The successful life cycle of the pasture weed giant rats tail grass (*Sporobolus pyramidalis*)

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DECLARATION OF ORIGINALITY

This thesis reports the original research work of the author, except as acknowledged in the text. The material has not been submitted, either in whole or in part for a degree at this or any other University.

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ABSTRACT

Giant rats tail grass (Sporobolus pyramidalis) *is an unpalatable, perennial, tussock grass that has invaded at least 200 000ha of pasture-land in Queensland. This exotic weed from southern Africa has proven to be difficult to control using conventional weed control techniques, with infestations often re-establishing after substantial control efforts. Clearly, a greater knowledge of the life cycle of giant rats tail grass was required to identify its weaknesses and strengths, which could then be targeted or avoided within control strategies.*

For this thesis, three field experiments were conducted to observe the response of giant rats tail grass to various pasture management techniques (fire, slashing, fertiliser, cultivation, sown competitive species and herbicides – Chapter 4) and levels of pasture competition (manipulated via sowing competitive species with a range of growth habits and vigour – Chapter 5; by creating artificial canopy gaps and root exclusion tubes in a native pasture – Chapter 6). The impact of these treatments was assessed in relation to the life cycle stages (soil seed bank, seedling, mature plant) and transitions (germination and emergence, survival and growth, seed production) of giant rats tail grass.

Many strengths within the life cycle of giant rats tail grass were identified and characterised (eg. large long-lived soil seed bank, tough persistent seedlings), while only a small number of weaknesses were discovered (eg. seedling emergence and survival of very young seedlings is sensitive to high pasture competition). The results of this thesis have highlighted why giant rats tail grass has become such a problem weed within Queensland's grazing industry. However, the information gained will allow the strengths of this weed to be addressed within current control strategies (eg. recognizing the need to maintain the pasture in a healthy competitive condition for many years following the removal of giant rats tail grass plants to prevent re-establishment from the long-lived soil seed bank), therefore increasing the likelihood of successful long-term control.

The major strengths identified within the life cycle of giant rats tail grass were: the large (generally 1000-10000 seeds/m^2) long-lived (>3years) soil seed bank; the ability

of seedlings to germinate and emerge from only a proportion of the soil seed bank whenever conditions are suitable (eg. above-average rainfall seasons); 6-8 week old seedlings which have begun to tiller are tough and able to survive intense pasture competition; the mature plants are resistant to common agronomic manipulations (fire, slashing, fertiliser) and are long-lived (no plant death due to age was identified during 3 years of experiments); the leaf blades of mature plants are tough and therefore avoided by livestock, which selectively graze other species; the high seed production (up to 80000 seeds/m^2*); and, very high seed viability (generally >90%).*

The weaknesses identified within the life cycle of giant rats tail grass included: seedling emergence and early survival is sensitive to plant competition (no seedlings established within a healthy native pasture sward under full competition); the soil seed bank can be significantly depleted by a fire event (a variable 10-90% reduction), however it is generally replenished by the high seed production in the subsequent season; giant rats tail grass plants are sensitive to some herbicide techniques and if ***all*** *giant rats tail grass plants are selectively removed from a pasture containing an appropriately managed, vigorous competitive species, successful control is possible; and, some vigorous competitive sown pasture species have been identified for use within giant rats tail grass control strategies in south-east Queensland.*

A recurring theme throughout the thesis is the importance of a competitive, well-managed pasture sward to minimise gaps within the pasture throughout the year thus preventing giant rats tail grass seedling establishment from the long-lived soil seed bank. Without a vigorous, competitive pasture being present, any attempts to control giant rats tail grass will be futile.

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CHAPTER 1 Introduction

1.1 *Background*

Giant rats tail grass (*Sporobolus pyramidalis* P.Beauv. – GRT) is a perennial, tussocky weed of pasture (Jacobs & McClay 1993). Giant rats tail grass has low grazing quality, tough leaf blades and is considered unpalatable to livestock (Sharma 1984; Gibbs Russell *et al.* 1991). Therefore, cattle selectively graze palatable species and avoid giant rats tail grass, allowing it to increase in the pasture at the expense of more productive pasture species. Giant rats tail grass can impact on the productivity and viability of grazing land and established infestations are difficult and expensive to control (McIntosh *et al*. 1999). Giant rats tail grass can also invade roadsides, amenity, riparian and natural areas.

Giant rats tail grass is native to Africa (Jacobs & McClay 1993) and was probably introduced into Australia in the 1960's as a contaminant of imported pasture seed (Bishop *et al*. 1993; DNR 1998). Since its arrival, giant rats tail grass has spread considerably in coastal and sub-coastal Queensland and in northern New South Wales. It currently occupies approximately 200 000ha, but has the potential to invade 223 million ha of northern Australia (McIntosh *et al*. 1999; NRM 2001).

Some control/management strategies have been devised for giant rats tail grass based on practical experience and initiative (DNR 1998), as little was known about the specific ecology, weaknesses and strengths of this serious weed. These control strategies have achieved only limited success (G. Elphinstone *pers. com.*). Therefore, a project was devised to better understand the ecology of giant rats tail grass. It was expected that this improved understanding would contribute to the development of successful control/management strategies tailored specifically for this troublesome weed.

1.1.1 Giant rats tail grass project history

The giant rats tail grass project (Formal title: Ecology, management and control of giant rats tail grass. MLA project number: DAQ 106) began in 1996, jointly funded by external industry funding sources (see Acknowledgments) and the Department of Primary Industries - Queensland. The project objective was to develop technologies to enhance the sustainability and productivity of those grazing lands in Queensland currently or potentially affected by giant rats tail grass. This was to be done by:

- Investigating the ecology of giant rats tail grass, identifying potential weaknesses in its life cycle and defining factors contributing to its competitive advantage and spread.
- Developing long-term cost-effective strategies for grazing management, pasture replacement and herbicidal control which capitalise on identified weaknesses in its life cycle.

Two people were assigned to work on the ecology of giant rats tail grass. I was employed by the Department of Primary Industries - Queensland to study the overall life cycle and competitive ability of giant rats tail grass, as well as assess the impact of pasture management techniques and evaluate competitive sown pastures for use in controlling giant rats tail grass. Wayne Vogler (through the University of Queensland – Gatton) was assigned to study the seed ecology (predominantly) of giant rats tail grass (Vogler 2002). Our studies ran concurrently and cooperation has ensured our individual work was complementary, avoiding repetition.

The project was also overseen by an industry Advisory Committee and reviewed by external funding body review panels to ensure the project's integrity and relevance to the Australian grazing industries.

1.2 *Objective of this study and scope of thesis*

The objective of this study was to develop an understanding of the life cycle, ecology and competitive ability of giant rats tail grass and to identify any weaknesses and strengths within its life cycle, which may be targeted or avoided to improve the success of giant rats tail grass control/management strategies.

This objective was achieved by conducting a literature review and three field experiments.

In the first experiment (reported in Chapter 4), a giant rats tail grass infested pasture was manipulated using various techniques available to land managers. The response of giant rats tail grass and other species in the pasture were monitored, with emphasis on different giant rats tail grass life cycle stages and transitions, eg. seed bank, seedling emergence, growth or decline of plants and seed production.

In the second experiment (reported in Chapter 5) the competitive abilities of eighteen sown pasture species were evaluated when sown into soil containing a giant rats tail grass soil seed bank. The ability of the sown pasture to compete with giant rats tail grass from sowing; the ability of established sown pasture to suppress newly established giant rats tail grass plants; and, the ability of established sown pasture to prevent further giant rats tail grass seedling establishment were monitored.

The previous two experiments highlighted the importance of pasture competition in limiting the establishment of giant rats tail grass from the soil seed bank. Therefore, a third experiment (reported in Chapter 6) was conducted to investigate the competitive ability of giant rats tail grass during emergence and establishment, and define the role of pasture competition, both above- and below-ground, in combating the invasion of giant rats tail grass.

This thesis contains eight chapters:

1. Introduction, background and objectives of the study.
2. Review of literature, on the problem of giant rats tail grass, expected life cycle and response to various management techniques, highlighting gaps in current knowledge.
3. General materials and methods, providing a description of the research sites and pasture population dynamics sampling techniques.
4. An experiment investigating the ecological response of giant rats tail grass to pasture management techniques.
5. An evaluation of sown pasture species for competitive ability against giant rats tail grass at sowing and as established swards.
6. An experiment to define the competitive ability of giant rats tail grass and the role of shoot and root competition in combating the invasion of giant rats tail grass.
7. General discussion, bringing together key outcomes from the three field experiments, with an emphasis on describing and understanding the strengths and weaknesses in the life cycle of giant rats tail grass.
8. References.

CHAPTER 2 Review of literature

2.1 *Scope of review*

The review defines why giant rats tail grass (*Sporobolus pyramidalis* P.Beauv. - GRT) is a problem and amalgamates available information on its ecology, life cycle, management and control. Research priorities were identified where inadequate information existed. Some of these priorities were covered in a concurrent project in which the seed ecology of giant rats tail grass was investigated (Vogler 2002) and in other studies. The summary at the end of this chapter highlights the gaps in current knowledge that will be addressed in this thesis.

2.2 *The problem, distribution, description, identification and origin of giant rats tail grass*

At the commencement of this study in 1997, there was little published information on the ecology of giant rats tail grass. Therefore, three other case study species that had apparent similarities to giant rats tail grass (eg. unpalatable, perennial, tussocky, grass weeds of pasture in Australia) were also reviewed. These species were used to provide an indication of possible giant rats tail grass ecology and how it may respond to different management options. The case study species chosen were, *Sporobolus fertilis* (giant parramatta grass), *Nassella trichotoma* (serrated tussock) and *Aristida ramosa* (purple wiregrass).

2.2.1 The problem and distribution of giant rats tail grass

Giant rats tail grass is a weed of pasture and native vegetation areas (Jacobs & McClay 1993). It appears to be an aggressive weed, which can quickly out-compete desirable pasture plants when they are weakened (eg. by over-grazing, drought, mechanical disturbance or fire) and is difficult to control (Delaney 1991; DNR 1998). The productive capacity of a pasture dominated by giant rats tail grass is reduced (Delaney 1991) and property values can be halved (G. Graham *pers. com.*).

As well as reducing palatable pasture productivity, giant rats tail grass can reduce cattle productivity. Mature giant rats tail grass leaf blades are tough, have low grazing quality and are unpalatable to livestock (Sharma 1984; Gibbs Russell *et al.* 1991; LANDS 1995). Commercial properties have shown that cattle grazing giant rats tail grass dominated pastures can take up to 12 months longer to reach equivalent weights compared to cattle from giant rats tail grass free pastures (LANDS 1995). Stocking rates for beef and dairy cattle may need to be halved to maintain production per animal on heavily infested pasture (McIntosh *et al*. 1999; NRM 2001). Giant rats tail grass is never high in protein, and during the dry season nutrient levels in these grasslands in Africa fall well below those needed for livestock maintenance (Howell 1988).

Giant rats tail grass is also an environmental hazard, as severe infestations may cause degradation by reducing biodiversity (McIntosh *et al.* 1999; NRM 2001), especially in riparian areas where an almost pure monoculture of giant rats tail grass can occur.

Giant rats tail grass produces many seeds (Andrews *et al.* 1996) that appear to be efficiently dispersed to new areas via many dispersal vectors, including cattle and livestock, vehicles and machinery, water, hay and pasture seed (Delaney 1991; and recent work by Bray *et al*. 1998a; 1998b; 1999).

A confident identification of giant rats tail grass can be difficult, as it is similar to some native (eg. *Sporobolus diandrus, S. sessilis, S. laxus*) and other introduced (*S. fertilis, S. jacquemontii*) *Sporobolus* species (Simon & Jacobs 1999) and the seeds of all *Sporobolus* species can not be differentiated in pasture seed samples using visual seed identification techniques (DNR 1998). The confusion about identity appears to hinder the early control of isolated infestations.

Giant rats tail grass does not have highly specialised environmental requirements. It is adapted to a range of soil types from sands to heavy clays (Howell 1988; Gibbs Russell *et al*. 1991) and especially low fertility soils (Jacobs & McClay 1993). In Australia, giant rats tail grass currently infests coastal and sub-coastal areas from northern New South Wales to north Queensland (NRM 2001). In 1995 it was estimated that 90 000ha in Queensland were invaded by giant rats tail grass (J. Wright *pers. com.*), but more recent estimates suggest the area is closer to 200 000ha (McIntosh *et al*. 1999; NRM

2001). Alarmingly, recent modelling has predicted that giant rats tail grass has the potential to invade 108 Mha in Queensland and 223 Mha in Australia (Vogler *et al*. 1997; McIntosh *et al*. 1999; NRM 2001). Based on the distribution of giant rats tail grass in its native environment in Africa, it is estimated that it could spread to virtually anywhere with more than 600mm annual rainfall (Delaney 1991) and possibly down to 500mm annual rainfall (Vogler *et al*. 1997). Giant rats tail grass appears to be very drought hardy and is able to compete in both dry and wet conditions. *Sporobolus* species (in particular *S. asper*) in the USA rapidly develop a root system, which although not deep, is dense, widely spreading, and profusely branched, with the roots of a single plant removing soil water from an area of $0.65m^2$ to a depth of 0.46m (Weaver 1930). Therefore, these plants are well adapted to secure water from dry soil and during years of drought their dominance is conspicuous (Weaver 1930).

Giant rats tail grass appears to pose a greater problem in Australia than in Africa, as little ecological research has been conducted on this species in its native environment, even though there is a long history of pasture ecology research in Africa. One possible scenario is that giant rats tail grass is pre-adapted to Australian environmental and management conditions. This combined with a lack of pests and diseases that may be present in its native range mean that it has become a major problem in Australia. Another scenario is that post-invasion evolution (Blossey & Notzold 1995) has occurred to make giant rats tail grass more weedy in Australia. However, there is little evidence for post-invasion genetic changes associated with increases in size and competitive ability in weeds over such short time-frames (Willis *et al.* 2000).

2.2.2 The problem and distribution of the case study species

The problem and distribution of the case study species (*Sporobolus fertilis* - giant parramatta grass, *Nassella trichotoma* - serrated tussock and *Aristida ramosa* - purple wiregrass) will be reviewed briefly. A point that will be highlighted is that the case study species appear to fill a similar ecological role as giant rats tail grass in pastures, resulting in similar problems. The case study species are perennial, tussocky, grass weeds of pasture in Australia, with low palatability.

2.2.2.1 Giant parramatta grass

Giant parramatta grass (*Sporobolus fertilis*) is a serious, aggressive weed that has invaded large areas of pasture along the eastern Australian coast (Mears *et al*. 1996), particularly on the north coast of New South Wales (Betts & Moore 1996). Giant parramatta grass is generally regarded as a weed of disturbed areas and pastoral areas with summer rainfall (Jacobs & McClay 1993) and is closely related to giant rats tail grass, but originates from tropical Asia rather than Africa (Jacobs & McClay 1993).

The problems caused by giant parramatta grass are very similar to those of giant rats tail grass. Betts & Moore (1996) listed the following threats to grazing land posed by giant parramatta grass:

- It reduces pasture production, animal performance and the value of grazing land.
- It is a vigorous, persistent and very invasive perennial grass of poor quality and low palatability.
- It is well adapted to a wide range of climatic and pasture conditions.
- It produces large numbers of seed that remain viable in the soil for several years.
- Its seed is spread by vehicles, machinery, livestock and floods, but not by wind.

Due to the serious threat posed by giant parramatta grass, ecological studies have been conducted to improve our understanding of this weed (eg. Elks 1992; Andrews 1995a; Andrews *et al*. 1996; 1997).

2.2.2.2 Serrated tussock

Serrated tussock (*Nassella trichotoma*) is a fibrous grass with very low palatability and is eaten by stock only in exceptional circumstances (Green 1956). It is an aggressive plant which can invade weakened native and improved pastures and then build up rapidly to the stage of complete infestation (Green 1956). In heavy infestations, serrated tussock smothers native and introduced pasture species and because of its very low palatability, stock prefer other species, which are quickly and selectively eaten out (Green 1956; Campbell 1998).

Serrated tussock reduces livestock productivity. In one case study, the sheep carrying capacity of an infested paddock was only 25% of similar land free of serrated tussock (Green 1956). Campbell (1998) reported that serrated tussock can reduce carrying capacity by up to 90% and put an end to productive sheep grazing.

The seeds of serrated tussock are readily dispersed over long distances, as the inflorescences with seeds still attached, break off and are tumbled or carried by wind up to 16km (Healy 1945). Seed may also be spread by water, machinery and man (Campbell 1998), in livestock intestines (Campbell 1962), in wool and agricultural seed (Healy 1945).

Serrated tussock is a major problem in temperate Australia, invading and infesting pastures in the central and southern tablelands in New South Wales, Victoria and Tasmania (Campbell 1998). It is adapted to a large range of soils, both fertile and infertile and with a light or heavy texture (Green 1956). Hot summer temperatures appear to limit its spread into northern Australia (Campbell 1998). Serrated Tussock is a native of South America (Jacobs & Everett 1993), occurring in Peru, Chile, Uruguay and Argentina (Healy 1945).

The serious problems posed by serrated tussock mean that ecological studies have been conducted on most stages of its life cycle, including its seed banks, seedling establishment and seed production (eg. Healy 1945; Taylor 1987; Campbell 1998).

2.2.2.3 Purple wiregrass

Purple wiregrass (*Aristida ramosa*) is an Australian native grass (Stanley & Ross 1989), but is of little fodder value. It is stemmy, producing a small amount of leaf in relation to the size of the plant and is relatively unpalatable to stock, being eaten only when the plant is young (Harradine & Whalley 1978; Anderson 1993). The three-awned seeds are sharp and cause mechanical injury to the mouth and eyes of stock and contaminate wool (Harradine & Whalley 1978; Stanley & Ross 1989; Anderson 1993). Although native, purple wiregrass appears to be increasing at the expense of more palatable species in many grazed pastures (Harradine & Whalley 1980; Orr *et al*. 1997).

Purple wiregrass occurs in coastal and sub-coastal districts and tablelands of Victoria, New South Wales and Queensland and usually grows in low fertility, dry habitats in eucalypt woodlands on a range of soil types, although lighter textured soils are favoured (Anderson 1993).

The ecology of purple wiregrass has been studied due to its increased abundance in grazed pastures (Harradine & Whalley 1978; 1980; Campbell 1996; Orr & Paton 1997; Orr *et al.* 1997).

2.2.3 Plant description and identification problems

2.2.3.1 Giant rats tail grass and giant parramatta grass

Giant rats tail grass is a robust, tufted, perennial grass growing to 1.7m tall. The inflorescence can be up to 40cm long and 3cm wide. The inflorescence can change shape from a "rats tail" spike when young to an elongated pyramid shape when flowering (DNR 1998), although not always. The tufts are difficult to pull out by hand and the stems and leaves are tough. Giant rats tail grass produces a large amount of seed (Anderson 1993) and is a C4 tropical grass (Gibbs Russell *et al*. 1991).

The description of giant rats tail grass sounds remarkably similar to the description of giant parramatta grass. Giant parramatta grass is a coarse, tussocky, perennial grass that grows to a height of 0.7-2m. The inflorescence is up to 40cm long and resembles a rat's tail. Single tussocks can grow to a basal diameter of 40cm and produce more than 200 inflorescences per year (Moore & Betts 1993). Giant parramatta grass produces large amounts of seed (Andrews *et al.* 1996) and is also a C4 grass (Gibbs Russell *et al*. 1991).

There are five introduced *Sporobolus* R.Br. species in Australia with a similar appearance. They include the following species and are part of a group called the *Sporobolus indicus* complex (Simon & Jacobs 1999).

- *Sporobolus pyramidalis* P.Beauv – giant rats tail grass
- *S. natalensis* (Steud.) – also called giant rats tail grass
- *S. fertilis* (Steud.) – giant parramatta grass – was *S. indicus var. major*

- *S. africanus* (Poir.) – parramatta grass – was *S. indicus var. capensis*
- *S. jacquemontii* Kunth – american rats tail grass

Within the *Sporobolus indicus* complex, positive identification of individual species is a major problem. Giant rats tail grass and giant parramatta grass are often confused with each other and with other native (eg. *S. diandrus* P.Beauv, *S. sessilis* B.K.Simon, *S. laxus* B.K.Simon) and introduced *Sporobolus* species (Betts & Moore 1996; McIntosh *et al*. 1999). Comments such as "a number of species including *S. africanus, S. fimbriatus*, *S. natalensis* and *S. pyramidalis* form an interlaced group of species, in which the typical forms are overshadowed by a large number of intermediates" (Gibbs Russell *et al*. 1991) and "the recognition of species, especially in the *Sporobolus indicus* complex presents enormous problems due to the continuous morphological intergradation throughout the genus" (Simon & Jacobs 1999) appear commonly in the taxonomic literature on *Sporobolus*. Vieritz (1993), Andrews (1995a), and Simon & Jacobs (1999) provide a summary of *Sporobolus* taxonomic reviews. Many *Sporobolus* taxa have been grouped together and separated many times, undergoing up to 5 name changes in the last 30 years.

The current botanical key for separating *Sporobolus* species uses the length and shape of glumes and overall plant size for identification (Simon & Jacobs 1999). These floret characters are too small for many land managers to recognise and plant size is subjective and related to environmental and management conditions (eg. plant height is affected by drought, soil fertility and slashing). These problems, together with the reclassification of some *Sporobolus* taxa, subsequent name changes and minimal differentiating characters have caused confusion in Australia, making legislative and on-ground management of these populations difficult (Andrews 1995a).

2.2.3.2 Description and identification of case study species

The other case study species also have problems with description and identification. Green (1956) published a good basic description of serrated tussock (also Healy 1945; Campbell 1960b). This species appears to be a useful, fine-leafed grass similar to many native tussock grasses, which makes it inconspicuous, often resulting in apathy by many landowners towards its early control, so an infestation can be well established before its presence is recognized (Green 1956).

Purple wiregrass is a stemmy, tufted, perennial grass, 30-80cm tall (Anderson 1993). The leaves are small and harsh and the general appearance of the plant is one of dead stalks with few green leaves and tillers for most of the year (Harradine & Whalley 1980). Many *Aristida* species of similar appearance occur in Australia (Stanley & Ross 1989), and most land managers group them together under the common name wiregrass and regard them as one entity. Because wiregrasses are generally poor fodder, this grouping usually presents few identification problems, although there is evidence that all wiregrasses do not react similarly to fire, a common management tool (D. Orr *pers. com.*).

2.3 *Ecological framework for free-seeding, perennial tussock grasses*

Different life cycle stages of giant rats tail grass have been reviewed in this section. Possible weaknesses or strengths in the life cycle and gaps in current knowledge are highlighted.

The life cycle of a free-seeding perennial tussock grass (Fig 2.1) involves a number of relatively distinct, identifiable stages (eg. soil seed bank, seedling, flowering plant), which are linked by transitions (eg. seed germination, seedling emergence, seedling growth and survival, seed production). The life cycle for an invading weed often starts with dispersed seed being transported from another infestation into the soil seed bank (Harper 1977). The seed germinates and a seedling emerges to produce a seedling. The seedling establishes, survives and grows to produce a flowering plant. The flowering plant produces seed that usually enters the soil seed bank nearby with a small percentage of seed transported to new areas via dispersal agents, thus repeating the cycle. In each stage and transition, losses can occur (eg. seedling dies due to moisture or nutrient stress). Management can increase or decrease these losses thus affecting the life cycle and modifying the established population.

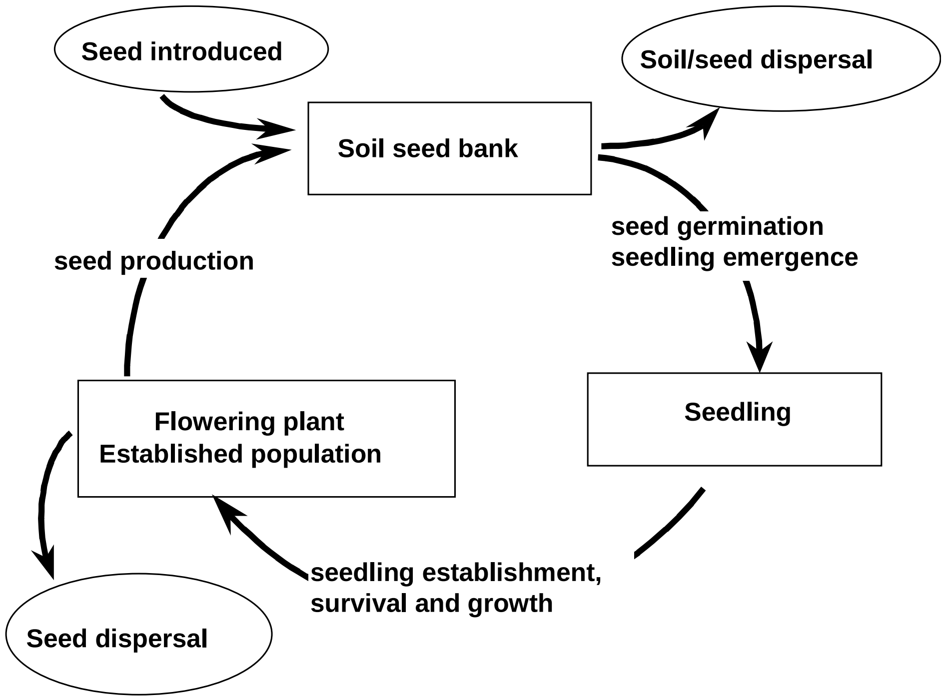

Figure 2.1 Life cycle of a free-seeding perennial tussock grass
(adapted from Grime 1983; Louda 1989; Simpson *et al*. 1989; O'Connor 1991).

Andrews (1995a) and Andrews *et al.* (1996; 1997) investigated the seed ecology (ie. seed production, soil seed bank, seed germination and seedling emergence) section of the life cycle of giant parramatta grass, with occasional measurements on giant rats tail grass. Due to a close taxonomic relationship between giant parramatta grass and giant rats tail grass, their behaviour should be similar, and therefore, this work will be referred to extensively in the following seed and seedling sections. Vogler (2002) has recently conducted more detailed studies on the seed and seedling ecology of giant rats tail grass.

2.3.1 Soil seed banks

There are large numbers of seed lying dormant in most soils (Cook 1980a). All viable seed present on or in the soil constitutes the soil seed bank (Simpson *et al*. 1989). An understanding of the soil seed bank provides a basis for informed manipulation of species composition by shifting the opportunities for seedling establishment in one direction or another (Grime 1989).

2.3.1.1 Soil seed bank size

The soil seed bank beneath an established giant rats tail grass infestation is expected to be large. Giant parramatta grass soil seed banks (Andrews *et al.* 1996) and giant rats tail grass soil seed banks (Andrews 1995a) ranged from 1650 to 21300 seeds/m^2 and 900 to 7250 seeds/m^2 respectively depending on year and grazing intensity. Serrated tussock also develops a large soil seed bank with 44000 to 75000 seeds/m^2 recorded (Healy 1945; Joubert 1984). By contrast the soil seed banks of the native purple wiregrass are small, often less than 50 seeds/m^2 (Campbell 1996).

Once a giant rats tail grass seed has entered the soil seed bank, followed by seedling emergence and survival to reproductive maturity, the giant rats tail grass soil seed bank size has the potential to increase quickly, due to the large seed production of giant rats tail grass (Andrews *et al.* 1996).

2.3.1.2 Soil seed bank longevity

In the absence of further seeding, the numbers of viable weed seeds in the soil are expected to decrease exponentially from year to year (Roberts & Dawkins 1967). However, there is great variation between species in the potential lifespan of their seeds (Roberts & Dawkins 1967; Roberts & Feast 1973a; 1973b; Cook 1980a; Williams 1984). This variation in combination with varying seed production can result in a large difference between the species frequency in the soil seed bank and that of the standing vegetation (Baker 1989).

Many workers have estimated the rate of seed loss from the soil seed bank and concluded that the loss is dependent on species, when the last seed input occurred and land management (eg. Roberts & Dawkins 1967; Williams 1984; Andrews 1995a).

The soil seed banks of giant parramatta grass and giant rats tail grass appear to be long-lived. One year after burial of fresh seed, the viability of *Sporobolus* seed ranged between 51-71%, with an estimated time of 7-14 years (10 years for giant rats tail grass) for soil seed banks to decline to 1% (Andrews 1995a). However, this time period was predicted after monitoring the soil seed banks for only 18 months. Recent work by

Vogler (2002) on giant rats tail grass has produced similar results following monitoring over a 3 year period. Serrated tussock also has long-lived soil seed banks with small quantities of seed surviving for 13 years (Campbell & Vere 1995) and possibly up to 20 years (Taylor 1987). The soil seed banks of the native purple wiregrass on the other hand are relatively short-lived, with few seeds remaining after one year (Campbell 1996).

