Alien grass infestation in renosterveld fragments: effect on threatened life-history types and potential controls

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Moraea tulbaghensis and alien grass (Photograph by I. Ebrahim)

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ABSTRACT

Alien grasses are thought to pose a significant threat to the growth and survival of indigenous species. Within the Cape Floristic Region, there is concern surrounding the establishment of alien grasses in renosterveld fragments This study aimed to determine the impact of alien grass infestation on the life history type of *Moraea tulbaghensis*, a threatened geophyte endemic to renosterveld. *Moraea tulbaghensis* was found to be unaffected by varying densities of alien grass infestation. A second aspect of this study attempted to evaluate potential control methods for alien grasses that would not detrimentally affect indigenous species. Organic amendments in the forms of woodchips and sugar were applied to the alien grass *Lolium multiflorum*, and the endemic threatened species *Lampranthus filicaulis* and *Moraea tulbaghensis*. Additional nitrogen was applied to particular treatments in order to gauge the various responses of alien and indigenous species to nitrogen enrichment. Organic amendments were found to be ineffective in controlling germination and growth of *Lolium multiflorum* over 5 months, whilst nitrogen enrichment significantly enhanced its growth. *Moraea tulbaghensis* was unaffected by all treatments, and *Lampranthus filicaulis* was found to respond positively to nitrogen addition. This demonstrates that organic amendments are ineffective in controlling alien grass growth in the short term. These findings also suggest that the threat of alien grass infestation may vary according to indigenous life history type, and warrant further investigation.

INTRODUCTION

Alien invasions are presently second only to land use change as the major cause for extinctions (D'Antonio & Vitousek 1992). Grass invasions are widespread throughout the world, are active and aggressive competitors with indigenous species, and have the potential to alter ecosystem processes (D'Antonio & Vitousek 1992, Dukes & Mooney 1999). European grasses have become well established in Mediterranean-climate regions (Kruger *et al.* 1989 in Richardson *et al.* 1992, D'Antonio & Vitousek 1992), and within South Africa they are notably evident in lowland areas of the Cape Floristic region (Vlok 1988). Very little is known about the consequences of alien grass impact on different life-history types. In the interest of preserving biodiversity, a better understanding of the threat of alien grasses is required in order for effective control methods to be applied.

The Cape Floristic Region (CFR) is an area of remarkable plant diversity (Goldblatt & Manning 2000) that is exposed to many threats associated with human impact. Agriculture is the largest threat to vegetation in the CFR. Its effect is most prominent in renosterveld, which has been extensively transformed for agricultural use (Rebelo 1992, Von Hase *et al.* 2003). As a result, fragments of lowland fynbos and renosterveld persist within a mosaic of wheat fields. Many fragmented landscapes within the CFR border on agricultural lands, particularly wheat, and runoff from crop fertilizers appears to be enriching remnant patches of indigenous renosterveld with unnaturally high nitrogen levels (SANBI obs). Alien grasses are known to displace indigenous perennial species in nitrogen-rich environments (Vlok 1988, Davidson *et al.* 1990 in Zink & Allen 2001) and are commonly associated with disturbance (Vlok *et al.* 1988). As a result, alien grasses are readily establishing themselves in fragments that are already highly threatened due to human land use.

As a result of severe habitat fragmentation, less than 5% of renosterveld is preserved (Rebelo 1992). Consequently, conservation of renosterveld fragments is imperative for the survival of an alarming number of endemic and threatened species that occur in this vegetation type (Von Hase *et al.* 2003). A large number of the rare and endemic plants are Iridaceae, a family characteristic of Renosterveld vegetation. Almost 250 Iridaceae species are endemic to renosterveld, and of these 160 are known to be rare or threatened (Von Hase *et al.* 2003, Victor *et al.* in prep.).

From current research it is often assumed that alien grass invasion threatens the survival of indigenous species, as alien grasses have rapid growth rates and high reproductive potential (Holmes & Rice 1996, Monaco *et al.* 2003). They are also known to shade out indigenous species, (D'Antonio & Vitousek 1992), alter soil nutrient cycling (Ehrenfeld 2003) and reduce soil water availability for indigenous species (Melgoza *et al.* 1990 in Levine *et al.* 2003). As a result alien grasses can readily outcompete indigenous species for habitat space, light and nutrients. Vlok (1988) demonstrated that invasion of alien grasses in fynbos resulted in a significant decrease in density and number of indigenous annuals and geophytes. Consequently, the invasion of alien grasses at localities where restricted endemic and threatened species occur may result in the decline and eventual extinction of these plants (Vlok 1988). Once established, alien grasses can potentially alter ecosystem processes by modifying nutrient regimes, affecting soil microclimate, and increasing frequency and intensity of fires (D'Antonio & Vitousek 1992). Thus alien grass invasions can be detrimental for the survival of indigenous species, as well as having potential ecosystem-level effects.

