0	100	0	50	0	50	0.426

Table 6.7: Relative abundance, relative frequency, indicator value and Monte Carlo test probability of the indicator values for each species in the early and late harvested treatments in March 2000 (0 indicates than this species was not found in any of the replications, while 100 indicates that this species was found in all of the replications)

Scientific name	Relative Abundance		Relative frequency		Indicator values		Monte Carlo Probability
	Early	Late	Early	Late	Early	Late	
Acacia mearnsii	58	42	100	100	58	42	0.274
Alloteropsis semialata	71	29	100	25	71	7	0.094
Aristida junciformis	100	0	25	0	25	0	1.000
Arundinella nepalensis	23	77	50	75	11	58	0.210
Bidens pilosa	18	82	50	50	9	41	0.646
Bromus catharticus	100	0	50	0	50	0	0.442
Eragrostis curvula	31	69	75	100	23	69	0.128
Harpochloa falx	100	0	100	0	100	0	0.026
Helichrysum tenax var. *tenax*	69	31	50	25	34	8	0.713
Heteropogon contortus	100	0	75	0	75	0	0.142
Hyparrhenia dregeana	0	100	0	100	0	100	0.026
Leonotus leonurus	100	0	50	0	50	0	0.468
Melinis nerviglumis	55	45	50	100	28	45	0.751
Panicum natalense	100	0	50	0	50	0	0.442
Phytolacea dodecandra	80	20	50	25	40	5	0.422
Rubus cuneifolius	100	0	25	0	25	0	1.000
Themeda triandra	100	0	100	0	100	0	0.026
Wahlenbergia undulata	0	100	0	50	0	50	0.380

6.3.2 Diversity from thatching versus planted plugs

The number of species present showed a number of treatment effects (Table 6.8). In November 1998 the early harvested treatment contained a greater number of species (P ≤ 0.05) than all other treatments except the *T. triandra/H. contortus* combination (at 15 cm spacing), which in turn is greater than the *H. dregeana* at 30 cm spacing and the late harvested thatch. By March 1999 two thatching treatments were greater than all other treatments (P ≤ 0.05), though this difference was only significant between the early thatch and the planted treatments and between the late thatch and the *T. triandra/H. contortus* combination at 30 cm spacing. By March 2000 there were fewer treatment differences with the early harvested thatch being greater than the late harvested thatch and the planted treatments (P ≤ 0.05), except for the *T. triandra/H. contortus* combination at 30cm spacing. These results show a great variation and change within the treatments over the duration of the study period.

Table 6.8: The mean number of species comparing the thatching trial (early and late harvested thatch) and the planting density trial (*Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), at 15 cm and 30 cm plant spacings), at Kamberg, KwaZulu-Natal (different letters indicate a difference at the 5% level using least significant differences)

Treatment	November 1998	March 1999	March 2000
15 cm Hyp	5.25 b c	6.50 b c	7.50 b
15 cm Them/Het	6.00 a b	6.25 b c	7.75 b
30 cm Hyp	3.25 c	6.00 b c	7.00 b
30 cm Them/Het	4.25 b c	5.25 c	8.00 a b
Early	8.50 a	10.00 a	10.00 a
Late	3.25 c	8.50 a b	6.50 b

The Shannon diversity index showed different treatment effects over time (Table 6.9). In November 1998 the early harvested thatch, the *T. triandra/H. contortus* combination at both the 15 cm and 30 cm spacing had a greater Shannon diversity index than the remaining treatments (P ≤ 0.05). In March 1999 there were no significant treatment differences (P > 0.05). But in March 2000 treatment effects became obvious again, where the *H. dregeana* at 30 cm spacing had a greater diversity than the early and late harvested thatch (P ≤ 0.05), while the planted treatments did not show any significant differences in diversity (P > 0.05).

Table 6.9: The mean Shannon diversity index comparing the thatching trial (early and late harvested thatch) and the planting density trial (*Hyparrhenia dregeana* (Hyp) and the *Themeda triandra/Heteropogon contortus* combination (Them/Het), at 15 cm and 30 cm plant spacings), at Kamberg, KwaZulu-Natal (different letters indicate a difference at the 5% level using least significant differences)

Treatment	November 1998	March 1999	March 2000
15 cm Hyp	1.032 a b	1.405 a	1.799 a b c
15 cm Them/Het	1.393 a	1.376 a	1.607 a b c
30 cm Hyp	0.640 b	1.497 a	1.876 a
30 cm Them/Het	1.025 a	1.326 a	1.851 a b
Early	1.499 a	1.186 a	1.412 c
Late	0.516 b	1.248 a	1.463 b c

6.4 Discussion and conclusions

This trial showed that seed bearing thatch harvested in early summer (December) improves species composition compared to thatch harvested in late summer (April). In November 1998 and March 2000 the early harvested treatment had a greater number of species per plot, and thus higher species richness. This is likely to be due to the fact that there were a larger number of species flowering in the early part of the summer.

Although the species richness differed between the two treatments, there was little difference in the diversity (Shannon diversity index) of the species that established under the two treatments. It was only in November 1998 that the early treatment showed a greater diversity to the late treatment. This indicates that although there were different numbers of species, when the abundance and evenness of these species is taken into account the actual diversity did not differ by the end of the trial.

The MRPP showed that there were compositional differences between the two treatments throughout the trial. Further investigation using the indicator species method showed that a number of species were indicative of the different treatments over time. The indicators of the early harvested treatment were *E. muticus* and *L. simplex* in November 1998; *A. semialata, B. salviifoli* and *H.* falx in March 1999; and *H. falx* and *T. triandra* in March 2000. This indicates that these species all flowered and produced viable seed in the early summer when the seed bearing thatch was harvested. It is interesting to note how the indicator species change from November 1998 through to March 2000, suggesting that some of these species germinated and developed rapidly from the seed, while other took longer, possibly due to long seed dormancy such as *T. triandra* (Baxter 1996).

The indicators of the later summer harvesting of thatch were *A. mearnsii* in November 1998 and *H. dregeana* in March 1999 and March 2000. The occurrence of *A. mearnsii* as an indicator of the late harvested treatment only in November 1998 is because these plots were left exposed from January 1998 through to April 1998 (till the thatch was harvested and spread out on these plots) and thus there was no shading from the thatch material to prevent the *A. mearnsii* seedlings from germinating. Later on in the trial *H. dregeana* became the indicator of the late harvested treatment as the seeds of this species only ripen late in the summer.

Both treatments provided good species diversity, although compositional differences were evident in the different treatments. As the early harvested treatments produced the greatest number of species it would be recommended to harvest seed bearing thatch in the early summer months, but good results are still possible when harvesting seed bearing thatch as late as April. These results are applicable only to this area as the flowering and seed biology of the species may vary in areas that are subject to a different climate. For conclusive answers seed bearing thatch should be harvested and used for re-vegetation over a number of seasons, as weather conditions experienced in the summer of 1997/1998 will have influenced the flowering and seed ripening of the plants in the veld in that particular season.

The comparison of the number of species and the Shannon diversity index between the thatching and planted plugs showed vary variable results over the study period. Species numbers present in the early harvested thatch consistently showed a greater number of species than the other treatments, whereas the Shannon diversity index of the early harvested treatment went from being the most diverse in November 1998 to the least diverse in March 2000. With the highly variable results found from this comparison, it is difficult to recommend a particular treatment with respect to biodiversity.

From the results at the end of the study period the early harvested treatment and the *T. triandra/ H. contortus* combination at 30 cm spacing would be recommended to maximize the number of species present. With respect to the Shannon diversity index, which incorporates the evenness of the species as well as species numbers, the four planted treatments would be recommended. Thus, looking at both measures of the diversity, the *T. triandra/H. contortus* combination at 30 cm spacing would be recommended to maximize biodiversity.

6.5 Summary

Seed bearing hay, otherwise known as thatch, can be used to re-vegetate cleared sites. Seed bearing thatch was collected twice, early summer (December 1997) and late summer (April 1998). The thatch was dried for two weeks before being spread out on the plots. The species germinating from these two harvesting times were measured by counting the number of rooted individuals in a 0.5 m by 0.5 m ($0.25m^2$) quadrat. The average number of species occurring in each treatment showed that throughout the trial the early harvested thatch produced the greatest number of species compared to the late harvested thatch. The Shannon diversity index, which takes into account species richness and evenness, indicated that in November 1998 the early harvested thatch had a significantly greater diversity than the late harvested thatch, although by the end of the trial in March 2000, this response was reversed, although the difference was not significant. The MRPP technique confirmed that there was a significant compositional difference between the two treatments. This compositional difference was further investigated using the indicator species method. By the end of the trial *H. falx* and *T. triandra* were indicators of the early harvested treatment, while *H. dregeana* was an indicator of the late harvested thatch. A comparison of the biodiversity that developed in the thatching trial and the planting density trial indicated that the *T. triandra/H. contortus* combination at 30 cm spacing would be recommended to maximize biodiversity.

7. Time of year of planting and survival of plugs in the nursery

7.1 Introduction

As a result of the poor survival experienced with the January 1998 planting, two trials were set up to investigate the effect that time of planting, nursery age and plug volume (the volume of the cavity in the seedling trays in which plugs were grown) has on the survival of *T. triandra* and *H. dregeana*. Two different plug volumes were used to assess plug volume, namely 96 plugs per tray and the current standard plug volume of 200 plugs per tray, used throughout the current research. The larger plug volume has a much greater volume of rooting medium, and thus is able to establish a better root system in the trays than the smaller plugs volume. Plants with larger root systems are less likely to suffer from 'transplant shock' (Zandstra & Liptay 1999). One disadvantage of the large plug size is the added expense in raising the plugs, as fewer plants can be raised in the same amount of nursery space as the smaller plug size.

Time of planting is likely to affect the survival of the plugs, but thus far no research has been done to establish the ideal time of year to plant out plugs of indigenous grasses. In previous trials the plugs were planted in late December or early January (after the majority of the summer rains had fallen) giving the plants three to four months to establish themselves before the days become shorter and the temperatures fall in autumn.

The nursery age aspect of the trial was initiated because of a very poor survival from the initial planting in January 1998, where plants that had been kept in the nursery for a long period of time (necessary to accumulate sufficient material for the trial). The plants grew too tall for the seedling trays by the time they were planted out. These mature plants became moribund and lodged, especially *H. dregeana*. This tall, moribund material had a large leaf area at planting, allowing a high rate of transpiration, thereby increasing the level of 'transplant shock' of the plugs, as shown by Zandstra & Liptay (1999) and Anastasiou & Brooks (2003).

7.2 Materials and methods

Every month a seedling tray of each of *T. triandra* and *H. dregeana* of each plug volume were raised in the nursery. After six weeks twenty plants of each were planted into the field at Kamberg and the remainder of the tray stayed in the nursery. During the winter months, the plugs took longer to reach an age where they could be planted out into the field and thus plugs put into the nursery during June and July were planted out at eight weeks of age not six weeks. The plants that stayed in the nursery were all kept in the same mist house and were not clipped or trimmed during the trial.

The first batch of plugs was planted in October 1998 and the remainder were maintained in the nursery for 13 months, while the final batch was planted out in November 1999. Plug survival was recorded as described in Chapter 2, monthly from November 1998 to November 1999 and again in

March and May of 2000. The analysis of these survival data were compounded by the range of plug ages due to different planting dates. A comparison of survival of the plugs at May 2000 would compare plugs with ages ranging from 6 months to 19 months. To avoid this, the survival of the plugs at six months from planting was used as a means of comparing plugs at a similar age. The survival of the plugs planted was plotted versus date of planting. As no replication was done in this trial, no statistical analysis was possible.

In February 2000 the survival of the plugs remaining in the nursery were recorded and expressed as a percentage of the plugs that had remained in the tray. By the end of the study period the ages of these plugs ranged from three months old to 15 months old. Again, there was no replication and thus no statistical analysis was possible.

7.3 Results

7.3.1 Time of year of planting

Analysis of the plug survival data (Figure 7.1) indicated that the larger plugs (98 plugs per tray) had a better survival than the smaller plugs (200 per tray) for each species, except in February 1999 for *H. dregeana*, April 1999 for *T. triandra* and June 1999 and October 1999 for both species. The survival of *T. triandra* was generally greater than *H. dregeana*. The summer planting dates of 1998 (October 1998 to February 1999) showed the greatest survival, with December 1998 showing the greatest survival for all treatments. The following summer (October to December of 1999) had a very low survival.

7.3.2 Nursery age of plugs

The survival of plugs retained at the nursery in seedling trays decreased as the length of time in the nursery increased. There was a very low survival rate for plugs in the nursery for 15 months, averaging 2.2% survival (Figure 7.2). There was very little consistency in the survival of larger and smaller plugs. The plugs at three and four months of age showed the best survival, averaging 28.7% and 24.6% for three months and four months respectively (Figure 7.2).

7.4 Discussion and conclusions

The survival of the plugs planted into the field, achieved best survival rates when planted from October 1998 through to February 1999. In contrast, the 1999 season had lower survival rates from October 1999 to December 1999. This contrast could have been as a result of differences in the weather of each season. Further investigation into the ideal time for planting should include an analysis of the preceding weather conditions and total seasonal rainfall. It is important to bear in mind that the dates are applicable to the season within which this trial was established. There was also no replication in this trial and thus other unaccounted factors may have affected the survival of the plugs.

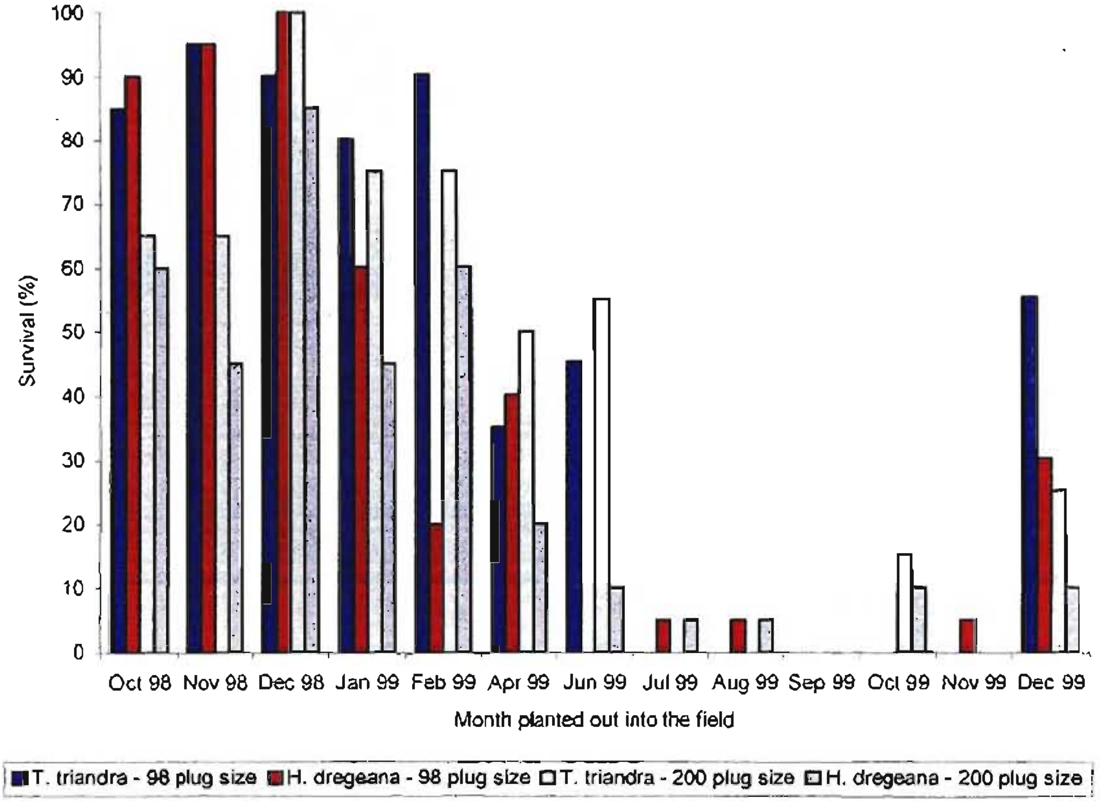


Figure 7.1: Survival at six months of age, of the *Themeda triandra* and *Hyparrhenia dregeana* of different volumes, planted at different times of the year, at Kamberg, KwaZulu-Natal, 1998 to 1999.