Soil surface cover and management can affect the soil seed bank longevity. Giant parramatta grass and giant rats tail grass soil seed banks decline faster under a bare surface than under vegetation (Andrews 1995a; Andrews *et al.* 1996; Vogler 2002). Andrews *et al.* (1996) estimated that the time required for giant parramatta grass soil seed banks to decline to 15 seeds/m^2, was 6.8 years in vegetated plots and 4.8 years in bare plots.

Cultivation or soil disturbance increases the rate of soil seed bank decline. Roberts & Dawkins (1967) and Roberts & Feast (1973a) studied the numbers of viable weed seeds in previously cultivated pasture-land in England. They found the rates of seed loss were equivalent to 22% and 34% per year respectively in undisturbed and cultivated soil, with the percentage loss increasing with increased regularity of cultivation (up to 56% loss per year in plots dug 7 times per year).

Potentially, the rate of giant rats tail grass soil seed bank decline can be influenced by pasture management, manipulating ground cover and soil disturbance.

2.3.1.3 Seed distribution down the soil profile

An understanding of the spatial distribution of weed seeds in the soil seed bank may be important for determining their location and targeting their destruction. Most giant rats tail grass seeds are likely to be near the soil surface as there are no seed burial structures, such as the hygroscopic awn on serrated tussock seed (Healy 1945), and most giant parramatta grass seed was found in the top 1cm of soil (Andrews 1995a). Recent studies by Vogler (2002) have confirmed that 70% of giant rats tail grass seed is within the litter and top 1cm of soil.

Andrews (1995a) found that no giant parramatta grass or *S. africanus* seedlings emerged from seed buried at a depth of 5cm, therefore seed permanently buried below this depth can be regarded as excluded from the effective soil seed bank (Baker 1989). However, if the seed is subsequently dug up during pasture renovation, animal activity or any other process, the seed will re-enter the system and if still viable, will possibly reinfest a previously 'weed-free' pasture.

2.3.2 Seed germination

Knowledge of the germination requirements of a weed is necessary to predict when germination and emergence may occur in the field. The germination requirements also need to be understood and met in the laboratory to design and conduct tests for seed viability and soil seed bank size (Simpson *et al*. 1989).

Seed dispersal and germination are the most hazardous stages in the life cycle of a plant (Plummer 1943; Solbrig 1980). Due to the high mortality rate that can occur during germination, it could be expected that seeds of undomesticated plants would possess mechanisms enabling germination only when the risks were low (Solbrig 1980). These mechanisms are referred to as dormancy. Even though external conditions for germination appear to be met, viable seeds may not germinate because they are dormant. There are three types of dormancy (Harper 1977):

1. Innate dormancy
2. Induced dormancy
3. Enforced dormancy

Innate dormancy is a mechanism that is present in some plants and prevents viable seeds germinating immediately after seed fall when conditions may not be suitable for successful germination, establishment and reproduction (eg. late in the growing season). Induced dormancy occurs when germinable seeds are exposed to certain conditions (eg. some Leguminosae seed exposed to intense drought - Harper 1977) that result in the seed becoming dormant and remaining dormant for a significant time even when the inducement conditions are removed. Enforced dormancy is where germinable seeds are prevented from germinating due to environmental conditions (eg. water shortage, unsuitable temperature, light conditions), but if the environmental conditions are corrected, the seed will germinate (Harper 1977). Dormancy mechanisms and the inherent viability of seed determine the potential longevity of the seeds in the soil seed bank (Garwood 1989).

Primary dormancy is a term often used to refer to innate dormancy, while secondary dormancy refers to both induced and enforced dormancy (Baker 1989).

Some work has been conducted on the primary dormancy of giant rats tail grass and giant parramatta grass. Andrews *et al.* (1997) found that most fresh (recently shed or harvested) and apparently dormant (innate) *Sporobolus* seed will germinate when subjected to alternating temperatures (in the order of 35^{o}C day/15^{o}C night) and light, while few seeds germinated when subjected to constant temperatures in the dark. This temperature/light requirement was reduced substantially when the seed was 6 months old, probably due to the primary dormancy breaking down. Toole (1941) also found that germination of *S. cryptandrus* was higher with alternating temperatures than with constant temperatures. The recent work of Vogler (2002) generally agrees with Andrews *et al.* (1997). The requirement of alternating temperatures may be a method of gap or bare ground detection (Thompson & Grime 1983), as diurnal temperature fluctuations under a pasture canopy or at depth in the soil are reduced.

Giant rats tail grass may have a light requirement for germination under certain circumstances. Andrews *et al.* (1997) tested a number of light treatments including white light, dark and green (reduced ratio of red:far red wavelengths) light on the germination of giant parramatta grass seeds. When fresh seeds were exposed to alternating temperature, light treatments had no effect on the germination, but at constant temperatures the light treatment used had a marked effect on germination, with reduced germination in the green light treatment and negligible germination in the dark treatment (Andrews *et al.* 1997). Green light simulates light under a foliage canopy (Harper 1977).

The hypothesis that constant temperature and weak light would inhibit germination of buried seed and seed under a dense pasture cover where establishment is unlikely, was supported by giant parramatta grass field emergence studies where emergence in vegetated plots was negligible (Andrews *et al.* 1996).

Time of year, season and management may affect giant rats tail grass seed germination and emergence. Andrews *et al.* (1996) found most giant parramatta grass seedlings germinated in spring and autumn with few in summer and winter. Fertilising pasture appeared to inhibit giant parramatta grass seedling establishment by increasing pasture growth and competition. This increased the mortality rates of young seedlings and reduced potential safe sites for establishment (Andrews 1995a).

2.3.3 Seedling establishment and development

Little information is available on giant rats tail grass seedling establishment and development. Andrews (1995a) found that both level of competition and moisture conditions were important in determining the number of giant parramatta grass seedlings that establish and the rate of their development. He concluded that pasture competition was probably the most important factor in seedling establishment, as *Sporobolus* seedlings were sensitive to competition from surrounding plants, even during periods of above-average rainfall. Serrated tussock seedlings are also sensitive to competition, with most seedlings that emerge in dense stands of serrated tussock or in vigorous improved pasture killed by competition in their first or second season (Campbell 1998). In one serrated tussock experiment, 4000 seedlings/m^2 established on bare soil in the first year, but interplant competition reduced this population to 20 plants/m^2 after three years (Campbell 1958, cited by Campbell 1998).

Another factor that may affect pasture competition and giant rats tail grass seedling establishment is grazing. Seedling of serrated tussock grow relatively slowly; it invades because animals graze more palatable plants (Campbell 1998), therefore reducing pasture competition.

Emerged seedlings may form a seedling bank (Chippindale 1932; 1948; Simpson *et al*. 1989), the behaviour of which is ecologically similar to a soil seed bank in that the seedlings stop growing and wait for the removal of inhibitions to their development. Changes in environmental conditions (eg. increased light or moisture) can remove the inhibition and stimulate growth (Simpson *et al*. 1989) enabling a seedling to develop into a mature plant.

2.3.4 Plant growth and population dynamics

Most plants are plastic in their growth form. They can develop tillers, leaves and inflorescences to a variable degree depending on environmental circumstances and competitive interactions (White 1980), and these may be managed.

Circumstantial evidence suggests that tussocks of giant rats tail grass are long-lived and tolerant of most management tools eg. slashing, fire, fertilising and grazing (McIntosh *et al*. 1999). However, fire may have a role in manipulating giant rats tail grass populations. Campbell (1996) found the plant density and basal area of purple wiregrass was significantly reduced after 3 years of annual burning compared to unburnt treatments. Orr *et al.* (1997) also investigated the effect fire on the population dynamics of pastures containing *Aristida* species and came to similar conclusions.

Applying fertiliser may not directly affect giant rats tail grass, as some grasses do not respond to fertiliser use (Harradine & Whalley 1978). Fertiliser may however, promote the growth of companion species possibly increasing plant competition to the stage of out-competing giant rats tail grass tussocks. Andrews (1995a) proposed that studies of the relative growth responses of giant parramatta grass and alternative useful species to fertiliser applications would be helpful in the development of guidelines for the management of giant parramatta grass infestations.

Other management tools may also affect mature giant rats tail grass plants (eg. slashing, herbicides), but they will be discussed separately in later sections.

Anecdotal evidence suggests that mature giant rats tail grass tussocks may break up into smaller segments, especially when subjected to treatments such as fire, herbicide application or regular slashing. Giant rats tail grass however, is not generally regarded as spreading or reproducing vegetatively, as some grasses eg. *S. virginicus* or *Digitaria didactyla* do via stolons. There is debate regarding what constitutes asexual or vegetative reproduction (Abrahamson 1980). Therefore a decision needs to be made on whether broken-up plants have reproduced asexually to form new plants or remained segments of the original plant, although possibly with reduced basal area. Orr *et al*. (1997) found tussocks of *Aristida* species tended to break up into separate segments with increasing age. These segments were regarded as part of the original tussock and the tussock was considered to be alive if one or more segments of that tussock remained.

2.3.5 Seed production and incorporation into the soil seed bank

Visual inspection suggests that seed production of giant rats tail grass is high, but what proportion of the seed fall enters the soil seed bank is unknown. Giant rats tail grass seed appears to be produced throughout the year with a peak in summer and autumn (McIntosh *et al.* 1999). Little is known about the effect of management on seed production of this species.

Andrews *et al.* (1996) recorded the giant parramatta grass seed fall in excess of 146000 seeds/m^2 during one season and estimated a potential seed production of 668000 seeds/m^2 by counting the potential sites for a seed to be produced (pedicel number) on an inflorescence. Serrated tussock also produces large numbers of seed, with individual inflorescences producing 50-70 seeds, while a large tussock may produce thousands of inflorescences (Green 1956). Work in New Zealand (reported by Green 1956), found that individual serrated tussock plants may produce more than 100000 seeds/year or approximately 247000 seeds/m^2. By comparison the seed production of the native purple wiregrass was measured at 8100 seeds/m^2 over a season (Campbell 1996), which is substantially lower than the other reviewed case study species.

Although giant parramatta grass produces a large number of seed, only a small proportion is incorporated into the soil seed bank (Andrews *et al.* 1996). Williams (1984) found that the chance of seeds of most species becoming incorporated into a long-term soil seed bank (seeds still present >6 months after seed shed) in dense undisturbed swards was very low. For example, in one season only about 20% of *Agrostis capillaris* seeds shed in late summer became incorporated.

The distribution of giant rats tail grass seed production throughout the year will be important for determining the effectiveness of any treatment for modifying seed production. Giant rats tail grass seed may be produced throughout the year with a peak in summer and autumn (McIntosh *et al.* 1999). Andrews *et al.* (1996) found that various defoliation treatments could prevent seed fall of giant parramatta grass when applied at particular times.

Plant competition may play a role in reducing seed production, as increased plant density can reduce seed production per plant (Silvertown 1982), presumably by limiting resources to individual plants and reproductive shoots. Seed production of a species per unit area may not be reduced if the additional plants are the same species, however if the additional plants are a different species (eg. a weed), seed production per unit area is likely to be reduced. Separating the impact of competition on a plant and unit area basis may be important for understanding the response of giant rats tail grass to competition.

2.3.6 Seed dispersal

The seed dispersal characteristics of a species influence its present ecological range and population size and determine whether the range is expanding and the population increasing (Harper 1977). Seed dispersal is one of the most hazardous stages in the life cycle of a plant with many seeds being killed or deposited in unsuitable habitats during the process (Solbrig 1980). There is also a wide variation between species in the capacity for seed dispersal, although most seeds enter the soil near the parent plant (Cook 1980a).

Giant rats tail grass seeds appear to be well-adapted for efficient dispersal, as the pericarp becomes mucilaginous when wet (Guerin 1899 cited by Toole 1941; Jacobs & McClay 1993), enabling the seed to stick to many surfaces. This physical adaptation combined with a large seed production (Andrews *et al.* 1996), means that many seeds (probably a small percentage of the large number produced) could be dispersed to new areas via a range of dispersal vectors. Giant rats tail grass seed dispersal vectors could include cattle manure (Andrews 1995b), cattle coats, other livestock, vehicles, machinery, water, hay and pasture seed (McIntosh *et al*. 1999). The large range of vectors makes control of seed dispersal difficult, although many of these vectors are under human influence (eg. cattle movement) and could be managed (Andrews 1995b; also see Bray *et al.* 1998a; 1998b; 1999 for work conducted in concurrent studies).

Efficient seed dispersal is also a feature of the two exotic case study species, giant parramatta grass (Betts and Moore 1996) and serrated tussock (Campbell 1998). Serrated tussock in particular produces enormous numbers of seed that are widely distributed by wind, providing little opportunity for controlling dispersal. Serrated tussock seed is also dispersed by other vectors including water, machinery, man and livestock (coats and intestines) (Campbell 1998). Serrated tussock seeds have been found 15.5km from the nearest infestation (Green 1956). Recent studies by Vogler (2002) found that wind dispersal in giant rats tail grass was limited, with no seeds collected in seed traps 3m downwind of an infestation.

For districts not yet infested with giant rats tail grass, an understanding of the weaknesses and strengths of giant rats tail grass seed dispersal is extremely important for minimizing further spread. Giant rats tail grass seed transport has not been investigated further in this thesis, although once giant rats tail grass seed has entered a pasture, the role of pasture competition in preventing or limiting seedling establishment has been examined (see Chapter 6).

2.4 *Effect of management and control techniques on giant rats tail grass*

As indicated earlier, pasture management and weed control techniques may be useful for manipulation of giant rats tail grass at different stages in its life cycle. A combination of management tools may help to shift and maintain the pasture species composition, limiting giant rats tail grass to a small proportion of the pasture. It is also important to identify management practices that contribute to increasing giant rats tail grass in the pasture. Understanding the processes that increase or decrease giant rats tail grass in a pasture may help tailor management strategies to avoid an increase and dominance of this species.

In this section of the literature review, various management and control techniques are reviewed for indications of how they may affect the population dynamics of giant rats tail grass. The case study species will be used if little information is available on how giant rats tail grass responds to the various techniques.

2.4.1 Grazing

Giant rats tail grass demonstrates tolerance of grazing (Edroma 1981) and resistance to grazing through low palatability (Lungu *et al.* 1995). Throughout its range in Africa, giant rats tail grass is a species characteristic of heavily grazed areas. This may be because it has a very strong root system, so the shoots are not uprooted (Lock 1972), and because the young shoot bases are deep inside the tussock base and thus protected from close grazing (Howell 1988). Some work has been conducted on the effect of grazing on giant rats tail grass. Edroma (1981) conducted a clipping experiment and found that giant rats tail grass grew vigorously and produced more herbage when grazed (clipped) than when ungrazed. Fitzgerald (1993) and Lungu *et al.* (1995) using livestock grazing experiments found that heavy stocking increased the basal area, frequency and proportion of giant rats tail grass plants in the pasture, probably due to the selective grazing of more palatable species.

Purple wiregrass appears to behave similarly, remaining dominant in unburnt grazed areas (Campbell 1996). Also, basal area decreased once grazing was removed. This suggests that purple wiregrass has a competitive advantage under moderate to heavy grazing, probably because the desirable grasses are being selectively grazed (Campbell 1996), reducing pasture competition. Parramatta grass (*S. africanus*) also thrives when pasture competition is poor, such as when pastures are unfertilised, run down or overgrazed (Dyason 1988).

Bishop *et al*. (1993) suggest that overgrazing is the major reason why giant rats tail grass has invaded many pastures in Queensland. Grazing sown pastures too heavily, not adjusting stocking rates in below-average rainfall years and generally inadequate knowledge of pasture management was suggested as the cause of overgrazing.

Grazing and pasture management by manipulating pasture competition is likely to be a key to preventing invasion of giant rats tail grass, or maintaining giant rats tail grass at a low level where it has already invaded.

2.4.2 Competitive pasture species and swards

Establishment and maintenance of competitive pastures will probably be crucial in a long-term giant rats tail grass control program. Competitive, healthy, well-managed pasture is recognised as an essential component for long-term weed control in pastures (Betts 1989). Irrespective of what initial method is used for control of serrated tussock, the final and most permanent treatment must be the establishment and maintenance of an improved pasture sward (Campbell 1960a). An example in this case would be, leniently grazed pasture dominated by *Phalaris aquatica* that is protected from reinfestation by removal of invading tussocks (Campbell 1998).

Bishop *et al.* (1993) suggest that giant rats tail grass has been allowed to invade many pastures in Queensland, due to a failure to sow giant rats tail grass infested areas with vigorous, stoloniferous, sward forming grasses with use of optimum fertiliser inputs and lenient grazing and a failure to act early on small infestations.

Some sown pasture species have been recommended for use in giant rats tail grass areas in Queensland (DNR 1998) based on landholder experience and simple demonstration plots. However, little formal assessment of sown pasture species for use in giant rats tail grass control strategies has been conducted, although some informal rating has been conducted at Mackay and Bundaberg (H. Bishop & J. Wright *pers. com.*).

2.4.3 Herbicides

Many references exist on the use of herbicides to change the botanical composition of pastures (eg. Smith & Cole 1972; Campbell & Gilmour 1979; Brecke 1981; Young *et al.* 1998) and occasionally soil seed banks (Bourdot & Hurrell 1992). Few herbicide applications appear to be effective in the long-term, as the target species often recover in the ensuing years from the soil seed bank. In many cases the pastures have not been monitored past the initial kill so the long-term effectiveness is unknown.

Currently, only two herbicides are registered for post-emergent use on giant rats tail grass in Australia - glyphosate and flupropanate (DNR 1998). Don Loch (*pers. com.)*

has evaluated a large range of chemicals for potential use on giant rats tail grass with little success.

Two methods are available for applying post-emergent glyphosate; using a spray apparatus or using a wick wiper where the chemical is wiped on the plant by brushing a herbicide saturated wick over the plant canopy (DNR 1998). The wick wiper allows non-selective herbicides to be applied selectively to tall species, thus avoiding short or heavily grazed palatable species.

To date the use of herbicides has achieved mixed results with many giant rats tail grass infestations recovering quickly after application. This may be partly due to operator error and in some cases not following strict application schedules (G. Elphinstone *pers. com.*).

2.4.4 Fire

Fire and fire management may have an effect on giant rats tail grass. Cox & Morton (1986) investigated fire in relation to *S. wrightii* (big sacaton) in the USA. They found that spring and autumn burning resulted in a long-term reduction in live biomass and standing crop, whereas mid-summer burning allowed the live biomass of *S. wrightii* to recover in one year and standing crop in 3 years.

The investigations conducted by Campbell (1996) highlighted the role of spring burning in increasing the proportion of desirable *Heteropogon contortus* at the expense of the undesirable purple wiregrass. Fire restricts the recruitment potential of purple wiregrass through its deleterious effects on both seed and seedlings. Burning also sets back the established plants. Orr *et al*. (1997) burnt *Aristida* pastures once per year for three years and found burning reduced the basal area of *Aristida* in the first year, but after the second burning the basal area did not appear to drop further. Concurrently, *Aristida* plant density only declined after burning in the third year. Burning often reduced the number and size of segments within *Aristida* plants rather than causing the death of whole plants (Orr *et al*. 1997).

Burning is not always detrimental to weeds. Experience with burning serrated tussock in New Zealand and New South Wales indicated that burning by itself was not only futile as a method of control, but is one of the most efficient means of promoting serrated tussock (Green 1956).

There appears to be some confusion regarding the effect of fire on giant rats tail grass infestations. Experiences of some landholders indicates that fire is highly detrimental, quickly creating a dense giant rats tail grass infestation, while other landholders have found no harmful effects of fire and maintain that the fresh shoots provide some useful short-term forage (G. Elphinstone *pers. com*.).

Potentially, burning giant rats tail grass infested pasture may reduce root and shoot competition and allow more giant rats tail grass seed in the soil seed bank to germinate and establish and thus increase the density of the infestation. A combination of high light levels, high temperatures and temperature fluctuations can induce giant rats tail grass (Andrews 1995a; Andrews *et al.* 1997) and some other grasses, for example *H. contortus* and *Themeda triandra* (Tothill 1969; Lock & Milburn 1970) to germinate and grow. Burning can increase light intensity, soil temperatures, soil temperature fluctuations and availability of soil water through reduced mature-plant transpiration (Tothill 1969; Ruyle *et al*. 1988). This may allow giant rats tail grass seeds to germinate and establish, although Cook (1980b) found, that apart from a couple of specific examples, there were few data indicating that burning reduced root competition sufficiently in a pasture sward to improve establishment of over-sown legume and particularly grass species. Cook's paper added that burning might increase establishment in situations where competition for light (shoot competition) is important, such as humid coastal environments receiving more than 1000mm rainfall, or where the soil fertility is high enough to support a dense sward.

2.4.5 Cultivation

Roberts & Dawkins (1967) studied the effect of regular cultivation on the soil seed bank in previously cultivated pasture-land in England. They found that the numbers of viable weed seeds in the soil seed bank declined faster with more regular cultivation and that more seedlings emerge with more regular cultivation. Bourdot & Hurrell (1992) found the soil seed bank of *Stipa neesiana* was depleted by 66%, 68% and 77% per year with 1, 2 and 6 cultivations per year respectively. Seed losses were not assigned to seed germination or seed mortality.

Cultivation will probably have a large effect on the giant rats tail grass soil seed bank and the impact on seedling emergence and seed mortality should be monitored.

2.4.6 Slashing

Landholder experience suggests that slashing has no effect on the abundance of giant rats tail grass. Rodel & Scheerhoorn (1976) mowed star grass *(Cynodon nlemfuensis* cv No2) pastures in Africa containing giant rats tail grass every 15 days to a height of 5cm over a range of nitrogen fertiliser levels and found that mowing had no effect on reducing the giant rats tail grass infestation. However, some circumstantial evidence in Queensland suggests that giant rats tail grass was reduced with regular slashing of an invaded sports ground (G. Elphinstone *pers. com*.).

Giant rats tail grass is a tall grass (~1.7m), which may mean it is at a competitive disadvantage with regular slashing, compared other shorter species that have a greater proportion of their shoot biomass below slashing height. Surprisingly however, Edroma (1981) found that giant rats tail grass was more resistant to the effects of repeated clipping than many other species and concluded that close clipping (simulating heavy grazing) was responsible for creating and maintaining dominance by *Sporobolus*.

Slashing at specific times may potentially reduce giant rats tail grass seed production and therefore affect the soil seed bank (Bourdot & Hurrell 1992; Andrews *et al.* 1996).

2.4.7 Fertilisation

Giant rats tail grass is regarded as a pioneer (or seral) perennial species in Africa and can take up, utilise and respond to nitrogen fertiliser more than many other annual and climax perennial species, such us *Hyparrhenia filipendula* (Wiltshire 1972; Bate & Heelas 1975). Work by Rodel & Scheerhoorn (1976) indicated that the fertiliser response of giant rats tail grass depended on the amount of fertiliser applied. When less than 340kg N/ha/year was applied to star grass *(Cynodon nlemfuensis* cv No2) pasture on silt-rich soil, giant rats tail grass invaded and tended to assume dominance. It reached up to 60% of the total basal cover after two years when only 170kg N/ha/year was applied, but if the level of nitrogen fertiliser was increased above 350kg N/ha/year the proportion of giant rats tail grass was reduced. However, it was suggested that the cost of applying this amount of fertiliser would be prohibitive.

Fertiliser application is regarded as an important part of establishing and maintaining a competitive pasture sward where weed control is crucial (Campbell 1960a; Betts 1989; Bishop *et al*. 1993; Campbell 1998). Currently, there are no data on the effect of applying fertiliser on the competitive ability of giant rats tail grass nor its effect on giant rats tail grass seedling emergence and establishment in Queensland.

2.4.8 Biological control

Biological control was not investigated in this project, but will be reviewed briefly. Hetherington (1997) tested four species of *Bipolaris* fungi for their potential for giant rats tail grass bio-control. Under natural conditions ovariicolous *Bipolaris* was unable to reduce recruitment of weedy *Sporobolus*. Therefore it was suggested that it was unlikely that enhancement of the disease through inundative release of *Bipolaris* as a bio-herbicide would provide control, largely due to the abundant seed production and compensatory mechanisms of *Sporobolus*. Biological control of giant rats tail grass should be pursued due to the serious economic impact of the weed, however success will be complicated by the genetic diversity within giant rats tail grass (Hetherington & Irwin 1999). Recently, a stem-boring wasp (*Tetramesa spp.*) and a leaf infecting smut (*Ustilago sporoboli-indici*) that are potential control agents for giant rats tail grass have been identified in South Africa. Plans are underway to conduct host-specifity testing for these organisms (B. Palmer *pers. com.*).

2.5 *Summary of topics which will be addressed in this thesis*

Gaps in the current knowledge of giant rats tail grass that will be addressed in this thesis are listed in this section. The relevant chapter numbers are shown in brackets.

Gaps in the current knowledge of giant rats tail grass ecology include:

- A lack of understanding of the weaknesses and strengths of giant rats tail grass throughout its life cycle in Australian pastures (Chapters 4, 5 and 6).
- Changes in giant rats tail grass soil seed bank size and longevity (soil seed bank dynamics) when subjected to a range of management techniques (eg. fire, cultivation, slashing, fertiliser and grazing) (Chapter 4).
- Giant rats tail grass germination and seedling emergence in the field as affected by plant competition and different levels of pasture cover (Chapters 4, 5 and 6).
- Survival and growth of giant rats tail grass seedlings and their susceptibility to pasture competition (Chapters 4, 5 and 6).
- Effect of management tools (eg. fire, slashing, fertiliser and grazing) on the growth and survival of mature giant rats tail grass tussocks and their relationship with associated pasture species (Chapter 4).
- Effect of management tools (eg. fire, slashing, fertiliser and grazing) on seed production of giant rats tail grass (Chapter 4).
- An assessment of pasture species with strong competitive ability against giant rats tail grass, at different stages of establishment (Chapters 4 and 5).

CHAPTER 3 General materials and methods

This chapter contains a description of the experimental sites and the rainfall they received during the experimental period. General sampling methods and sample processing techniques are also described. The limitations of the techniques are discussed.

3.1 *Site descriptions*

Four field sites in south-east Queensland were used for the experiments; Gympie, Kilcoy, Foxtail Flats (south-east of Miriam Vale) and Gayndah. The chosen sites each had different soil types and climatic conditions, but each site was relatively uniform in terms of soil type and giant rats tail grass density.

3.1.1 Gympie site

The Gympie site was a field site for the management manipulations experiment (Chapter 4) and sown competitive species evaluation (Chapter 5). The site was located 26km north-east of Gympie near the township of Goomboorian (26^{o}03'3"S, 152^{o}46'33"E). The area of the site was approximately 2.5ha, fenced out of a larger paddock. The soil ranged from a black earth to a brown clay (Ug5.11) on a gentle (<6%) toe slope. The soil analysis data are presented in Table 3.1. The property was historically a dairy farm, but has run beef cattle for at least the last 25 years. The main pasture species were *Sporobolus pyramidalis* (giant rats tail grass), the stoloniferous grasses *Chloris gayana* (rhodes grass) and *Axonopus affinis* (carpet grass), and the often prostrate grass *Paspalum dilatatum* (paspalum)

The monthly rainfall for the experimental period is presented in Figure 3.1 with the long-term average annual rainfall for the site being ~1400mm. Rainfall during the experiment was below average, except in early 1999 when rainfall was well above average. Rainfall in 1997 was very low.

Table 3.1 Soil analysis data for the four giant rats tail grass project research sites at two soil profile depths (cm).

(Gympie – Gym.; Kilcoy – Kil.; Foxtail Flats – Fox.; Gayndah – Gayn.) Except for the Gayndah site, soil was collected and analysed from the research site. The Gayndah site data was from a sampling location near the research site (Reid *et al.* 1986).