Although alien species are frequently implicated in population decline and extinction of indigenous species, few cases have been thoroughly documented (Mooney and Cleland 2001, Gurevitch and Padilla 2004). According to Goldblatt (1979 in Richardson *et al.* 1992) invasive herbaceous species are not thought to be a cause of extinction in the Fynbos biome. It has been argued that invasive species too often 'take the blame', where as it is more likely that multiple threats act synergistically to cause extinctions (Gurevitch and Padilla 2004), such as the combination of habitat fragmentation, pollinator decline and alien invasion. There is no doubt that alien species can detrimentally effect ecosystem function (D'Antonio & Vitousek 1992), but it is suggested that one must first accurately identify the threat in order to better focus efforts on the most effective way to mitigate those threats. One aspect of this study attempts to investigate whether a highly endemic and threatened life history type, a geophyte in the Iridaceae family, is being negatively impacted by the presence of alien grasses.

A second aspect of this study investigates whether the application of organic amendments to sites with alien grasses will control alien grasses without negatively impacting on endemic indigenous species found there. The application of organic amendments such as charcoal, sugar, wood chips and wood bark have been suggested as a restoration tool for grass-invaded areas (Zink & Allen 2001, Suding *et al.* 2004, Schutz unpubl.). Organic amendments result in immobilization of soil nitrogen by microbial activity (Lambers *et al.* 1998). The process of immobilization occurs when micro-organisms utilize soil nutrients if their requirements are not met by the decomposition of organic matter, and as a result these nutrients become unavailable to plants (Zink & Allen 2001). Thus the addition of nutrient-poor organic amendments increases microbial activity, which in turn increases soil immobilization and reduces the amount of nitrogen available for plant uptake. As the establishment of alien grasses appears dependent on a nutrient-rich environment (Monaco *et al.* 2003), organic amendments appear to be a fairly economical method of controlling their spread.

Context of study

The specific questions of this study are:

1. To what extent do alien grasses pose a threat to the growth and survival of a particular life history type (geophyte) within a fragmented and disturbed habitat? The prediction is that high densities of alien grasses decrease the density of geophytes and consequently pose a substantial threat to their establishment and survival. This prediction is based primarily on the findings of Vlok (1988), who correlated high alien grass density with a decline in density and diversity of indigenous annuals and geophytes.

2. Are the organic amendments woodchips and sugar effective in controlling alien grass growth without hampering survival of two particular life history types of indigenous threatened species? The prediction is that nitrogen immobilization resulting from organic carbon addition will inhibit alien grass growth. As demonstrated by Schutz (unpublished), sugar addition reduces germination and growth of alien grasses but negatively impacts indigenous species growth. It is predicted that woodchips will be comparatively more effective than sugar in controlling alien grass growth as they are less likely to inhibit indigenous species growth.

METHODS

Choice of study species

Three species were used in this experiment: *Lolium multiflorum* (Poaceae), *Moraea tulbaghensis* (Iridaceae) and *Lampranthus filicaulis* (Aizoaceae). *Lolium multiflorum* var. plank is an annual grass native to Southern Europe, commonly known as Italian ryegrass (Hannaway *et al.* 1999). *Lolium multiflorum* was originally hybridized and bred as a high performance pasture grass, but has become widespread in cultivated lands and disturbed areas (Bromilow 1995). *M. tulbaghensis* is an endangered geophyte (Victor *et al.* in prep.) that is found on clay flats in Renosterveld from Tulbagh to Wellington (Goldblatt & Manning 2000). Seed was collected by D. Raimondo and G. Hansford in Gouda in November 2004. *L. filicaulis* is a vulnerable mesemb (Victor *et al.* in prep.) that occurs naturally in moist depressions on lateritic soils from the Cape Peninsula to the Cape Flats (Goldblatt & Manning 2000). *L. filicaulis* seed was collected from Uitkamp, Durbanville in October 2004. Both *M. tulbaghensis* and *L. filicaulis* are endemic to the Cape Floristic Region. These two species were chosen in order to examine responses of threatened plants with different life histories.

<u>Examining the impact of alien grass on the population dynamics of *Moraea tulbaghensis*</u>

In order to test question 1, the impact of alien grass on the population dynamics of *Moraea tulbaghensis* was investigated by sampling the density and size of individuals growing in areas with varying densities of alien grass infestation.

On 16 September field data were collected in Gouda, Tulbagh District, Western Cape. Two sites where *Moraea tulbaghensis* occur were sampled. Both are commonages that are frequently burnt. To determine the relative densities of alien grasses and *Moraea tulbaghensis*, 0.5 x 0.5m quadrats were sampled for number of *M. tulbaghensis* flowers, number of juveniles (<15cm), number of adults (>15cm), and percentage cover of alien and indigenous grass. Five quadrats of data were recorded in low, medium and high densities of alien grass with and without *Moraea tulbaghensis* present. Sampling was performed by walking 5 steps and distributing the quadrat at random. As the site contained alien grasses at different densities, five quadrats of data were recorded in low, medium and high alien grass density with and without *M. tulbaghensis* present.

It was not possible to examine the effect of alien grasses on *Lampranthus filicaulis* due to time constraints and accessibility to sites where this threatened species occurs.