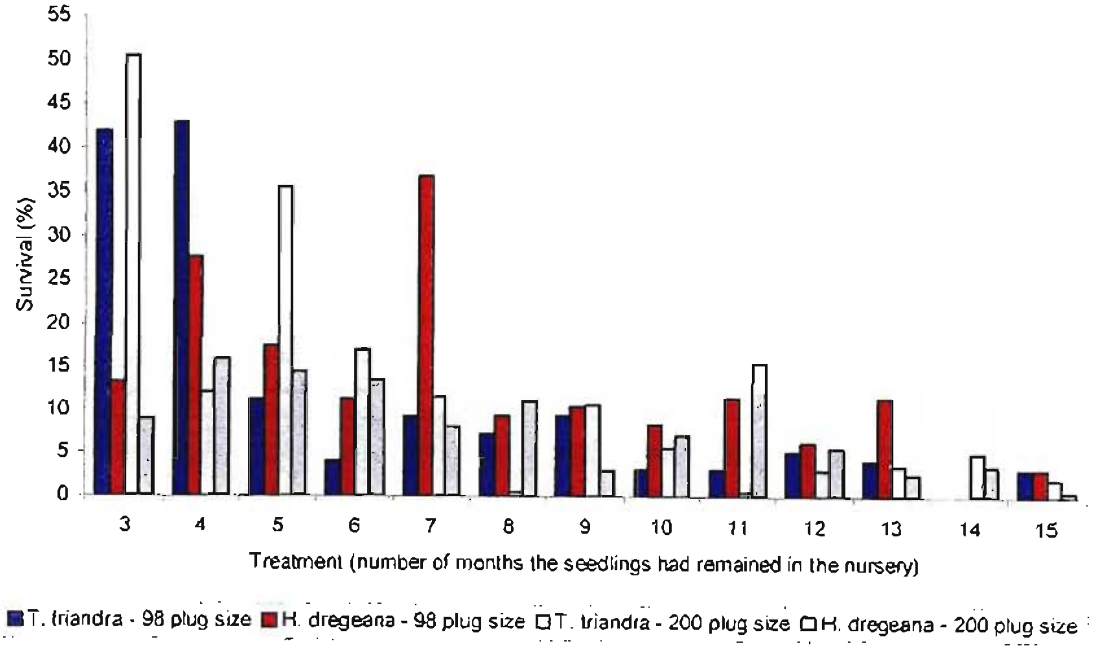


Figure 7.2: Survival of *Themeda triandra* and *Hyparrhenia dregeana* plugs in the seedlings trays kept in the nursery, ranging from 3 months to 15 months old (from left to right), at Crammond, KwaZulu-Natal.

A long term trial would be required to determine more precisely the months and conditions best suited to planting. Careful note of the weather on the day of planting, the rainfall in the preceding weeks and the soil conditions, for example, soil moisture, should be recorded at each planting. Scott (2003) showed that the soils beneath *A. mearnsii* plantations had water repellent characteristics, due to the accumulation of hydrophobic substances in the soil from plant litter. Such water repellent characteristics could create severe water stress for a plug, regardless of recent rainfall or not.

The summer months are ideal, as the trial site is in a summer rainfall area, therefore in years of average rainfall the soil will be moist at this time of the year. The temperatures would be warm and the day length would be long, which are factors that will encourage growth of the plants. If planted too late in the season then the plugs run the risk of being frosted and dying off before they become well established, and as the winters are dry, the plugs would suffer from water stress if planted in autumn or winter. The larger plugs of each species tended to show a higher survival than the smaller plugs, supporting the findings of Zandstra & Liptay (1999), who found that plants with a larger root volume are less likely to suffer from 'transplant shock'.

The survival of the plugs in the trays kept in the nursery was on the whole poor, but it must be noted that these trays were not clipped or trimmed at any stage, thus tall material would have accumulated, even on the three month old trays, resulting in increased plug mortality.

In conclusion, it is important to plant the plugs once sufficient rainfall has been received, i.e. the plugs must be planted out in early summer. The plugs should not be kept in the nursery for longer than three months, to avoid excessive mortalities. It is also important to keep the seedling trays clipped to prevent tall, moribund plugs developing.

7.5 Summary

Low plug survival was observed at the initial planting of the first trials. A secondary trial was then established to investigate the survival of *T. triandra* and *H. dregeana* plugs planted at different times of the year, the effect of plug volume (size of plugs) and the nursery age of plugs. Two plug sizes were used, 98 seedlings per tray (larger root volume) and 200 seedlings per tray (the standard size used in the previous research, smaller root volume). Every six weeks a seedling tray of each species and each plug size was propagated in the nursery and 20 of each was planted into the field at Kamberg. The survival of plugs in the field six months after planting indicated that the summer planting dates of 1998/1999 had the best survival, whereas the following summer showed very poor survival. Generally the larger plug size exhibited a higher survival, with *T. triandra* higher than *H. dregeana*. The nursery age experiment measured the survival of plugs that were left in the nursery ranging from three months to 15 months. The three month old plugs had the highest survival, although even this was unacceptably low. There were no trends in the nursery age data with regards to plug size or species. No replication was carried out so these data are by no means definitive. However, indications are that plugs should not be kept in the nursery for longer than three months and larger plugs should be used. The best time of year for planting appears to be mid summer, although further research on the effect of the weather on the day of planting, the rainfall preceding the planting date and the soil conditions, especially soil moisture at planting needs to be determined.

8. Can self sustaining populations of *Heteropogon contortus* and *Themeda triandra* be developed from parent plants planted as plugs?

8.1 Introduction

Acacia mearnsii, an invasive alien plant is being actively cleared from the uKhahlamba-Drakensberg World Heritage Site. Re-vegetation following the felling of *A. mearnsii* is required to prevent soil erosion and to control the re-growth of the *A. mearnsii.* Traditionally commercial *E. curvula* seed was used to re-vegetate these areas (Anon. 1995). Over time many of these re-vegetated areas have remained mono-specific stands of *E. curvula.* This is not ideal in a conservation area where biodiversity is important. Plugs of *T. triandra* and *H. contortus* have successfully been used to re-vegetate clear felled areas (Granger 1998 unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA).

Although *T. triandra* and *H. contortus* have shown satisfactory survival rates (Granger 1998 unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA), it is important to establish whether these plants produce viable seed, as the production of viable seed is critical to the self propagation and establishment of new individuals. The germination and survival of seedlings generated from nursery grown plants will ultimately determine the long term sustainability of the indigenous plug technique. The aim of this trial was to determine whether *T. triandra* and *H. contortus* plants grown from plugs could create a self sustaining population.

8.2 Materials and methods

The trial was established at Kamberg, on a site that had been cleared of *A. mearnsii* (using the method of clear felling) in 1996. This site was approximately 40 m by 20 m in size. The site was re-vegetated in 1996 using equal quantities of *T. triandra* and *H. contortus* plugs planted at approximately 30 cm intervals. The survival of these plants was observed to be satisfactory (Granger 1998 unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA).

In June 1998, all seedlings were tagged for monitoring purposes (Plate 8.1). In November 1998 the survival of the original tagged seedlings was determined. Any new seedlings that had established were tagged, thus creating two age groups of seedlings. The survival of both age groups of seedlings was monitored over the next two years. No further seedlings were tagged, but seeds of *H. contortus* were collected from this site in late summer 1999. Using a simple T-test (Steel & Torrie 1980), comparisons between age groups and species were made at the final measurements for survival (May 2000).

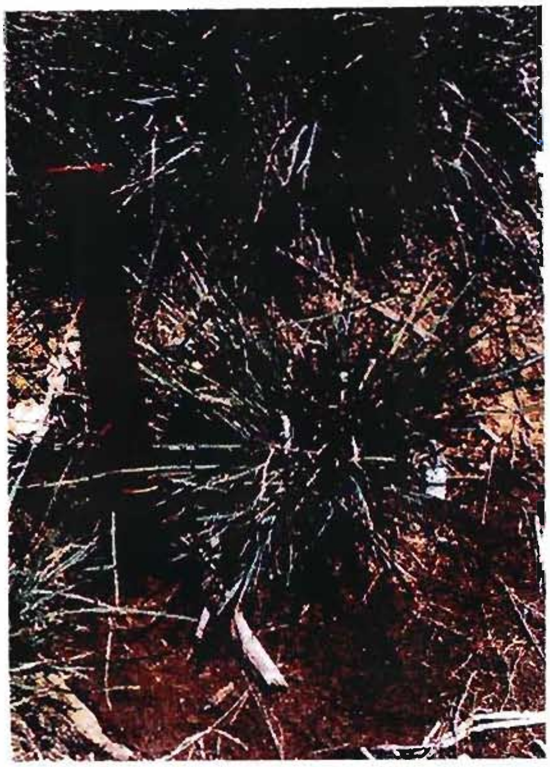


Plate 8.1: Tagged *Heteropogon contortus* seedling compared to a 30 cm ruler (November 1998).

The growth of a sub sample of 100 seedlings from each population (June 1998 and November 1998) of *H. contortus* and T. *triandra* seedlings was monitored over time. Measurements of tiller number per plant, plant basal area and mean plant height (see Chapter 2) were taken in June 1998, November 1998 and January, February, March and April of 1999. These data were analysed using Hunt & Parsons (1974) growth curves. The resultant growth curves were plotted over time with 95% confidence interval bands. Differences ($P \leq 0.05$) were identified by observation of non-overlapping confidence bands.

8.3 Results

In June 1998 a total of 676 seedlings were tagged, of these 661 were *H. contortus* seedlings and the remaining 14 were *T. triandra* plants. In November 1998 a further 436 seedlings were tagged. Of the second population of seedlings 418 were *H. contortus* plants and 18 were *T. triandra* plants.

The survival of each age group of seedlings over time is summarised in Table 8.1. By May 2000 total survival, averaged across both species, of the June 1998 population of seedlings was 78.4%. This was lower than the 91.1% survival of the November 1998 population of seedlings ($P < 0.01$). The survival of *H. contortus* seedlings were 78.3% and 91.6% for the June 1998 and November 1998 populations respectively, showing a difference between the two populations ($P < 0.001$). There was no difference ($P > 0.05$) in the survival of the *T. triandra* seedlings where 85.7% and 77.8% survived from the June 1998 and November 1998 populations respectively.

Table 8.1: Survival (%) of seedlings of *Heteropogon contortus* and *Themeda triandra* tagged in June 1998 and November 1998, Kamberg, KwaZulu-Natal

Age group	Species	November 1998	January 1999	February 1999	March 1999	April 1999	March 2000	May 2000
June 1998	*H. contortus*	84.9	84.4	83.1	83.1	82.9	80.5	78.3
	T. triandra	92.9	92.9	92.9	92.9	85.7	85.7	85.7
November 1998	*H. contortus*		99.8	97.6	97.6	97.4	94.3	91.6
	T. triandra		83.3	83.3	83.3	83.3	83.3	77.8

The June 1998 populations for both species showed a linear increase in tiller number per plant, but were not different from each other (P > 0.05) (Figure 8.1). The November 1998 population initially started off with less tillers per plant (in November 1998), but soon reached similar levels to the June 1998 population, with no differences (P > 0.05) between species or populations. The November 1998 population also showed much greater variation in the number of tillers per plant, evident from the larger 95% confidence intervals.

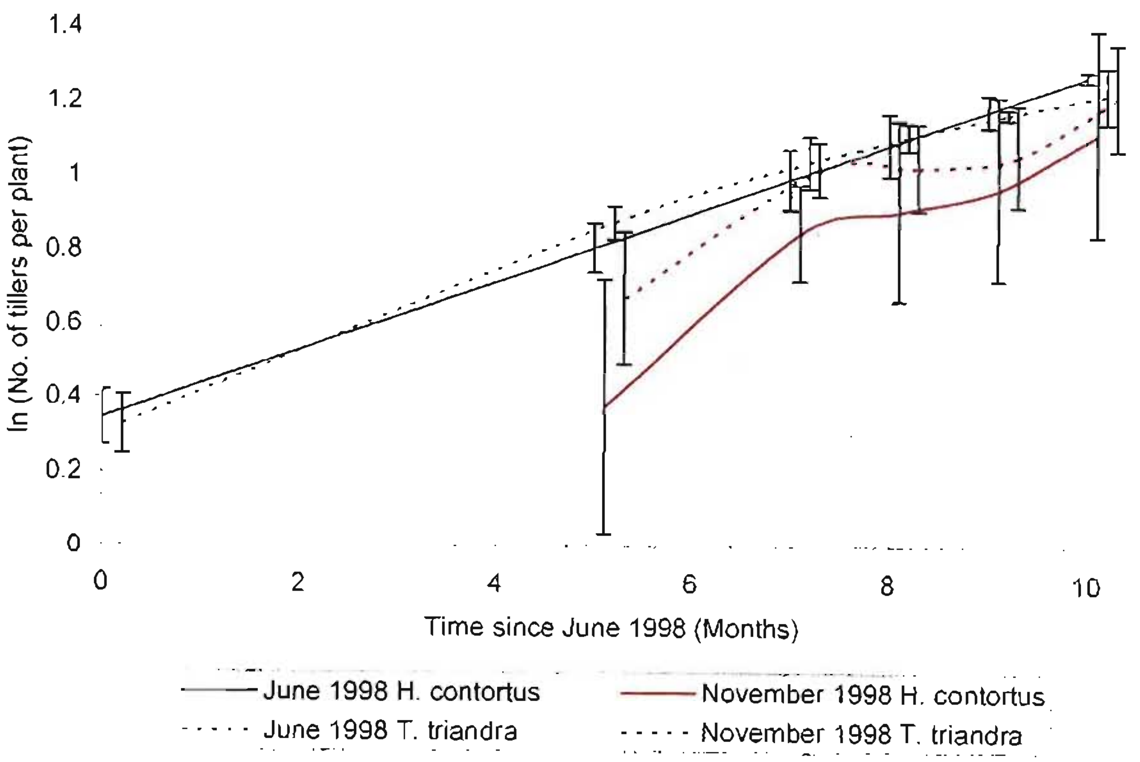


Figure 8.1: Growth rate of the natural log of number of tillers per plant for the *Heteropogon contortus* and *Themeda triandra* seedlings which established in a mature sward planted from plugs in 1996, at Kamberg, KwaZulu-Natal (June 1998 to April 1999).