Soil attribute	Units	Gym. 0-10	Gym. 10-20	Kil. 0-10	Kil. 10-20	Fox. 0-10	Fox. 10-20	Gayn. 0-10	Gayn. 20-30
pH	-	6.0	6.1	5.7	5.9	6.4	7	7.7	8.2
EC	mS/cm	0.12	0.11	0.07	0.04	0.05	0.03	0.06	0.21
Cl	mg/kg	38	42	33	31	34	37	60	270
N	mg/kg	3.4	-	12.6	1.5	10.1	3.3	-	-
P	mg/kg	29	-	33	-	8	-	-	-
S	mg/kg	39.7	-	14.5	-	5.3	-	-	-
Ca	meq/100g	19	18	6.7	5.1	1.2	0.94	18	18
Mg	meq/100g	10	10	2.4	1.9	0.65	0.47	13	15
Na	meq/100g	1.2	1.5	0.33	0.37	0.15	0.15	1.7	3.9
K	meq/100g	0.36	0.16	0.31	0.16	0.22	0.08	0.94	0.46
C. Sand	%	21	-	14	-	14	-	16	15
F. Sand	%	15	-	23	-	60	-	20	20
Silt	%	14	-	41	-	20	-	15	14
Clay	%	41	-	18	-	9	-	49	48
15Bar	%	28	-	15	-	5	-	21	-
OC	%	4.6	-	3.8	-	1.1	-	1.34	0.94
ESP	%	3.9	5.1	3.3	4.9	6.8	9.1	5.1	10.4

C.Sand = coarse sand, F.Sand = fine sand

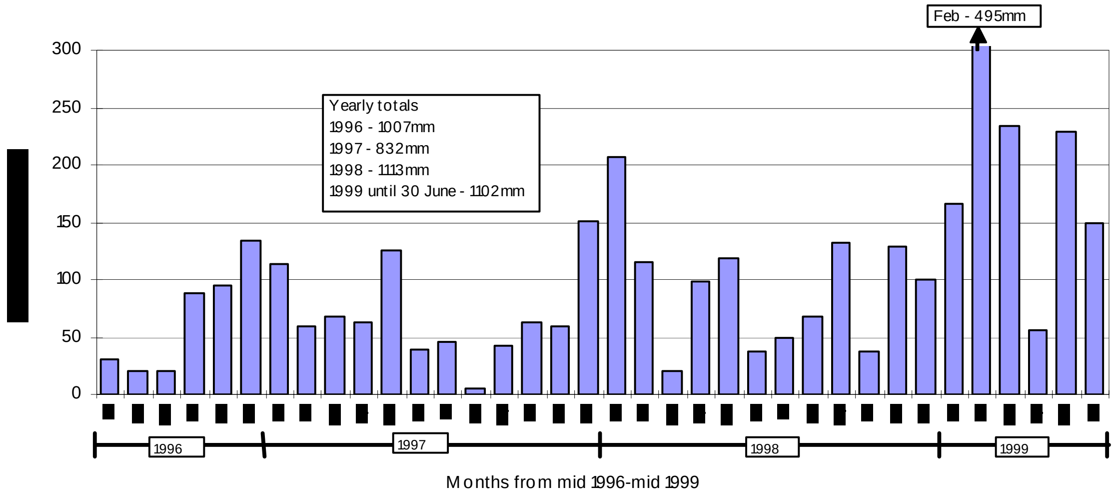

Figure 3.1 Monthly rainfall at the Gympie giant rats tail grass site from mid-1996 to mid-1999. Long-term average annual rainfall for the site is ~1400mm. Experiments began at the site in November 1996.

3.1.2 Kilcoy site

The Kilcoy site was a field site for the management manipulations experiment (Chapter 4) and sown competitive species evaluation (Chapter 5). The Kilcoy site (26^{o}48’53”S, 152^{o}33’53”E) was located approximately 13km north of the Kilcoy township on a gently undulating terrace plain. The area of the site was approximately 3ha, fenced out of a much bigger paddock and was approximately 80m from a creek. The soil type was a Brown Dermosol Gn3.90 (loam). The soil analysis data are presented in Table 3.1. The property was historically a dairy farm but has run beef cattle for in excess of 20 years. The main pasture species were *S. pyramidalis*, the stoloniferous grasses *A. affinis* and *Digitaria didactyla* (blue couch) and the often prostrate grass *P. dilatatum*.

The monthly rainfall for the experimental period is presented in Figure 3.2, with the long-term average annual rainfall for the site being ~1000mm. In 1997, the rainfall was below average, while in late 1998 and early 1999 the rainfall was above-average.

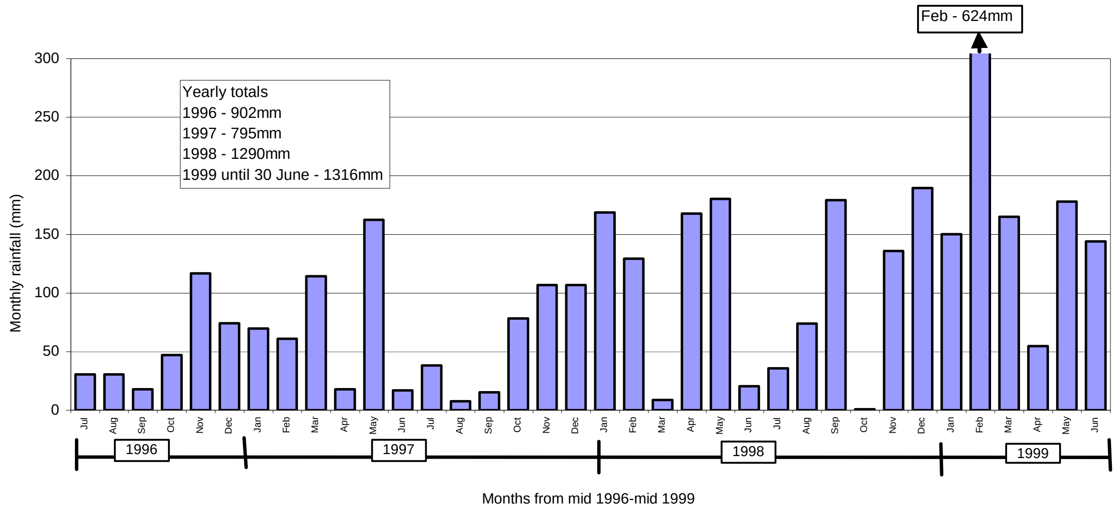

Figure 3.2 Monthly rainfall at the Kilcoy giant rats tail grass site from mid-1996 to mid-1999. Long-term average annual rainfall for the site is ~1000mm. Experiments began at the site in February 1997.

3.1.3 Foxtail Flats site

The Foxtail Flats site was a field site for the management manipulations experiment (Chapter 4) and sown competitive species evaluation (Chapter 5). The Foxtail Flats site (24°24'42"S, 151°46'59"S) was approximately 28km south-east of Miriam Vale on a 1% footslope. The site area was approximately 2.5ha and was the fenced off corner of a much larger paddock. Soil type was a Redoxic Hydrosol or Soloth, which was very slowly permeable and poorly drained. The soil had a sandy loam topsoil over a clayey subsoil. The soil analysis data are presented in Table 3.1. The property historically carried beef cattle, with stylos oversown in the 1970's. The dominant pasture species were *S. pyramidalis*, with small amounts of the native tussock grasses *Heteropogon contortus* (black spear grass), native *Sorghum* species and the upright *Imperata cylindrica* (blady grass). Little stoloniferous grass was present at this site.

The monthly rainfall for the experimental period is presented in Figure 3.3 with the long-term average annual rainfall for the site being ~1200mm. Rainfall was well below average in 1997.

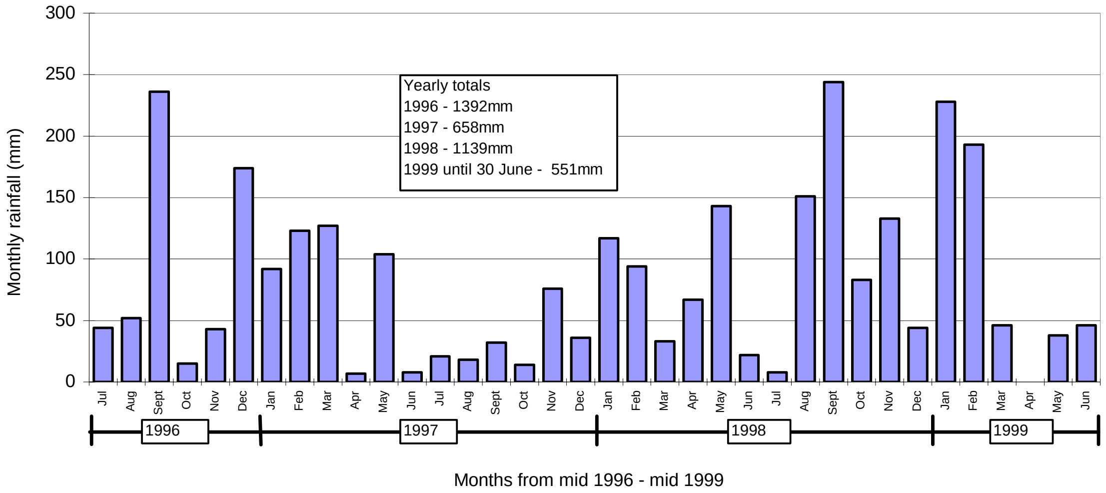

Figure 3.3 Monthly rainfall at Foxtail Flats service station (~6km south of the Foxtail Flats giant rats tail grass site) from mid-1996 to mid-1999.
Long-term average annual rainfall for the site is ~1200mm. Experiments began at the site in March 1997.

3.1.4 Gaydah site

The Gayndah site was the location of the plant house (soil seed bank sample processing), a field site for the sown competitive species evaluation Chapter 5) and the sole site for the seedling competition experiment (Chapter 6). The Gayndah site was located at Brian Pastures Research Station (25°39'S, 151°45'E), 18km ESE of Gayndah in the Central Burnett region. The area of the site was approximately 2ha that had been fenced off from grazing for 2.5 years to limit further spread of giant rats tail grass. The site was located on a gently undulating brown clay (Reid *et al.* 1986 - Barambah soil type). The soil analysis data are presented in Table 3.1. The property has been used for beef cattle grazing. The main pasture species were the native tussock grasses *H. contortus*, *Bothriochloa bladhii* (forest bluegrass) along with some *S. pyramidalis*.

The monthly rainfall for the trial period is presented in Figure 3.4, with the long-term average annual rainfall for the site being ~710mm. Rainfall in 1997 was below average and in 1998 above average.

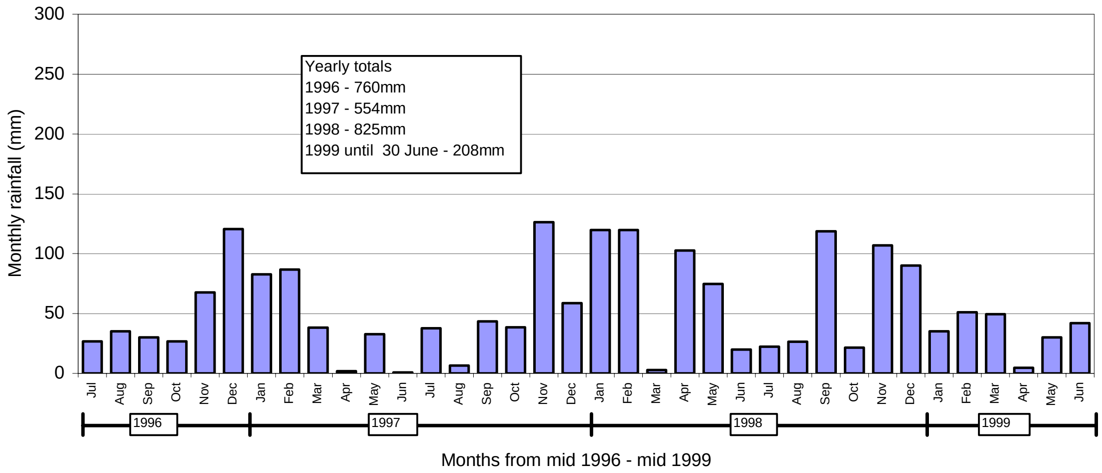

Figure 3.4 Monthly rainfall at the Gayndah giant rats tail grass site from mid-1996 to mid-1999. Long-term average annual rainfall for the site is ~710mm. The sown pasture species evaluation (Chapter 5) began in October 1997 and the competition experiment (Chapter 6) in February 1998.

3.2 *Sampling methods for perennial tussock grass ecology*

The general sampling methods and sample processing techniques used in the experiments are described in this section. Any debate about a technique in the literature will be discussed and the basis for choices between alternative methods will be described.

3.2.1 Laboratory seed germination

Seed viability was tested by germinating seeds in the laboratory using an incubation cabinet. The seeds were placed in petri dishes on wet filter paper, and placed in the incubator. The incubator was run on a 15/35^{o}C night/day cycle, as giant rats tail grass requires alternating temperatures and light to germinate (Andrews *et al.* 1997). Deionised water was used to wet the filter paper, although water quality had no reported effect on giant parramatta grass germination (Andrews 1995a).

Seed was stored dry (glumes and other spikelet parts were often still attached), in plastic or paper bags in the laboratory until required. Storage periods were not considered to be a problem, as Andrews (1995a) found that a storage period of 3 years had no effect on seed viability of giant parramatta grass and parramatta grass (*S. indicus*), although it reduced seedling vigour as measured by coleoptile length. Seedling vigour is not a major consideration when measuring seed viability.

3.2.2 Soil seed bank size

Three issues arise when sampling the soil seed bank; depth of soil to sample; surface area of soil to sample; and, the technique used to process the soil sample and estimate the number of seeds. These issues will be briefly reviewed in relation to giant rats tail grass and the actual technique used will be described at the end of this section.

3.2.2.1 Soil seed bank sample depth

Most seeds in the soil seed bank, including seeds of giant parramatta grass and *Stipa neesiana*, are found in the top 2.5cm (McIvor 1987; Bourdot & Hurrell 1992; Andrews 1995a) or 5cm (Jones & Bunch 1977; Graham & Hutchings 1988) of soil. Soil seed bank samples are usually restricted to the 0-5cm zone when only major differences are required, as seeds below 5cm are unlikely to emerge in undisturbed pasture (Andrews 1995a). Sampling to 10cm has the disadvantage of doubling the amount of soil to be processed (Jones & Bunch 1977) and seeds that are permanently buried too deeply are not an effective part of the soil seed bank (Harper 1977).

Cultivation may distribute seed over a greater depth range. These seeds have the potential to germinate and emerge with re-cultivation (Froud-Williams *et al*. 1984) and therefore sampling the soil seed bank to 10cm should be considered if there is a possibility of seed buried at depth being brought to the surface by cultivation (Jones & Bunch 1988).

3.2.2.2 Soil seed bank sample area and core number

Significant spatial variation can occur in the numbers of seeds in the soil seed bank (Champness 1949). Therefore reliable monitoring of changes in soil seed bank size can be difficult. There are two parts to estimating the size of the soil seed bank; surface area sampled and number of individual cores sampled.

Forcella (1984) suggested a soil seed bank sample area of 200cm^2 per plot and 800-1000cm^2 per treatment was sufficient to characterise the diversity of species in a pasture soil seed bank. Forcella (1984) believed that a soil sample that is large enough to contain representative numbers of most taxa should also be large enough to statistically determine the densities of these species. In the literature a large range of soil surface areas have been sampled and used to determine soil seed bank size, for example; 81 cm^2/plot (Williams 1984), 180 cm^2/plot (Roberts & Dawkins 1967; Roberts & Feast 1973a), 245 cm^2/plot with 2 plots per treatment (McIvor 1987) and 462 cm^2/plot (Graham & Hutchings 1988).

The second aspect of soil seed bank sampling is determining how to sample the required surface area. Sampling many cores and bulking to produce 1 sample per plot reduces individual core variability (Jones & Bunch 1977). One method is to sample many cores in a grid pattern across the plot or paddock (Jones & Bunch 1988).

3.2.2.3 Processing of soil seed bank samples

Two techniques are available for processing soils to determine the size of the soil seed bank (Simpson *et al*. 1989):

1. Seed separation from the soil sample and subsequent identification and counting (measures total soil seed, may need to subsequently test for seed viability)
2. Seedling emergence from the soil sample followed by identifying and counting the seedlings (counts germinable seeds only).

Seed separation and counting method: Jones & Bunch (1988) describe a method for seed recovery from soil using wet sieving, aspiration, flotation and a second aspiration, followed by hand separation. This technique was designed to separate legume seed with a seed weight of 0.3mg to 12.5mg. Therefore, this technique may not be suitable as giant rats tail grass seed is small (0.1 mg/seed, Sharma 1984; 0.14 mg/seed, Andrews 1995a). The separation technique recovers seeds in a specific size class and allows assessment of the percentage of hard seed, which is useful for legumes.

Experience with heavier textured soils suggests that they are difficult to wash out (the Gympie and Gayndah site soils are heavy textured) and the technique uses some chemicals for floating off organic material that can be toxic to humans, for example perchlorethylene (Jones & Bunch 1988). Andrews (1995a) used a similar method for separating out giant parramatta grass seed, which were then immersed and incubated at alternating temperatures and the germinated seeds counted. Ter Heerdt *et al*. (1996) found that the seed separation method was very time consuming and ineffective for small-seeded species, especially in large-scale studies.

Another similar method for separating seeds from soil without sieving is to make a slurry using a concentrated inorganic salt solution which is then centrifuged (Luschei *et* *al.* 1998). This technique was good for counting seeds, but can affect seed viability (Luschei *et al*. 1998).

The seed separation method was not used in this study due to the difficulty of separating small seed from soil (especially heavy textured soils) and the time required to process a large number of samples. The seed viability can also change with sample processing.

***Seedling emergence method*:** Roberts & Dawkins (1967) described a method for germinating seeds from a soil sample to estimate the soil seed bank size. The soil sample was spread out in shallow trays over a layer of sand. The soil was kept moist. The emerged seedlings were identified, counted and removed. The soil was periodically disturbed to encourage further germination. McIvor (1987) used a similar method but with only a single germination period, which probably resulted in an underestimation of the total number of viable seeds. Forcella (1984) determined that three to four sample mixings were sufficient to promote the germination and emergence of most species with viable seeds in the soil.

This method requires that the soil be regularly watered to prevent seedling death prior to identification and counting. Orr *et al.* (1996) investigated two methods of watering for determining the size of the germinable soil seed bank. The two methods were overhead spraying (sprinklers) and the capillary method (pots sitting in shallow trays of water). The overhead sprinkler method produced significantly higher seedling emergence than the capillary method and gave more reliable estimates of seed numbers. They considered that using overhead sprinklers more closely resembled the natural processes in the field, where seeds are subjected to daily fluctuations in moisture potential, rather than being continuously wet as occurs with the capillary method. Problems were also encountered with the capillary method as some seedlings were 'damped-off', possibly killed by microbial or fungal attack due to the soil remaining too wet (Orr *et al*. 1996).

The depth of the soil layer on top of the sand also requires consideration. A soil layer approximately 1cm deep should allow most giant rats tail grass seeds to emerge, as Andrews (1995a) found that most giant parramatta seeds emerged from a depth of 1cm, with few seedlings emerging from 2cm.

The seedling emergence method only measures those seeds in the soil seed bank that are germinable and vigorous enough to emerge, producing an identifiable seedling under plant house conditions (Simpson *et al*. 1989). Seeds that do not germinate, or germinate but do not produce an identifiable seedling are not counted. Therefore, this method may provide an underestimate of the total number of seed in the soil seed bank (Simpson *et al*. 1989).

3.2.2.4 Technique used for giant rats tail grass soil seed bank sampling and processing

The soil seed bank was sampled using a soil corer (5cm diameter) that was pushed into the soil to a depth of 5cm. Occasionally a core did not remove the full 5cm profile. A core was rejected if less than approximately 3.5cm of the profile was sampled. Generally ten cores per plot were collected at each sampling (196 cm^2/plot). Ten cores were sampled in a grid pattern across the plot. The permanent quadrats and seedling count mesh (Chapter 4) were avoided when sampling soil cores. The ten cores for each plot were bulked and placed in a paper bag. The sample was dried in a plant house or in a forced-air drier at 40^oC. The cultivation treatment (October 1997 to spring 1999) and competitive species treatments prior to sowing (October 1997 only) in the management manipulations experiment (Chapter 4) were sampled to a depth of 10cm due to the mixing of the soil by cultivation, potentially bringing buried seed to the surface. After sowing, the competitive species treatments were only sampled to 5cm, as giant rats tail grass seeds that are permanently buried beyond this depth are not an effective part of the soil seed bank (Harper 1977).

The seedling emergence method (or germinable seed bank method) was used to estimate seed numbers in the soil seed bank. The dried soil sample from each plot was crushed to break up individual cores and spread in a plastic germination tray (28x35cm) on a 1.5-2cm deep bed of sand. The bottom of the plastic tray was covered with shade cloth or weed matting to prevent the sand falling through the drainage holes. The soil layer was approximately 1-1.5cm deep. Samples from the cultivation and competitive species treatments that were sampled to a depth of 10cm (twice the soil volume) were split and spread on two trays. The trays within each site were randomly placed on tables in a plant house and watered by overhead sprinklers.

Giant rats tail grass seedlings were identified (see McIntosh *et al.* 1999 for illustration of main distinguishing character – no visual hairs at the joint between the leaf blade and leaf sheath), counted and removed periodically. Seedlings of other species were removed but not counted. When seedlings stopped emerging, the sprinklers were turned off and the trays allowed to dry. The soil layer was then broken-up, mixed and again spread in the tray. Samples were subjected to at least two drying cycles following the initial seedling flush until few seedlings were emerging. The 'growing-out' process generally took ten months. Some trays were kept longer to see if more giant rats tail grass seedlings would emerge, but few did, so the cycle number and time period were regarded as satisfactory. The number of seedlings counted per sample was converted to seedlings per unit area sampled and used as an estimate of the germinable soil seed bank (giant rats tail grass seeds/m^2) for each plot.

3.2.3 Population dynamics sampling

Detailed studies on the dynamics of plant populations in response to management practices provide a clear understanding of the plant processes that cause species to respond differently to imposed management practices (Campbell 1996). A number of techniques can be used to study the population dynamics of certain species or communities of species. Techniques that will be used are, charting permanent quadrats and the BOTANAL technique that estimates individual species yield and frequency for a plot.

3.2.3.1 Review of charting tufted perennial grasses in permanent quadrats

Charting or mapping plants in permanent quadrats (plot or transect) that can be revisited at a later date, can be a powerful tool for determining how certain species react to different management regimes. Many workers have used charting as an effective tool for examining the population dynamics of tufted, perennial grasses (eg. Williams 1970; Campbell 1996; Orr *et al.* 1997) and woody plants (Back *et al.* 1997). Campbell (1996) and Orr *et al.* (1997) used charting to study the population dynamics of the desirable

Heteropogon contortus (black speargrass) and the undesirable *Aristida ramosa* (purple wiregrass) in response to spring fires and defoliation strategies. Population size, recruitment and survival were monitored to study the impact of the different strategies. Other measurements can also be recorded for individual charted plants including, basal diameter (to calculate basal area), plant height and inflorescence number.

A number of techniques can be used to map the plants in a permanent quadrat, eg. using a pantograph (Williams 1970; Campbell 1996; Orr *et al*. 1997), using photography or digital image capture (Owens *et al.* 1985; Roshier *et al.* 1997) or by charting free hand (R. Silcock *pers. com.*). Charting free hand was choosen for use in the giant rats tail grass studies, as giant rats tail grass plants are tall tussocks and form dense infestations. This means that operation of a pantograph would be difficult and probably less accurate (R. Silcock *pers. com.*), while photography and prediction of basal area under a dense canopy cover would be virtually impossible.

One issue that arises with charting is that tussocks can split into a number of segments. Therefore the issue of whether asexual reproduction has occurred to form new plants or whether the segments are still part of the original plant needs to be resolved (Abrahamson 1980). Orr *et al*. (1997) found that as tussocks of *Aristida* species age they tend to break down into separate segments. Each segment was recorded and regarded as part of the original plant, and at subsequent recordings, that plant was considered to be alive if one or more segments remained. Such fragmentation is not as problematic where basal area of each plant species is used for data analysis instead of plant number.

3.2.3.2 Technique used for charting giant rats tail grass plants in permanent quadrats

Charting permanent quadrats was used in the management manipulations experiment (Chapter 4). Three permanent quadrats (0.5x0.5m) were randomly located in each plot. The 5x5m plots (inside a 1m border) were divided into 25 locations of $1m^2$ and three locations were randomly chosen for quadrat installation. Each quadrat was then positioned, ensuring there were giant rats tail grass plants in the quadrat and preferably the tussocks were either fully in or out of the quadrat. Two pegs were positioned in diagonal corners to permanently locate each quadrat. Pegs in plots that were slashed or wick wiped were hit down to height of ca. 5cm to avoid damage. A taller marker peg was located near the top left peg and was used to locate the permanent quadrat pegs. The marker peg was removed before and replaced after each slashing. The permanent quadrat pegs were removed from the cultivation and competitive pasture treatments after the initial sampling. The distance from the permanent quadrat to the plot corners was measured to allow relocation of the permanent quadrats at a later date. After the original sampling the cultivation plots were not charted again until the final sampling. Permanent quadrats were relocated to the original pre-sowing positions in the competitive species plots after sowing.

Charting involved individually mapping all giant rats tail grass plants within each permanent quadrat (other species not measured). This was done using two operators. One operator located a plant in the quadrat and relayed the plant position and shape to the second operator. The second operator transcribed the position and shape onto a recording sheet with the outline of a quadrat. Accurate mapping was achieved by using a coordinate system from two sides of the quadrat (eg. tussock is an oblong contained within 13 and 17cm from the side and, 6 and 12cm from the top of the quadrat). At subsequent recordings the original charts were placed under tracing paper to enable faster mapping and to check on plants that may have died, ensuring they were not missed.

Other measurements were recorded for each mapped plant including:

- Basal diameter in two perpendicular directions.
- Plant height from the ground to the tip of the tallest inflorescences or green part of leaves when pulled straight up.
- Number of inflorescences that still had inflorescence branches attached (old inflorescences that had lost all their branches were not counted).

Data collected on giant rats tail grass by charting included:

- Basal area (cm^2/m^2).
- Plant density (plants/m^2).
- Plant height (cm).
- Inflorescence density (inflorescences/m^2).
- Plant death and recruitment.

Basal area for circular or oval shaped plants was estimated by averaging the two basal diameters and calculating the area of a circle. Correction factors were applied for long/narrow plants and "horse-shoe" shaped plants. The correction factor for a particular plant shape (eg. horse-shoe) was derived from twenty plants. The ratio was calculated between the actual basal area and the calculated basal area assuming the plant was circular (i.e. area of a circle using the mean of the two basal measurements). Actual basal area was measured by placing a grid over the plant outline and counting the squares.

The permanent quadrats were sampled approximately every six months from summer 1996/97 until autumn 1998, with a final sampling a year later in autumn 1999.

3.2.3.3 Technique for determining pasture yield and botanical composition

BOTANAL is a technique used to estimate yield, botanical composition and other important attributes of pastures using calibrated visual estimation (Tothill *et al*. 1992). The major advantage of BOTANAL is that it allows rapid and non-destructive measurements, which is important in small plots and takes only one-tenth the time required for cutting and sorting the same number of quadrats (Waite 1994).

BOTANAL sampling was conducted approximately every 6 months in the management manipulations experiment (Chapter 4). At most sampling dates two operators assessed 12 quadrats (0.5x0.5m) each per plot (total of 24 quadrats/plot). The operators walked (~1.5m apart) across the plot and assessed 6 quadrats within 5m, then moved down the plot and walked back across the plot assessing another 6 quadrats. Data were entered directly into hand-held computers and analysed using the BOTANAL program (Tothill *et al*. 1992).

Data collected for each plot using the BOTANAL technique were:

- Dry matter yield of the plot (kg/ha).
- Species or species group contribution to total yield (percentage of dry weight method).

- Frequency of species or species group (percentage of quadrats containing a particular species or species group).

Large numbers of species occur in a pasture but often only in small amounts. Therefore groupings were made for various minor plant types (eg. broad leaf weeds). A relatively low number of species make up the majority of the pasture (eg. carpet grass) and these were assessed individually. Species and species groups used in the BOTANAL assessment were:

1. giant rats tail grass *Sporobolus pyramidalis*
2. blue couch *Digitaria didactyla*
3. carpet grass *Axonopus affinis*
4. paspalum *Paspalum dilatatum*
5. rhodes grass *Chloris gayana*
6. creeping blue grass *Bothriochloa insculpta*
7. black spear grass *Heteropogon contortus*
8. other sown/naturalised grasses
9. other native grasses
10. sedges
11. dead giant rats tail grass still standing and attached (no live tillers)
18. sown/naturalised legumes
19. broad leaf weeds, native legumes
20. bare ground

3.2.4 Seedling emergence assessment

Permanent quadrats were used in the management manipulations experiment (Chapter 4) and competition experiment (Chapter 6) to measure seedling emergence. Only the method used in the management manipulations experiment (Chapter 4) will be described in this section.