Data analysis

Correlation analysis was performed on the data using Statistica version 7 (Statsoft 2002) to test the effect of alien grass density on number and size of *Moraea tulbaghensis* individuals.

<u>Effects of organic amendments on alien grasses and indigenous species</u>

In order to test question 2, the growth of the three species with two organic treatments, sugar and woodchips, and nitrogen were tested in a greenhouse experiment. Six different treatments were set up for each of the three study species, *Lampranthus filicaulis, Moraea tulbaghensis* and *Lolium multiflorum*. The design was separated into pots with and without pots of additional nitrogen. Within this split design, treatments consisted of a control, the addition of sugar and the addition of woodchips. For each treatment 6 20m by 20m pots were used and filled with soil provided by Kirstenbosch Botanical Gardens. Soil consisted of course sand, loam and leaf litter in the ratio 2:1:1 in order to have the same composition as typical fynbos soil. Five seeds were planted in each pot, approximately equidistant to each other. Pots were placed in the Karoo Greenhouse at the South African National Biodiversity Institute. All seeds were planted on the 26th and 27th of May 2005. The seeds were planted just below the soil surface at a depth 2.5 times the size of the seed. Eight grams of nitrogen was added to the relevant treatments, in the form of solid fertilizer that contained 24.710 mmol/kg of nitrogen, in order to approximately double the amount of nitrogen in the system. Enough woodchips and sugar was added to completely cover the surface of the soil in each pot. Each treatment consisted of 6 replicates, resulting in 36 pots for each species, 108 pots in total.

Woodchips and sugar were chosen as suitable carbon sources. These two sources differ as sugar is soluble and a readily accessible form of carbon, whereas woodchips decompose slowly and provide carbon over a longer period of time. Nitrogen was added for two purposes. A known amount of nitrogen was added to the system in order to accurately gauge how much inorganic nitrogen is removed from the system over the time period of the experiment. If organic amendments increased microbial activity, inorganic nitrogen usually used by plants would be immobilized by microbes. Nitrogen was also added to reflect the environmental impact of nitrogen enrichment of renosterveld fragments from fertilizer runoff upon which this experiment is based.

Plants were watered by hand every 3 days. All *Lampranthus filicaulis* individuals were harvested on 12 September 2005, and *Lolium multiflorum* individuals were harvested on 14 September 2005. For both species this was done by cutting off the above ground biomass, and then washing the soil off the roots with a high pressure hose through a 0.5mm sieve. Roots and shoots were dried in a 70 degrees Celsius oven for 72 hours, and then weighed with a fine balance scale.

Moraea tulbaghensis individuals were harvested on the 27[th] September. As the individuals were very small (av. < 8cm), measurements were taken of leaf length and length from root to tip, and the wet weight was obtained with a fine balance scale. Due to the small size of the *Moraea tulbaghensis*, wet weight was chosen as an acceptable measure as all pots were evenly watered and thus would have little variation in water content.

Soil samples were taken of all controls at the beginning of the experiment, and of all treatments the day the plants were harvested. Limited financial resources resulted in the analysis of selective soil samples from *Lampranthus filicaulis* pots. Samples from treatments of control, woodchips, nitrogen, and nitrogen + woodchips treatment were analyzed for NH_4 and NO_3 content by BemLab, Somerset West. These treatments were chosen as there was very little or no growth in the particular pots, thereby allowing us to attribute potential nitrogen changes to microbial activity rather than plant uptake.

Data analysis

The data were analyzed using Statistica version 7 (Statsoft 2002). In order to determine the application of parametric or non-parametric tests variables were tested for normality using the Shapiro–Wilk test and for equal variance using Levene's test for Homogeneity of variances. Where conditions of normality were not met the data were log transformed, and where this transformation was unsuccessful the Kruskal-Wallis non-parametric test was used to test the averages for significant differences. Where low replication prevented application of analysis of variance, a Chi-squared analysis was used and the mean and standard deviation of the data were determined.

RESULTS

Examining the impact of alien grasses on population dynamics of *Moraea tulbaghensis*

The number of *Moraea tulbaghensis* plants are not correlated to the density of alien grasses present (Figure 1 and 2). There is no evident relationship between alien grass density and number of *Moraea tulbaghensis* adults (Figure 1). The observed trend displays that *Moraea tulbaghensis* juveniles increase with increasing density of alien grass although there is no significant correlation (p>0.05) (Figure 2).