Plant basal area followed a growth pattern similar to that of the tiller number per plant, although the variation of the June 1998 seedlings was less. Significant differences were apparent (Figure 8.2).

The June 1998 *H. contortus* seedlings had a consistently greater ($P \leq 0.05$) basal area than the *T. triandra* seedlings of the June 1998 seedlings and November 1998 seedlings, but was not different ($P > 0.05$) from the *H. contortus* seedlings from November 1998. The plant basal area of both species from November 1998 and the *T. triandra* from June 1998 were not different from each other at the end of the trial ($P > 0.05$).

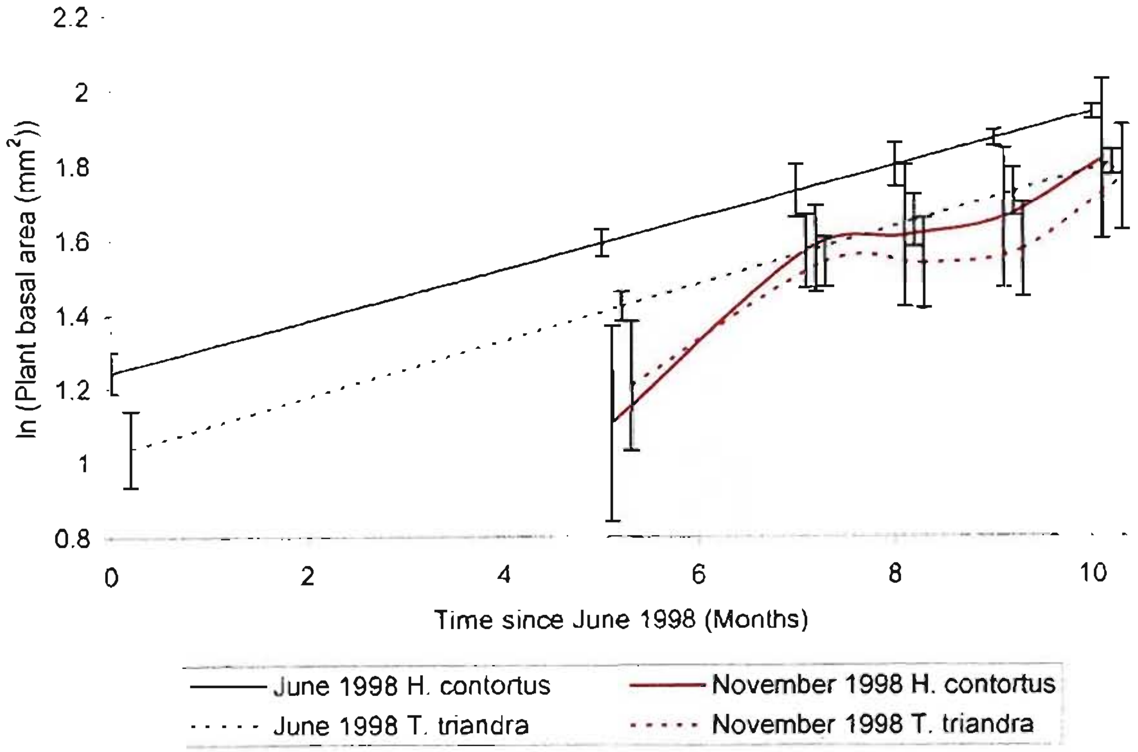


Figure 8.2: Growth rate of the natural log of plant basal area for the *Heteropogon contortus* and *Themeda triandra* seedlings which established in a mature sward planted from plugs in 1996, at Kamberg, KwaZulu-Natal (June 1998 to April 1999).

Mean plant height showed very little change for any of the species or population groups, with no differences ($P > 0.05$), except for the June 1998 seedlings in November 1998, when the *H. contortus* seedlings were taller than the *T. triandra* seedlings ($P \leq 0.05$) (Figure 8.3).

8.4 Discussion and conclusions

In the first population, *H. contortus* seedlings had a lower survival than *T. triandra* seedlings. In the second population this trend was reversed with the *H. contortus* seedlings showing improved survival. This change in survival rates is difficult to explain with the limited data collected in this trial. The first population may have consisted of seedlings that had germinated in the past two years, whereas the population tagged in November 1998 consisted of seedlings that had germinated only in the past four months. Few significant differences were found for the plant growth, indicating that the two species and the two populations grew at similar rates.

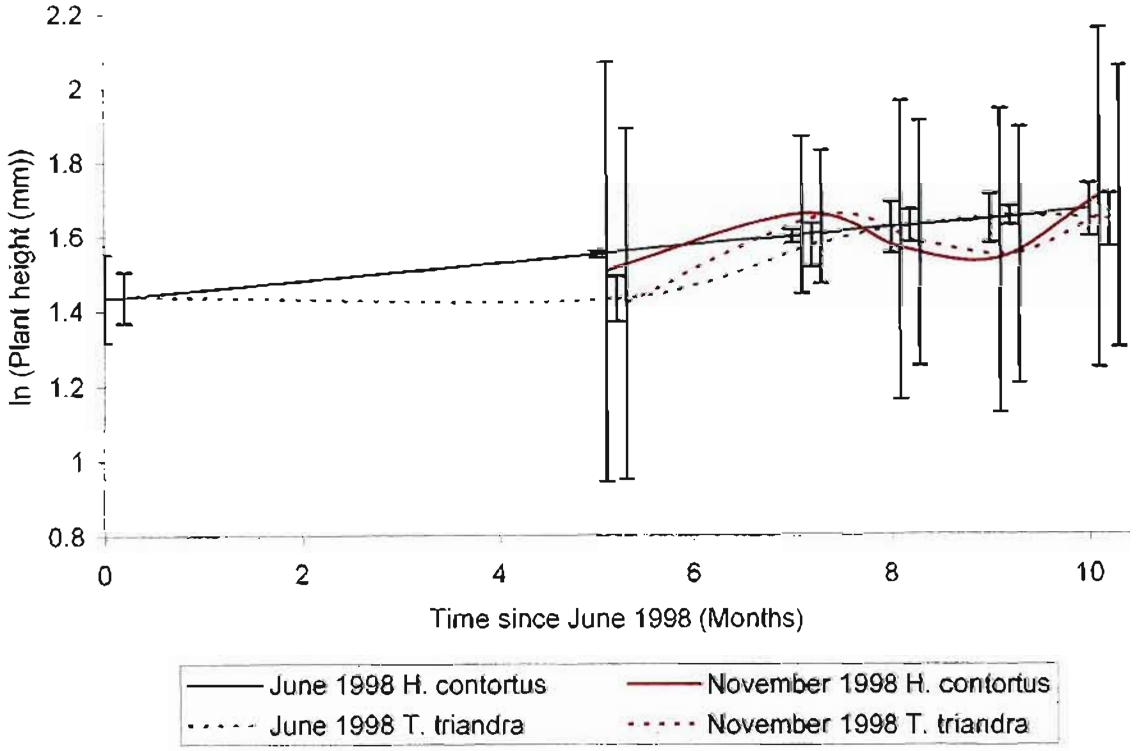


Figure 8.3: Growth rate of the natural log of mean plant height for the *Heteropogon contortus* and *Themeda triandra* seedlings which established in a mature sward planted from plugs in 1996, at Kamberg, KwaZulu-Natal (June 1998 to April 1999).

The *H. contortus* plants originally planted into the cleared area (approximately 40 m by 20 m) produced a total of 1080 seedlings from planting (April 1996) until November 1998. If the *H. contortus* seeds were not collected as mentioned earlier, it is likely that this number would have increased each season. Due to the high number of seedlings established during the period of observation, and the good survival rate of these seedlings, it appears that *H. contortus* is able to establish a self sustaining population. Given the good seedling establishment of *H. contortus* it is possible that lower planting densities of plugs could be used as these seedlings establish in the gaps between plants, ensuring a good basal cover in a relatively short period of time. The advantage of a lower planting density is a reduction in the costs of re-vegetation. Further research is required to determine the optimum planting density, as it is likely that there would be a trade off between reduced planting costs and increased runoff and erosion with reduced planting densities.

A total of only 32 *T. triandra* seedlings established during the period of the trial. The low number of seedlings may be due to the problems that Baxter (1996) found with low viability and germination of *T. triandra* seeds. In addition, the Drakensberg ecotope of *T. triandra* does not rely on seed production but rather tiller initiation as a means of propagation (Everson 1985, Everson 1994, Baxter 1996). Although the survival of these seedlings was high, this species cannot rely on seedling recruitment for longevity in these situations due to the low seedling establishment rate. It would, therefore, not be possible to reduce the planting density of *T. triandra* as the gaps between plants would not be filled quickly by seedlings and the soil would be exposed to increased levels of erosion. Further investigation is required to determine whether it is the lack of seed production from mature *T. triandra* plants or other factors such as poor viability of the seed and high seed predation which results in the low seedling numbers of *T. triandra*.

8.5 Summary

Nursery raised plugs of *T. triandra* and *H. contortus* were planted in an equal mix in an area that was cleared of *A. mearnsii* in 1996. In June and November of 1998, the seedlings from these mother plugs were tagged and monitored. The June 1998 population consisted of 661 *H. contortus* seedlings and 14 *T. triandra* seedlings, while the November 1998 population consisted of 418 *H. contortus* seedlings and 18 *T. triandra* seedlings. By May 2000 the June 1998 population had a survival of 78.4% and the November 1998 population a survival of 91.1%. The growth of the seedlings was monitored from June 1998 to April 1999. Both species from both populations increased in tiller number per plant and basal area over the study period, although at the end of the study period there were no differences in tiller number per plant between either species or population. The only differences in basal area were that the *H. contortus* seedlings of the June 1998 population had a greater basal area than the *T. triandra* seedlings at the end of the study period. The mean plant height showed very little change over time and there were no significant differences between species or population groups. This trial showed that *H. contortus* can maintain a self seeded population, whereas *T. triandra* only produced very low numbers of seedlings.

9. Re-infestation of *Acacia mearnsii* in the re-vegetated areas

9.1 Introduction

After clearing *A. mearnsii* from an area, re-vegetation is only the first step in eradicating the wattle. *Acacia mearnsii* is a prolific seeder and thus the soil seed bank will contain a large number of seeds that will germinate (especially after a fire). These *A. mearnsii* seedlings and coppice growth from stumps can result in *A. mearnsii* re-establishing itself should an appropriate follow up program (for a number of years after initial clearing) not be established (Campbell *et al.* 2000b).

A follow up program usually entails spraying the seedlings with a suitable herbicide, for example triclopyr herbicides (Vermeulen *et al.* 1998). If seedlings are allowed to get too big (> 1.5 m in height) the herbicides tend not to give 100% kill (Vermeulen *et al.* 1998) and manual removal would be required. A common practice is to re-vegetate (following initial clearing) with a grass species that will provide high biomass and burn the area the following season. This fire will stimulate the *A. mearnsii* seeds in the soil to germinate, thus depleting the soil seed bank. A herbicide spray of these seedlings will kill off the seedlings and thus the re-emergence of *A. mearnsii* seedlings in years to come will be greatly reduced (Campbell *et al.* 2000b).

The need for costly herbicide follow ups can be reduced by encouraging the competition for resources between re-vegetated grasses and the *A. mearnsii* seedlings (Campbell *et al.* 2000b). This chapter examines the re-infestation of *A. mearnsii* seedlings that germinated per square meter for the treatments used in trials discussed in this thesis.

9.2 Materials and methods

For each trial planted at Kamberg that was cleared of *A. mearnsii* in October 1997, the number of *A. mearnsii* seedlings m^{-2} was recorded. A 0.5 m by 0.5 m quadrat was used to determine plant species that established or were planted in each plot. Six quadrats were recorded in each of the 4 m by 4 m plots and 12 quadrats in the 15 m by 15 m plots. The number of *A. mearnsii* seedlings per quadrat was averaged for each treatment and converted to number of *A. mearnsii* seedlings m^{-2}.

For all trials the number of A. *mearnsii* seedlings m^{-2} were counted in November 1998, before the study area was sprayed with a triclopyr herbicide to control the *A. mearnsii* re-growth (except the burning trial which was recorded in October 1999). The number of A. *mearnsii* seedlings m^{-2} was not recorded for the Terrasorb®-Agrilen® trial as this trial had to be replanted in January 1999. The data for the planting density trial and the over-sowing trial were compared to investigate the effect of over-sowing with *E. curvula* on the re-growth of the *A. mearnsii* seedlings.

The numbers of *A. mearnsii* seedlings m^{-2} were compared within each trial as well as between trials. An ANOVA was used to test for differences between treatments. The three assumptions for ANOVA, namely, experimental error is normally distributed, a common variance and that treatment and environmental effects are additive, were checked in all cases (Steel & Torrie 1980) and no transformation of the data were required to meet these assumptions. As each treatment only has two levels the F-test within the ANOVA is sufficient to detect differences between the treatment levels (Stevens *pers. comm.* Department of Agriculture and Environmental Affairs, Cedara. Private Bag X9059, Pietermaritzburg, 3200, KwaZulu-Natal, RSA).

9.3 Results

9.3.1 Planting density and species mix trial

An ANOVA (Table 9.1) showed no treatment differences ($P > 0.05$) for either plant spacing or species. Although, for both species the 30 cm spacing had a lower number of *A. mearnsii* seedlings than the 15 cm spacing, with 48.8 and 45.3 seedlings germinating under *H. dregeana* at the 15 cm and 30 cm spacing respectively and 45.0 and 39.8 seedlings germinating per meter under the *T. triandra/ H. contortus* combination respectively (Figure 9.1).

Table 9.1: Summary of the F-probability values from the ANOVA investigating the effect of plant spacing and species on the emergence of *Acacia mearnsii* seedlings m^{-2}, at Kamberg, KwaZulu-Natal

Treatment	F-probability values
Spacing (15 cm vs. 30 cm)	0.498
Species (*Hyparrhenia dregeana* vs. *Themeda triandra/Heteropogon contortus*)	0.467
Spacing.Species	0.895

Note: Values ≤ 0.05 are considered significantly different

9.3.2 Over-sowing with Eragrostis curvula

Within the treatments that were all over-sown with *E. curvula* there were no treatment differences ($P > 0.05$) (Table 9.2). The *H. dregeana* at 15 cm spacing showed the least number of *A. mearnsii* seedlings m^{-2} (15.8 seedlings m^{-2}), followed by *E. curvula* alone (16.5 seedlings m^{-2}), the *T. triandra/H. contortus* combination at 15 cm (21.0 seedlings m^{-2}), *H. dregeana* at 30 cm spacing (23.0 seedlings m^{-2}) and finally the *T. triandra/H. contortus* combination at 30 cm (30.5 seedlings m^{-2}) (Figure 9.2).