The total number of giant rats tail grass seedlings (seedlings/m^2) to emerge in each treatment was estimated by regularly counting and removing seedlings that emerged in an elongated permanent quadrat (Note: Emerged identifiable seedlings, not the number of established or recruited seedlings. Recruited seedling are defined as having survived greater than 8 weeks, see Section 6.5.2.2 & Fig. 6.13). A single, elongated quadrat (2.2x0.19m – 0.41m^2) made from concrete reinforcing mesh was located permanently in each plot. A long, narrow quadrat was used instead of a square quadrat because it extends across a number of microsites. The narrow quadrat also made the search for giant rats tail grass seedlings easier. The quadrat was randomly located in each plot, with care taken to avoid the permanent charting quadrats. Seedling counts were conducted usually every 8-12 weeks or after there appeared to be a significant germination event. The permanent quadrat in the cultivation treatment was removed and relocated before and after each cultivation.

The charting technique also located and measured emerged seedlings and then followed those plants for the duration of the experiment.

3.2.5 Seed production measurement

Two measures of reproductive success were used in this study. The numbers of inflorescences were counted for individual plants during charting in the management manipulations experiment (Chapter 4) and at each sampling date in the competition experiment (Chapter 6), while the actual seed fall was measured over two seasons using seed traps in five treatments in the management manipulations experiment (Chapter 4).

The seed traps were germination trays (28x35cm) lined with fine nylon mesh (250µm) glued to the tray with silicon. Water was able to quickly drain through holes in the bottom of the trays, preventing germination of trapped seed. Metal frames with steel mesh across the top were made to hold the trays and prevent damage from grazing cattle. Five treatments in the management manipulations experiment (Chapter 4) were sampled (control, slash, fire, fertiliser and farmer management treatments). Two trays were installed per plot. The trays were emptied twice in the 1997/98 season and once at the end of the 1998/99 season. Problems were encountered with the nylon mesh shrinking and pulling away from the tray. Therefore repairs were required regularly, especially in plots with short pasture (eg. the slash treatment) where the trays were exposed to the sun. Some giant rats tail grass seed would have been lost; therefore seed production values may be an underestimate. Prior to slashing of the slash treatment, the inflorescences hanging directly above the seed trap were cut off and added to the trap.

The seed traps were removed immediately prior to slashing and burning and replaced soon after.

Seed trap samples contained seeds of a range of species and often a lot of plant debris, insect carcasses and occasionally soil. This made the processing of samples difficult and time consuming (3-7 hours per sample). Hence, it was decided to process only one seed trap from each treatment per site. The giant rats tail grass seeds were separated from larger and smaller material using sieves and then aspirated to remove light material. The sample was then hand sorted to separate and count the giant rats tail grass seeds. Seed number was then converted to seed production/m^2.

3.2.6 Total ground cover estimation

Total ground cover in the management manipulations experiment (Chapter 4) and competitive species evaluation (Chapter 5) was estimated by visual assessment, initially using the standards from a pasture monitoring manual (Forge 1994). Estimates were recorded to the nearest 5% cover for each plot and were generally a consensus between two operators.

CHAPTER 4 Ecological response of giant rats tail grass to pasture management manipulations

4.1 *Summary*

Managing pastures to maintain good ground cover will limit the establishment of the unpalatable pasture weed giant rats tail grass (*Sporobolus pyramidalis*). If bare areas are created within the pasture, giant rats tail grass seedlings will establish from the substantial, long-lived soil seed bank. Once established, giant rats tail grass plants are tolerant of common agronomic manipulations and are difficult to remove without the use of targeted intensive practices such as herbicides.

An experiment was conducted at three sites in south-east Queensland to investigate the impact of various pasture management techniques (including fire, slashing, fertiliser, cultivation, sowing competitive pasture species and herbicides) on the life cycle of giant rats tail grass. The manipulations trialled highlighted the importance of a vigorous competitive pasture to maintain ground cover as part of the strategy for targeting the giant rats tail grass plants. Without a competitive pasture being present and able to compete (ie. not selectively overgrazed), any giant rats tail grass control attempted is unlikely to be successful.

Other key findings were:

- Soil seed banks can be reduced temporarily with a fire, but are generally replenished in the next season by the large seed production.
- Fire and seasonal conditions appear to interact to allow significant seedling establishment in above-average rainfall years and little establishment in average or below-average rainfall years.
- Slashing, cultivation and broadacre application of an unselective herbicide by themselves will not control giant rats tail grass and are likely to increase its dominance.
- The most successful treatment was the selective herbicide treatment, however the companion pasture species and the availability of suitable selective herbicides requires careful consideration.

4.2 *Introduction*

Giant rats tail grass (*Sporobolus pyramidalis*) is an unpalatable, perennial, introduced tussock grass that has become a serious pasture weed in coastal and sub-coastal Queensland. Giant rats tail grass currently infests at least 200 000ha (McIntosh *et al.* 1999; NRM 2001). This weed has proved difficult to control and has demonstrated tolerance and/or resilience to most pasture management techniques, with infestations continuing to expand and increase in density (G. Elphinstone *pers. com.*). An understanding of the ecology and life cycle of giant rats tail grass would help identify the plants weaknesses and strengths, which could be potentially targeted or avoided in the development of effective control/management strategies.

Many management techniques are available for land managers to use for weed control/management and for manipulating the pasture species composition. These techniques have had various levels of success depending on the species involved, subsequent management and the objectives to be met. Management techniques include:

- slashing (see Rodel & Scheerhoorn 1976; Kleinschmidt & Johnson 1977; Edroma 1981; Bourdot & Hurrell 1992; Andrews *et al.* 1996).
- fire (see Green 1956; Campbell 1961a; Cook 1980b; Cox & Morton 1986; Campbell 1996; Orr *et al.* 1997).
- fertiliser (see Wiltshire 1972; Bate & Heelas 1975; Rodel & Scheerhoorn 1976; Harradine & Whalley 1978; Bishop *et al.* 1993; Campbell 1998).
- herbicides (see Campbell 1961b; Smith & Cole 1972; Hawton 1976; Campbell & Gilmour 1979; Brecke 1981; Betts 1989; Bourdot and Hurrell 1992; Campbell & Nicol 1998; Young *et al*. 1998).
- cultivation and physical removal of selected species (eg. with a hoe) (see Roberts & Dawkins 1967; Froud-Williams *et al.* 1984; Graham & Hutchings 1988; Betts 1989; Bourdot & Hurrell 1992; Bourdot *et al.* 1992).
- pasture replacement (see Campbell 1960a; Robinson & Whalley 1988; Betts 1989; Bishop *et al*. 1993; Campbell 1998).
- various grazing management strategies, including spelling or removing grazing altogether (see Edroma 1981; Howell 1988; Bishop *et al.* 1993; Fitzgerald 1993; Lungu *et al.* 1995; Campbell 1996; Orr & Paton 1997).

An experiment was designed to investigate the impact of various pasture management techniques on the life cycle of giant rats tail grass (see Fig 2.1 for a simple life cycle diagram). The life cycle stages and transitions studied included:

- the growth or decline of established plants
- seedling emergence and recruitment
- changes in soil seed bank size
- seed production
- the increase or reduction in abundance of other species in the pasture sward.

The treatments imposed manipulated giant rats tail grass as part of the pasture sward, which generally contained a number of pasture species.

The techniques trialled are unlikely to be control strategies by themselves. Combinations of these techniques will probably be necessary to manage giant rats tail grass as part of an integrated management strategy. However, in this experiment, we concentrated on understanding how the various pasture management techniques (eg. pasture opened up by herbicide spraying) individually affected the pasture sward and the life cycle of giant rats tail grass. This understanding, should allow a number of techniques to be amalgamated into control/management strategies that will have a high chance of success in a particular situation, breaking the life cycle of giant rats tail grass.

The experiment was conducted at three giant rats tail grass infested sites in south-east Queensland. Each site had a different soil and pasture type, and was in a different climatic zone.

4.3 *Materials and methods*

4.3.1 Experimental design and treatments

The experiment was conducted independently at three sites; Gympie, Kilcoy and Foxtail Flats (see site descriptions - Chapter 3). The sites were fenced to exclude stock, although the sites were grazed periodically once the treatments were established. The experimental design was a randomised block design with three blocks. The blocks were located by visual assessment to ensure there was a uniform soil type, landscape position and giant rats tail grass density within each block. The treatment plots were 7x7m (49 m^2/plot), but only the centre 5x5m (25 m^2/plot) was sampled, giving a 1m buffer from surrounding plots and laneways.

The experiment consisted of 13 treatments (Table 4.1), with 12 treatments within the randomised block design and one treatment (farmer management) located outside the exclosure fence and subject to grazing and farmer management.

Most treatments were initially applied at Gympie in December 1996 (Table 4.2), Kilcoy in February 1997 (Table 4.4) and Foxtail Flats in March 1997 (Table 4.6), with some treatments subsequently re-applied a number of times.

4.3.2 Data collection

A range of sampling techniques were used to measure the response of giant rats tail grass and other species to the treatments. Techniques (described in Section 3.2) included:

- population dynamics sampling (charting and BOTANAL)
- counting emerged giant rats tail grass seedlings
- monitoring the giant rats tail grass soil seed bank
- measuring giant rats tail grass seed production, and
- estimating ground cover

A visual assessment (general description) of each plot was conducted regularly at about 8-12 week intervals. This assessment was qualitative rather than quantitative in nature. The factors that were noted in the visual assessment were; presence and density of inflorescences, plant death, presence of seedlings, where the seedlings were located relative to other plants and canopy cover, sward structure, ground-cover structure and general appearance of the plot. The visual assessment was conducted to help explain changes between the census dates for population dynamics sampling.

All plots were sampled for giant rats tail grass soil seed bank size and population dynamics (charting and BOTANAL) prior to the treatments being imposed. The sampling schedules are presented for the Gympie (Table 4.3), Kilcoy (Table 4.5) and Foxtail Flats (Table 4.7) sites.

4.3.3 Statistical analysis

Analysis of variance (ANOVA) was used following transformation of the data if necessary. Data from each site have been analysed separately, due to inherent differences between sites (eg. different pasture species) and the treatments were sometimes applied slightly differently. Treatments at each site were analysed together for each sampling date, except for the farmer management treatment, which was analysed separately (farmer management plots are outside the exclosure) and compared to the control. At the Kilcoy site the farmer management treatment was wick wiped so it was also compared to the wick wipe treatment. Significant differences between the farmer management and control treatments must be treated with care, because the statistical assumption that the farmer management and control treatments are randomly allocated to a plot is violated.

Most of the data are presented as graphs. Due to the large number of treatments, the competitive species and cultivation treatments are usually presented on separate graphs. The control treatment is presented on all graphs to allow comparison. The error bars displayed on graphs are the LSD at the 5% level. The graphs indicate when transformations were applied. Data values reported in the text are back-transformed means.

Table 4.1 Treatments imposed in investigate the life cycle and response of giant rats tail grass (GRT) to various management manipulations at three sites.

No.	Name	Treatment technique	Comments
1	Wick wipe (herbicide)	A selective herbicide application technique using glyphosate (1 part glyphosate : 2 parts water) to remove tall GRT. Wiped once each summer.	- selective kill of mature GRT plants in the sward - competition from mature companion plants - GRT has to regenerate from seedlings and seed - mulch layer still intact, no soil disturbance - mature GRT root competition reduced
2	Selective (herbicide)	Selective kill of GRT plants by painting them with a glyphosate solution (1 part glyphosate : 2 parts water) or spot spray (20ml glyphosate/L of water). Treatment simulates the action of a selective broad-acre herbicide not affecting other plants. The herbicide was applied twice in the first year.	- selective kill of GRT plants - competition from mature companion plants - GRT has to re-establish from seed - kills seedlings, juveniles and mature GRT plants - mulch layer still intact, no soil disturbance - GRT root competition reduced - equivalent to accurate spot spraying - difficult to find small GRT plants hidden within the sward
3	Unselective (herbicide)	A broad-acre spray of the non-selective herbicide glyphosate (4 – 5L glyphosate/ha) was applied twice in the first year.	- death of all plants (seedlings and mature) - seedling competition (GRT and other species) - GRT and other species regenerate from seed - mulch layer still intact, no soil disturbance - no root competition - equivalent to over-spraying when spot spraying
4	Fire	Plots were burnt once per year in late spring where possible. The initial burn at Kilcoy and Foxtail Flats was in late summer. Paraquat (1.5l Gramoxone/ha) was used to simulate a frost and dry off the plant material to enable a burn if too green. Kilcoy required extra dry matter to enable a burn in spring 1997 (applied as grass hay ~ 4000kg DM/ha).	- remove mulch and above-ground plant parts - fire and temperature effect - fire may kill seed and seedlings, stimulate seed to germinate - opens up gaps in the sward (bare ground) - root competition not reduced - GRT and other species regenerate from tussock base and seed - no soil disturbance
5	Slash/rake	Plots were slashed (~10-13cm high) approximately 4 times per year and raked to remove mulch. A tractor mounted slasher or a self-propelled sickle-bar mower was used for slashing.	- remove excess mulch and most above-ground plant parts - similar to burn treatment in that it removes plant above-ground biomass - GRT and other species regenerate from tussock base and seed - no soil disturbance - root competition not reduced
6	Slash	Plots were slashed (~10-13cm high) approximately 4 times per year. A tractor mounted slasher or a self-propelled sickle-bar mower was used for slashing.	- removes above ground plant parts - mulch left on soil surface - GRT and other species regenerate from tussock base and seed - no soil disturbance - root competition not reduced
7	Fertiliser	Plots were slashed initially and nitrogen fertiliser was applied each year, preferably in early summer, 100 kg N/ha/year (Gympie received 2 applications 1996/97). Crop King 88 containing N, P, S and K was applied initially, whereafter N was applied as urea or Nitram.	- fertiliser response - apply high level of fertiliser - response of GRT and other plants to increased fertility - mulch layer still intact, no soil disturbance - root competition not reduced

Table 4.1 continued.

8	Cultivation	Plots were cultivated approximately 4 times per year to 7-10cm depth, plots required occasional broad-acre application of glyphosate (20ml glyphosate/L) to remove GRT plants not killed by cultivation. A chisel type plough, tractor mounted rotary hoe and a self-propelled rotary hoe were used.	- GRT and other species regenerate from seed - seedling competition - effect of cultivation in killing/controlling GRT - stimulation of seed reserves to germinate - no new GRT seed into soil - cultivation suspected of stimulating thickening up of GRT sward - major soil disturbance - no root competition
9	Rhodes (competitive pasture)	Plots were sprayed with glyphosate, cultivated and sown to Callide rhodes grass at double standard sowing rates (5kg/ha) (seed scattered, raked into soil surface and rolled)	- *Chloris gayana* (Callide rhodes grass) - quick establishment, becomes good competitor from planting - problem; rhodes usually does not persist strongly for many years (quick rundown) - stoloniferous species; spreads without seed germination and establishment - major initial soil disturbance - no root competition at sowing
10	Bisset (competitive pasture)	Plots were sprayed with glyphosate, cultivated and sown to Bisset bluegrass at double standard sowing rates (5kg/ha) (seed scattered, raked into surface and rolled)	- *Bothriochloa insculpta (*Bisset bluegrass) - Bisset is a dense mat forming grass, and provides good long-term competition - stoloniferous species; spreads without seed germination and establishment - problem; Bisset is generally relatively slow to establish and does not provide early competition - major initial soil disturbance - no root competition at sowing
11	Rhodes/Bisset (competitive pasture)	Plots were sprayed with glyphosate, cultivated and sown with a mixture of Bisset bluegrass and Callide rhodes grass, sown at 2.5kg/ha each. (seed scattered, raked into surface and rolled)	- seed mixture contains species with quick establishment, good early competitor (Callide) and a good long-term competitor (Bisset) - should create continuous high competition - major initial soil disturbance - no root competition at sowing
12	Control	No treatment imposed (relatively ungrazed)	- just leave plots (do nothing) - sward not in climax (or equilibrium) state because grazing has been reduced, so expect change with time - root competition maintained - mulch layer still intact, no soil disturbance
13	Farmer management	(outside exclosure) no treatment imposed except the farmers/graziers normal management, similar to control. At Kilcoy these plots were wick-wiped. At Foxtail Flats these plots were burnt spring 1998.	- commercial grazed paddock - selective grazing - pasture not static, may change with time and management - management dictated by farmer - monitor what happens under a grazing situation - root competition maintained - mulch layer still intact, no soil disturbance - these plots were not part of the randomised block design, but were located to cover a similar range of GRT densities and land forms

Table 4.2 Gympie site: calendar of when treatments were applied.

Treatment name	Action	1996	1996	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1999	1999	1999	1999	1999	1999	1999	1999	1999	1999
		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Wick wipe	wick wipe			X													X													X							
	slash														X																						
Selective	selective		X											X		X																					
Unselective	sprayout		X											X																							
Fire	sprayed gramoxone		X																				X														
	burn		X									X												X													
Slash/rake	slash and rake		X			X			X						X			X				X				X		X									
Slash	slash		X			X			X						X			X				X				X		X									
Fertiliser	slash		X																																		
	fertiliser		X		X									X												X											
Cultivation	cultivate		X	X	X				X			X			X			X				X						X									
Competitive pasture	cultivate		X	X	X				X			X																									
rhodes, bisset and	sprayout				X								X																								
rhodes/bisset	plant					X							X																								
Control																																					
Farmer management																																					

Table 4.3 Gympie site: sampling schedule

Sampling name	Action	1996	1996	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1999	1999	1999	1999	1999	1999	1999	1999	1999	1999
		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Seedling counts	quadrat installed				X																																
	count seedlings						X		X	X		X		X		X	X				X				X			X				X					
Visual assessment	conducted				X				X	X	X	X		X		X	X				X				X			X				X					
Botanal	conducted	X						X				X									X				X						X						
Charting	conducted		X					X				X									X										X						
Seed bank	collect samples		X										X													X											X
Photographs	taken								X			X					X									X		X			X						
Seed production	traps installed													X																							
	traps emptied																	X				X											X				

Table 4.4 Kilcoy site: calendar of when treatments were applied.

Treatment name	Action	1997 Jan	1997 Feb	1997 Mar	1997 Apr	1997 May	1997 Jun	1997 Jul	1997 Aug	1997 Sept	1997 Oct	1997 Nov	1997 Dec	1998 Jan	1998 Feb	1998 Mar	1998 Apr	1998 May	1998 Jun	1998 Jul	1998 Aug	1998 Sept	1998 Oct	1998 Nov	1998 Dec	1999 Jan	1999 Feb	1999 Mar	1999 Apr	1999 May	1999 Jun	1999 Jul	1999 Aug	1999 Sep	1999 Oct
Wick wipe	wick wipe		X												X												X								
	slash												X																						
Selective	selective		X											X	X																				
Unselective	sprayout		X								X			X																					
Fire	sprayed gramoxone		X																		X														
	burnt			X								X										X													
Slash/rake	slash and rake		X					X					X	X		X				X			X			X									
Slash	slash		X					X					X	X		X				X			X			X									
Fertiliser	slash		X																				X												
	fertiliser		X									X											X												
Cultivation	cultivate		X					X		X				X		X				X			X			X									
Competitive pasture	cultivate		X					X		X																									
rhodes, bisset and	sprayout		X								X																								
rhodes/bisset	plant										X																								
Control																																			
Farmer management	wick wipe		X												X														X						

Table 4.5 Kilcoy site: sampling schedule

Sampling name	Action	1997 Jan	1997 Feb	1997 Mar	1997 Apr	1997 May	1997 Jun	1997 Jul	1997 Aug	1997 Sept	1997 Oct	1997 Nov	1997 Dec	1998 Jan	1998 Feb	1998 Mar	1998 Apr	1998 May	1998 Jun	1998 Jul	1998 Aug	1998 Sept	1998 Oct	1998 Nov	1998 Dec	1999 Jan	1999 Feb	1999 Mar	1999 Apr	1999 May	1999 Jun	1999 Jul	1999 Aug	1999 Sep	1999 Oct
Seedling counts	quadrat installed						X																												
	count seedlings						X	X				X		X	X					X			X			X		X			X				
Visual assessment	conducted				X	X		X				X		X	X					X			X			X		X			X				
Botanal	conducted		X								X							X					X							X					
Charting	conducted		X								X								X											X					
Seed bank	collect samples		X								X												X												X
Photographs	taken													X												X				X					
Seed production	traps installed											X																							
	traps emptied															X				X													X		

Table 4.6 Foxtail Flats site: calendar of when treatments were applied.

Treatment name	Action	1997 Jan	1997 Feb	1997 Mar	1997 Apr	1997 May	1997 Jun	1997 Jul	1997 Aug	1997 Sept	1997 Oct	1997 Nov	1997 Dec	1998 Jan	1998 Feb	1998 Mar	1998 Apr	1998 May	1998 Jun	1998 Jul	1998 Aug	1998 Sept	1998 Oct	1998 Nov	1998 Dec	1999 Jan	1999 Feb	1999 Mar	1999 Apr	1999 May	1999 Jun	1999 Jul	1999 Aug	1999 Sep	1999 Oct	1999 Nov
Wick wipe	wick wipe			X											X												X									
	slash												X																							
Selective	selective			X										X																						
Unselective	sprayout			X										X																						
Fire	sprayed gramoxone			X																		X														
	burn			X								X										X														
Slash/rake	slash and rake			X				X					X			X				X			X			X										
Slash	slash			X				X					X			X				X			X			X										
Fertiliser	slash			X																			X													
	fertiliser			X								X											X													
Cultivation	cultivate			X				X		X			X			X				X			X			X										
Competitive pasture	cultivate			X				X		X																										
rhodes, bisset and	sprayout			X								X																								
rhodes/bisset	plant											X																								
Control	2 blocks burnt											X																								
Farmer management	Burnt																				X															

Table 4.7 Foxtail Flats site: sampling schedule

Sampling name	Action	1997 Jan	1997 Feb	1997 Mar	1997 Apr	1997 May	1997 Jun	1997 Jul	1997 Aug	1997 Sept	1997 Oct	1997 Nov	1997 Dec	1998 Jan	1998 Feb	1998 Mar	1998 Apr	1998 May	1998 Jun	1998 Jul	1998 Aug	1998 Sept	1998 Oct	1998 Nov	1998 Dec	1999 Jan	1999 Feb	1999 Mar	1999 Apr	1999 May	1999 Jun	1999 Jul	1999 Aug	1999 Sep	1999 Oct	1999 Nov
Seedling counts	quadrat installed				X																															
	count seedlings				X		X		X			X		X	X					X			X			X			X							
Visual assessment	conducted			X			X		X			X		X	X					X			X			X			X							
Botanal	conducted			X								X					X						X						X							
Charting	conducted			X							X						X												X							
Seed bank	collect samples			X								X										X														X
Photographs	taken														X											X			X							
Seed production	traps installed											X																								
	traps emptied															X				X													X			

4.4 *Results*

4.4.1 Soil seed banks of giant rats tail grass

Except in a few cases, the giant rats tail grass soil seed bank did not change substantially throughout the experiment. Initially the giant rats tail grass soil seed banks were large and even in treatments where mature seeding plants were removed a substantial soil seed bank remained after approximately three years.

Data were natural log (ln) transformed (ln(seed number/m^2+1)) prior to analysis. There were no treatment differences at any site prior to the treatments being imposed, except when comparing the control and farmer management treatment at Gympie.

4.4.1.1 Gympie giant rats tail grass soil seed banks

There was no significant difference in soil seed bank size prior to the treatments being imposed in December 1996 (grand mean 5290 seeds/m^2) and most treatments did not change substantially during the experiment (Fig 4.1). The fire treatment giant rats grass soil seed bank increased from 5090 seeds/m^2 in October 1997 to 8140 seeds/m^2 prior to the burn in spring 1998. Following the fire the soil seed bank dropped substantially to 780 seeds/m^2 (10% of pre-burn soil seed bank), significantly lower than the control. However, by October 1999 the soil seed bank had recovered to 8020 seeds/m^2 (the highest treatment), although not significantly different from the control. The giant rats tail grass seed banks in the unselective herbicide treatment dropped to 1600 seeds/m^2 by October 1999, significantly lower than the control, while the wick wipe and selective herbicide treatments maintained their soil seed bank size (mean 3740 seeds/m^2).

The giant rats tail grass soil seed bank response to the competitive species treatments was similar to the unselective herbicide treatment, declining to a mean of 1550 seeds/m^2 at October 1999, significantly lower than the control (Fig 4.2). There was no difference between the sown pasture species. The soil seed bank in the cultivation treatment increased significantly by the end of year one, possibly due to a greater soil volume being sampled (10cm compared to 5cm deep), but declined sharply thereafter to become the lowest treatment with 550 seeds/m^2 at October 1999.

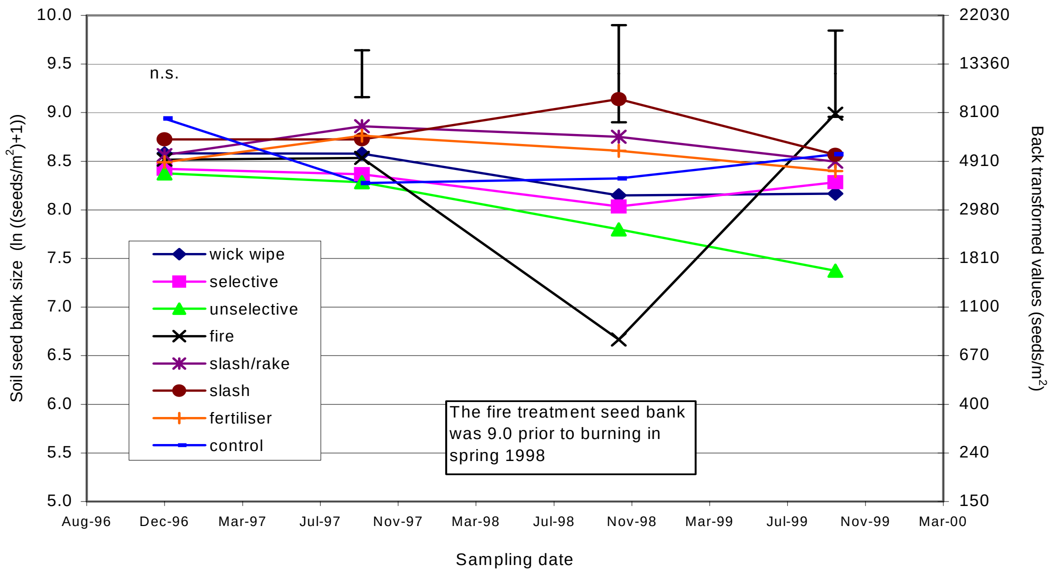

Figure 4.1 Giant rats tail grass soil seed bank size for various management treatments at Gympie. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

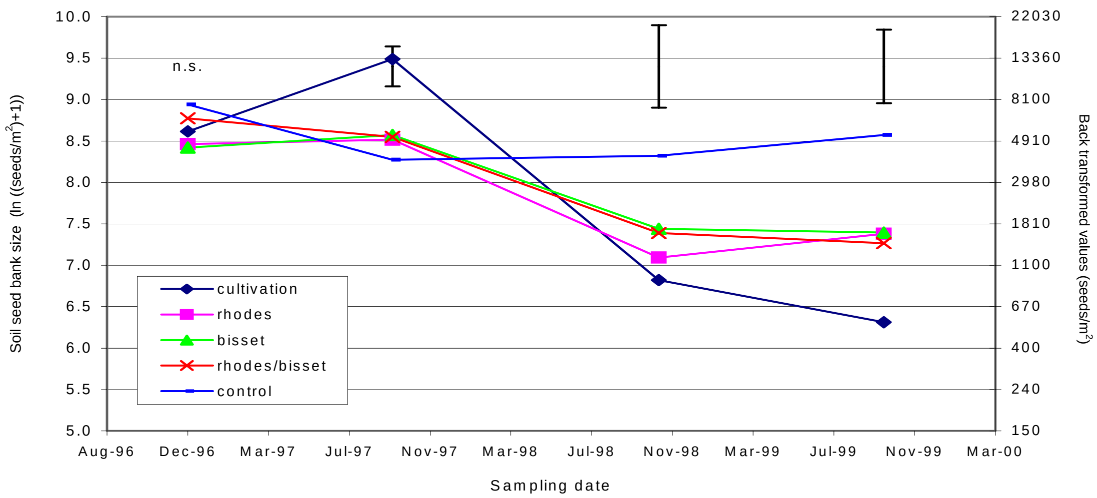

Figure 4.2 Giant rats tail grass soil seed bank size for the cultivation and competitive species treatments at Gympie.

The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment giant rats tail grass soil seed bank was not significantly different from the control following the initial sampling (data not presented).