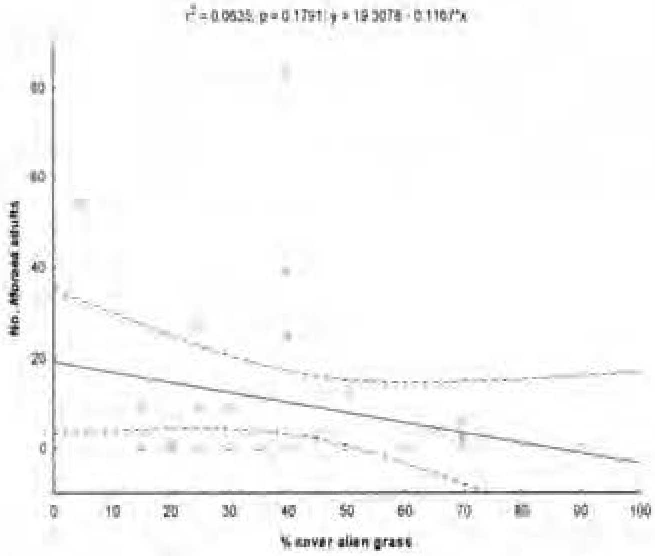

Figure 1: Scatterplot showing the relationship between percentage cover alien grass and number of *Moraea tulbaghensis* adults. There is no significant relationship (p>0.05).

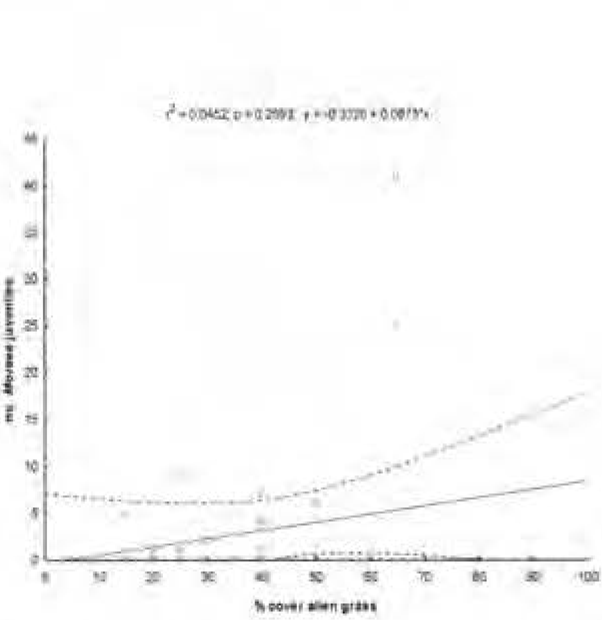

Figure 2: Scatterplot showing the relationship between percentage cover alien grass and number of *Moraea tulbaghensis* juveniles. There is no significant relationship ($p>0.05$).

Effect of organic amendments on alien grass and threatened species

Lolium multiflorum seedlings first appeared on the 30th of May, 3 days after the seeds were sown. *Lampranthus filicaulis* seedlings first emerged on the 22nd of June. *Moraea tulbaghensis* seedlings appeared towards the end of August. Mould appeared on the 6th of June in all pots of the sugar addition treatment. After watering the mould hardened and died, leaving a white crust on the surface of the soil. This did not appear to impact the growth of *Lolium multiflorum* individuals. *Moraea tulbaghensis* and *Lampranthus filicaulis* seeds remained dormant.

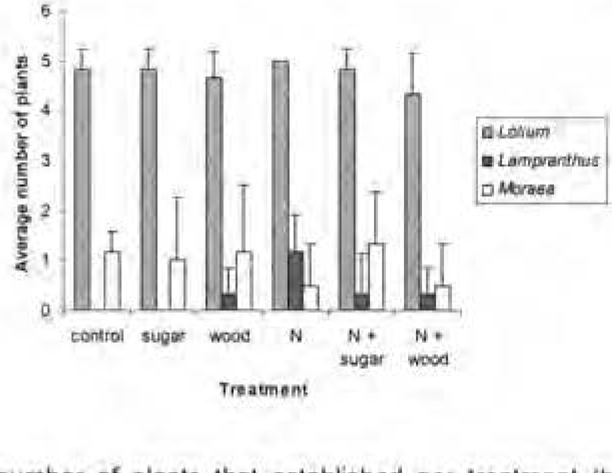

Figure 3: Mean number of plants that established per treatment (bars denote standard deviation).

It is evident that *Lolium multiflorum* had much higher success of germination and growth in comparison to the indigenous species. No *Lampranthus filicaulis* plants grew in control and sugar addition treatment. Establishment of *Moraea tulbaghensis* was low across all treatments, with most individuals emerging in the control, wood and N + sugar addition treatments.

Treatment effects on *Lolium multiflorum* and *Lampranthus filicaulis*

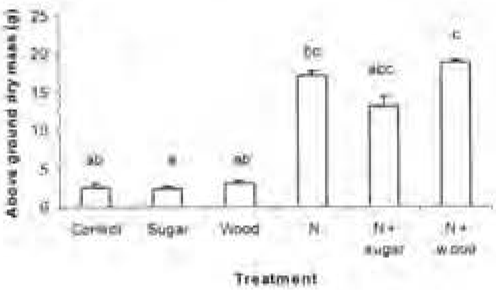

Figure 4: Mean above ground biomass of *Lolium multiflorum* in all treatments. Letters indicate significant differences according to the Kruskal-Wallis test ($p<0.05$, Kw = 29.3453).