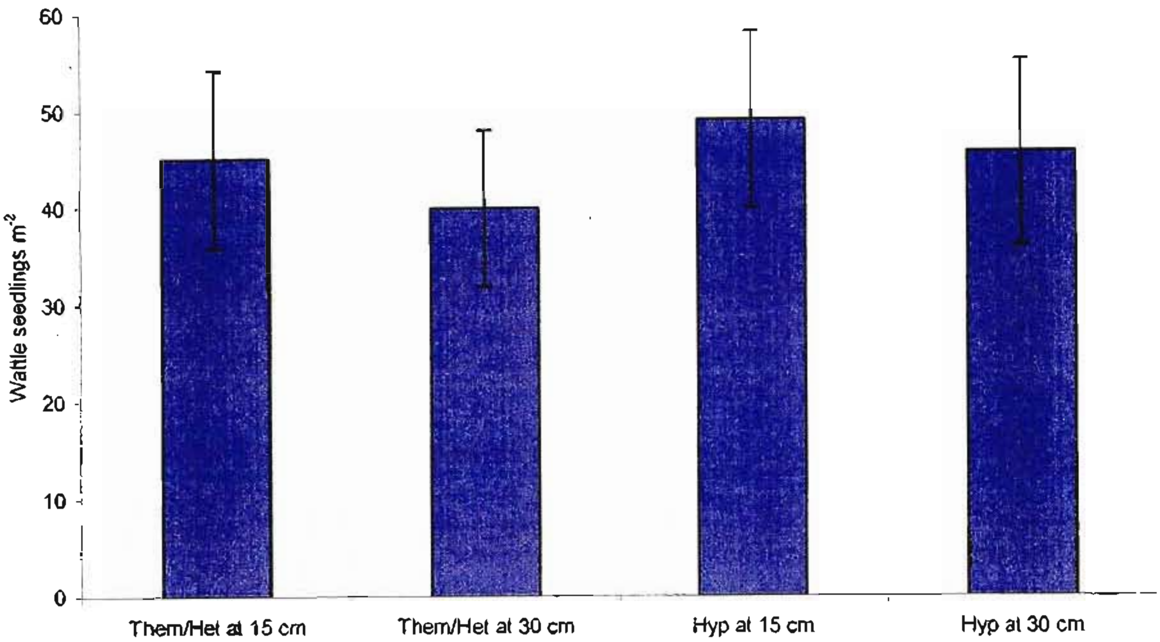


Figure 9.1: *Acacia mearnsii* seedlings m^{-2} for the *Themeda triandra/Heteropogon contortus* combination (Them/Het) and *Hyparrhenia dregeana* (Hyp) each planted at 15 cm and 30 cm spacing, at Kamberg, KwaZulu-Natal.

Table 9.2: Summary of the F-probability values from the ANOVA investigating the effect of plant spacing and species over-sown with *Eragrostis curvula* on the emergence of *Acacia mearnsii* seedlings m^{-2}, at Kamberg, KwaZulu-Natal

Treatment	F-probability values
E. curvula vs. no *E. curvula*	0.479
Species (*Hyparrhenia dregeana* vs. *Themeda triandra/Heteropogon contortus*)	0.412
Spacing (15 cm vs. 30 cm)	0.285
E. curvula.Spacing.Species	0.878

Note: Values ≤ 0.05 are considered significantly different

9.3.3 Effect of over-sowing with Eragrostis curvula *compared to no over-sowing*

A comparison of the treatments from the planting density trial, which were not over-sown with *E. curvula* and the same treatments over-sown with *E. curvula* showed treatment difference for over-sowing versus not over-sowing ($P < 0.001$) (Table 9.3). This treatment difference was brought about by over-sowing with *E. curvula, which* resulted in a suppression of the *A. mearnsii* seedlings. For all treatments, except the *T. triandra/H. contortus* combination at 30 cm the over-sown treatment had a significantly lower number of *A. mearnsii* seedlings m^{-2} ($P \leq 0.05$) (Figure 9.3).

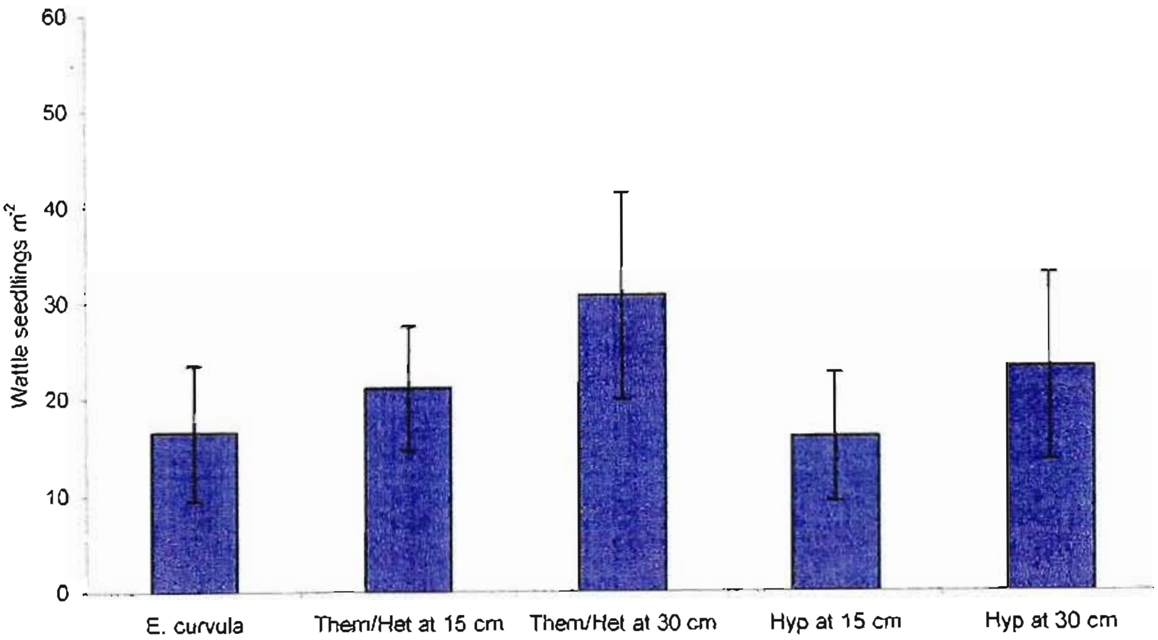


Figure 9.2: *Acacia mearnsii* seedlings m^{-2} for the *Themeda triandra/Heteropogon contortus* combination (Them/Het) and *Hyparrhenia dregeana* (Hyp) each planted at 15 cm and 30 cm spacing over-sown with *Eragrostis curvula*, at Kamberg, KwaZulu-Natal.

Table 9.3: Summary of the F-probability values from the ANOVA investigating the effect of over-sowing with *Eragrostis curvula* on the emergence of *Acacia mearnsii* seedlings m^{-2}, two plant spacings and two planted species, at Kamberg, KwaZulu-Natal

Treatment	F-probability values
Over-sowing with *E. curvula*	<0.001
Spacing (15 cm vs. 30 cm)	0.690
Species (*Hyparrhenia dregeana* vs. *Themeda triandra/Heteropogon contortus*)	0.868

Note: Values ≤ 0.05 are considered significantly different

9.3.4 Burning trial

The treatment effect in the burning trial showed a F-probability values of 0.051 (Table 9.4), which is only just not significant. This occurred as the *E. curvula* treatment had a lower number of *A. mearnsii* seedlings m^{-2} (6.7 seedlings m^{-2}) compared to the other five treatments (which collectively averaged 42.6 seedlings m^{-2} (P ≤ 0.05) (Figure 9.4)). The remaining five treatments did not differ (P > 0.5) (Figure 9.4).

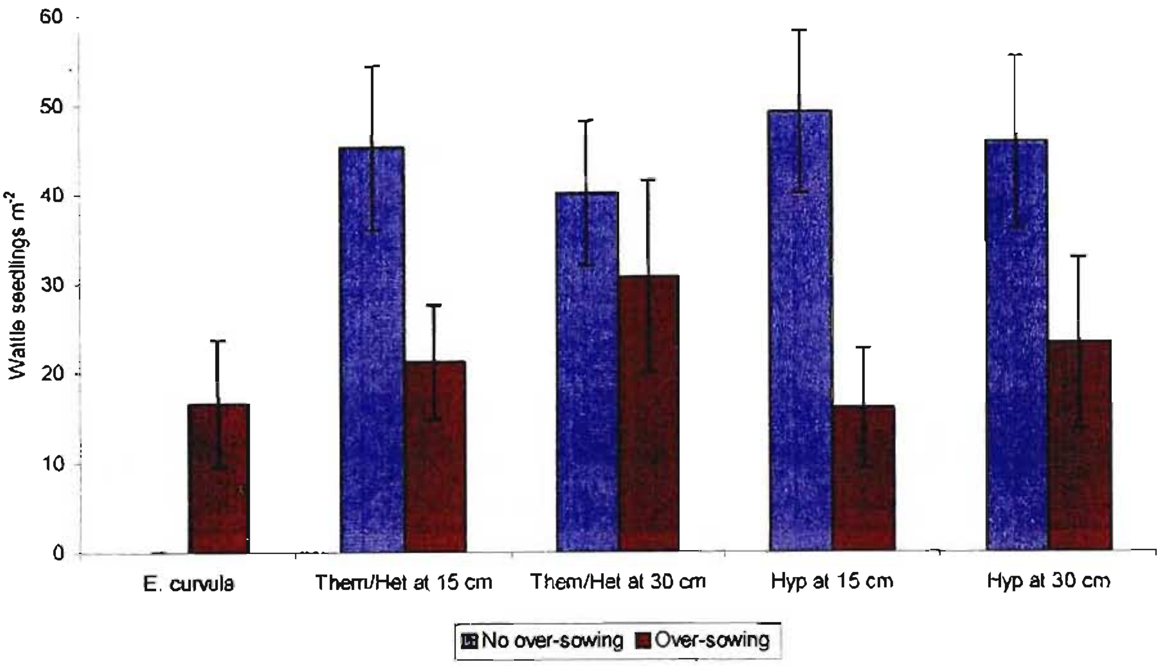


Figure 9.3: *Acacia mearnsii* seedlings m^{-2} for the *Themeda triandra/Heteropogon contortus* combination (Them/Het) and *Hyparrhenia dregeana* (Hyp) each planted at 15 cm and 30 cm, both with and without over-sowing with *Eragrostis curvula*, at Kamberg, KwaZulu-Natal.

Table 9.4: Summary of the F-probability values from the ANOVA investigating the effect of not planting, species planted and over-sowing on the emergence of *Acacia mearnsii* seedlings m^{-2}, at Kamberg, KwaZulu-Natal

Treatment	F-probability values
Treatment	0.051
Note: Values ≤ 0.05 are considered significantly different	

9.3.5 *Thatching trial*

Thatch harvested in the early summer had a lower ($P < 0.001$) number of *A. mearnsii* seedlings m^{-2} (18.2 seedlings m^{-2}) than thatch harvested in the late summer (46.7 seedlings m^{-2}) (Figure 9.5) (Table 9.5).

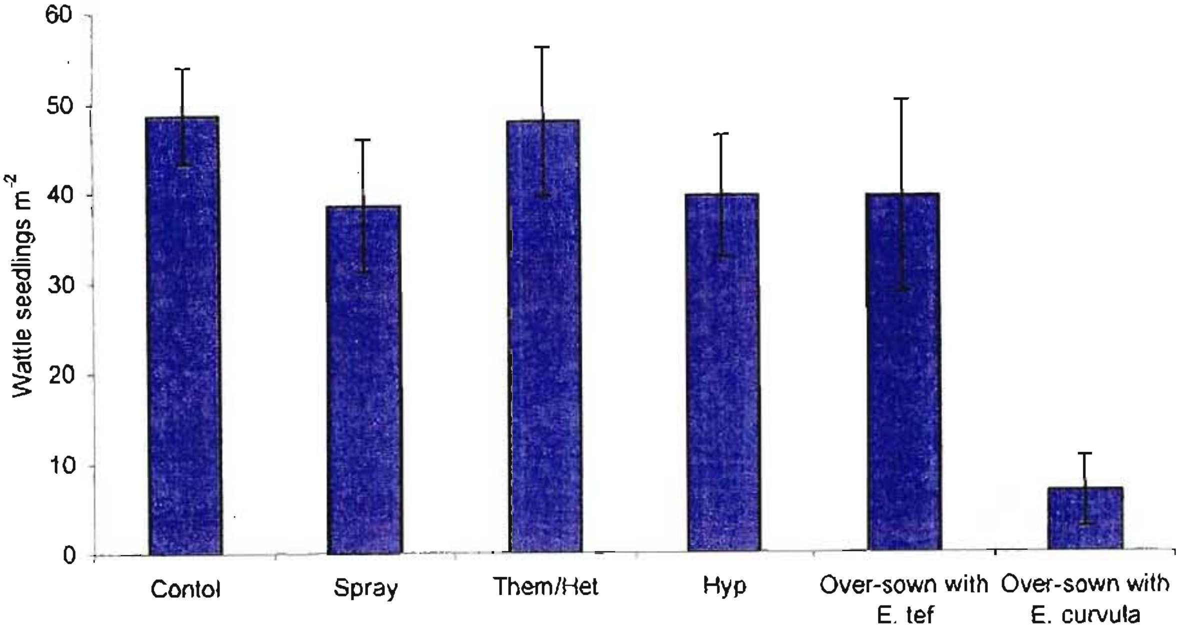


Figure 9.4: *Acacia mearnsii* seedlings m^{-2} for the control, control and spray, the *Themeda triandra/Heteropogon contortus* combination (Them/Het), *Hyparrhenia dregeana* (Hyp) and *T. triandra*, *H. contortus* and *H. dregeana* over-sown with either *Eragrostis curvula* or *E. tef*, at Kamberg, KwaZulu-Natal.

Table 9.5: Summary of the F-probability values from the ANOVA investigating the effect of time of harvesting of thatching material on the emergence of *Acacia mearnsii* seedlings m^{-2}, at Kamberg, KwaZulu-Natal

Treatment	F-probability values
Treatment (early harvested vs. late harvested thatch)	<0.001
Note: Values ≤ 0.05 are considered significantly different	

9.4 Discussion and conclusions

The plant spacing and species of plugs used for planting do not appear to have an effect on the germination of the *A. mearnsii* seedlings as none of these treatments showed any differences. This also applied to the plots left unplanted in the control and spray treatments of the burning trial. Real differences only appeared with the over-sowing of *E. curvula* due to its dense sward and high levels of competition for resources. An increased survival of the planted plugs may result in an increase in their ability to suppress wattle seedlings, by providing more competition.