4.4.1.2 Kilcoy giant rats tail grass soil seed banks

There was no significant difference between treatments prior to the treatments being imposed in February 1997 (grand mean 5600 seeds/m^2). Most treatments retained their relative rankings throughout and were not altered substantially by management. The giant rats tail grass soil seed bank in the control rose to 10500 seeds/m^2 at October 1998 (Fig 4.3), but then fell to 6720 seeds/m^2 by October 1999, becoming similar to the initial sampling. The fertiliser treatment giant rats tail grass soil seed bank temporarily increased after the fertiliser was applied (15100 seeds/m^2 at October 1997), but then decreased remaining similar to the control. The fire treatment giant rats tail grass soil seed bank dropped from 4230 seeds/m^2 initially to 2630 seeds/m^2 at October 1997, significantly lower than the control. The soil seed bank then fluctuated greatly and increased substantially prior to the fire in spring 1998 (9510 seeds/m^2), but following the fire the soil seed bank dropped to 2240 seeds/m^2 (24% of pre-burn soil seed bank). By October 1999 the fire treatment soil seed bank had again increased (5140 seeds/m^2).

The giant rats tail grass soil seed banks in the herbicide treatments dropped from a mean of 6420±1700 seeds/m^2 initially to 2840± 840 seeds/m^2 at October 1998 significantly lower than the control. By October 1999, the wick wipe treatment had dropped further to 1720 seeds/m^2 (the lowest treatment) and was significantly lower than the control. The unselective and selective herbicide treatments increased and were not significantly different from the control (mean 3860 seeds/m^2).

The rhodes grass treatment giant rats tail grass soil seed bank dropped significantly lower than the control at October 1998 (Fig 4.4), remaining low with 2070 seeds/m^2 at October 1999. The rhodes/bisset treatment soil seed bank had also decreased by October 1999 (3140 seeds/m^2), but was not significantly different to the control. The bisset treatment remained similar to the control. The giant rats tail grass soil seed bank in the cultivation treatment unexpectedly increased to 11400 seeds/m^2, possibly due to a greater soil volume being sampled (10cm compared to 5cm deep), but then decreased markedly to October 1999 (3080 seeds/m^2).

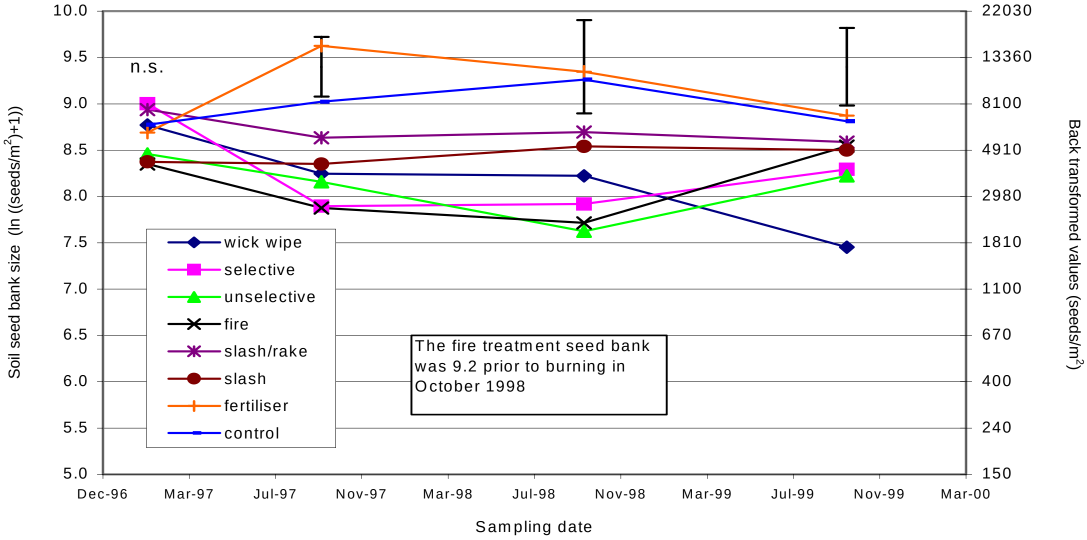

Figure 4.3 Giant rats tail grass soil seed bank size for various management treatments at Kilcoy. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

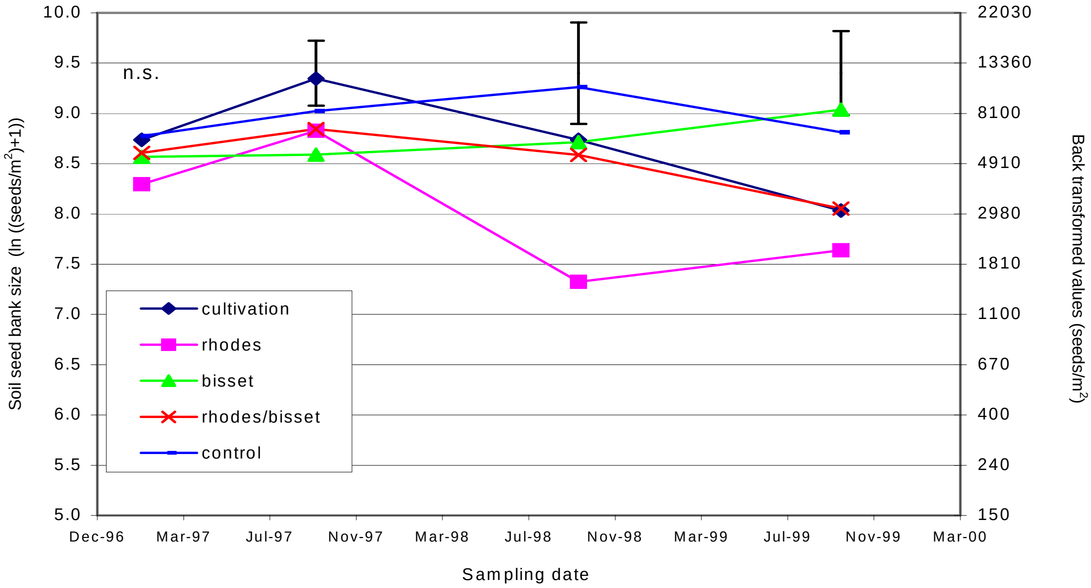

Figure 4.4 Giant rats tail grass soil seed bank size for the cultivation and competitive species treatments at Kilcoy.

The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment was wick wiped and was similar to the wick wipe treatment (data not presented), with 1990 seeds/m^2 at October 1999, significantly lower than the control.

4.4.1.3 Foxtail Flats giant rats tail grass soil seed banks

The Foxtail Flats site had the lowest initial giant rats tail grass soil seed bank size (mean 2570 seeds/m^2) of the three sites. After treatments were imposed the soil seed bank size fluctuated in many treatments, but remained similar to the control (Fig 4.5). Treatments that differed from the control during the experiment included, the fertiliser and herbicide treatments. The fertiliser treatment soil seed bank increased substantially between November 1997 and September 1998, to be significantly higher than the other treatments (20100 seeds/m^2). This soil seed bank had decreased by November 1999 (5910 seeds/m^2), but it was still significantly the highest treatment. The soil seed banks in the herbicide treatments declined to 930±180 seeds/m^2 at September 1998, significantly lower than the control, but then increased slightly and were similar to the control by November 1999.

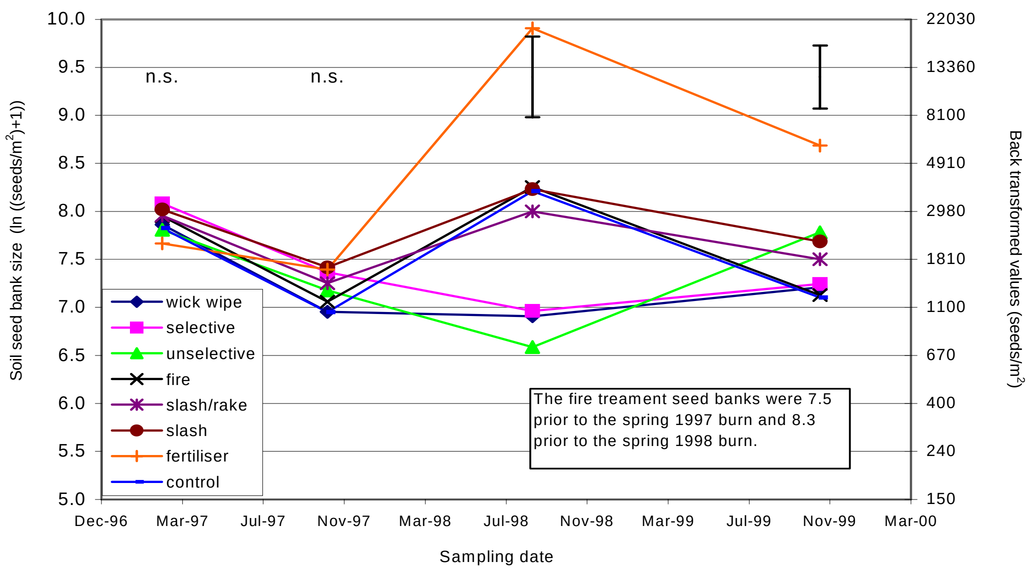

Figure 4.5 Giant rats tail grass soil seed bank size for various treatments at Foxtail Flats. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The giant rats tail grass soil seed bank size in the fire treatment was similar to the control throughout the experiment. The two fire events in spring 1997 and 1998 reduced the seed bank size to 64 and 93% of pre-burn seed banks respectively. The insignificant drop in soil seed bank size for the spring 1998 fire may be due to soil seed bank variation or sampling error as two blocks were 55% and 83% of pre-burn soil seed banks, while the third block had a much higher post-burn soil seed bank.

The giant rats tail grass soil seed bank size in the competitive species treatments was significantly lower than the control in September 1998 (Fig 4.6), but were similar at the other sampling dates. The cultivation treatment soil seed bank remained relatively stable until September 1998, but it unexpectedly increased slightly at November 1999.

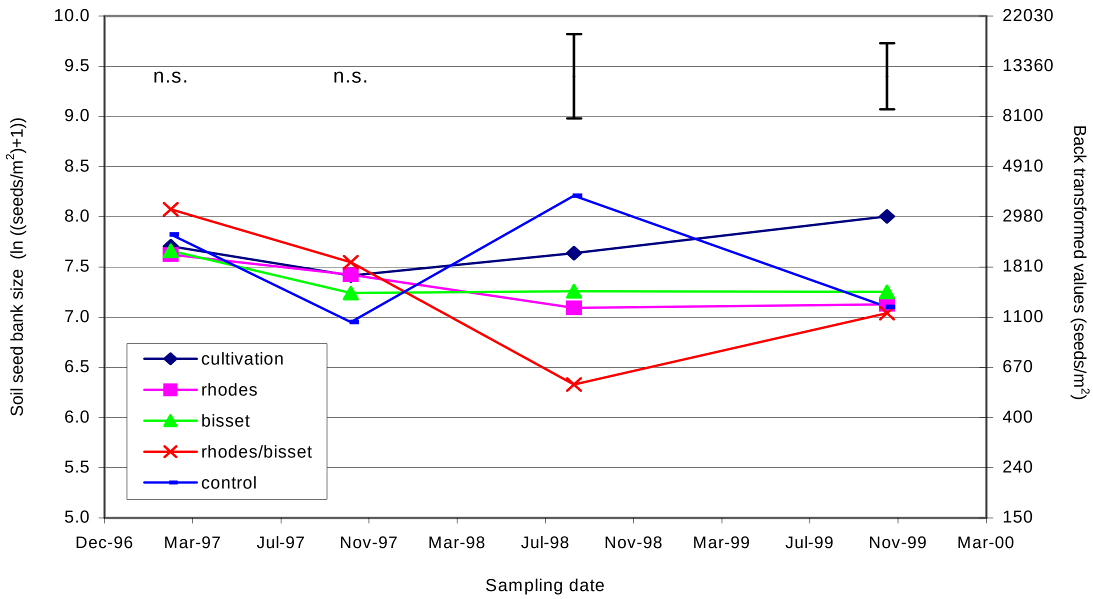

Figure 4.6 Giant rats tail grass soil seed bank size for the cultivation and competitive species treatments at Foxtail Flats.

The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The giant rats tail grass soil seed bank of the farmer management treatment remained similar to the control throughout the experiment (data not presented).

4.4.2 Basal area of giant rats tail grass

Basal area was calculated by measuring two perpendicular diameters and calculating the area for each giant rats tail grass tussock in the permanent quadrats during charting. There was no significant difference in giant rats tail grass basal area between the treatments prior to the treatments being imposed at any site. Following the treatments being imposed, significant differences developed as described in the following sections.

4.4.2.1 Gympie basal area

The giant rats tail grass basal area of the control treatment appeared to fluctuate with the seasons, ranging between 965 and 667 cm^2/m^2 (Fig 4.7) possibly in response to rainfall (Fig 3.1). The fertiliser treatment basal area was not significantly different from the control initially, but by June 1998 it had declined to a third of the control, which was maintained for the duration of the experiment. The basal area of the fire treatment dropped to 13% of the control after the first fire, but thereafter rose steadily to be 64% of the control at the final sampling, still significantly lower than the control. The herbicide treatments reduced the basal area enormously, and maintained the giant rats tail grass basal area at very low levels thereafter. There was no significant difference between the herbicide treatments at any sampling date, although the wick wiping treatment reduced the basal area more slowly. The basal area of the slash and slash/rake treatments was never significantly different from the control.

Sowing competitive pastures (incorporated cultivation and herbicide application) removed the initial giant rats tail grass basal area (Fig 4.8). At the final sampling 30 months later, the giant rats tail grass basal area remained very low, although plants were present in the plots.

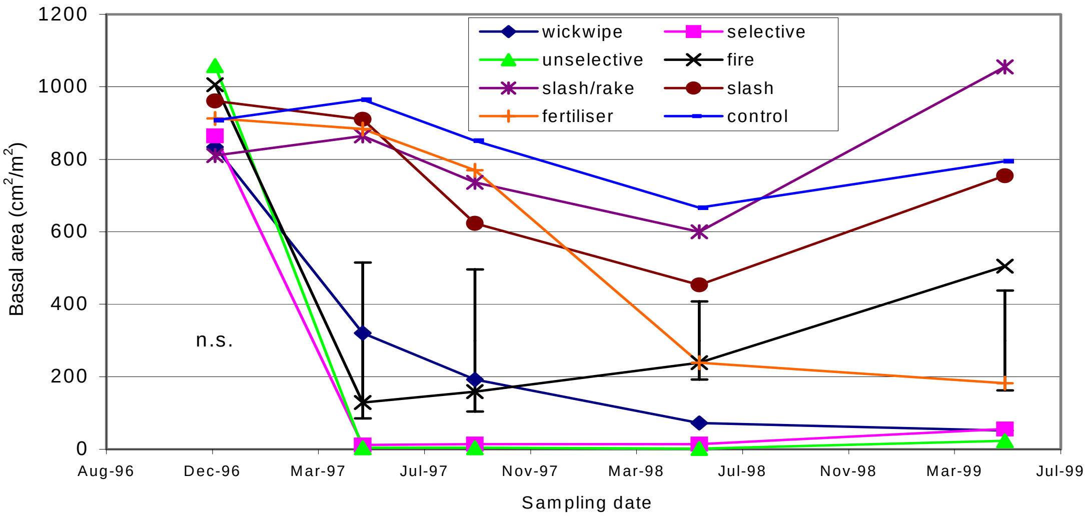

Figure 4.7 Giant rats tail grass basal area response for various management treatments at Gympie. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

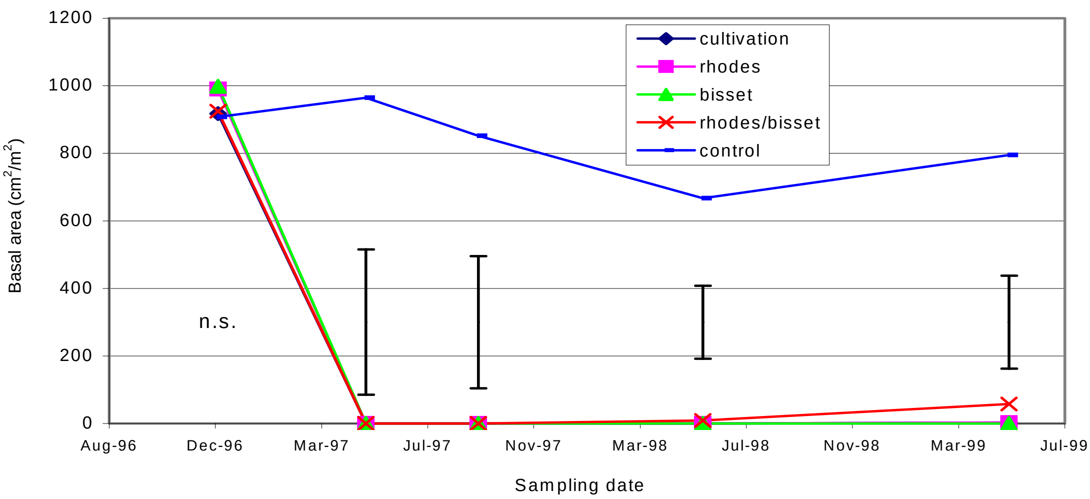

Figure 4.8 Giant rats tail grass basal area response following cultivation and sowing to competitive pasture species at Gympie.
The cultivation treatment had the same basal area as the rhodes treatment at the final sampling. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The giant rats tail grass basal area in the farmer management treatment, in contrast to the control treatment, rose steadily throughout the experiment (Fig 4.9) to end up 2.4 times higher than the initial sampling and 1.8 times higher than the control at the final sampling.

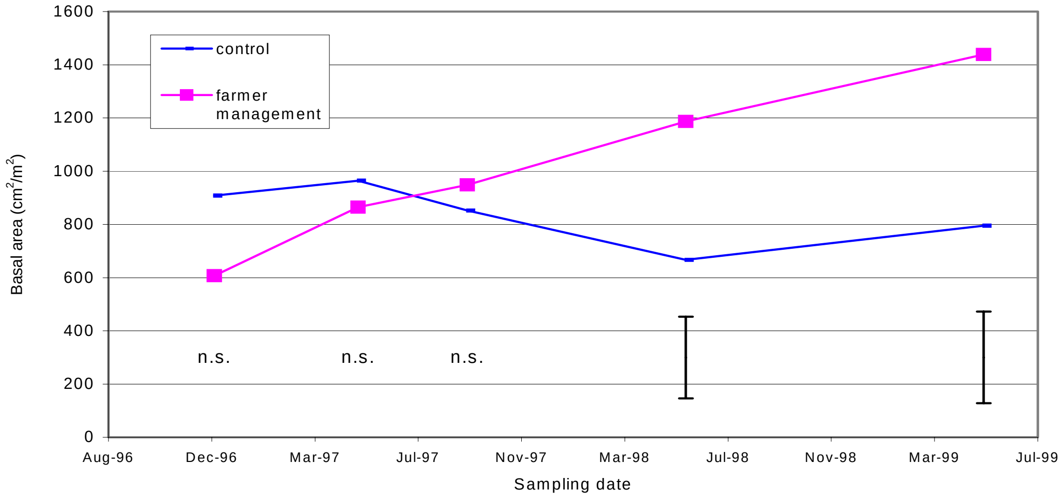

Figure 4.9 Giant rats tail grass basal area response for the farmer management and control treatments at Gympie.
Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

4.4.2.2 Kilcoy basal area

The mean giant rats tail grass basal area at the Kilcoy site was initially low, being 40% and 26% of the initial basal area at the Gympie and Foxtail Flats sites respectively.

The basal area of the control rose steadily during the experiment with the final basal area being 2.7 times higher than the initial basal area (Fig 4.10). The fertiliser treatment was not significantly different from the control throughout the experiment, although it was 25% higher than the control at the final sampling. The fire treatment basal area dropped slightly after the initial burn then rose steadily thereafter and was never significantly different from the control. The herbicide treatments reduced the basal area of giant rats tail grass, with the selective and unselective treatments being significantly lower than the control after the initial treatment. The wick wipe treatment was not significantly different from the control after only one wipe, but was significantly lower thereafter. At the final sampling the unselective treatment had the highest giant rats tail grass basal area of the herbicide treatments (67% of the initial basal area). The slash and slash/rake treatments were similar to the control throughout the experiment.

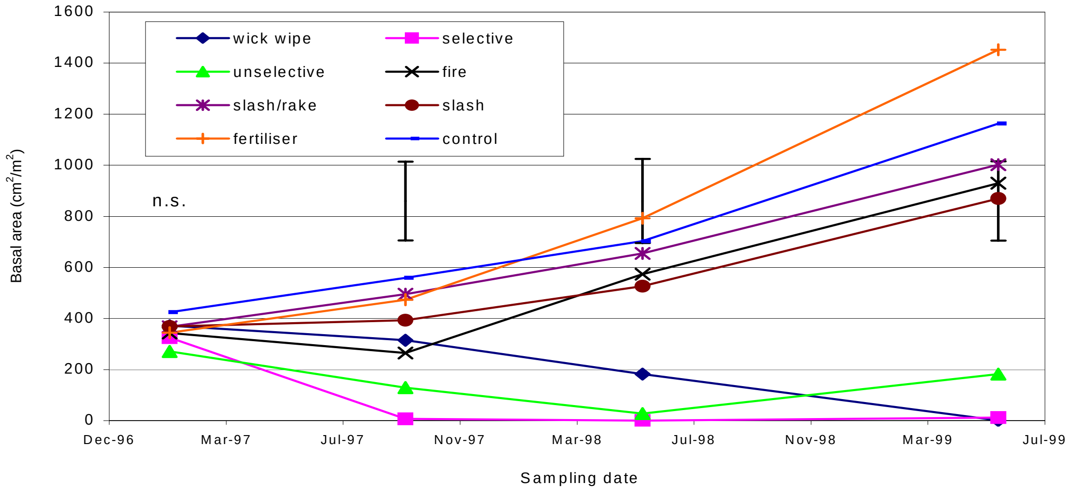

Figure 4.10 Giant rats tail grass basal area response for various management treatments at Kilcoy. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

Sowing competitive species (incorporated herbicide application and cultivation) removed all the initial giant rats tail grass basal area (Fig. 4.11). However, all treatments had some established giant rats tail grass plants at the final sampling. The rhodes treatment remained very low at 3% of the initial giant rats tail grass basal area, while the rhodes/bisset and bisset treatments were 39% and 64% of the initial basal area respectively.

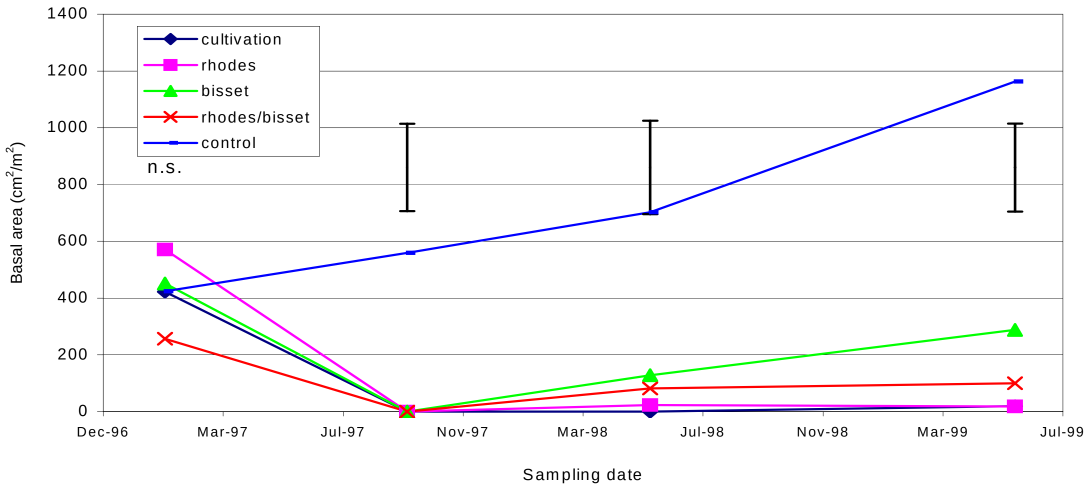

Figure 4.11 Giant rats tail grass basal area response for the cultivation and competitive species treatments at Kilcoy. The cultivation and rhodes treatments were similar at the final sampling. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment was wick wiped and the giant rats tail grass basal area decreased similarly to the wick wipe treatment (data not presented).

4.4.2.3 Foxtail Flats basal area

The Foxtail Flats site had the highest initial giant rats tail grass basal area (grand mean 1420 cm^2/m^2) of the three sites, being 50% higher than the Gympie site.

After the initial sampling there was a decline in the giant rats tail grass basal area for all treatments (Fig 4.12). This decline was possibly due to two causes, the low amount of rainfall received in 1997 (Fig 3.3) or sampling error (the thick rank giant rats tail grass at the initial sampling made it difficult to accurately define and measure tussock bases).

The control treatment basal area decreased until April 1998 and then rose by the final sampling to 62% of the initial basal area. Following the basal area being recorded, two of the three control plots were accidentally burnt in spring 1997, which probably contributed to the reduction in basal area in April 1998. The basal area of the single unburnt control plot increased by 30% during the experiment. The basal area in an unburnt fertiliser plot and unburnt slash plot also increased during the experiment by 32% and 20% respectively, although the basal area had dropped like all the others initially.

The fertiliser and slash treatments followed a similar pattern to the control throughout the experiment. The fire treatment basal area was not significantly different from the control until April 1998 (after 2 burns) when it became significantly lower until the end of the experiment (33% of the initial basal area; 55% of the control). The herbicide treatments giant rats tail grass basal area decreased substantially after herbicide application and remained low thereafter, although some giant rats tail grass was present at the final sampling.

Sowing competitive pasture (incorporated herbicide application and cultivation) removed all the initial giant rats tail grass basal area (Fig 4.13). Following sowing the basal area of giant rats tail grass increased in the competitive pasture treatments. At the final sampling there were no significant difference between competitive pasture treatments, although the rhodes treatment had the lowest giant rats tail grass basal area.

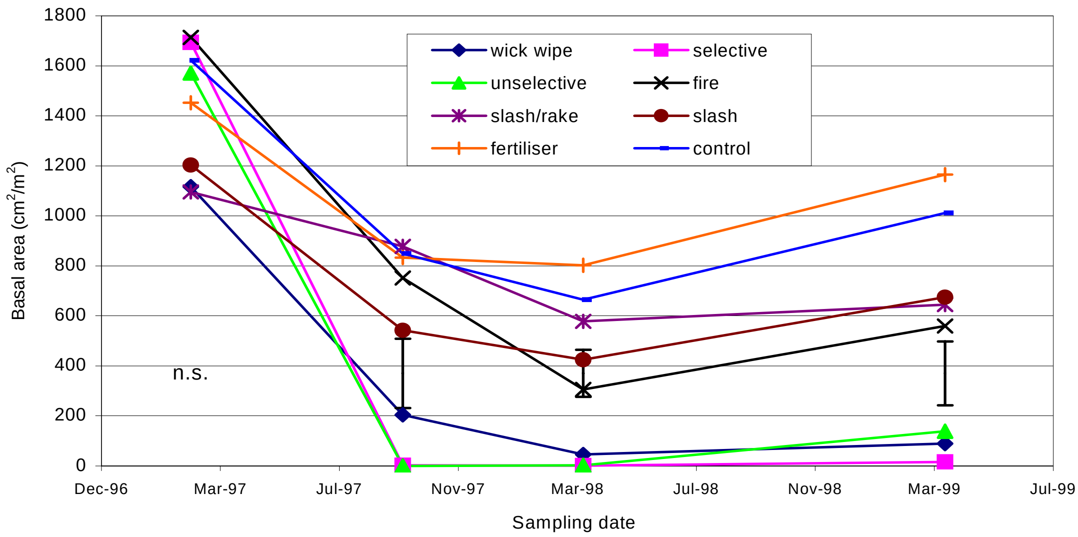

Figure 4.12 Giant rats tail grass basal area for various management treatments at Foxtail Flats. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

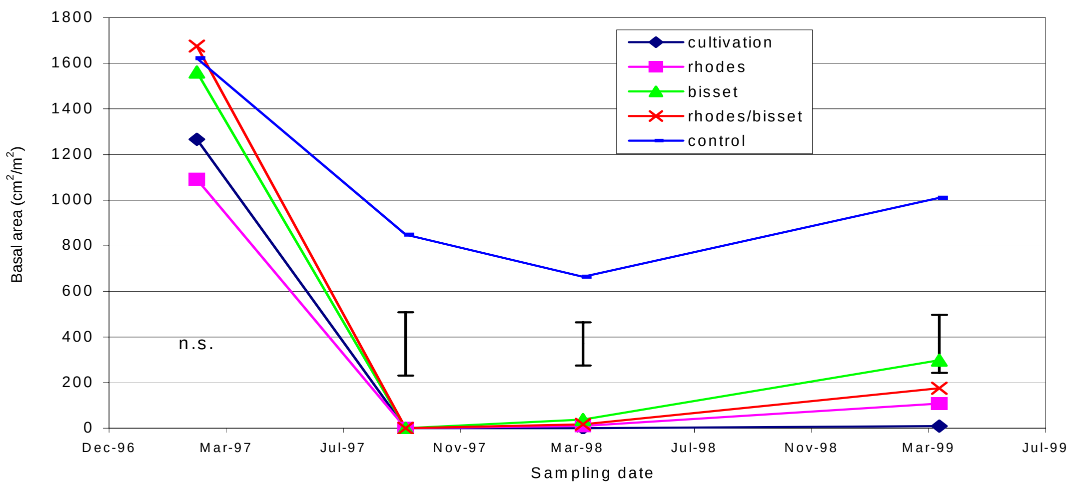

Figure 4.13 Giant rats tail grass basal area response for the cultivation and competitive species treatments at Foxtail Flats.
Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The basal area of the farmer management treatment remained similar to the control treatment (data not presented).