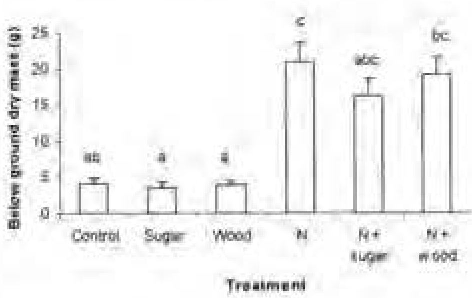

Figure 5: Mean below ground biomass of *Lolium multiflorum* in all treatments. Letters indicate significant differences according to the Kruskal-Wallis test ($p<0.05$, Kw = 6.8799).

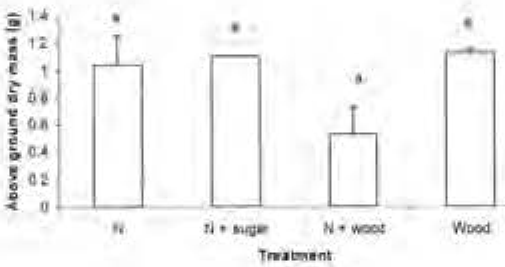

Figure 6: Mean above ground biomass of *L. filicaulis* individuals between treatments. There were no significant differences in observed vs. expected values according to the Chi-Squared test ($H_{(3,10)}$ = 2.4764, $p>0.05$).

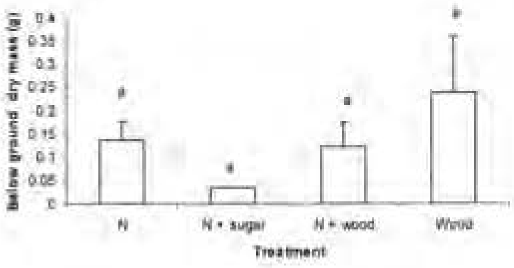

Figure 7: Mean below ground biomass of *L. filicaulis* between treatments. There were no significant differences in observed vs. expected values according to the Chi-Squared test ($H_{(3, 10)}$ = 2.2145, $p>0.05$).

Lolium multiflorum biomass in the nitrogen + sugar treatment is not significantly different to treatments without nitrogen addition. Above and below ground biomass of plants grown in nitrogen and nitrogen + wood differed significantly from treatments without nitrogen addition.

(Figure 4 & 5). *Lampranthus filicaulis* individuals did not grow in the control or sugar addition pots. Thus data existed only from Woodchips, nitrogen + woodchips, nitrogen, and nitrogen + sugar. No significant differences were found in mean above or below ground biomass of *Lampranthus filicaulis* between treatments (Fig 6 & 7). However, it is evident that *Lampranthus filicaulis* plants had lowest above ground biomass in the nitrogen + wood treatment, and lowest below ground biomass in the nitrogen + sugar treatment. Above and below ground biomass in the wood treatment was high.

Treatment effects on *Moraea tulbaghensis*

Moraea tulbaghensis size, in terms of both leaf length and root to tip length, did not vary significantly between treatments (Figure 8 & 9). Leaves were smallest in the sugar addition treatment, and largest in the nitrogen + wood treatment. There was almost no variation in root to tip length of *Moraea tulbaghensis* individuals between treatments.

There were no significant differences in wet weight of *M. tulbaghensis* between treatments (Kruskal-Wallis p>0.05, Kw = 8.707).

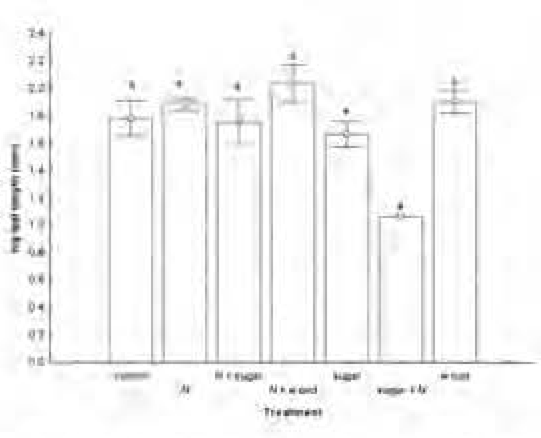

Figure 8: Mean differences in leaf length of *M. tulbaghensis* for all treatments. There were no significant differences in means according to the Kruskal-Wallis test (p>0.05, Kw = 7.084).

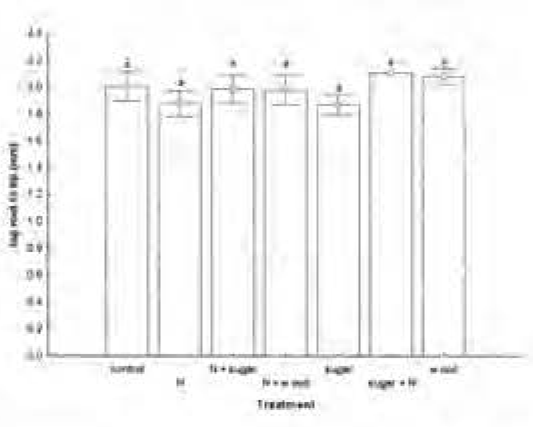

Figure 9: Mean differences in root to tip length of *M. tulbaghensis* for all treatments. There were no significant differences in means according to the Kruskal-Wallis test (p>0.05, Kw = 4.415).