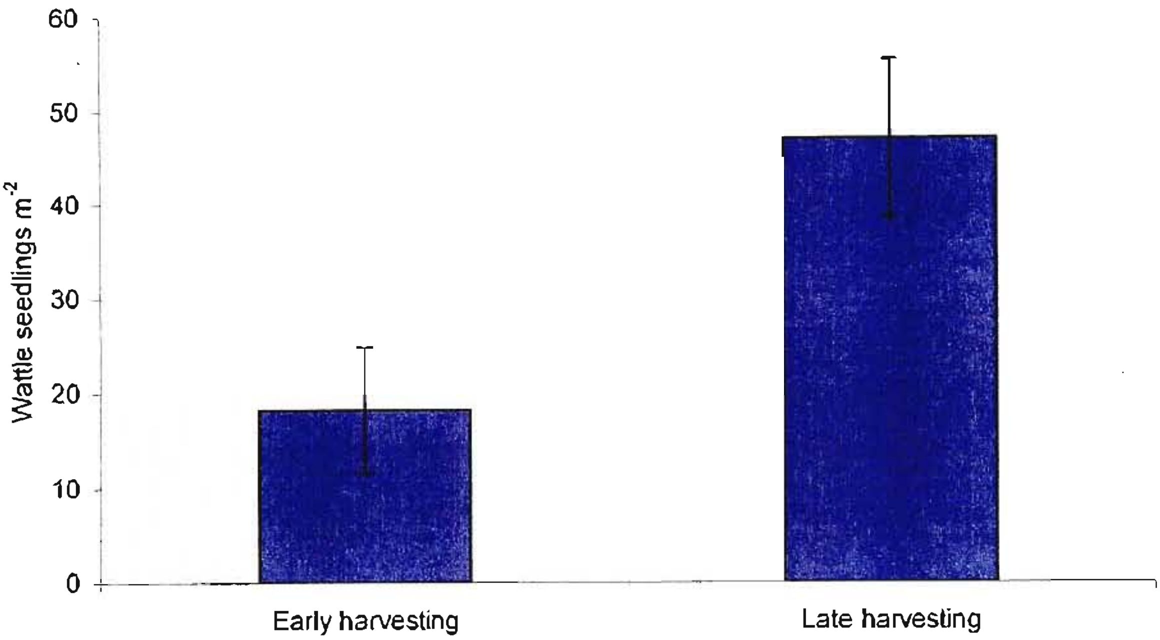


Figure 9.5: *Acacia mearnsii* seedlings m^{-2} for areas re-vegetated using thatch harvested in early or late summer, at Kamberg, KwaZulu-Natal.

In the thatching trial, the early harvested thatch suppressed A. *mearnsii* seedlings compared to the later summer thatch. This difference was attributed to the fact that in the early harvested thatch the thatch was spread on the ground soon after clearing, whereas the late harvested thatch was only spread out on the ground four months later. During these four months, the later harvested thatch plots were left bare and the wattle seedlings could germinate with no competition from the thatched material. The thatched plots had a think layer of thatching material on the soil surface preventing wattle seedlings from germinating.

The above results show that over-sowing with *E. curvula* in the first 10 months from planting (November 1998) can reduce the number of *A. mearnsii* seedlings m^{-2} from 44.8 seedlings m^{-2} to 21.4 *A. mearnsii* seedlings m^{-2}. This reduction in *A. mearnsii* seedlings was brought about by an increase in the competition for resources from the dense *E. curvula* sward. The burning trial showed that over 21 months (October 1999) the reduction in the *A. mearnsii* seedlings per square metre by over-sowing with *E. curvula* was substantial, with the over-sown treatment having only 6.7 wattle seedlings m^{-2} compared to an average of 43.5 wattle seedlings m^{-2} for the plug planted treatments. The thatching trial further confirmed that shading reduces the number of *A. mearnsii* seedlings that re-emerged as the early summer harvested treatment (thatch spread out in January 1998) showed only 18.2 *A. mearnsii* seedlings m^{-2} compared to the late summer harvested treatment (thatch spread out in April 1998) which averaged 46.7 *A. mearnsii* seedlings m^{-2}.

Although high levels of shading suppress the re-growth of *A. mearnsii,* it may not help with the reduction of the soil seed bank levels in the long term. If the site is cleared of vegetation or burnt in the future there will be a flush of *A. mearnsii* germinating from this soil seed bank.

9.5 Summary

Follow up treatments are necessary after re-vegetating sites cleared of *A. mearnsii* as it is a prolific seeder and the seed remains viable for many years. The ability of the various trials, where nursery raised plugs were used to suppress the re-growth of *A. mearnsii* were investigated by determining the number of *A. mearnsii* seedlings per metre squared. Plant spacing and species of plugs did not have a significant effect on the number of *A. mearnsii* seedlings per metre squared. Over-sowing with *E. curvula* did however significantly suppress the wattle re-growth. In the thatching trial the early harvested plots showed lower numbers of *A. mearnsii* per metre squared than the late harvest plots, as they were covered with a thick layer of thatch soon after the *A. mearnsii* was cleared which suppressed the *A. mearnsii* re-growth. Suppression of *A. mearnsii* re-growth needs a high degree of shading, as achieved in the early harvested thatch and the plots over-sown with *E. curvula*.

10. General discussion, conclusions and management implications

In the past, re-vegetation of the cleared *A. mearnsii* sites was done by the sowing of commercially available *E. curvula* seed, but it was noted that this practice resulted in the establishment of a mono-specific sward of *E. curvula,* limiting biodiversity as well as having a low basal cover (Dawson 1987). The trial in Chapter 3, Section 3.5 indicates that these mature swards of *E. curvula* have a lower diversity than the surrounding veld. Nursery raised plugs were used as an alternative for re-vegetation by Granger (1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA) and plugs of *T. triandra* and *H. contortus* proved successful. Further research was required regarding the practicality of this method on a large scale. The current study investigated various aspects of the practical application of this method with plugs of *T. triandra, H. contortus* and *H. dregeana*, while answering a number of discrete questions posed at the start of the trial. An area of approximately 7,000 m^2 of cleared land was planted to the various treatments, requiring approximately 52,000 plugs. The logistics of raising and transporting this many seedlings shows that it is possible to produce sufficient plant material for large-scale re-vegetation work.

Planting density was one of the first aspects considered. Closer plant spacing would provide better ground cover and thus better soil protection, potentially enabling better control of *A. mearnsii* re-growth. On the other hand, a dense planting would increase the costs of re-vegetation significantly and increase the level of competition for resources, such as light, nutrients and moisture (Wolfson & Tainton 1999). This competition in turn would impact negatively on the plugs survival and growth. Decreaser species the climax species of the area are common in good condition veld, do not develop tillers under conditions of intense shade (Everson 1985, Everson CS *et al.* 1988). Since these species are reliant on tiller production as a means of propagation in the KZN Drakensberg (Everson 1985, Everson 1994). The increased levels of competition for sunlight that occur in dense planting would be detrimental to these species. In the planting density trial (Chapter 3, Section 3.3) the 30 cm spacing of plugs showed improved survival and increased tiller numbers and plant basal area compared to the 15 cm spacing (although these differences were not significant). Langer *et al.* (1964) found that shading decreased tillering rates of timothy grass (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) and that large numbers of plants tended to have few tillers, whereas fewer plants had greater numbers of tillers. The 15 cm spacing showed an increase in plant height, although again not significantly so. In re-vegetation, basal cover is of great importance for protection of the soil. The 30 cm spacing encouraged lateral plant development, as well as improved survival and is therefore recommended for re-vegetation using planted plugs. The lower planting density (30 cm spacing) would also help limit the costs of re-vegetation as fewer plants are required. On average 16 plants m^{-2} (160,000 plants ha^{-1}) were needed for this spacing, as apposed to 49 plants m^{-2} (490,000 plants ha^{-1}) for the 15 cm spacing. It took 10 days to plant the trial area of approximately 7,000 m^2. In a field scale situation where the need for planting small plots to specific patterns of species is not required, less supervision over planting would be required and it would take less time to plant the same size area. To assess the cost of re-vegetation using plugs, a further study of planting rate is required (to determine man hours needed), but was outside the scope of the current study.

Eragrostis curvula was used in the past for re-vegetation as the seed was easily available and it produced rapid aerial cover and a high biomass. Ground cover was achieved rapidly and sufficient fuel was available to use fire to reduce the soil seed bank of *A. mearnsii.* This method, however, results in very low bio-diversity. A trial (Chapter 3, Section 3.4) was established to investigate the effects of over-sowing *E. curvula* on the survival and growth of nursery raised plugs. *Eragrostis curvula* would potentially provide the benefits of rapid cover and high fuel load, while the planted plugs of *T. triandra, H. contortus* and *H. dregeana* would improve biodiversity. Under these over-sown conditions the 30 cm plant spacing had greater levels of tiller production and plant basal area than the 15 cm spacing for the *T. triandra/H. contortus* combination, whereas in *H. dregeana* the opposite occurred. This is supported by the work of Everson (1985) where *T. triandra* and *H. contortus* both increased tillering rates in areas that received frequent fires (in other words, low levels of shading), whereas *H. dregeana* (an Increaser I) was able to continue tillering under conditions of intense shade. Over-sowing with *E. curvula* had a detrimental effect on plug survival and growth of both species was suppressed compared to not over-sowing. In terms of plug growth over-sowing with *E. curvula* is not recommended.

In both the planting density trial and the over-sowing trial the survival of the *T. triandra/H. contortus* combination was greater than *H. dregeana*. The plant material used had grown tall and moribund in the trays and had a large leaf area but a very small cone of rooting medium, thus increasing the potential for transplant shock. The *H. dregeana* is by nature a tall growing plant and suffered the most from the accumulation of moribund material, which could have caused the very poor survival of this species. Subsequent to this trial the material in the nursery was mown regularly to prevent this build up of leaf material.

At the end of the study period, March 2000, both the number of species per plot and the Shannon diversity index of the plots were suppressed under the over-sown conditions. In the interest of maintaining the biodiversity of the area, the over-sowing of *E. curvula* is not recommended.

The mature sward of *E. curvula* (Chapter 3, Section 3.5) showed that an area cleared and re-vegetated to *E. curvula* 25 years previously, had very low species diversity compared to the neighbouring veld (14 species versus 34 species), confirming the impression of poor diversity in *E. curvula* areas. Plugs of *T. triandra* were planted into this mature sward to investigate whether the mature *E. curvula* tufts suppressed the growth of *T. triandra* seedlings. *Themeda triandra* as a Decreaser species cannot produce daughter tillers under intense shade conditions (Everson 1985, Everson CS *et al.* 1988). This was evident from the greater survival and lateral growth of plugs planted into the centre of a gap compared to those planted around the base of an *E. curvula* plant. The *E. curvula* was burnt three months before planting the plugs and is likely to have improved the survival of the plugs as all old moribund material was removed. The plugs planted into an unburnt area (in order to maximise shade levels on mature *E. curvula* tufts, killed by herbicide to give competition for sunlight, but no root competition) showed very poor survival and growth. This suggests that had the remainder of the trial not been burnt first, the survival of the control treatment may have been lower. In order to improve the biodiversity of these mature *E. curvula* swards, the area must be burnt three months prior to planting. If possible an additional mow would remove the re-growth before planting as the *T. triandra* plugs survived and grew well under the clip only treatment. The added benefit of spraying and clipping is not great enough to warrant the cost of the herbicide application. Where it is impractical to mow the *E. curvula* tufts one can plant directly into the sward if the area has been burnt within the past three months.

The biomass estimates in the burning trial (Chapter 5), showed that *E. curvula* over-sown over *T. triandra, H. contortus* and *H. dregeana* produced the greatest biomass (1.2 kg m^2), whereas plugs planted on their own could only produce 0.4 kg m^2 for the *T. triandra/H. contortus* combination and 0.7 kg m^2 for *H. dregeana*. Furthermore, when one looks at the re-growth of *A. mearnsii* (Chapter 9) it was obvious that *E. curvula* had the greatest impact on suppressing *A. mearnsii* seedlings, evident when comparing the planting density trial, over-sowing trial and the burning trial (Chapter 9, Sections 9.3.3 and 9.3.4). Thus, the requirement for follow up herbicide treatments to control the regrowth of *A. mearnsii* is greatly reduced when using *E. curvula* (Campbell *et al.* 2000a). When the objective of re-vegetation is to return the site to a state similar to the natural veld for the area it is obvious that *E. curvula* should not be used. This creates a major dilemma as *E. curvula* is detrimental to biodiversity, but it is able to provide better control of the *A. mearnsii* re-growth than indigenous grasses. Investigations into reducing the rate of over-sowing (the standard rate for hay pastures (Bartholomew 2000) were used in this trial) need to be studied before a conclusive answer can be reached. Lower sowing rates could still be effective at controlling *A. mearnsii* re-growth, while not out competing the planted plugs. One of the biggest problems of this research was the poor survival of the plugs, whereas Granger (1998, unpublished data, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, RSA) found a satisfactory survival rate. Further research is required into improving the survival of the plugs. Once good survival rates are achieved (> 90%) plugs may provide sufficient fuel load and adequate competition to suppress *A. mearnsii* re-growth.

Transplant shock is a common problem when planting nursery raised seedlings into the field (Zandstra & Liptay 1999, Anastasiou & Brooks 2003). Transplant shock is often a result of the roots being restricted to the rooting cone from the seedling tray and being unable to obtain sufficient moisture to replace that lost through evapotranspiration. Irrigation after transplanting is an obvious solution in field crops, but is seldom practical or possible in the remote areas where re-vegetation takes place and thus alternative solutions are needed. Two methods of moisture amelioration were investigated, firstly a starch based polymer with a high water holding capacity (Terrasorb®) placed into the planting hole. Secondly, a seven day period of artificial shade provided by suspending Agrilen® a white, needle punched geo-fabric 0.3 m above the site. This trial was planted in January 1999 whereas the first trials were planted in January 1998. The overall survival of this trial was greater than the previous trials, even for the control treatment (no moisture amelioration). Younger plant material was used in this trial and thus the improved survival can be attributed to this younger material compared to the older material that was used in the first trial. The material used in the first trials had been allowed to grow out in the trays and thus accumulated a large amount of moribund material, which would have increased the evapotranspiration and thus the transplant shock. The two moisture ameliorant treatments did not have a significant effect on the survival of either species. The lateral development of the *H. dregeana* was greatest for the Terrrasorb® with Agrilen® and the control compared to the Terrasorb® only and Agrilen® only. The control and Terrasorb® showed the greatest lateral growth for *T. triandra*. The treatments did not have any effects on plant height within each species. There were no dramatic improvements in survival or growth when using Terrasorb®, unlike the results shown by Verschoor & Rethman (1992). This poor response may be due to the high clay content and low soil pH (below 6), both factors which Verschoor & Rethman (1992) found decreased the effectiveness of Terrasorb®. The lack of response to Agrilen® was likely to have been because the Agrilen® rested on the plants by the end of the seven day period due to storm winds and heavy rain. Agrilen® is commonly used to protect plants from frost damage as it helps to maintain heat. Poor ventilation would have occurred once the Agrilen® settled onto the plants. In addition, the hot summer days of January could have created conditions that were too hot for the plugs. It is thus not recommended to use either method of moisture stress amelioration, although one must bear in mind that in a drought year the benefits of some form of moisture amelioration is more likely to be positive.

Seed bearing thatch has often been used for re-vegetation (McDougall 1989), but the low seed viability of *T. triandra* in the KZN Drakensberg (Baxter 1996) and the low reliance of these species on the production of seeds for reproduction (Everson 1985) mean that it is a less reliable means of re-vegetation. Seed bearing thatch was harvested in early summer (harvested in December 1997, spread out in January 1998) and late summer (harvested at the beginning of April 1998 and spread out at the end of April 1998) (Chapter 6). The species composition was different between the two harvesting periods. The early harvested thatch produced the greatest number of species, although the Shannon diversity index did not show a significant difference by the end of the study period (March 2000). The species indicators for each treatment changed over time, showing that some species germinated rapidly, while others had longer seed dormancy and thus took longer to become evident in the trial plots. In November 1998 the indicators of the early harvested treatment were *E. muticus* and *L. simplex*, in March 1999 these indicators became *A. semialata, B. salviifolia* and *H. falx* and by March 2000 the indicators were *H. falx* and *T. triandra*. The indicator of the late harvested treatment was *A. mearnsii* in November 1998 and *H. dregeana* in both March 1999 and 2000. The presence of *A. mearnsii* as an indicator in the late harvested thatch is because these plots were left exposed from January through to April 1998, whereas the early harvested plots were covered with a thick layer of thatch. This thatch would have suppressed the germination of the *A. mearnsii* seedlings. It is recommend that if thatching is to be used to re-vegetate areas cleared of *A. mearnsii* then this should be done as soon after clearing as possible to prevent re-growth of the *A. mearnsii*. While early summer thatch will give a greater number of species, both times of harvesting provided a diverse range of grasses and forbs. Comparing the biodiversity that developed in the thatching trial and the planting density trial indicated that the *T. triandra/H. contortus* combination at 30 cm spacing tended to maximize biodiversity.