4.4.3 Plant density of giant rats tail grass

There was no significant difference between treatments for giant rats tail grass plant density at the initial sampling. Giant rats tail grass plant density data was collected by repeatedly charting permanent quadrats.

4.4.3.1 Gympie giant rats tail grass plant density

The giant rats tail grass plant density in the control treatment remained constant at around 18 plants/m^2 throughout the experiment (Fig 4.14), as did the slash and slash/rake treatments. The plant density in the fertiliser treatment declined linearly with time from 21 to 5 plants/m^2, but was never significantly different from the control. The fertiliser and wick wipe treatments had a similar pattern of decline. The fire treatment giant rats tail grass plant density decreased slightly after the first fire, but then remained steady, not significantly different from the control until the final sampling when density increased dramatically (103 plants/m^2), becoming significantly higher than the other treatments (except the slash/rake treatment).

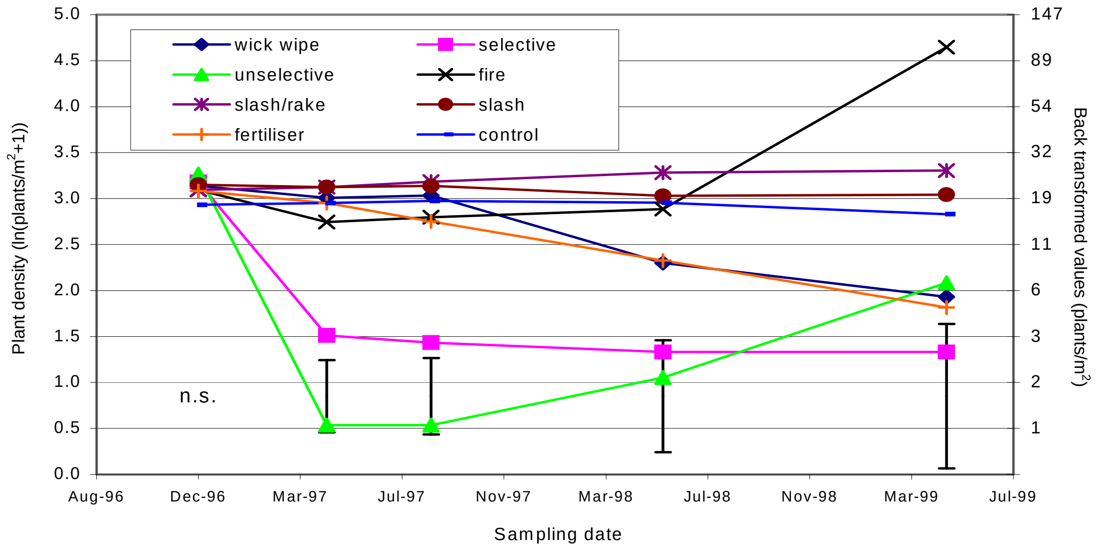

Figure 4.14 Giant rats tail grass plant density response for various treatments at Gympie. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The response of giant rats tail grass plant density to herbicide treatments varied with application type, particularly following the initial treatment. The wick wipe treatment did not substantially reduce plant density after the first treatment, whereas the selective and unselective treatments reduced plant density to 15% and 4% of the initial plant density respectively. The selective herbicide treatment plant density remained stable for the remainder of the experiment, however the unselective treatment plant density increased at the final sampling and was not significantly different to the control. Wick wiping decreased giant rats tail grass plant density slowly, but was never significantly different from the control.

Sowing competitive species (incorporated cultivation and herbicide application) removed all the initial giant rats tail grass plants (Fig 4.15), however new plants did subsequently establish. The rhodes/bisset treatment had the most new giant rats tail grass plants followed by the rhodes and bisset treatments respectively. Surprisingly, the giant rats tail grass plant density in the cultivation treatment at the final sampling (recently new plants) was not significantly different from the control (5.2 plants/m^2, 33% of control).

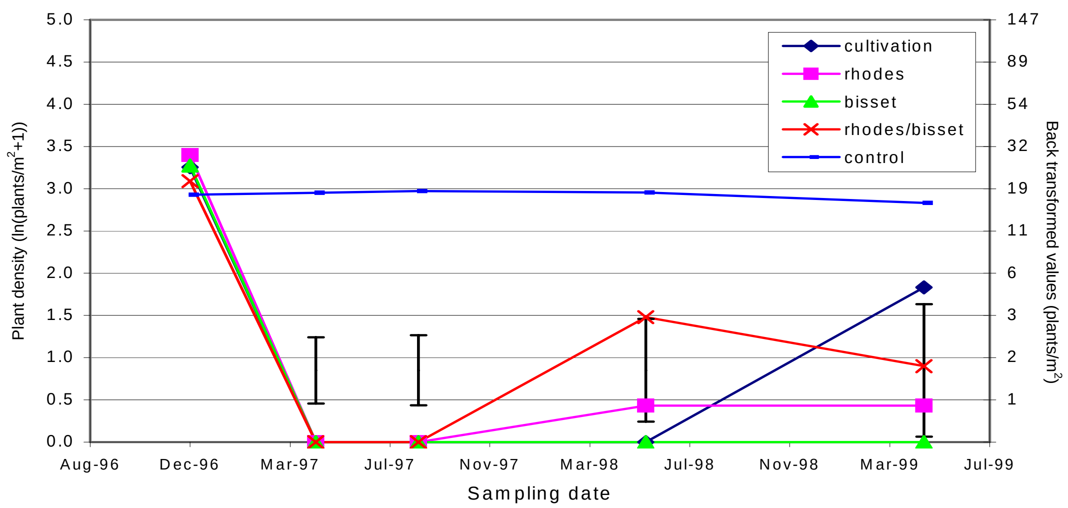

Figure 4.15 Giant rats tail grass plant density response for the cultivation and competitive species treatments at Gympie.
The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment plant density response was similar to the control (data not presented), unlike the basal area response (Fig 4.9).

4.4.3.2 Kilcoy giant rats tail grass plant density

The control, slash, slash/rake, and fertiliser treatments giant rats tail grass plant density remained constant throughout the experiment (Fig 4.16). The fire treatment giant rats tail grass plant density was slowly decreasing to June 1998 (75.6% of initial plant density), but then increased sharply to become significantly higher than the control (5.8 times higher than the control). Selective herbicide application reduced giant rats tail grass plant density sharply and it remained significantly lower than the control (4.5% of initial plant density at final sampling). The wick wipe treatment had a similar density to the selective treatment at the final sampling, however the plant density did not decrease substantially until after the third wick wipe. The unselective herbicide treatment decreased plant density but was never significantly different from the control.

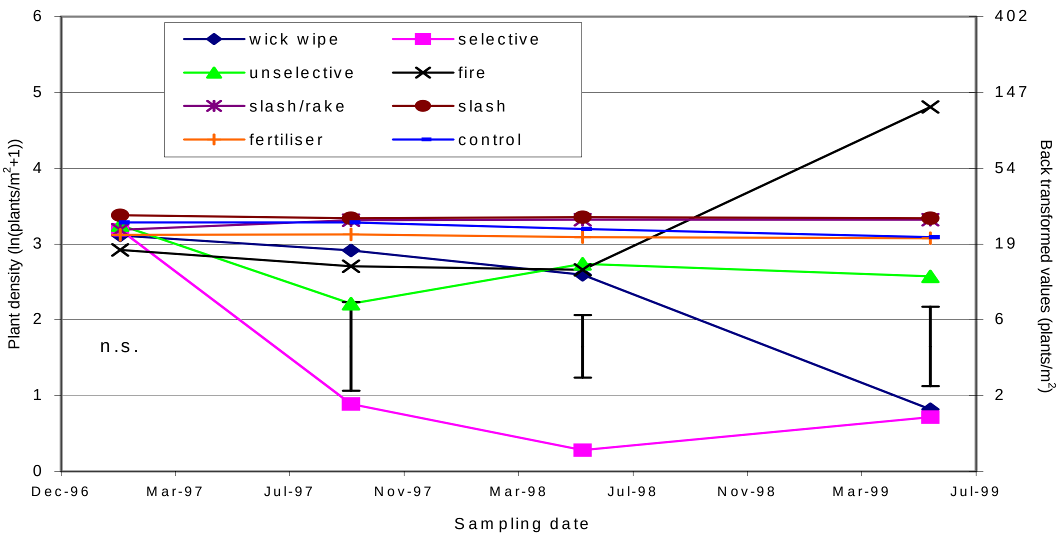

Figure 4.16 Giant rats tail grass plant density response for various treatments at Kilcoy. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The competitive species treatments at this site followed a different response pattern compared to the Gympie site. Giant rats tail grass plant density was significantly higher than the control following sowing (Fig 4.17), but by the final sampling the plant density had dropped, with the rhodes/bisset and rhodes treatments not significantly different from the control, while the bisset treatment plant density was three times greater than the control. Many giant rats tail grass plants had established in the cultivation treatment between the last cultivation and the final sampling (4 months), with plant density similar to the control.

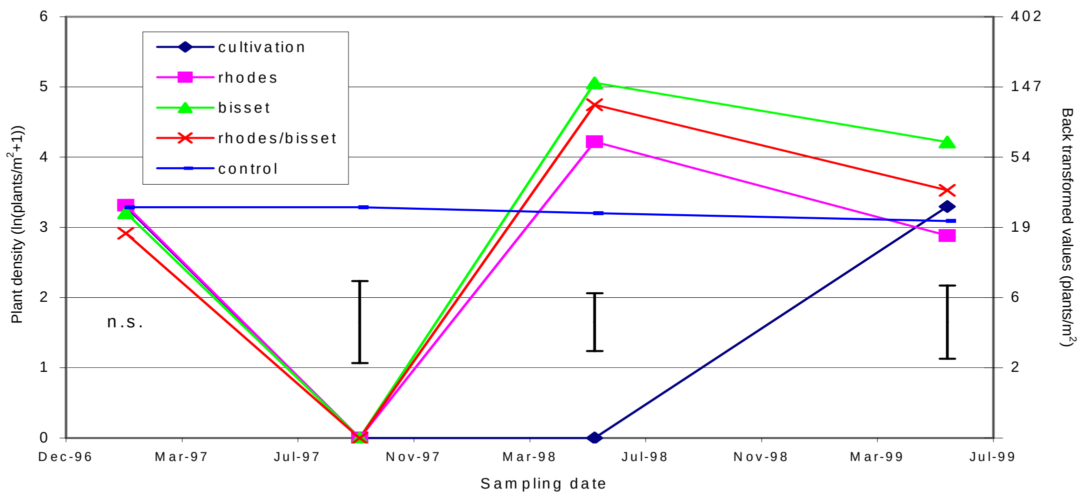

Figure 4.17 Giant rats tail grass plant density response for the cultivation and competitive species treatments at Kilcoy.
The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment was wick wiped and the giant rats tail grass plant density declined similarly to the wick wipe treatment (data not presented).

4.4.3.3 Foxtail Flats giant rats tail grass plant density

The control, fertiliser, slash, slash/rake and fire treatments giant rats tail grass plant density remained relatively static until April 1998, whereafter all treatments increased in plant density (Fig 4.18). The fertiliser and fire treatments had the greatest increase in density. As expected the selective and unselective treatments giant rats tail grass plant density dropped substantially after the initial herbicide application, but by the final sampling density had increased and was similar to the control. Giant rats tail grass plant density did not change substantially with the wick wipe treatment in contrast to the other sites.

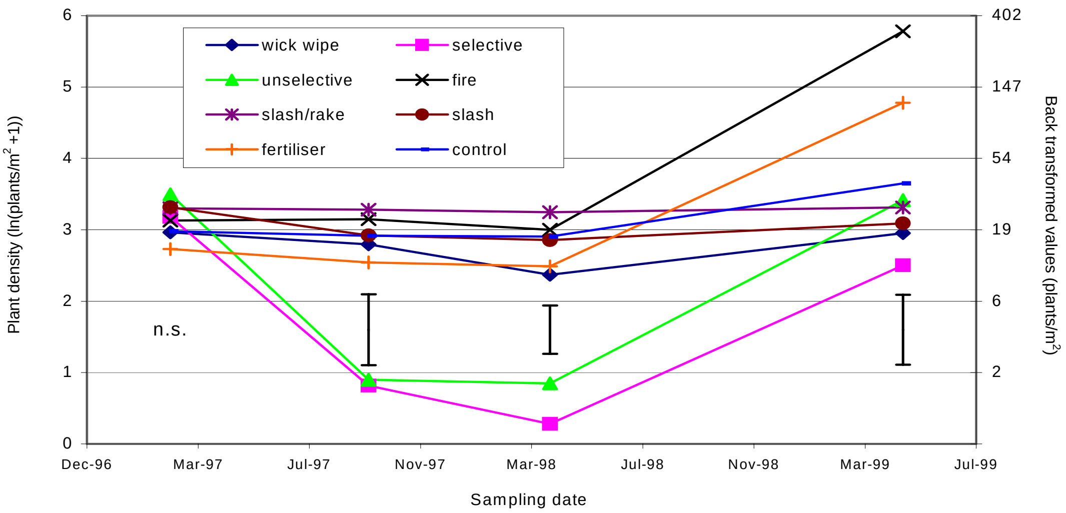

Figure 4.18 Giant rats tail grass plant density response for various treatments at Foxtail Flats. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

Sowing competitive species (involved cultivation and herbicides) removed all the initial giant rats tail grass plants, however many giant rats tail grass seedlings subsequently established (similar to the Kilcoy site, Fig 4.17) and survived for the duration of the experiment (Fig 4.19). Many giant rats tail grass seedlings established between the last cultivation and the final sampling in the cultivation treatment (~3 months), resulting in little change in plant density compared to the initial sampling date.

There was no difference between the farmer management and control treatments for giant rats tail grass plant density response throughout the experiment (data not presented).

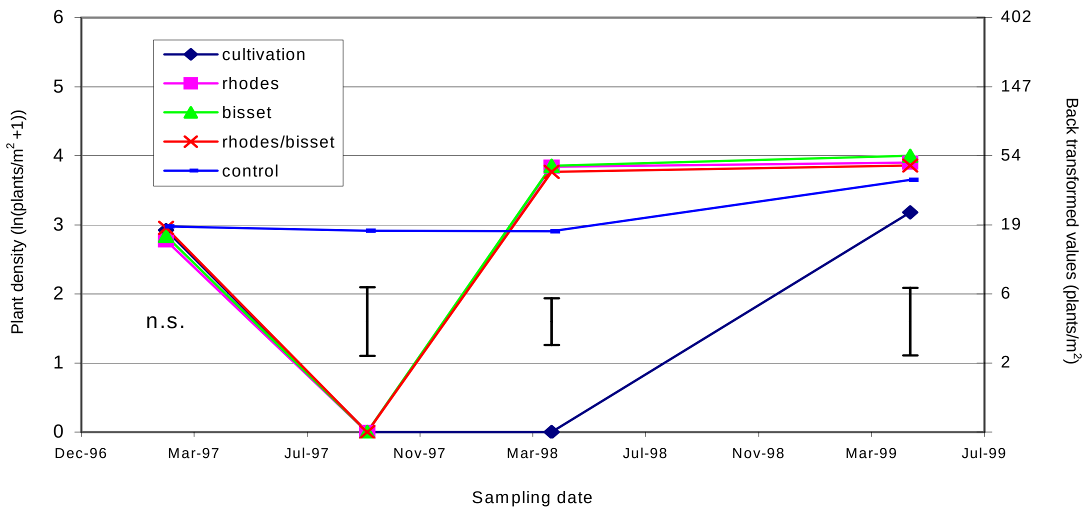

Figure 4.19 Giant rats tail grass plant density response for the cultivation and competitive species treatments at Foxtail Flats.
The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

4.4.4 Pasture species percent composition

Pasture species percent composition data was collected using the percentage-dry-matter-yield BOTANAL procedure (Tothill *et al*. 1992). Only data for giant rats tail grass are presented but other major species are referred to in the text. There were generally no significant differences between treatments prior to the treatments being imposed.

4.4.4.1 Gympie pasture species percent composition

Prior to treatments being imposed at Gympie, the pasture was uniformly 98.2 to 99.9% giant rats tail grass (Fig 4.20), with rhodes grass contributing around 1% (data not presented) to the pasture yield. During the experiment the control treatment progressively dropped in proportion of giant rats tail grass to 49.6% at the final sampling, with rhodes grass generally making up the rest of the bulk of the pasture. All the other pasture species (predominately paspalum and carpet grass) rarely contributed more than 10% to the pasture yield across all treatments and sampling dates (data not presented). Therefore rhodes grass proportion of the pasture generally mirrors the giant rats tail grass data.

The general fall in giant rats tail grass proportion of the pasture and increase in rhodes grass from the start of the experiment coincided with cattle being excluded from the site, while a general rise across all treatments in giant rats tail grass between October 1998 and April 1999 coincided with a high rainfall season and cattle allowed regular access to the site.

The proportion of giant rats tail grass in the fertiliser treatment dramatically decreased with time to 10.2% at the final sampling, being replaced by rhodes grass. The pattern of giant rats tail grass decline in the fertiliser treatment was similar to that of the wick wipe herbicide treatment. The fire treatment proportion of giant rats tail grass decreased to 33.8% in May 1997 after one fire, but had risen by September 1998 to have the highest giant rats tail grass proportion, with reciprocal changes in rhodes grass.

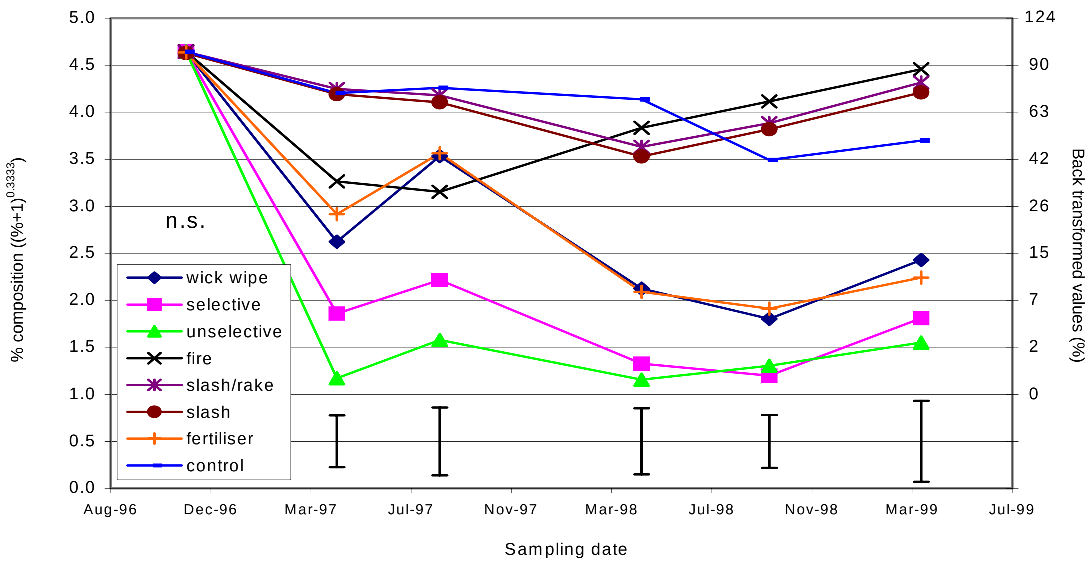

Figure 4.20 Giant rats tail grass percent composition response for various management treatments at Gympie.

Rhodes grass generally made up the rest of the pasture bulk and therefore mirrors the giant rats tail grass data. Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

There was a significant difference between the three herbicide treatments in the proportion of giant rats tail grass surviving the first application of herbicide (Fig 4.20), with the unselective treatment the lowest (0.6%), followed by the selective (5.4%) and wick wipe treatments (17%, dropped to 9% after the second wick wipe). The herbicide treatments were predominately rhodes grass with low amounts of giant rats tail grass for the remainder of the experiment.

The competitive species treatments at the final sampling contained low amounts of giant rats tail grass (Fig 4.21). The bisset and rhodes/bisset treatments contained 78% and 37% bisset bluegrass respectively at the final sampling (data not presented), with rhodes grass making up the remainder.

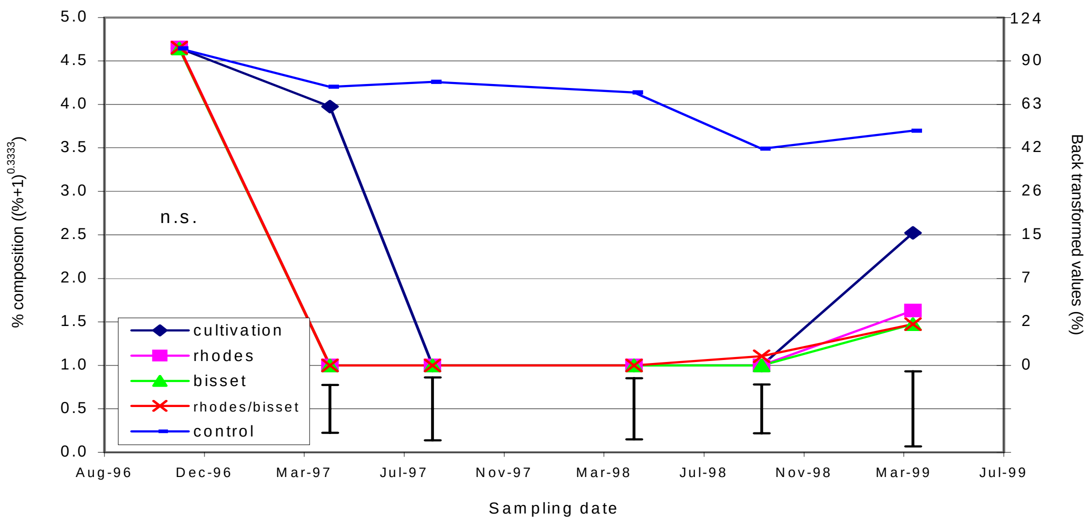

Figure 4.21 Giant rats tail grass percent composition response for the cultivation and competitive species treatments at Gympie.
Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment giant rats tail grass percent composition, in contrast to the control treatment, remained constant throughout the experiment (Fig 4.22) and was significantly higher than the control towards the end of the experiment. The farmer management treatment was subjected to continuous grazing and rhodes grass did not increase.

4.4.4.2 Kilcoy pasture species percent composition

The bulk of the pasture at Kilcoy, other than in the sown pasture treatments, can be split into two species groups: 1. giant rats tail grass, and 2. naturalised, stoloniferous grasses (predominately couch, carpet grass and paspalum). Only the giant rats tail grass percent composition data are presented, as the bulk of the remaining pasture generally contained the naturalised, stoloniferous grasses so the graphs are close to being a mirage image.

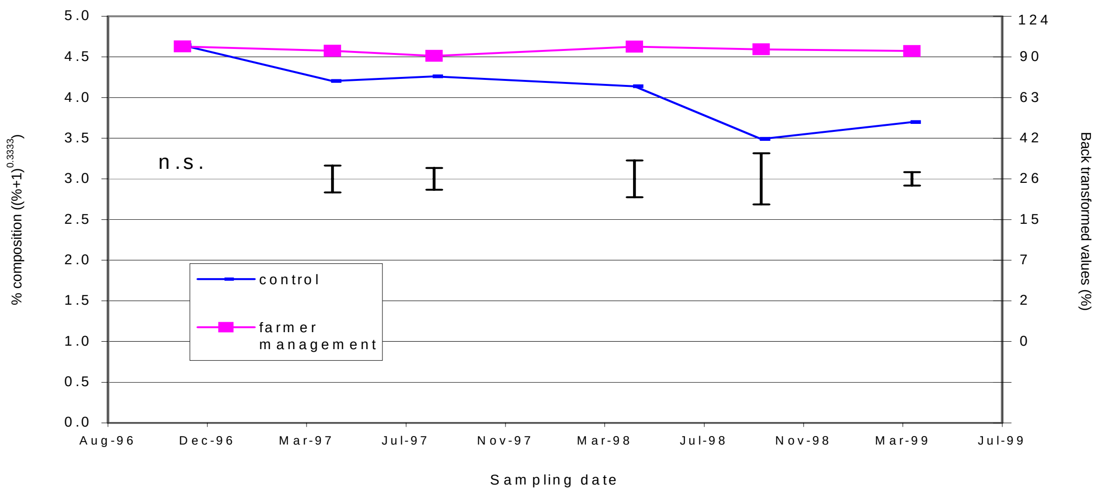

Figure 4.22 Giant rats tail grass percent composition response for the farmer management and control treatments at Gympie.
Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The giant rats tail grass proportion of the pasture in the control and fertiliser treatments rose steadily throughout the experiment from about 60% to >90% (Fig 4.23), with a reciprocal decline in naturalised, stoloniferous grasses. From May 1998, these two treatments had total dry matter yields of >9000 kg/ha (data not presented). This large bulk of predominately giant rats tail grass would have overshadowed the shorter stoloniferous species. From October 1998 to May 1999, there was an increase in the giant rats tail grass across all treatments, which coincided with increased assess of cattle to the site.

The percentage of giant rats tail grass in the fire treatment was never significantly lower than the control throughout the experiment. The selective herbicide treatment quickly reduced the giant rats tail grass proportion of the pasture, while the unselective and wick wipe treatments responded more slowly. At the final sampling, the giant rats tail grass in the unselective treatment had increased to become a substantial proportion of the pasture (38%).

Following the removal of giant rats tail grass (herbicide application and cultivation) and sowing the competitive species treatments, the giant rats tail grass percent composition steadily increased (Fig 4.24). At the final sampling, the bisset treatment contained 43% giant rats tail grass and 55% bisset bluegrass, while the rhodes treatment only contained 3% giant rats tail grass and 97% rhodes grass. The rhodes /bisset treatment contained 90% rhodes grass and only 0.5% bisset bluegrass at the final sampling.

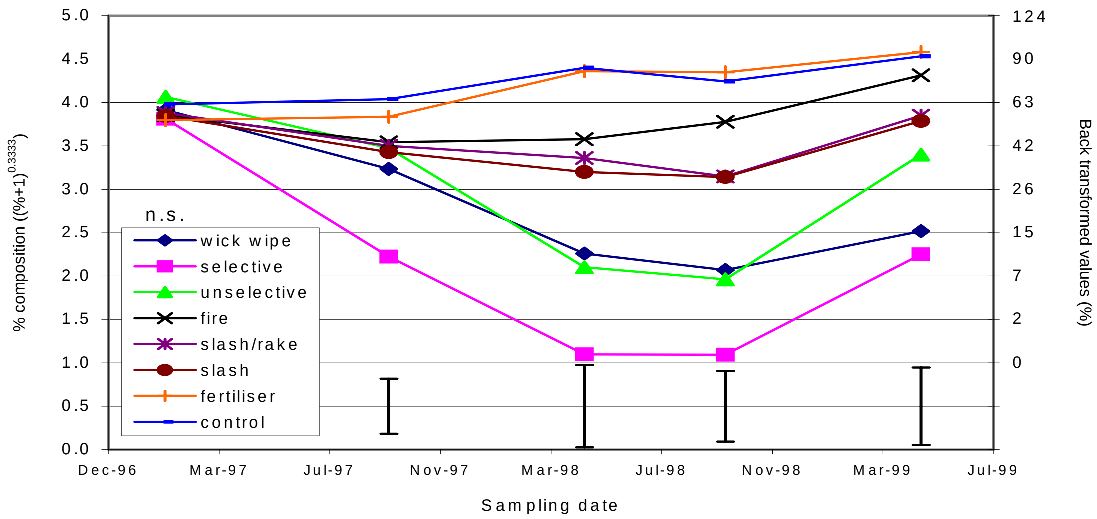

Figure 4.23 Giant rats tail grass percent composition response for various treatments at Kilcoy. Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The giant rats tail grass percent composition in the farmer management treatment (which was wick wiped) was similar to the wick wipe treatment (data not presented).