Nitrogen availability

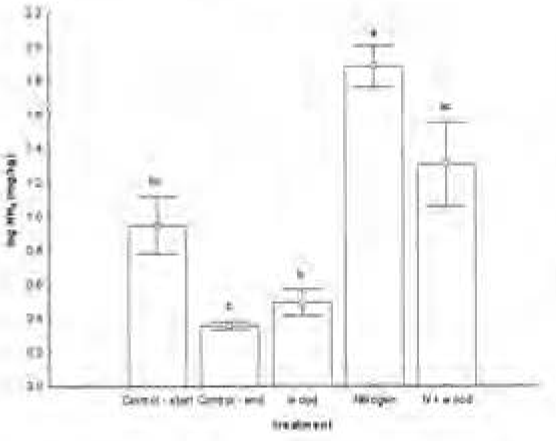

Figure 10: Mean differences in NH_4 levels between treatments. The means were found to be significantly different (one-way ANOVA $p<0.05$, $F = 17.57$, $df = 10$). Letters indicate significant differences according to Post Hoc Tukey test

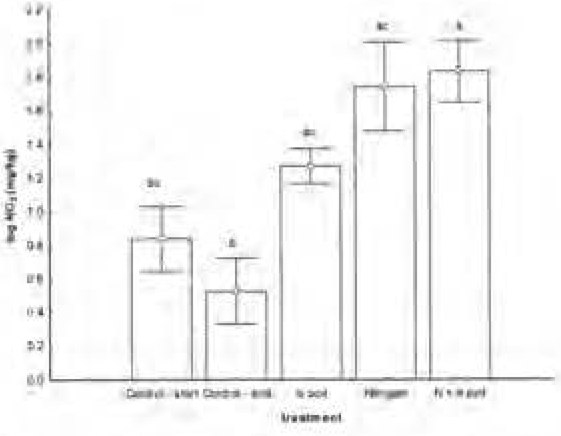

Figure 11: Mean differences in NO_3 levels across treatments. The means were found to be significantly different (one-way ANOVA $p<0.05$, $F = 8.3309$, $df = 10$). Letters indicate significant differences according to Post hoc Tukey test.

There are significant differences in NH_4 and NO_3 levels across treatments. NO_4 levels decreased in the control and wood addition pots, whereas NO_3 decreased only in the control. The addition of wood lowers NH_4 levels (fig 10) but not NO_3 levels (fig 11). NO_3 levels have increased over time in the wood addition pots.

DISCUSSION

Examining the impact of alien grasses on population dynamics of *Moraea tulbaghensis*

It is evident that alien grasses do not impact *M. tulbaghensis* density (Figure 1 & 2). This particular life history type can competently compete with alien grasses possibly because it can allocate resources to underground storage organs, and consequently is not actively competing for the same resources. Thus once the bulb is established this organ facilitates growth and survival. Juvenile *Moraea tulbaghensis* are also evidently unaffected by alien grass growth. Potentially this is due to their thin, narrow leaf shape, enabling them to grow straight up through grass cover in order to access light. Geophytes are known to respond well to disturbance (Rossitor 1966 in Vlok 1988), especially fire, as many have fire-stimulated flowering (Le Maitre and Midgley 1992). As a result they can potentially remain unaffected by disturbance such as burning that stimulates alien grass invasion.

Effect of organic amendments on alien grass and threatened species

Lolium multiflorum

Organic amendments have no significant effect on grass growth, subsequently their addition for the purpose of controlling alien grasses is questionable. Suding *et al.* (2004) found that alien plant competitive ability was not reduced after two years of sugar application. Since sugar addition is intended to immobilize nitrogen, Suding *et al.* (2004) suggested that competitive advantage of invasive species may be limited by phosphorus, rather than nitrogen. The relative contribution of phosphorus to nitrogen to plant growth was not examined in this study, but from the vigorous response of *Lolium multiflorum* to nitrogen addition it is clear that nitrogen addition significantly enhances alien grass growth.

However, Zink & Allen (1998) found that in comparison to the alien grass *Avena fatua*, indigenous species had increased survival in organic mulch addition after two years. Their study concluded that immobilization of nitrogen as a result of carbon addition increased indigenous species' competitive ability in comparison to alien grasses. This was attributed to the reduction in available nitrogen establishing an environment more suitable for indigenous plant growth, thus allowing them to outcompete *Avena fatua* that was suffering the effects of reduced nitrogen. The successful application of organic amendments in Zink & Allen's (1998) study demonstrates that wood is effective in improving indigenous species growth and survival, rather than suppressing alien grass growth and survival. Although not in the context of a competition experiment, *Lampranthus filicaulis* biomass was highest in the treatment with wood addition (Figure 6 & 7), suggesting our study may demonstrate a similar effect of the wood addition enhancing growth of indigenous species.