A number of nursery practices were investigated to ensure the survival of transplanted plugs. The scheduling of planting indicated that the summer months (October to February) were the best months for planting, although results varied between the two seasons that were studied. During the 13 months that the plugs were planted out into the field, a great deal of variation in moisture levels of the soil profile over a very short distance was observed. On some occasions the topsoil layers were dry even after over night rain. Scott (2003) showed that the soil under *A. mearnsii* plantations has hydrophobic properties. Burning of *A. mearnsii* trash results in high soil temperatures which sterilizes the soils, causing a breakdown in the soil structure, reducing water penetration, destroying humus and preventing grass and other plants from colonizing the area for three or more years after the burn (Campbell *et al.* 2000b). The hydrophobic nature of the compounds in the plant litter layer would explain this apparent dry profile even after rain. Soil data were not recorded in any of the field trials, but soil factors could well have played a role in the poor survival of the planted plugs. The survival of the plugs kept in the nursery show that unclipped plants should not be retained longer than three months. Even at three months of age, at best a survival rate of 50% was possible in seedling trays. Although the results were very variable, the larger plug size (98 plugs per tray) tended to have a greater survival than the smaller plug size (200 seedlings per tray). Zandstra & Liptay (1999) showed that plants with a larger root volume are less susceptible to transplant shock.

Re-vegetation provides short term cover, but it is important that the species used in re-vegetation are perennials and able to form a self sustaining population. Seedlings of *H. contortus* and *T. triandra* that established from parent plants (planted as plugs two years previously) were monitored. The June 1998 population consisted of 661 *H. contortus* seedlings and 14 *T. triandra* seedlings, while the population that was tagged in November 1998 consisted of 418 *H. contortus* seedlings and 18 *T. triandra* seedlings. It was apparent that *H. contortus* could produce a large number of seedlings, while *T. triandra* did not. This follows the findings of Everson CS (1985) and Everson TM (1994), who found that in the KZN Drakensberg, *T. triandra* does not rely on seed production as a means of propagation, but rather relies on vegetative re-growth.

10.1 Management implications

A number of management guidelines become obvious during the course of the study. These are summarized as follows:

1. Plugs must not be allowed to become moribund in the seedling trays and should not be kept in the nursery for longer than three months.
2. The summer months, October to February, are the best for planting plugs into the field.
3. A plant spacing of 30 cm should be used.
4. At present the *T. triandra/H. contortus* combination is the first choice for re-vegetation as it had a greater survival than *H. dregeana*.
5. Over-sowing with *E. curvula* had:
    a. A negative impact on the planted plugs,
    b. A negative impact on the biodiversity , but

   c. Provided high levels of biomass and controlled *A. mearnsii* re-growth.
6. Seed bearing thatch can be used for re-vegetation and must be spread out onto the site as soon as possible to prevent *A. mearnsii* re-growth.
7. To improve the biodiversity of mature *E. curvula* sites the area must be burnt prior to planting and if possible any re-growth must be mown before planting.

10.2 Future research

Although this study has provided answers for many of the questions which initiated this study, many new areas of research have been identified. The more important of these are:

1. Can the survival of the planted plugs be improved?
2. If the survival of the plugs is improved, will *A. mearnsii* re-growth be controlled and would a continuous fuel load develop, which could then be burnt.
3. Can lower seeding rates of *E. curvula* be used to improve the biomass and control of *A. mearnsii* re-growth while not out competing the planted plugs or severely depleting the biodiversity?
4. Is the boundary between mature *E. curvula* swards and the neighbouring veld static, or is there movement of species between these two areas, and if so, by how much?
5. Would mowing or burning of mature *E. curvula* swards improve the colonization of species from the neighbouring veld into these areas?
6. How severe are the hydrophobic properties of the soils under *A. mearnsii* plantations and can they be ameliorated?
7. What is the long term fate of the sites re-vegetated using plugs (for example 10 years later)?
8. The use of plugs requires the seed material to be harvested, what is the optimum harvest date for this seed collection and how does the preceding weather conditions affect the maturing and ripening of the seeds?

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Appendix A - Benchmark for Bioresource Group 8 (Moist Highland Sourveld)

Table A.1: Benchmark for Bioresource Group 8 (Moist Highland Sourveld) (from Camp 1997)

Group	Species	Grazing value	Benchmark	
			%	Score
Increase I	*Alloteropsis semialata*	3	2	6
	Eulalia villosa	3	1	3
	Trachypogon spicatus	3	2	6
	Tristachya leucothrix	9	20	180
		TOTAL	25	
Decreaser	*Brachiaria serrata*	3	1	3
	Diheteropogon amplectens	8	1	8
	Monocymbium ceresiiforme	6	2	12
	Themeda triandra	10	45	450
		TOTAL	49	
Increaser IIa	*Eragrostis capensis*	2	1	2
	Harpochloa falx	3	3	9
	Heteropogon contortus	6	4	24
		TOTAL	8	
Increaser IIb	*Eragrostis curvula*	5	1	5
	Eragrostis plana	3	1	3
	Eragrostis racemosa	2	1	2
	Hyparrhenia hirta	3	1	3
		TOTAL	4	
Increaser IIc	*Microchloa caffra*	1	1	1
	Forbs	0	5	0
	Sedges	0	1	0
		TOTAL	7	
Increaser III	*Diheteropogon filifolius*	0	2	0
	Elionurus muticus	0	5	0
		TOTAL	7	
		GRAND TOTAL	100	717

Soil analysis results

Soil	Density (g/ml)	P (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Acidity (Al + H) (cmol/l)	Total cations (cmol/l)	Acid Sat (%)	pH (KCl)	Zn (mg/l)	NIRS organic C (%)
Wattle	0.33	17	187	843	170	0.2	6.29	3	4.23	5.6	>5
Veld	0.81	6	136	162	72	1.78	3.53	50	4.05	1.5	>5

Fertilizer recommendations – Tropical grass species

Soil	Yield (t/ha)	N required (kg N/ha)	Phosphorous			Potassium			Lime			Zn Fertilizer required
			Soil test (mg/l)	Optimum (mg/l)	Fertilizer required (kg P/ha)	Soil test (mg/l)	Optimum (mg/l)	Fertilizer required (kg P/ha)	Acid Sat. sample (%)	Optimum (%)	Lime required (kg/ha))	
Wattle	6	110	17	7	20	187	100	0	3	40	0	No
	10	230	17	8	20	187	120	0	3	40	0	No
	14	350	17	10	20	187	140	0	3	40	0	No
Veld	6	110	6	7	20	136	100	0	50	40	1500	No
	10	230	6	8	22	136	120	0	50	40	1500	No
	14	350	6	10	43	136	140	10	50	40	1500	No

Appendix C - Determination of the required sample size

The sample size required, to determine a difference, with a given confidence level ($P \leq 0.05$) was calculated. Tiller number per plant, plant basal area and plant height were measured in a two year old, planted sward of *T. triandra* and *H. contortus*. Similar readings were taken in the one month old sward of this trial. Forty, randomly selected individuals of each species were selected in each area.

The means and variances for each species at each site were calculated and used to determine the required sample size. The formula of Bonham (1989) was used to calculate the required sample size, in order to deal with the observed variability of the data.

$$n = \frac{z^2 s^2}{d^2 x^2}$$

Where: n = sample size,

z = standardized normal variate of a selected probability level (95% = 1.96),

s = standard deviation of the sample data,

d = accepted error as a fraction of mean,

x = mean of the test sample.

The accepted error (d) was set at 20% or 0.2 for heuristic reasons. This formula was applied to all of the variables measured and the largest resultant sample was used, as this would cover the variability of all the variables.

Figure C-1 summarizes the results for each variable and data set that were measured. The largest sample size that was calculated was 30 for the tiller numbers of *H. dregeana* and the basal area of the young *H. contortus* plants. Although other species and variables could be measured at a lower sample size, in order to keep the trial standard, 30 plants in each plot were tagged and all the measurements were made on these plants. Over sampling of the other variables is accepted in favour of the improved estimates of precision and the convenience of managing the trial within a uniform framework.

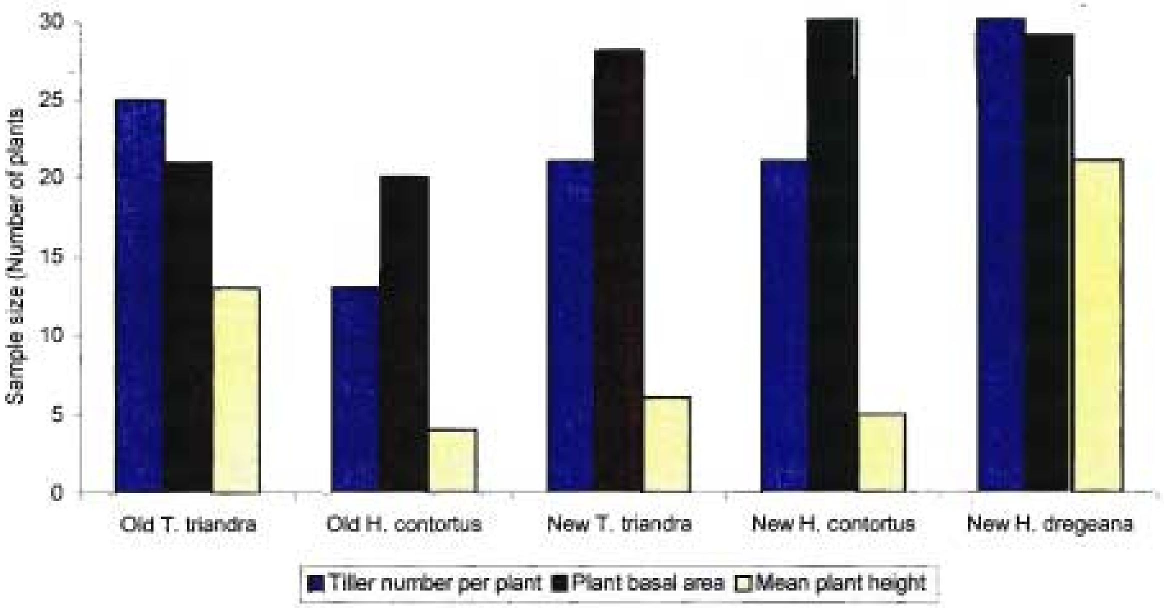

Figure C-1: Bar graph of the sample size required for each plant variable for *Themeda triandra*, *Heteropogon contortus* and *Hyparrhenia dregeana* in each sample area.

Appendix D - Comparison of the plant growth of *Themeda triandra* and *Heteropogon contortus*

The data for *Themeda triandra* and *Heteropogon contortus* from the plots where these two species were grown together were used to determine whether or not these two species respond differently. All three variables of plant growth were used in this investigation. The data were subjected to analysis using HP curves (Hunt & Parsons 1974) to investigate the characteristics of plant growth.

The growth curve for number of tillers per plant (Figure D-1A) shows that within each planting density the growth curves for the two species are not different ($P > 0.05$). A similar pattern emerges for plant basal area (Figure D-1B) and plant height (Figure D-1C). It can therefore be concluded that for the duration of the study period, the two species responded in a similar manner and can therefore be treated as one statistical entity. The data for the two species can thus be pooled for the statistical analyses (Steel & Torrie 1980).

From Figure D-1A it can be seen that the number of tillers per plant, for *T. triandra* follows a linear increase; while on the other hand, *H. contortus* had a more exponential growth rate. This suggests that if the trial had continued the two species may have begun to respond differently. For both species the 15 cm spacing had a lower number of tillers per plant than the 30 cm spacing, indicating increased competition at the closer spacing.

The basal areas exhibited a linear increase, except for that of *H. contortus* at 15 cm spacing, which was exponential (Figure D-1B). Again, for the period of the study the assumption of a similar growth for the two species is valid, but this may have changed as time progressed. The responses of the two planting densities are divergent, with the 30 cm spacing increasing at a faster rate than 15 cm spacing plants. This indicates that a competitive effect is hindering the plant growth at the closer spacing.

Plant height shows a quadratic response for all treatments (Figure D-1C). Plant height data are subject to large variation. The main reason for this is the effect of grazing animals. Although all plants showed signs of grazing, the severity of defoliation differed between plants. In both species the 30 cm spacing had a lower height at the end of the trial than the 15 cm spacing. This may be a competitive response, as the closer spacing will force plants to compete for light and therefore attain a greater height.

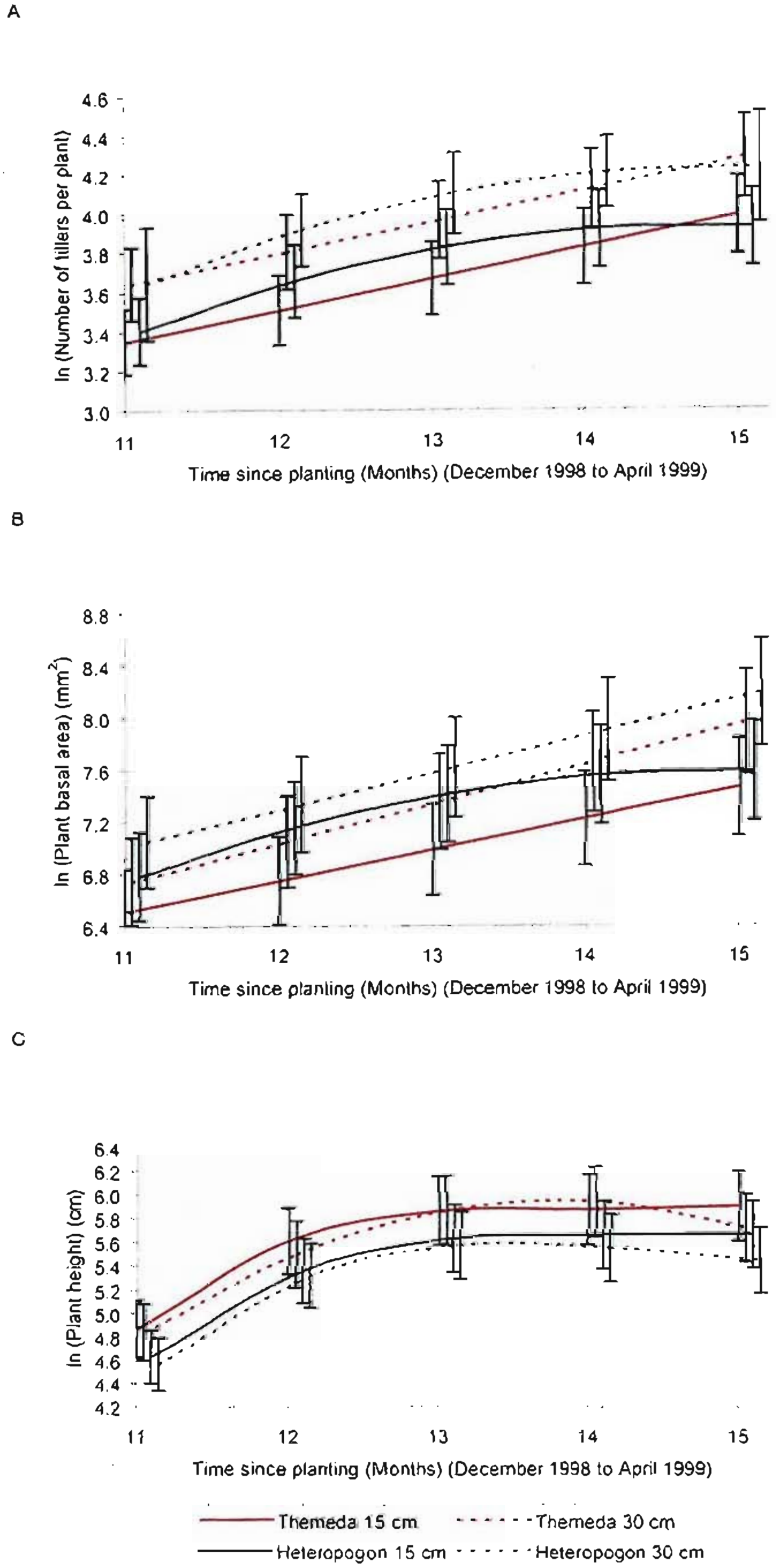

Figure D-1: Plant growth curves of the natural log of tiller numbers per plant (A), natural log of plant basal area (B) and natural log of plant height (C), for *Themeda triandra* and *Heteropogon contortus* at 15 cm and 30 cm spacing, Kamberg, KwaZulu-Natal.