Rhodes grass, although only a small proportion of the pasture at the initial sampling increased in some plots of certain treatments (wick wipe, selective, unselective, fertiliser and farmer management treatments) (data not presented).

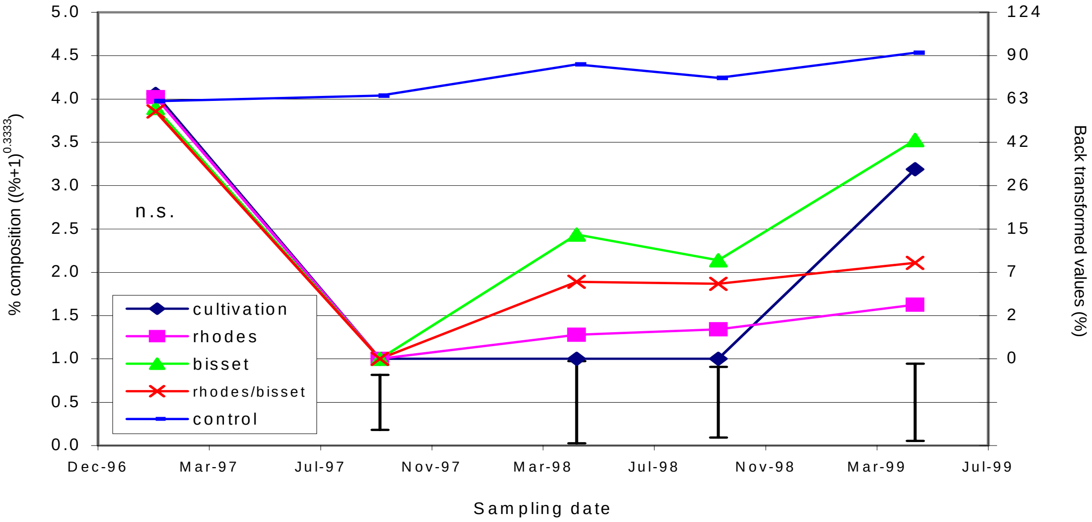

Figure 4.24 Giant rats tail grass percent composition response for the cultivation and competitive species treatments at Kilcoy.
Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

4.4.4.3 Foxtail Flats pasture species percent composition

At the initial sampling the total dry matter yield at Foxtail Flats site was very high (grand mean 18000 kg/ha) and giant rats tail grass made up greater than 90% of the pasture (Fig 4.25). The control, slash, slash/rake and fertiliser treatments proportion of giant rats tail grass remained high and static throughout the experiment. The selective and unselective herbicide treatments quickly reduced giant rats tail grass percent composition (mean 1% – not including dead attached giant rats tail grass) after treatments were imposed, however giant rats tail grass increased to 38.3% and 85% respectively by the final sampling. The wick wipe treatment giant rats tail grass percent composition declined fairly slowly and erratically but was significantly lower than the control at the final sampling. The bulk of the rest of the pasture in the herbicide treatments was made up of upright native grasses (eg. blady grass *Imperata cylindrica*, native *Sorghum* spp.).

The giant rats tail grass percent composition in the competitive species treatments increased at each sampling date following sowing (Fig 4.26). The rhodes and rhodes/bisset treatments contained 38% giant rats tail grass at final sampling, while the bisset treatment contained 85% giant rats tail grass at final sampling. The rhodes and rhodes/bisset treatments contained 60% and 61% rhodes grass respectively at the final sampling. The bisset and rhodes/bisset treatments only contained 14% and 2% bisset bluegrass respectively at the final sampling.

There was no difference between the control and farmer management treatments, with both treatments containing 90-99% giant rats tail grass throughout the experiment (data not presented).

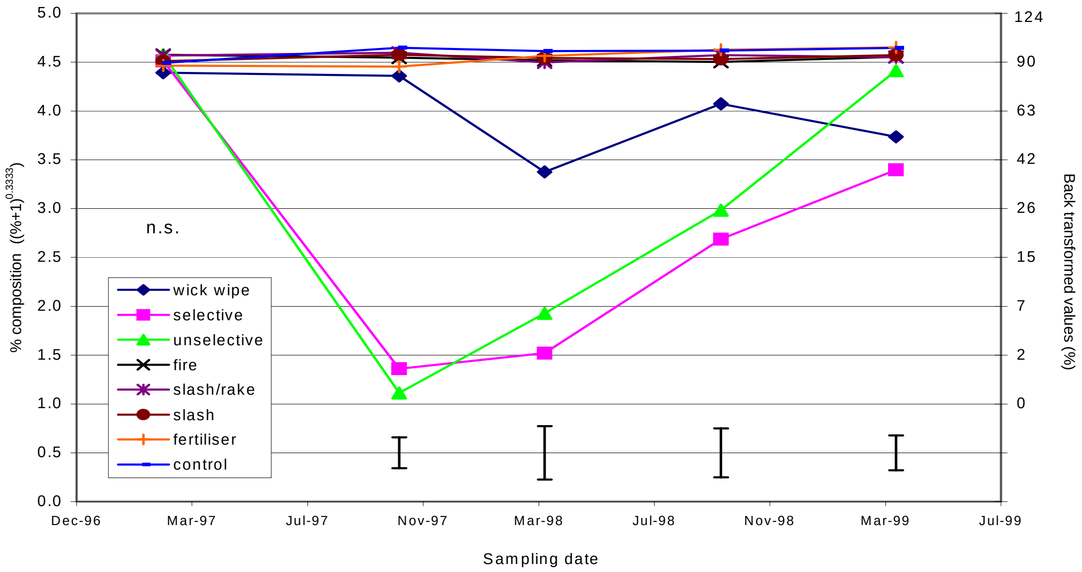

Figure 4.25 Giant rats tail grass percent composition for various treatments at Foxtail Flats. Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

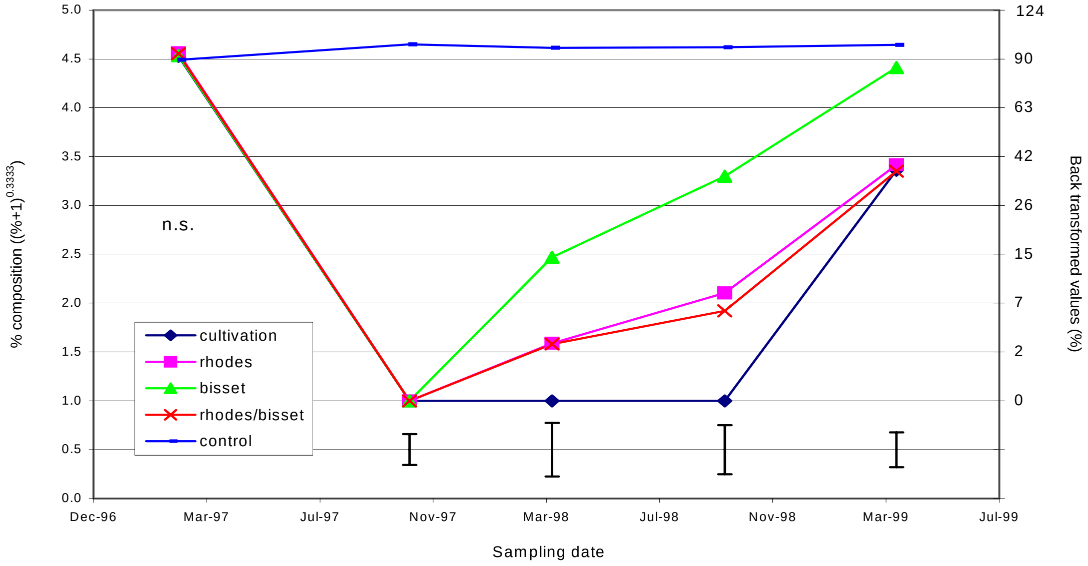

Figure 4.26 Giant rats tail grass percent composition response for the cultivation and competitive species treatments at Foxtail Flats.
Data are cube root transformed ($(\%+1)^{0.3333}$) and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

4.4.5 Giant rats tail grass seedling number

Within an elongated permanent quadrat in each plot, newly emerged giant rats tail grass seedlings (not necessarily recruited into the plant population, as defined by the seedling surviving for >8 weeks) were identified and counted every 8-12 weeks. The seasonal (1997/98 and 1998/99) and total seedling number for each plot were analysed following natural log (ln) transformation.

4.4.5.1 Gympie giant rats tail grass seedling number

The cultivation and fire treatments had the highest total giant rats tail grass seedling number with 380 and 344 seedlings/m^2 respectively and were significantly higher than the other treatments (Fig 4.27). The control, fertiliser, herbicide and slashing treatments had few or no seedlings identified and counted.

The fire treatment had more of giant rats tail grass seedlings counted in the 1998/99 season than the 1997/98 season (335 seedlings/m^2 compared to 4.1 seedlings/m^2) which coincides with high rainfall over the 1998/99 summer and the dramatic increase in plant density measured with charting (Fig 4.14). By comparison the cultivation treatment had the majority of seedlings counted in the 1997/98 season (365 seedlings/m^2 compared to 14.6 seedlings/m^2 in the 1998/99 season). The herbicide, slashing, competitive species and control treatments had some giant rats tail grass seedlings counted in the 1997/98 season and none in the 1998/99 season.

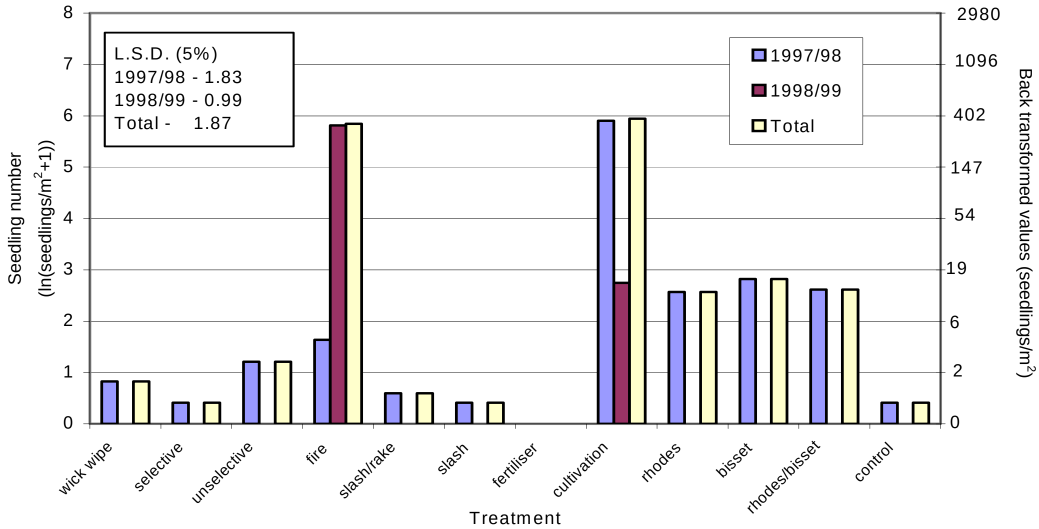

Figure 4.27 Number of giant rats tail grass seedlings for various treatments at Gympie. The data are natural log (ln) transformed and the right y-axis contains back transformed values.

The farmer management treatment had the same giant rats tail grass seedling number as the control (data not presented).

4.4.5.2 Kilcoy giant rats tail grass seedling number

The control, wick wipe and slash/rake treatments had no giant rats tail grass seedlings identified and counted throughout the experiment (Fig 4.28), while the slash and fertiliser treatments had a few seedlings counted (<2.2 seedlings/m^2).

Total seedling numbers in the fire (696 seedlings/m^2), cultivation (557 seedlings/m^2) and competitive species treatments (mean 210 seedlings/m^2) were not significantly different. The unselective herbicide treatment (111 seedlings/m^2) was significantly higher than the other herbicide treatments.

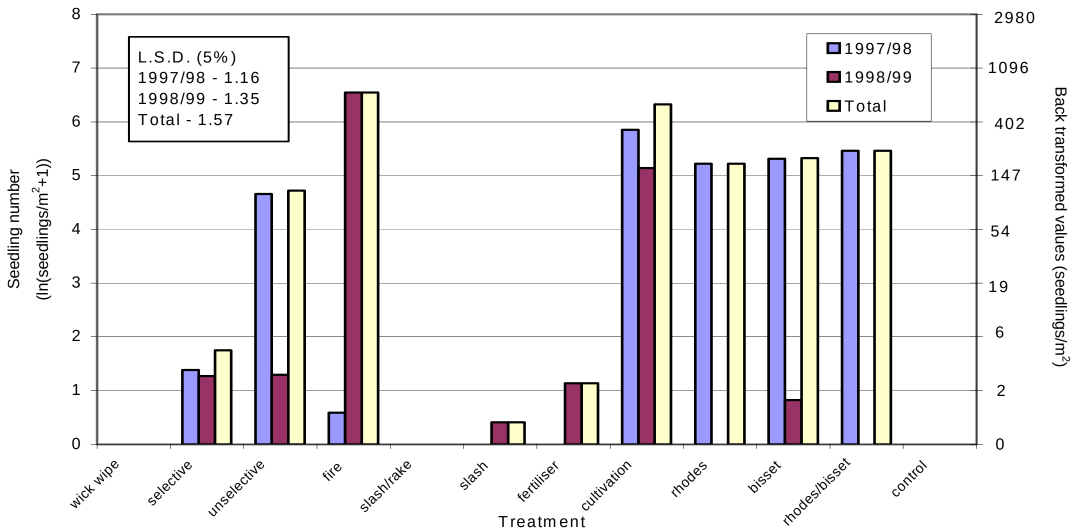

Figure 4.28 Number of giant rats tail grass seedlings for various treatments at Kilcoy. The data are natural log (ln) transformed and the right y-axis contains back transformed values.

The relative counts from 1997/98 and 1998/99 seasons were inconsistent across treatments. The competitive species and unselective herbicide treatments had most seedlings emerge in the 1997/98 season, contrasting with the fire and fertiliser treatments, while the cultivation and selective herbicide treatments had a similar number of seedlings emerging in both seasons. The competitive species treatments had many seedlings emerge during sown pasture establishment (1997/98 season) with few seedlings emerging thereafter (also see Fig 4.17).

The farmer management treatment had no giant rats tail grass seedlings identified and counted throughout the experiment (data not presented).

4.4.5.3 Foxtail Flats giant rats tail grass seedling number

The Foxtail Flats site had giant rats tail grass seedlings counted in all treatments in each year (Fig 4.29), contrasting with the other sites.

The fire (1190 seedlings/m^2), cultivation (510 seedlings/m^2) and slash/rake treatments (360 seedlings/m^2) had the highest total seedling number emerging, but only the fire treatment was significantly higher than the control (42 seedlings/m^2). By comparison, the wick wipe treatment had the lowest total seedling number recorded (2.3 seedlings/m^2). The selective, slash, slash/rake, fertiliser and control treatments had substantially more giant rats tail grass seedlings at the Foxtail Flats site than at the Gympie and Kilcoy sites, possibly due to the difference in associated pasture species.

The number of differed greatly between seasons, but the direction of differences was not consistent. The competitive species had more seedlings counted in the 1997/98 season during pasture establishment. The competitive species treatments at Foxtail Flats still had seedlings emerging in the 1998/99 season, which contrasts with the other sites, where only the bisset treatment at Kilcoy had some seedlings counted in the second season.

The farmer management treatment (1.4 seedlings/m^2) had fewer seedlings than the control (3.3% of control), but the difference was not significant (data not presented).

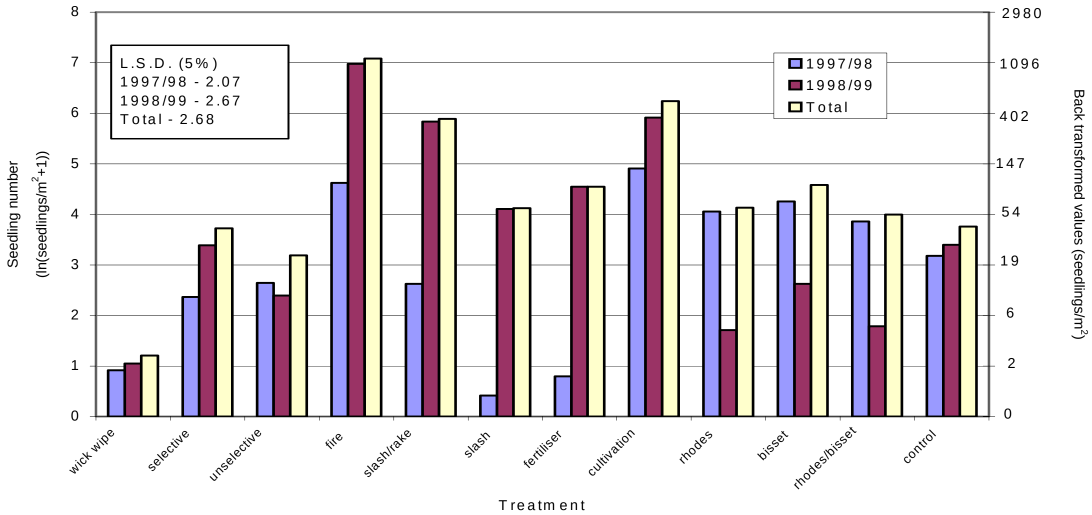

Figure 4.29 Number of giant rats tail grass seedlings for various treatments at Foxtail Flats. The data are natural log (ln) transformed and the right y-axis contains back transformed values.

4.4.6 Total ground cover

The total ground cover was usually estimated at the same time as giant rats tail grass seedlings were counted (every 8-12 weeks). Most treatments remained at or close to 100% ground cover throughout the experiment, so data were not analysed. Data have been presented for treatments that did differ from 100% ground cover and are the mean of the three blocks at a site.

4.4.6.1 Gympie total ground cover

Most treatments at Gympie were close to 100% ground cover (data not presented), with only the cultivation, fire and competitive species treatments (prior to pasture establishment) differing substantially (Fig 4.30). The fire treatment ground cover dropped temporarily following burning in spring 1997 (80% cover) and spring 1998 (50% cover).

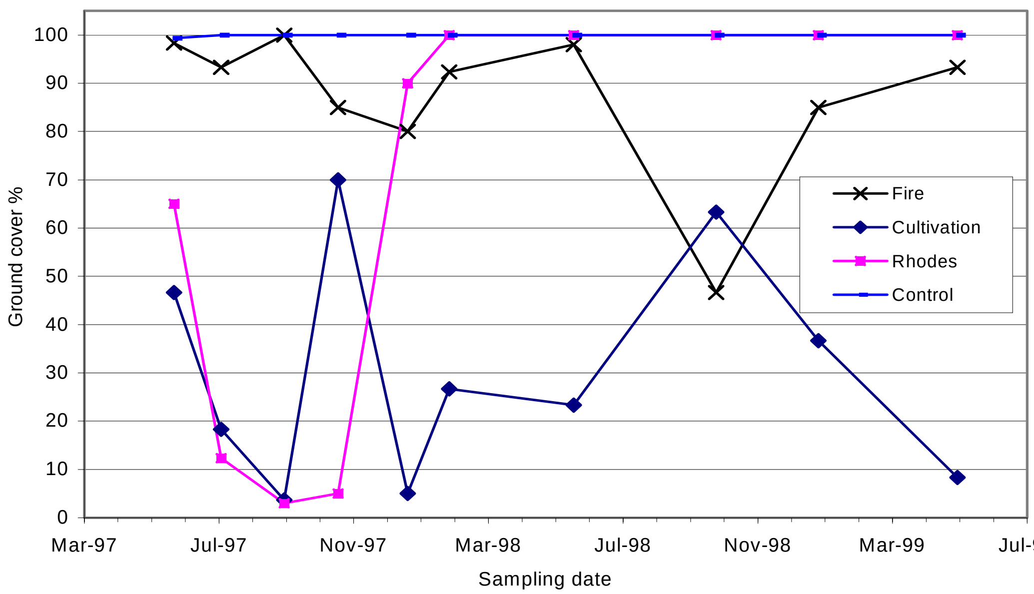

Figure 4.30 Total ground cover (%) response for the fire, cultivation and rhodes treatments at the Gympie site that varied substantially (more than 10%) from 100% cover.
Data are means of 3 blocks and have not been statistically analysed. The bisset and rhodes/bisset treatments were similar to the rhodes treatment.

4.4.6.2 Kilcoy total ground cover

Kilcoy total ground cover was similar to that of the Gympie site with the cultivation, competitive species, fire and unselective treatments the only treatments varying substantially from 100% total ground cover (Fig 4.31).

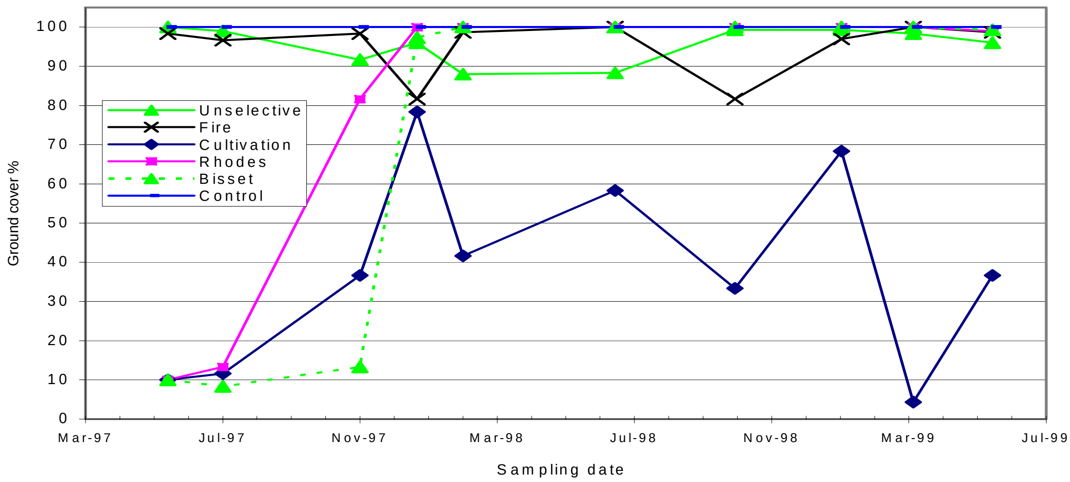

Figure 4.31 Total ground cover (%) response for the unselective, fire, rhodes, bisset and cultivation treatments at Kilcoy that varied substantially (more than 10%) from 100% cover. Data are means of 3 blocks and have not been statistically analysed. The rhodes/bisset treatment was similar to the bisset treatment.

The rhodes treatment increased total ground cover after sowing much faster than the bisset treatment (rhodes/bisset treatment was similar to the bisset treatment), although they all reached 100% ground cover in the 1997/98 wet season.

Following burning, the total ground cover of the fire treatment dropped to 80%, but recovered soon after. The total ground cover in the unselective herbicide treatment also dropped to approximately 90% cover for extended periods.

4.4.6.3 Foxtail Flats total ground cover

Compared to Gympie and Kilcoy sites, many treatments at Foxtail Flats were below 100% total ground cover for much of the experiment, which is probably due to the lack of stoloniferous grass species at this site (see section 4.4.4.3). The total ground cover in the fire treatment fluctuated between 25 and 80% cover (Fig 4.32), which was similar to the slash/rake treatment (30-70% cover). The slash treatment ground cover remained between 100 % and 75% cover.

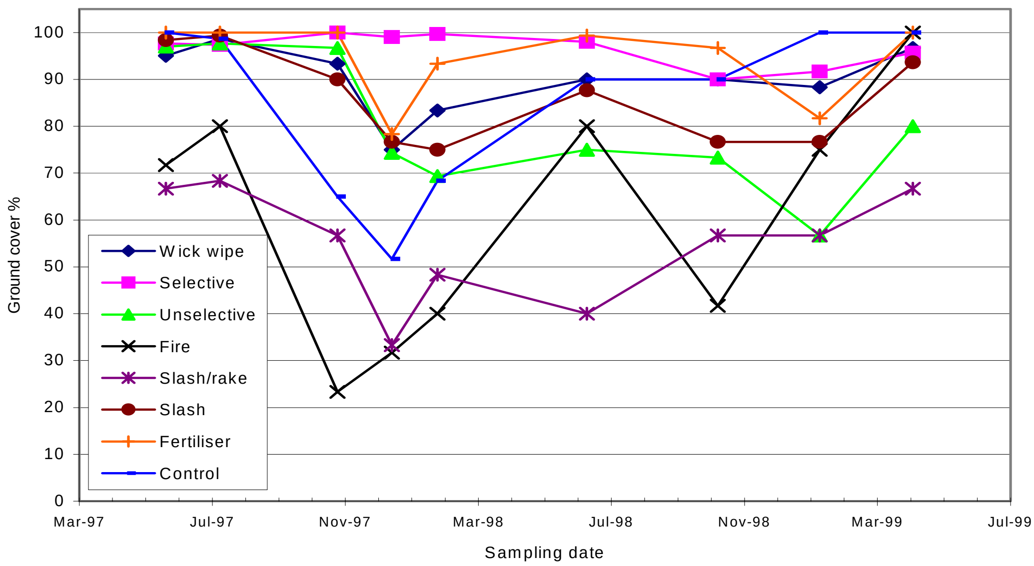

Figure 4.32 Total ground cover (%) response for various treatments at Foxtail Flats which varied substantially (more than 10%) from 100% cover.
Data are means of 3 blocks and have not been statistically analysed.

A bushfire reduced the control treatment ground cover in spring 1997 to 50% cover, but it then recovered and remained between 90 and 100% for the rest of the experiment. The unselective herbicide treatment ground cover dropped to 70-80% cover in spring 1997 as the dead giant rats tail grass trash decomposed, with cover remaining between 55 and 80% thereafter. By comparison the selective herbicide treatment remained between 90 and 100% for the whole experiment.

Once established, the competitive species treatments maintained the ground cover at 80-90%, which was lower than the Gympie and Kilcoy sites (Fig 4.33). The ground cover in the farmer management treatment was reduced by the bushfire in spring 1998.

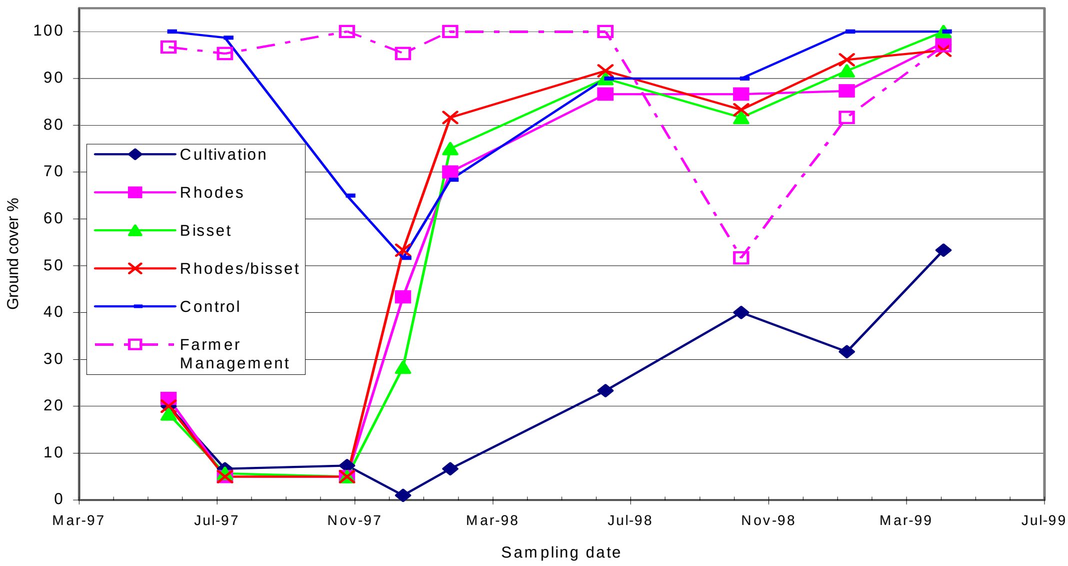

Figure 4.33 Total ground cover (%) response for the cultivation, competitive species and farmer management treatments at Foxtail Flats.
Data are means of 3 blocks and have not been statistically analysed.

4.4.7 Giant rats tail grass inflorescence density

Inflorescence density was determined during charting of the giant rats tail grass plants in the permanent quadrats. Inflorescences were counted if they still had seed-head branches attached. There were no significant differences between treatments in inflorescence density at the initial sampling at any site. At the spring 1997 charting, there were few inflorescences at any site, so data for this date were not analysed.