Lampranthus filicaulis

The fact that no significant difference in biomass of *Lampranthus filicaulis* individuals across treatments was evident (Figure 6 & 7) may be attributed to low germination and emergence of individuals, resulting in low replication of results. However, assuming that all *Lampranthus filicaulis* seeds were viable, nitrogen addition stimulated growth and germination of seeds, as plants grew in every pot of the nitrogen treatment and only in one or two pots of other treatments (Figure 1). Organic amendments had no significant effect on germination and growth. Above ground biomass was marginally lower in nitrogen + wood treatment, and below ground biomass appeared slightly lower in the nitrogen + sugar treatment, although these results were not significant and may be attributed to low replication.

Moraea tulbaghensis

It is challenging to make any conclusive comments on the effect of organic amendments on *Moraea tulbaghensis* due to late germination and growth of individuals. However, the lack of significant differences in growth across treatments (Figure 8 & 9) suggests there is not one particular treatment that effects their growth.

Sugar or Wood?

The response of species to different carbon sources varies. Amongst *Lolium multiflorum* individuals, sugar addition partially counteracts effects of nitrogen addition (Fig 4 & 5). It is possible that sugar addition stimulates bacterial activity, resulting in mould growth which hampers plant germination and growth. Woodchip addition marginally improves above ground grass growth rather than inhibiting it (Figure 4 & 5). It is possible that wood addition has a 'mulch' effect, aiding in retention of moisture in the soil which promotes plant growth and survival. It is possible that time is an important factor. Sugar is readily absorbed into the soil, and may need repeat application to have a continued effect. Woodchips on the other hand take a longer period of time to break down, thus having a 'slow release' effect on the soil, which proves to be more effective (e.g. Zink & Allen 1998).

Nitrogen

Both above and below ground biomass of *Lolium multiflorum* individuals are markedly increased by the addition of nitrogen (Fig 4 & 5). Monaco *et al.* (2003) found a notable increase in dry root mass of two alien grasses in nitrogen treatments in comparison to treatments without nitrogen addition, attributing it to the fact that species with high potential growth rates are more strongly effected by low nutrient availability than species with lower potential growth rates. Nitrogen is known to stimulate germination (Giba *et al.* 2003) and this effect was clearly seen with both *Lolium multiflorum* and *Lampranthus filicaulis*.

Zink & Allen (1998) demonstrated that organic mulch increased immobilization of nitrogen, but there was no significant difference in total soil nitrogen over the two year experiment. Suding *et al.* (2004) found that sucrose did reduce available nitrogen, but this still had no effect on the growth of alien weed as phosphorus was the limiting nutrient. Overall, decreased soil NH_4 levels in treatments with wood addition can be attributed to microbial immobilization of nitrogen. The increase in NO_3 levels in the wood addition treatment is an unexplained occurrence, and would benefit from re-examination.

<u>Lessons learnt from the study</u>

A number of changes to the project design would have potentially improved this study. Viability studies for indigenous seeds would prove useful, as low germination of *Moraea tulbaghensis* and *Lampranthus filicaulis* were difficult to attribute only to treatments. Original soil collected from the site of seed collection should be used in order to accurately gauge plant growth in natural soil conditions. For example, *Lampranthus filicaulis* grows specifically in lateritic soils (Goldblatt & Manning 2000), and thus could have responded differently in the current experiment due to unfamiliar soil type. As demonstrated by the success of Zink & Allen's (1998) study that was performed over 2 years, conducting the experiment over a longer period of time would allow for considerably greater plant growth which may in turn produce more informative results.

Conservation implications and recommendations

The findings that *Moraea tulbaghensis* densities are not negatively impacted by alien grass growth is significant. They are in contrast to Vlok's (1988) findings that geophyte density decreases with increasing alien grass density. At a single species level, alien grasses do not effect this particular life history, and highlights that it is not possible to generalize the impact of alien grasses on bulb species. It is possible that *M. tulbaghensis* was not affected by alien grasses at the study site due to the high fire frequencies. In areas without frequent fires the build up of grass biomass and litter may be more detrimental to geophyte densities. Further studies within Iridaceae at the species level would be informative in order to determine the mechanism that makes certain geophytes more vulnerable to the effects alien grass infestation than others.

This study demonstrates that nitrogen addition is a huge driver for increasing alien grass invasion. Alien grasses are conspicuously absent from undisturbed natural areas of the CFR (MacDonald & Morley 1988 in Richardson *et al.* 1992), and this study suggests that vigorous establishment of alien grasses is heightened by nitrogen enrichment. The principal threat to indigenous endemic and threatened species is nutrient enrichment of fragments due to fertilizer runoff, which potentially heightens the competitive ability of alien grasses against indigenous species.

Recommendations to constrain the threat of nitrogen enrichment are challenging. Agricultural use of fertilizers occurs on a massive scale throughout the lowlands of the CFR, and recommending a reduction in the application of fertilizers is unrealistic. Potential recommendations could include encouraging different land use around fragments, and preferentially conserving fragments that are uphill from agricultural land.