Appendix E - Summary of the data presented in the graphs

PLANTING DENSITY TRIAL

SURVIVAL (%)	Feb-98	Apr-98	Nov-98	Mar-00
Hyparrhenia dregeana 15 cm	38.56	19.86	7.08	6.91
Hyparrhenia dregeana 30 cm	56.55	32.09	9.08	9.03
Themeda triandra / Heteropogon contortus 15 cm	64.75	52.86	42.67	38.51
Themeda triandra / Heteropogon contortus 30 cm	62.67	55.80	50.27	44.92

PLANT GROWTH

Tiller number per plant	**Dec-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Hyparrhenia dregeana 15 cm	45.01	54.12	68.52	77.02	75.50
Hyparrhenia dregeana 30 cm	30.87	45.59	66.99	96.04	91.31
Themeda triandra / Heteropogon contortus 15 cm	28.87	38.91	42.68	638.49	1809.96
Themeda triandra / Heteropogon contortus 30 cm	36.06	46.18	58.57	975.68	2729.74

Plant basal area (mm2)	**Dec-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Hyparrhenia dregeana 15 cm	1300.01	1951.19	2740.26	3104.01	3504.66
Hyparrhenia dregeana 30 cm	1049.81	1688.12	2619.60	4113.47	4611.89
Themeda triandra / Heteropogon contortus 15 cm	729.62	1070.38	1534.27	1267.44	334.15
Themeda triandra / Heteropogon contortus 30 cm	896.15	1347.47	1940.02	1828.74	279.15

Plant height (mm)	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Hyparrhenia dregeana 15 cm	191.12	427.57	830.99	824.88	805.01
Hyparrhenia dregeana 30 cm	213.41	407.77	734.08	676.97	779.94
Themeda triandra / Heteropogon contortus 15 cm	117.23	240.64	327.55	253.06	66.23
Themeda triandra / Heteropogon contortus 30 cm	112.37	232.66	322.05	301.23	279.15

Flowering culms	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Hyparrhenia dregeana 15 cm	0.00	0.00	1.09	7.00	12.89
Hyparrhenia dregeana 30 cm	7.00	4.15	26.88	109.20	51.56
Themeda triandra / Heteropogon contortus 15 cm	1.50	1.63	0.00	0.00	0.00
Themeda triandra / Heteropogon contortus 30 cm	1.86	1.92	0.00	0.00	0.00

RELATIVE GROWTH RATE

Tiller number per plant (Tillers tiller^{-1} month^{-1})	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Hyparrhenia dregeana 15 cm	0.1614	0.1614	0.1614	0.1614	0.1614
Hyparrhenia dregeana 30 cm	0.3128	0.3128	0.3128	0.3128	0.3128
Themeda triandra / Heteropogon contortus 15 cm	0.1488	0.1488	0.1488	0.1488	0.1488
Themeda triandra / Heteropogon contortus 30 cm	0.1626	0.1626	0.1626	0.1626	0.1626

Plant basal area (mm mm^{-2} month^{-1})	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Hyparrhenia dregeana 15 cm	0.1614	0.1614	0.1614	0.1614	0.1614
Hyparrhenia dregeana 30 cm	0.3128	0.3128	0.3128	0.3128	0.3128
Themeda triandra / Heteropogon contortus 15 cm	0.1488	0.1488	0.1488	0.1488	0.1488
Themeda triandra / Heteropogon contortus 30 cm	0.1626	0.1626	0.1626	0.1626	0.1626

Plant height (mm mm^{-1} month^{-1})	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Hyparrhenia dregeana 15 cm	0.1614	0.1614	0.1614	0.1614	0.1614
Hyparrhenia dregeana 30 cm	0.3128	0.3128	0.3128	0.3128	0.3128
Themeda triandra / Heteropogon contortus 15 cm	0.1488	0.1488	0.1488	0.1488	0.1488
Themeda triandra / Heteropogon contortus 30 cm	0.1626	0.1626	0.1626	0.1626	0.1626

Flowering culms per plant (culms culm^{-1} month^{-1})	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Hyparrhenia dregeana 15 cm	0.1614	0.1614	0.1614	0.1614	0.1614
Hyparrhenia dregeana 30 cm	0.3128	0.3128	0.3128	0.3128	0.3128
Themeda triandra / Heteropogon contortus 15 cm	0.1488	0.1488	0.1488	0.1488	0.1488
Themeda triandra / Heteropogon contortus 30 cm	0.1626	0.1626	0.1626	0.1626	0.1626

OVER-SOWING TRIAL

SURVIVAL (%)	Feb-98	Apr-98	Nov-98
Hyparrhenia dregeana 15 cm	30.5	17.3	5.9
Hyparrhenia dregeana 30 cm	37.5	22.4	5.4
Themeda triandra / Heteropogon contortus 15 cm	53.1	39.2	29.5
Themeda triandra / Heteropogon contortus 30 cm	68.0	55.2	48.8

PLANT GROWTH

Tiller number per plant	Dec-98	Jan-99	Feb-99	Mar-99
Eragrostis curvula	30.47	47.58	63.03	59.75
E. curvula over *T. triandra / H. contortus* 15 cm	25.48	41.69	55.72	55.11
Themeda triandra / Heteropogon contortus 15 cm	23.71	31.86	35.93	33.25
E. curvula over *T. triandra / H. contortus* 30 cm	26.84	43.46	58.37	57.09
Themeda triandra / Heteropogon contortus 30 cm	27.04	34.32	38.72	37.30
E. curvula over *Hyparrhenia dregeana* 15 cm	26.88	41.65	55.53	54.65
Hyparrhenia dregeana 15 cm	29.06	36.84	45.13	35.91
E. curvula over *Hyparrhenia dregeana* 30 cm	29.59	46.23	58.03	56.56
Hyparrhenia dregeana 30 cm	21.14	28.57	40.09	31.24

Plant basal area (mm^2)	Dec-98	Jan-99	Feb-99	Mar-99
Eragrostis curvula	601.50	1132.00	2228.50	2220.50
E. curvula over *T. triandra / H. contortus* 15 cm	556.50	1073.00	1981.75	2057.50
Themeda triandra / Heteropogon contortus 15 cm	599.75	862.75	1083.25	974.25
E. curvula over *T. triandra / H. contortus* 30 cm	507.25	1061.25	2086.75	2136.50
Themeda triandra / Heteropogon contortus 30 cm	678.00	903.50	1103.50	1112.75
E. curvula over *Hyparrhenia dregeana* 15 cm	513.25	973.25	1961.25	2045.75
Hyparrhenia dregeana 15 cm	1098.00	1457.75	1908.50	1490.50
E. curvula over *Hyparrhenia dregeana* 30 cm	581.00	1189.75	2010.75	2095.75
Hyparrhenia dregeana 30 cm	880.50	994.25	1383.00	1000.00

Plant mean plant height (mm)	Dec-98	Jan-99	Feb-99	Mar-99
Eragrostis curvula	327.85	486.03	777.75	759.03
E. curvula over *T. triandra / H. contortus* 15 cm	257.90	401.60	696.58	679.38
Themeda triandra / Heteropogon contortus 15 cm	119.93	184.15	363.60	391.70
E. curvula over *T. triandra / H. contortus* 30 cm	260.70	405.88	709.60	705.50
Themeda triandra / Heteropogon contortus 30 cm	125.55	191.83	367.58	391.10
E. curvula over *Hyparrhenia dregeana* 15 cm	269.58	411.70	731.33	737.73
Hyparrhenia dregeana 15 cm	165.93	250.13	778.95	760.98
E. curvula over *Hyparrhenia dregeana* 30 cm	267.83	410.30	691.88	705.13
Hyparrhenia dregeana 30 cm	132.55	214.20	695.58	702.08

Number of flowering culms per plant	Dec-98	Jan-99	Feb-99	Mar-99
Eragrostis curvula	2.63	3.45	0.00	0.00
E. curvula over *T. triandra / H. contortus* 15 cm	1.89	1.93	0.00	0.00
Themeda triandra / Heteropogon contortus 15 cm	2.48	2.47	0.00	0.00
E. curvula over *T. triandra / H. contortus* 30 cm	2.03	2.45	0.00	0.00
Themeda triandra / Heteropogon contortus 30 cm	2.44	2.33	0.00	0.00
E. curvula over *Hyparrhenia dregeana* 15 cm	1.61	2.14	0.00	0.00
Hyparrhenia dregeana 15 cm	0.00	0.00	0.98	5.02
E. curvula over *Hyparrhenia dregeana* 30 cm	2.03	2.65	0.00	0.00
Hyparrhenia dregeana 30 cm	0.00	0.00	0.69	2.23

RELATIVE GROWTH RATE

Tiller number per plant (Tillers tiller^{-1} month^{-1})	**Dec-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Eragrostis curvula	0.51	0.34	0.16	-0.01	-0.18
E. curvula over *Themeda triandra / Heteropogon contortus* 15 cm	0.54	0.36	0.18	0.01	-0.17
Themeda triandra / Heteropogon contortus 15 cm	0.49	0.18	-0.00	-0.05	0.04
E. curvula over *Themeda triandra / Heteropogon contortus* 30 cm	0.54	0.36	0.18	0.00	-0.18
Themeda triandra / Heteropogon contortus 30 cm	0.25	0.16	0.07	-0.02	-0.11
E. curvula over *Hyparrhenia dregeana* 15 cm	0.51	0.34	0.17	0.01	-0.16
Hyparrhenia dregeana 15 cm	0.00	0.00	0.00	0.00	0.00
E. curvula over *Hyparrhenia dregeana* 30 cm	0.67	0.30	0.08	-0.00	0.06
Hyparrhenia dregeana 30 cm	0.00	0.00	0.00	0.00	0.00

Plant basal area (mm mm^{-2} month^{-1})	**Dec-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Eragrostis curvula	0.91	0.63	0.35	0.07	-0.21
E. curvula over *Themeda triandra / Heteropogon contortus* 15 cm	0.84	0.59	0.33	0.08	-0.18
Themeda triandra / Heteropogon contortus 15 cm	0.40	0.26	0.12	-0.03	-0.17
E. curvula over *Themeda triandra / Heteropogon contortus* 30 cm	0.96	0.67	0.37	0.07	-0.23
Themeda triandra / Heteropogon contortus 30 cm	0.32	0.23	0.13	0.04	-0.06
E. curvula over *Hyparrhenia dregeana* 15 cm	0.90	0.63	0.36	0.09	-0.18
Hyparrhenia dregeana 15 cm	0.00	0.00	0.00	0.00	0.00
E. curvula over *Hyparrhenia dregeana* 30 cm	0.84	0.58	0.32	0.06	-0.20
Hyparrhenia dregeana 30 cm	0.00	0.00	0.00	0.00	0.00

Plant mean plant height (mm mm^{-1} month^{-1})	**Dec-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Eragrostis curvula	0.58	0.40	0.22	0.03	-0.15
E. curvula over *Themeda triandra / Heteropogon contortus* 15 cm	0.66	0.46	0.25	0.04	-0.17
Themeda triandra / Heteropogon contortus 15 cm	0.73	0.52	0.31	0.11	-0.10
E. curvula over *Themeda triandra / Heteropogon contortus* 30 cm	0.67	0.46	0.26	0.05	-0.16
Themeda triandra / Heteropogon contortus 30 cm	0.71	0.50	0.30	0.09	-0.11
E. curvula over *Hyparrhenia dregeana* 15 cm	0.66	0.46	0.26	0.06	-0.14
Hyparrhenia dregeana 15 cm	0.49	0.72	0.61	0.16	-0.65
E. curvula over *Hyparrhenia dregeana* 30 cm	0.64	0.44	0.25	0.06	-0.14
Hyparrhenia dregeana 30 cm	1.06	0.75	0.45	0.15	-0.15

Number of flowering culms per plant (culms culm^{-1} month^{-1})	**Dec-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Eragrostis curvula	0.72	-0.74	-1.11	-0.39	1.41
E. curvula over *Themeda triandra / Heteropogon contortus* 15 cm	-0.37	-0.37	-0.37	-0.37	-0.37
Themeda triandra / Heteropogon contortus 15 cm	0.20	-0.75	-0.92	-0.30	1.11
E. curvula over *Themeda triandra / Heteropogon contortus* 30 cm	0.49	-0.67	-0.94	-0.32	1.18
Themeda triandra / Heteropogon contortus 30 cm	0.10	-0.73	-0.86	-0.28	1.02
E. curvula over *Hyparrhenia dregeana* 15 cm	0.65	-0.53	-0.85	-0.31	1.10
Hyparrhenia dregeana 15 cm	-1.15	0.57	1.27	0.93	-0.45
E. curvula over *Hyparrhenia dregeana* 30 cm	0.66	-0.65	-0.99	-0.35	1.26
Hyparrhenia dregeana 30 cm	0.43	0.43	0.43	0.43	0.43

MATURE ERAGROSTIS CURVULA TRIAL

Base = *Themeda triandra* plugs planted around the base of an *Eragrostis curvula* plant
Gap = *T. triandra* plug planted in to the gap between surrounding *E. curvula* tufts

SURVIVAL (%)
Base

Treatment of *E. curvula*	**Feb-99**	**Mar-99**	**Apr-99**	**Mar-00**	**May-00**
Control	85.8	82.5	80.8	75.8	74.2
Clip only	85.8	85.8	84.2	80.8	78.3
Spray only	50.0	45.0	43.3	42.5	42.5
Spray and clip	89.2	87.5	78.5	86.7	84.2

Gap

Treatment of *E. curvula*	**Feb-99**	**Mar-99**	**Apr-99**	**Mar-00**	**May-00**
Control	86.7	86.7	86.7	86.7	86.7
Clip only	100.0	100.0	100.0	100.0	100.0
Spray only	70.0	66.7	63.3	63.3	53.3
Spray and clip	93.3	93.3	93.3	90.0	86.7

RELATIVE GROWTH RATE
Tiller number (Tillers tiller^{-1})

Treatment of *E. curvula*	**Base**	**Gap**
Control	0.1683	0.2452
Clip only	0.1587	0.244
Spray only	0.1276	0.2436
Spray and clip	0.2473	0.2986

Basal area (mm^2 mm^{-2})

Treatment of *E. curvula*	**Base**	**Gap**
Control	0.395	0.587
Clip only	0.419	0.605
Spray only	0.333	0.544
Spray and clip	0.613	0.685

Plant height (mm mm^{-1})

Treatment of *E. curvula*	**Base**	**Gap**
Control	0.3946	0.3708
Clip only	0.3243	0.251
Spray only	0.1647	0.185
Spray and clip	0.351	0.3507

TERRASORB® AND AGRILEN® TRIAL

SURVIVAL (%)

Species	**Terrasorb®**	**Agrilen®**	**Feb-99**	**Mar-00**	**May-00**
Hyparrhenia dregeana	0	0	84.70	47.54	46.19
Themeda triandra	0	0	52.22	45.00	43.60
Hyparrhenia dregeana	1	0	90.13	35.90	35.09
Themeda triandra	1	0	59.68	39.63	37.91
Hyparrhenia dregeana	1	1	56.56	41.62	40.54
Themeda triandra	1	1	22.74	13.23	12.10
Hyparrhenia dregeana	0	1	59.86	29.37	27.31
Themeda triandra	0	1	34.49	24.19	23.05

PLANT GROWTH

Tillers per plant

Species	**Terrasorb®**	**Agrilen®**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Hyparrhenia dregeana	0	0	6.54	11.45	19.44	19.66
Themeda triandra	0	0	8.67	12.93	23.13	22.99
Hyparrhenia dregeana	1	0	5.32	9.65	14.61	14.61
Themeda triandra	1	0	7.59	13.08	19.55	19.26
Hyparrhenia dregeana	1	1	7.16	8.91	20.30	19.94
Themeda triandra	1	1	6.65	5.90	13.48	13.42
Hyparrhenia dregeana	0	1	7.17	9.10	14.41	14.88
Themeda triandra	0	1	7.14	8.21	14.59	14.14

Plant basal area (mm^2)

Species	Terrasorb®	Agrilen®	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Hyparrhenia dregeana	0	0	48.48	191.25	545.64	587.59
Themeda triandra	0	0	80.42	155.55	448.06	461.68
Hyparrhenia dregeana	1	0	36.74	121.70	371.83	371.64
Themeda triandra	1	0	68.76	158.85	399.45	420.24
Hyparrhenia dregeana	1	1	59.31	135.37	565.58	569.02
Themeda triandra	1	1	56.78	69.92	241.63	269.23
Hyparrhenia dregeana	0	1	59.27	135.32	389.22	438.91
Themeda triandra	0	1	59.04	94.69	258.91	297.85

Plant height (mm)

Species	Terrasorb®	Agrilen®	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
Hyparrhenia dregeana	0	0	197.26	216.18	193.36	203.11
Themeda triandra	0	0	110.08	121.73	126.62	122.68
Hyparrhenia dregeana	1	0	189.49	211.13	195.24	190.48
Themeda triandra	1	0	113.05	112.03	106.42	112.08
Hyparrhenia dregeana	1	1	153.75	231.82	207.52	191.79
Themeda triandra	1	1	154.88	91.38	99.83	86.91
Hyparrhenia dregeana	0	1	154.14	199.71	218.31	196.18
Themeda triandra	0	1	147.11	82.25	98.49	97.35

RELATIVE GROWTH RATE

Tiller plant (Tillers tiller^{-1})

Species	**Terrasorb®**	**Agrilen®**	**Jan 99 to Feb 99**	**Feb 99 to Mar 99**	**Mar 99 to Apr 99**
Hyparrhenia dregeana	0	0	0.38	0.62	-0.02
Themeda triandra	0	0	0.14	0.82	-0.01
Hyparrhenia dregeana	1	0	0.49	0.45	-0.05
Themeda triandra	1	0	0.23	0.58	-0.00
Hyparrhenia dregeana	1	1	0.11	0.91	-0.08
Themeda triandra	1	1	-0.03	1.12	-0.01
Hyparrhenia dregeana	0	1	0.09	0.50	-0.02
Themeda triandra	0	1	-0.11	0.82	0.01

Plant basal area (mm^2 mm^{-2})

Species	**Terrasorb®**	**Agrilen®**	**Jan 99 to Feb 99**	**Feb 99 to Mar 99**	**Mar 99 to Apr 99**
Hyparrhenia dregeana	0	0	1.06	1.24	-0.01
Themeda triandra	0	0	0.31	1.40	0.01
Hyparrhenia dregeana	1	0	0.96	1.28	-0.15
Themeda triandra	1	0	0.29	1.12	0.08
Hyparrhenia dregeana	1	1	0.55	1.74	-0.17
Themeda triandra	1	1	0.08	1.75	0.06
Hyparrhenia dregeana	0	1	0.49	1.21	-0.07
Themeda triandra	0	1	-0.15	1.32	0.22

Plant height (mm mm^{-1})

Species	**Terrasorb®**	**Agrilen®**	**Jan 99 to Feb 99**	**Feb 99 to Mar 99**	**Mar 99 to Apr 99**
Hyparrhenia dregeana	0	0	0.07	-0.11	0.05
Themeda triandra	0	0	0.10	0.07	0.01
Hyparrhenia dregeana	1	0	0.10	-0.08	-0.02
Themeda triandra	1	0	0.08	0.04	0.06
Hyparrhenia dregeana	1	1	0.42	-0.11	-0.09
Themeda triandra	1	1	-0.25	0.09	-0.05
Hyparrhenia dregeana	0	1	0.24	0.09	-0.08
Themeda triandra	0	1	-0.27	0.29	-0.01

BURNING TRIAL

SURVIVAL (%)

Species / Treatment	**Feb-98**	**May-98**	**Nov-98**
Themeda triandra / Heteropogon contortus	34.783	24.913	22.729
Hyparrhenia dregeana	23.230	17.131	8.8822
Hyparrhenia dregeana over-sown with *Eragrostis tef*	34.804	19.311	12.152
Themeda triandra / Heteropogon contortus over-sown with *E. tef*	41.335	22.133	20.856
Hyparrhenia dregeana over-sown with *Eragrostis curvula*	27.417	15.722	-
Themeda triandra / Heteropogon contortus over-sown with *E. curvula*	32.759	19.248	-

COMPARITIVE YIELD OF BIOMASS

Treatment	**Biomass (kg m^2)**
Control	0.632
Control + spray	0.702
Themeda triandra / Heteropogon contortus	0.377
Hyparrhenia dregeana	0.702
T. triandra, H. contortus and *H. dregeana* over-sown with *E. tef*	0.706
T. triandra, H. contortus and *H. dregeana* over-sown with *E. curvula*	1.158

THATCHING TIRAL

No. of species per 0.25 m^2	November 1998		March 1999		March 2000	
Scietific name	**Early**	**Late**	**Early**	**Late**	**Early**	**Late**
Acacia mearnsii	18.17	46.67	38.50	55.00	27.50	15.83
Alloteropsis semialata	0.50		2.17	0.17	2.00	0.50
Andropogon schirensis			0.33	1.83		
Aristida junciformis	2.33		0.50		0.67	
Arundinella nepalensis		3.83			0.50	1.33
Bidens pilosa					0.33	1.33
Bromus catharticus					0.33	
Brunsvigia natalensis	0.33		0.17	0.17		
Buddleia salviifolia			1.50			
Commelina africana	0.67	0.17		0.17		
Elionurus muticus	3.33					
Eragrostis curvula	0.33		1.67	3.67	2.00	3.83
Eragrostis racemosa		1.33	0.33	4.00		
Harpochloa falx	1.67		10.17		9.83	
Helichrysum tenax var. tenax	0.83	0.50	0.33	0.33	0.67	0.33
Heteropogon contortus	0.17		1.83		1.17	
Hyparrhenia dregeana				12.00		11.00
Hyparrhenia hirta				1.50		
Lasiosiphon capitatus	0.67		0.33			
Leonotus leonurus					0.67	
Loudetia simplex	5.50					
Melinis nerviglumis			1.83	1.67	3.00	2.00
Panicum natalense			0.33	1.33	1.00	
Phytolacea dodecandra			0.33		1.00	0.17
Rubus cuneifolius		0.33	0.17		0.17	
Senecio spp.		0.17		0.33		
Themeda triandra	0.33		0.50		0.83	
Tristachya leucothrix	1.67					
Wahlenbergia undulata		1.00		6.67		6.00

NUMBER OF SPECIES

Treatment	Nov 1998	March 1999	March 2000
Early harvested thatch	8.50	10.0	10.0
Late harvested thatch	4.30	8.50	6.50

SHANNON INDEX (H')

Treatment	Nov 1998	March 1999	March 2000
Early harvested thatch	1.50	1.19	1.41
Late harvested thatch	0.52	1.25	1.46

BIODIVERSITY MEASURES

PLANTING DENSITY TRIAL

No. spp. per plot

	Nov 1998	March 1999	March 2000
Themeda triandra / Heteropogon contortus 15 cm	6.00	6.25	7.75
Themeda triandra / Heteropogon contortus 30 cm	4.25	5.25	8.00
Hyparrhenia dregeana 15 cm	5.25	6.50	7.50
Hyparrhenia dregeana 30 cm	3.25	6.00	7.00

Shannon diversity index

	Nov 1998	March 1999	March 2000
Themeda triandra / Heteropogon contortus 15 cm	1.39	1.38	1.61
Themeda triandra / Heteropogon contortus 30 cm	1.03	1.33	1.85
Hyparrhenia dregeana 15 cm	1.03	1.41	1.80
Hyparrhenia dregeana 30 cm	0.64	1.50	1.88

OVER-SOWING TRIAL

No spp. per plot

	Nov 1998	March 1999	March 2000
Eragrostis curvula	3.00	2.75	1.50
Themeda triandra / Heteropogon contortus 15 cm	3.75	5.50	4.00
Themeda triandra / Heteropogon contortus 30 cm	3.50	5.50	4.00
Hyparrhenia dregeana 15 cm	4.50	3.75	3.00
Hyparrhenia dregeana 30 cm	4.75	3.25	3.00

Shannon diversity index

	Nov 1998	March 1999	March 2000
Eragrostis curvula	0.40	0.62	0.19
Themeda triandra / Heteropogon contortus 15 cm	0.99	0.53	0.11
Themeda triandra / Heteropogon contortus 30 cm	0.77	0.52	0.26
Hyparrhenia dregeana 15 cm	0.59	0.51	0.31
Hyparrhenia dregeana 30 cm	0.58	0.81	0.43

NURSERY AGE - SURVIVAL (%)

Age (months)	*Themeda triandra* 98 plugs per tray	*Hyparrhenia dregeana* 98 plugs per tray	*Themeda triandra* 200 plugs per tray	*Hyparrhenia dregeana* 200 plugs per tray
3	41.84	13.27	50.50	9.00
4	42.86	27.55	12.00	16.00
5	11.22	17.35	35.50	14.50
6	4.08	11.22	17.00	13.50
7	9.18	36.73	11.50	8.00
8	7.14	9.18	0.50	11.00
9	9.18	10.20	10.50	3.00
10	3.06	8.16	5.50	7.00
11	3.06	11.22	0.50	15.50
12	5.10	6.12	3.00	5.50
13	4.08	11.22	3.50	2.50
14	0.00	0.00	5.00	3.50
15	3.06	3.06	2.00	0.50

TIME OF YEAR OF PLANTING - SURVIVAL (%) AT SIX MONTHS OLD

Date planted	*Themeda triandra* 98 plugs per tray	*Hyparrhenia dregeana* 98 plugs per tray	*Themeda triandra* 200 plugs per tray	*Hyparrhenia dregeana* 200 plugs per tray
Oct 98	85	90	65	60
Nov 98	95	95	65	45
Dec 98	90	100	100	85
Jan 99	80	60	75	45
Feb 99	90	20	75	60
Apr 99	35	40	50	20
Jun 99	45	0	55	10
Jul 99	0	5	0	5
Aug 99	0	5	0	5
Sep 99	0	0	0	0
Oct 99	0	0	15	10
Nov 99	0	5	0	0
Dec 99	55	30	25	10

SEEDLING RECRUITMENT

Tiller number per plant		**Jun-98**	**Nov-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
June 1998 population	*Heteropogon contortus*	3.97	9.72	16.21	20.88	23.75	28.16
June 1998 population	*Themeda triandra*	4.08	10.08	16.33	18.67	20.92	27.33
November 1998 population	*Heteropogon contortus*		4.50	8.62	12.60	15.83	18.96
November 1998 population	*Themeda triandra*		7.23	14.23	16.15	19.38	26.54

Plant basal area (mm2)		**Jun-98**	**Nov-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
June 1998 population	*Heteropogon contortus*	30.54	132.04	336.32	462.86	544.28	807.29
June 1998 population	*Themeda triandra*	16.10	54.65	152.76	173.97	248.05	294.79
November 1998 population	*Heteropogon contortus*		21.79	89.19	161.82	222.66	379.54
November 1998 population	*Themeda triandra*		29.48	86.76	106.81	138.53	295.25

Plant height (mm)		**Jun-98**	**Nov-98**	**Jan-99**	**Feb-99**	**Mar-99**	**Apr-99**
June 1998 population	*Heteropogon contortus*	74.36	86.51	121.80	173.28	183.62	205.43
June 1998 population	*Themeda triandra*	66.33	62.58	120.92	148.33	159.08	160.08
November 1998 population	*Heteropogon contortus*		64.97	98.21	143.47	156.35	179.56
November 1998 population	*Themeda triandra*		73.23	107.08	146.69	158.69	163.69

NUMBER OF *A. MEARNSII* SEEDLINGS M-2

Spacing trial

	A. mearnsii m^{-2}
Themeda triandra / Heteropogon contortus 15 cm	45.00
Themeda triandra / Heteropogon contortus 30 cm	39.83
Hyparrhenia dregeana 15 cm	48.83
Hyparrhenia dregeana 30 cm	45.33

Oversowing trial

	A. mearnsii m^{-2}
Eragrostis curvula	16.50
Themeda triandra / Heteropogon contortus 15 cm	21.00
Themeda triandra / Heteropogon contortus 30 cm	30.50
Hyparrhenia dregeana 15 cm	15.83
Hyparrhenia dregeana 30 cm	23.00

Thatching trial

	A. mearnsii m^{-2}
Early harvested thatch	18.17
Late harvested thatch	46.67

Burning trial (October 1999)

	A. mearnsii m^{-2}
Control	48.56
Control and Spray	38.44
Themeda triandra / Heteropogon contortus	47.67
Hyparrhenia dregeana 15 cm	39.33
Over-sown with Eragrostis tef	39.22
Over-sown with Eragrostis curvula	6.67