Conclusions

Although requiring further investigation, preliminary answers have been obtained to the two questions upon which the study was based. Alien grasses do not appear to have a detrimental effect on the geophyte life history type. In the short term, application of organic amendments is unsuccessful in inhibiting grass growth, and has no apparent detrimental effect on the growth of the two indigenous life history types examined. Assuming viability of seeds, nitrogen addition does not hamper germination and growth of *Moraea tulbaghensis* and *Lampranthus filicaulis*. In contrast, mesembs appear to respond well to nitrogen addition. Renosterveld shale soils are naturally more nutrient rich than fynbos soils, which could explain why characteristic renosterveld species are not detrimentally affected by nitrogen addition.

The response to increased nitrogen of the two life history types examined appears positive considering the environmental scenario in which they find themselves. More pressing however, is the comparative response of alien grasses to nitrogen addition. It would prove highly informative to repeat organic amendment treatments in competition experiments with similar species using natural renosterveld soils and nitrogen enriched soils. In natural soil nutrient levels, it would be expected that organic amendments would effectively immobilise nitrogen and consequently inhibit establishment and growth of alien grasses. Taking into account the findings of Zink & Allen (1998), the competitive ability of alien grasses in soil with increased nitrogen may increase to a greater degree than that of indigenous species, but addition of organic amendments may effectively immobilize nitrogen, thereby improving indigenous species competitive ability against alien grasses over a longer time period.

Essentially, our study determines that organic amendments are ineffective in controlling alien grass germination and growth in the time period over which this study was conducted. From prior studies (e.g. Zink & Allen 1998, Monaco *et al.* 2003), it is evident that alteration of nutrient levels was performed in order to improve germination, emergence and growth of indigenous species in comparison to alien grass species, rather than to actively decrease alien grass growth.

Our project design does not allow us to compare relative success rates, but it does demonstrate that organic amendments do not have a detrimental effect on the two life history types of threatened species examined.

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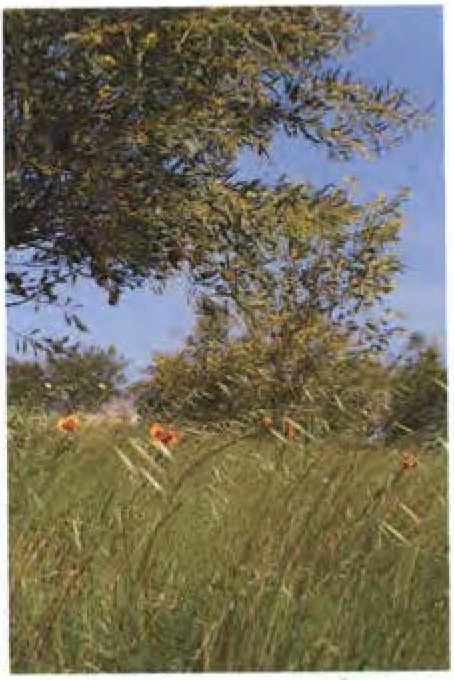
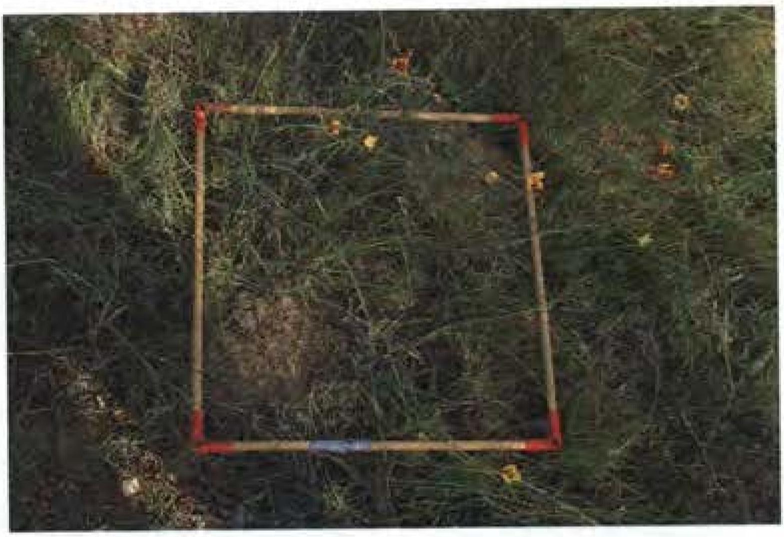
Appendix 1: Photographs of field experiment to examine the impact of alien grasses on population densities of *Moraea tulbaghensis*.



Moraea tubaghensis and alien grasses at Tulbagh study site



Moraea tulbaghensis and alien grasses at Tulbagh site

Appendix 2: Experimental layout to demonstrate effects of organic amendments on *Lampranthus filicaulis*

Appendix 3: Experimental layout to demonstrate the effect of organic amendments on *Lolium multiflorum*.