4.4.7.1 Gympie inflorescence density

The treatments tended to split into two significantly different groups at May 1997 that were generally maintained during the experiment (Fig 4.34). The slash, slash/rake, fire, control and fertiliser treatments had high densities of inflorescences, while the herbicide and competitive species treatments (mean 0.4 inflorescences/m^2) had low numbers.

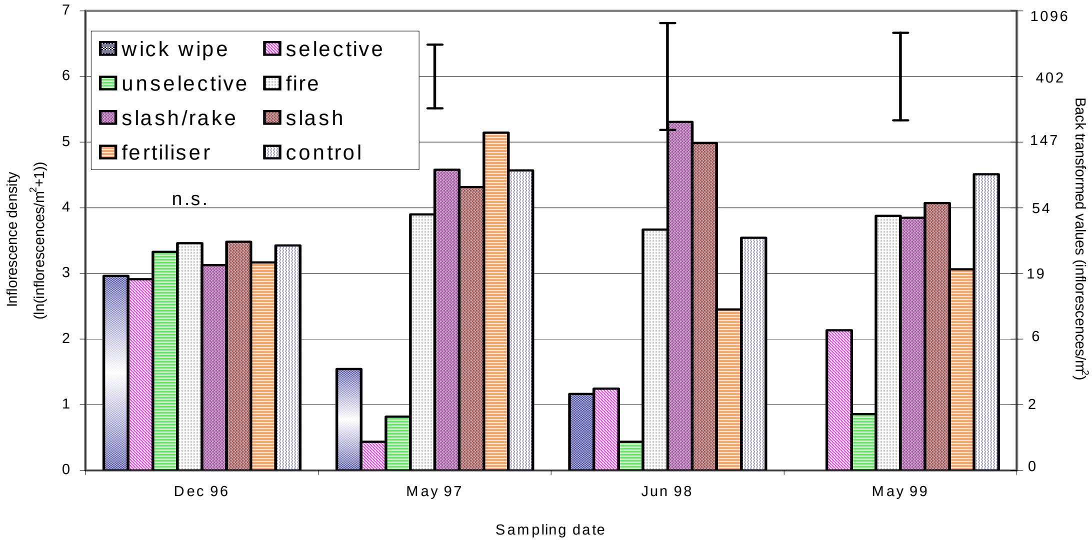

Figure 4.34 Giant rats tail grass inflorescence density response for various treatments at Gympie. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

The farmer management treatment was not significantly different from the control (data not shown).

4.4.7.2 Kilcoy inflorescence density

At June 1998, the treatments split into 2 distinct groups for giant rats tail grass inflorescence density (Fig 4.35). The highest densities were for the fertiliser, fire and control treatments (mean 133 inflorescences/m^2), while the lower densities were for the slash, slash/rake and the herbicide treatments. By the final sampling further changes had developed and although the fertiliser, control and fire treatments were still the highest (mean 96 inflorescence/m^2), the slash, slash/rake and unselective herbicide treatments had risen substantially (mean 28 inflorescences/m^2). The wick wipe and selective treatments had no inflorescences at the final sampling.

The rhodes and rhodes/bisset treatments had low numbers of giant rats tail grass inflorescences at the final sampling (mean 0.96 inflorescences/m^2), while the bisset treatment had 13.5 inflorescences/m^2 (data not shown). The farmer management treatment behaved similarly to the wick wipe treatment and was significantly lower than the control from June 1998 (data not shown).

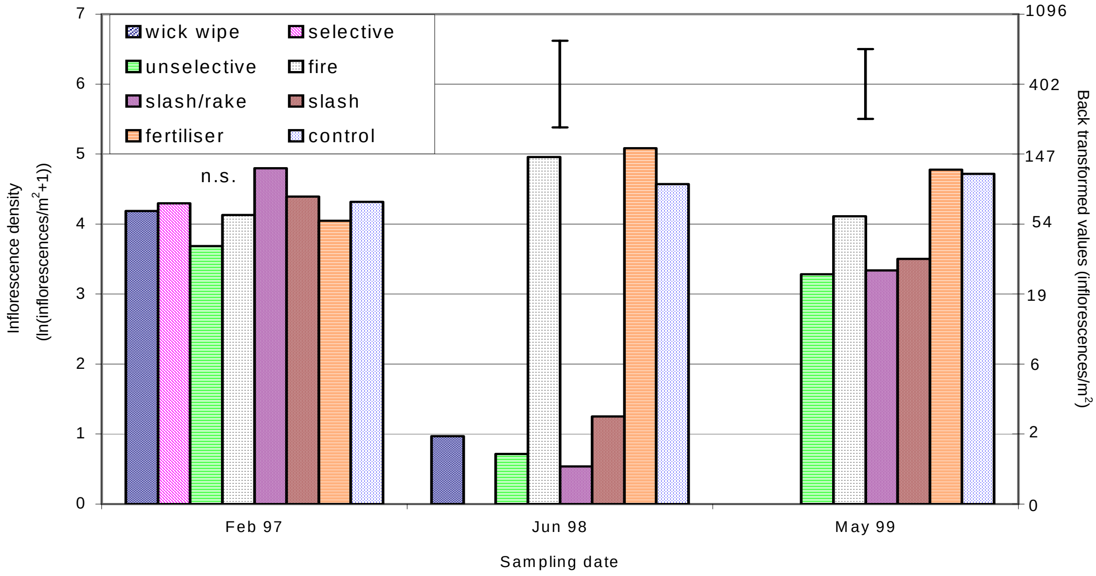

Figure 4.35 Giant rats tail grass inflorescence density response for various treatments at Kilcoy. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

4.4.7.3 Foxtail Flats inflorescence density

The Foxtail Flats site had a lower initial density of giant rats tail grass inflorescences (mean 6 inflorescences/m^2) (Fig 4.36) compared to the Gympie (mean 20 inflorescences/m^2) and Kilcoy (mean 63 inflorescences/m^2) sites. Seven months later in October 1997, the slash, slash/rake and fire treatments had 15, 2 and 5 inflorescences/m^2 respectively (data not shown), while the other treatments had no inflorescences. At April 1998, the slash and slash/rake treatments were overtaken by the control, fire and fertiliser treatments, which had the highest inflorescence density and by the final sampling in April 1999, only inflorescence counts remained low on the wick wipe and selective treatments.

The rhodes, rhodes/bisset and bisset treatments had 3, 5 and 16 inflorescences/m^2 respectively at the final sampling (data not shown). The farmer management treatment had a similar inflorescence density to the control (data not shown).

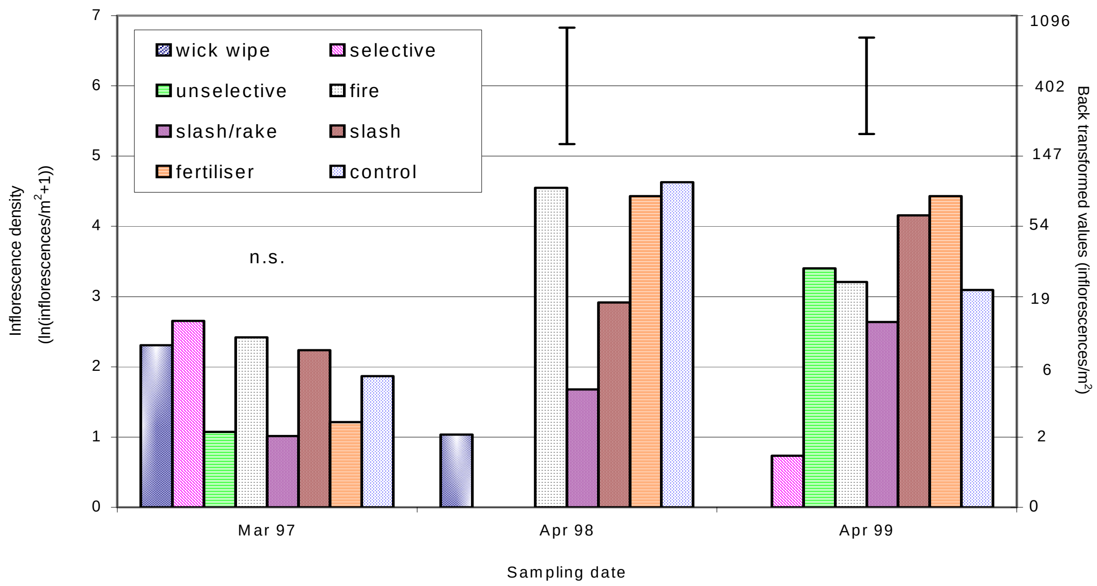

Figure 4.36 Giant rats tail grass inflorescence density response for treatments at Foxtail Flats. The data are natural log (ln) transformed and the right y-axis contains back transformed values. Error bars are LSD at 5% level (n.s. = no significant difference between treatments at that sampling date).

4.4.8 Giant rats tail grass seed production

Due to the large amount of time required to process the seed trap samples, generally only 1 seed trap from each treatment at each site has been processed. Therefore the data have not been statistically analysed and care must be taken when comparing treatment effects. Seed traps sometimes developed holes in the mesh, so some seed is likely to have been lost. Therefore values presented may be an underestimate.

4.4.8.1 Gympie seed production

Large numbers of giant rats tail grass seeds were produced in the 5 treatments sampled, with the control and fire treatments producing about 30000 seeds/m^2/year (Fig 4.37). The slash and fertiliser treatments produced the highest number of seeds in 1997/98 season, but fewer in 1998/99 season. The farmer management treatment produced fewer seeds than the control in 1997/98 season, but a similar number in the 1998/99 season.

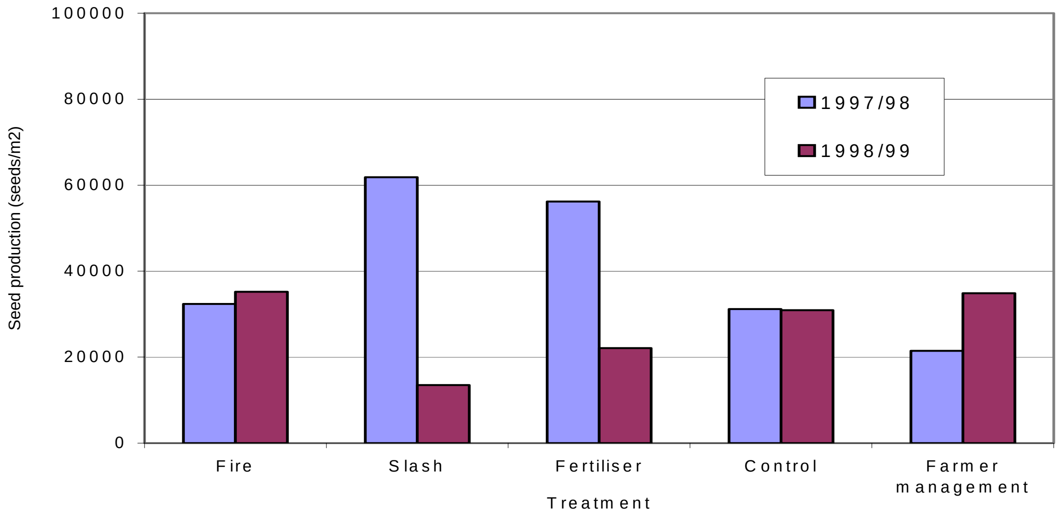

Figure 4.37 Giant rats tail grass seed production response for various management treatments at Gympie, measured using seed traps during 2 seasons.
Only one sample per treatment has been processed and the data are not statistically analysed.

4.4.8.2 Kilcoy seed production

All treatments except the fire treatment produced more seeds in 1997/98 season than in the 1998/99 season (Fig 4.38). The fertiliser treatment produced the largest number of seeds in each year. The slash treatment produced more seeds than the control in 1997/98, but fewer than the control in the 1998/99 season. The fire treatment produced similar numbers of seeds to the control in 1998/99, but far fewer in the 1997/98 season. The farmer management treatment produced the least number of seeds compared to other treatments, but this treatment had been wick wiped three times over the 2 seasons.

4.4.8.3 Foxtail Flats seed production

The control, fertiliser and fire treatments produced very large numbers of giant rats tail grass seeds in the 1997/98 season (>73000 seeds/m^2) (Fig 4.39). By comparison, much less seed was produced in the 1998/99 season, with the fertiliser treatment producing the most giant rats tail grass seed (3800 seeds/m^2).

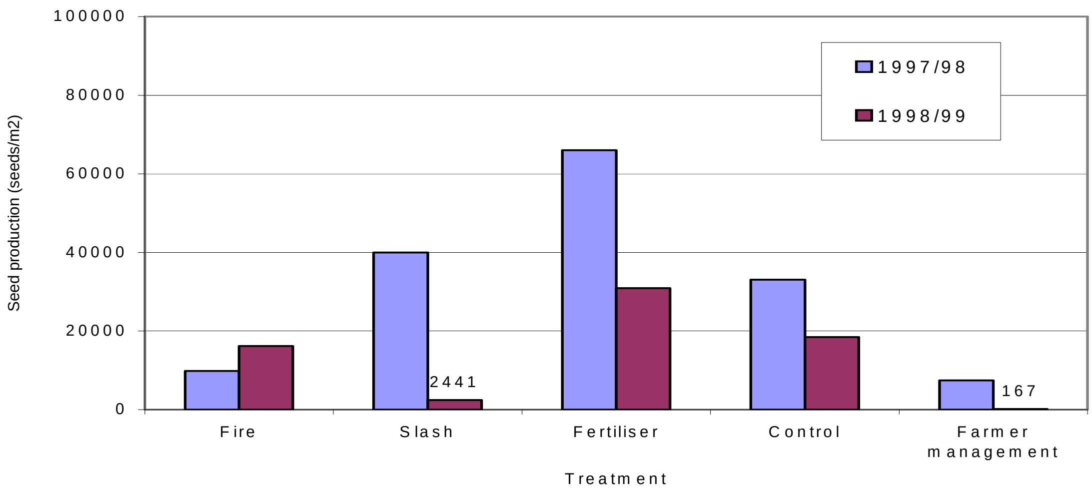

Figure 4.38 Giant rats tail grass seed production response for various management treatments at Kilcoy, measured using seed traps during 2 seasons.

Only one sample per treatment has been processed and the data are not statistically analysed.

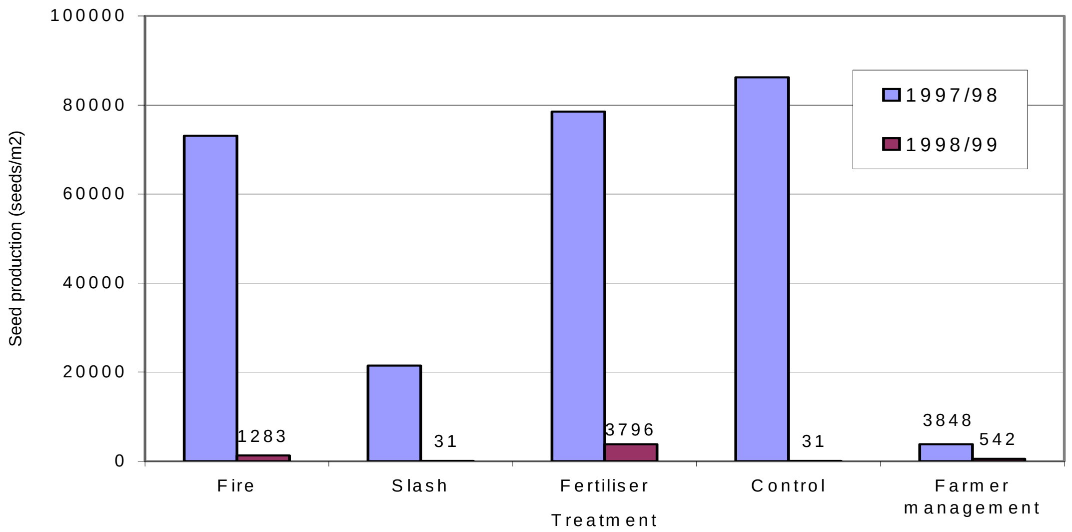

Figure 4.39 Giant rats tail grass seed production response for various management treatments at Foxtail Flats, measured using seed traps during 2 seasons.

Only one sample per treatment has been processed and the data are not statistically analysed.

4.5 *Discussion*

This discussion will focus on the results from the three sites in relation to the differences between individual treatments. The implications of the results of this experiment for understanding the life cycle stages and transitions of giant rats tail grass will be discussed in the General Discussion (Chapter 7), along with the results of the other experiments.

4.5.1 Control treatment

The control treatment was involved removing cattle grazing from a giant rats tail grass infested paddock and doing nothing else. Cattle were allowed access to the exclosure during the experiment, but they largely avoided the thick, rank giant rats tail grass in the control plots and preferred areas where giant rats tail grass had been disturbed. These disturbed areas eg. slashed laneways and other treatment plots, usually contained more palatable species or possibly better access to palatable species. The control treatment was used as a baseline against which the other treatments at each site were compared. Throughout the experiment the control plots did not change substantially with giant rats tail grass remaining the dominant species.

The control treatment at Gympie and Kilcoy had close to 100% ground cover throughout the experiment (Fig 4.30 and 4.31) and low seedling emergence (Fig 4.27 and 4.28). At the Foxtail Flats site, two of the three control plots were accidentally burnt in spring 1997, which resulted in these plots having a less dense canopy (Fig 4.32). The more open plots with few other stoloniferous species (Fig 4.25), provided conditions that were suitable for giant rats tail grass seedling emergence (Fig 4.29). No giant rats tail grass seedlings were counted in the unburnt control plot (data not presented).

Rhodes grass was the only species that showed indications of competing with giant rats tail grass. Rhodes grass increased its proportional contribution to total yield during the experiment at Gympie from 0.6% to 50% (Fig 4.20). Rhodes grass was probably able to increase inside the exclosure because grazing was controlled, so that selective grazing of the palatable rhodes grass was reduced (Anderson & Briske 1995; Moretto & Distel 1997). In the farmer management treatment (Fig 4.22) outside the exclosure, the rhodes grass was continually subjected to selective grazing, which resulted in rhodes grass remaining only a small proportion of the pasture, while giant rats tail grass increased. Lungu *et al.* (1995) also observed an increase in giant rats tail grass with higher stocking rates under both continuous and rotational grazing.

A simple state and transition model (Westoby *et al*. 1989) can be used to describe the giant rats tail grass situation (Fig 4.40).
State 1: pasture free of giant rats tail grass
State 2: giant rats tail grass invaded pasture
The transition (T1) between State 1 and 2 involves the introduction of giant rats tail grass seed and a reduction in pasture competitiveness of other species, possibly due to heavy grazing. This provides conditions suitable for germination and seedling establishment. Once the giant rats tail plants have established they are a persistent component of the pasture. Removing grazing and locking-up an infested giant rats tail grass paddock (State 2) appears unlikely to result in the death of giant rats tail grass plants and reversion to a pasture free of giant rats tail grass (State 1). The transition between State 2 and State 1 (T2) appears to require substantial additional inputs.

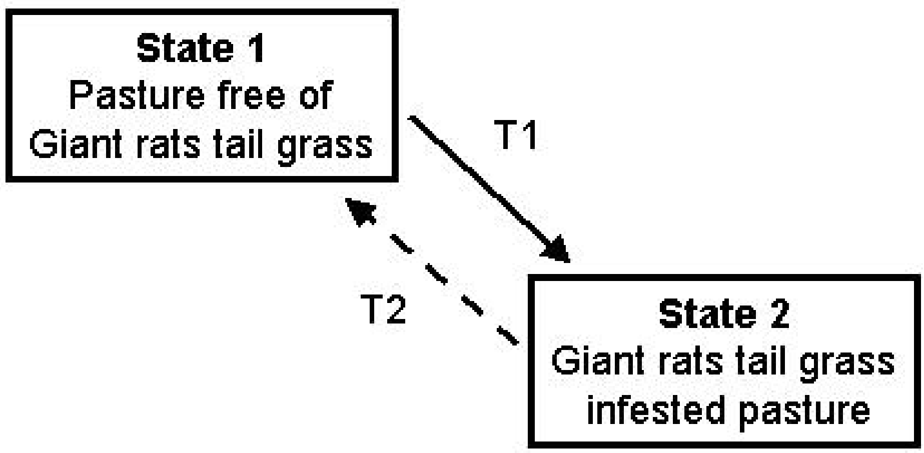

Figure 4.40 State and transition model for a giant rats tail grass infestation.
Transition 1 (T1) requires the introduction of giant rats tail grass seed into the pasture and reduced pasture competitiveness to allow seedlings to establish. State 2 (giant rats tail grass infested pasture) appears very stable. Transition 2 (T2) is unlikely to occur simply by removing grazing. Major inputs will be required to return to a pasture free of giant rats tail grass (State 1).

4.5.2 Slash and slash/rake treatments

Periodic slashing alone is of no benefit in controlling giant rats tail grass. The giant rats tail grass plants were not killed (Fig 4.14, 4.16 and 4.18), and inflorescence density (Fig 4.34, 4.35, 4.36) and seed production (Fig 4.37, 4.38 and 4.39) remained high. The slash, slash/rake and control treatments were similar throughout the experiment, with giant rats tail grass remaining dominant.

Earlier workers have also found various mowing/slashing treatments to be ineffective in rejuvenating giant rats tail grass invaded pastures (Parkin *et al.* 1980) and have found that these management options can encourage giant rats tail grass dominance in mixed swards (Edroma 1981). Slashing also does not kill the closely related species, giant parramatta grass (Betts 1989).

Few giant rats tail grass seedlings emerged at Gympie and Kilcoy in the slash and slash/rake treatments (Fig 4.27 and 4.28), probably because the space between giant rats tail grass tussocks usually contained other stoloniferous grass species (eg. rhodes grass, carpet grass, couch, paspalum). Therefore, competitive ground cover was maintained after slashing (section 4.4.6). At Foxtail Flats the pasture was close to 100% giant rats tail grass (Fig 4.25), with few other species between the tussocks. Therefore, slashing exposed bare areas between the tussocks (Fig 4.32), allowing giant rats tail grass seedlings to emerge (Fig 4.29). However, few seedlings established so that plant populations in the slash and slash/rake treatments at Foxtail Flats were stable (Fig. 4.18).

In this experiment the slash and slash/rake treatments produced high numbers of giant rats tail grass inflorescences (Fig 4.34, 4.35 and 4.36) and large amounts of seed (Fig 4.37, 4.38 and 4.39). However the soil seed banks were stable (Fig 4.1, 4.3 and 4.5). Giant rats tail grass tends to flower throughout the frost-free periods of the year (DNR 1998), so there is no specific flowering event, as occurs in grader grass (*Themeda quadrivalvis*) in response to day-length (Kleinschmidt & Johnson 1977). A single slashing of grader grass can significantly reduce seed production, eventually leading to soil seed bank decline.

Slashing alone is of no benefit in controlling giant rats tail grass. Slashing may encourage the spread of giant rats tail grass to new areas by seed transport on machinery and equipment. However, slashing may be useful for conditioning the pasture prior to using other control methods eg. wick wiping (Betts 1989) or by providing a more favourable environment for other competitive pasture species.

4.5.3 Fire treatment

Fire can reduce the proportion and basal area of unpalatable species, while increasing the recruitment and proportion of palatable species in some environments (Orr *et al.* 1997).

Fire reduced the basal area of giant rats tail grass after the initial burn (Fig 4.7, 4.10 and 4.12), probably because many old tillers were burnt out and the ability to define the tussock during recording without a big bulk of rank grass was improved. Subsequent fires did not reduce the basal area further at Gympie and Kilcoy, while at Foxtail Flats the second burn also reduced the basal area (Fig 4.12). Once giant rats tail grass basal area was reduced to less than 300 cm^2/m^2 (3%), the basal area appeared to increase with little effect of subsequent fires.

Fire had no effect on the density of original giant rats tail grass tussocks (Fig 4.14, 4.16 and 4.18) and failed to prevent a substantial increase in plant density at all sites after the third burn. The response of purple wiregrass (*Aristida ramosa*) to burning has some similarities and differences to the response of giant rats tail grass. Orr *et al.* (1997) found that burning reduced the basal area of purple wiregrass initially by reducing the number and size of segments within plants but did not cause the death of whole plants. This is similar to observations in this experiment. However, plant density of purple wiregrass did decline after the third year of burning (Orr *et al.* 1997), which contrasts with the response of giant rats tail grass where plant density and basal area increased.

The dramatic increase in giant rats tail grass plant density after the third burn in September 1998 was due to the emergence of large numbers of seedlings (Fig 4.27, 4.28 and 4.29). It is unlikely that all these seedlings would survive to maturity in the pasture, but many reached a size that is later shown to be tough and resistant to competition (see

Chapter 6). In the relatively dry 1997/98 season, it appeared that even though shoot competition was low (low cover due to exposed bare areas between tussocks; Fig 4.30, 4.31 and 4.32,), root competition from the burnt, regrowing tussocks was controlling giant rats tail grass seedling emergence (Fig 4.27, 4.28 and 4.29) and survival (Fig 4.14, 4.16 and 4.18). This theory is supported by Cook (1980b) who found that apart from a couple of specific examples, there were no data indicating that burning a pasture reduces root competition sufficiently to improve establishment of oversown species. He added that burning may increase establishment in situations where competition for light (shoot competition) is important, such as in humid coastal environments receiving more than 1000mm rainfall, or where the soil fertility is high enough to support a dense sward. The sites used in this experiment meet one or both these conditions.

Subsequently, in the higher rainfall 1998/99 season, competition for water (root competition) was probably less often limiting, which resulted in the emergence and establishment of large numbers of giant rats tail grass seedlings. This apparent variation in the importance of competition depending on seasonal conditions, was also reported by Hook *et al.* (1994). They found that prolonged drought may make large sward openings (normally a low competition zone) too dry for seedling establishment, while unusually wet conditions may make recruitment possible in small openings (normally a high competition zone), where competition for water would be acute under normal conditions.

Root competition appears to be important in average to dry years for preventing giant rats tail grass establishment, but shoot competition appears to be the major limiting factor to giant rats tail grass establishment in wet years. Treatments with a good ground cover in the wet 1998/99 season (eg. the control, selective and fertiliser treatments) had few or no seedlings emerging even though the soil appeared moist under the pasture canopy. Thus, the landholder concern that giant rats tail grass can increase with burning appears valid, as burning in wet years may allow germination and establishment to occur when conditions would not normally be suitable.

As well as increasing giant rats tail grass plant density under certain circumstances, regular burning appears to increase the giant rats tail grass proportion of the pasture (Fig 4.20 and 4.23), while reducing the amounts of other palatable species, eg. rhodes grass at Gympie (section 4.4.4.1) and carpet grass, couch and paspalum at Kilcoy (section 4.4.4.2).

The fire treatment reduced the giant rats tail grass soil seed bank immediately following a fire event, although this reduction was variable and ranged from 10-90% (Fig 4.1, 4.3 and 4.5). Joubert (1984) found that burning destroyed about 20% of the serrated tussock seeds present in the top layers (2cm) of soil. A temperature of 125^{o}C for 15s is required to kill giant rats tail grass seed (Vogler 2002). Temperatures likely to kill giant rats tail grass seed in the soil seed bank do not often occur. Bradstock & Auld (1995) studied fires in eucalypt woodlands and found that the majority of sensors between the soil surface and 3cm depth recorded temperatures below 60^{o}C. Only one maximum temperature exceeded 120^{o}C, at a depth of 0.4cm when burning 15700 kg/ha of on-ground fine fuel (<6mm diameter). Even though a fire event reduced the giant rats tail grass soil seed bank, the plants then produced many inflorescences (Fig 4.34, 4.35 and 4.36) and large numbers of seed (Fig 4.37, 4.38 and 4.39), replenishing the soil seed bank within 12 months.

Fire does not control giant rats tail grass and may make an infestation worse, as plant density and proportion of giant rats tail grass biomass in a pasture can increase. Green (1956) found that burning serrated tussock was not only futile as a method of control, but was one of the most efficient means of promoting infestation. Fire may have a role in reducing giant rats tail grass soil seed banks and structuring the pasture sward prior to other control treatments such as cultivation and wick wiping. Burning can also increase the efficiency of some herbicides for killing strongly perennial grasses such as serrated tussock (Campbell & Annand 1962), although results did appear to vary and may depend on season of burn (Campbell 1961a). This issue should be investigated for giant rats tail grass.

If burning is to become part of a pasture management strategy, the interaction between burning and type of season (eg. wet or dry) on giant rats tail grass seedling emergence and establishment should be investigated further. The importance and role of plant competition (root and shoot competition) on giant rats tail grass seedling emergence and establishment is reported in Chapter 6.

4.5.4 Fertiliser treatment

The fertiliser treatment generally remained similar to the control at the Kilcoy and Foxtail Flats sites. Inflorescence numbers (Fig 4.35 and 4.36) and seed production (Fig 4.38 and 4.39) were similar or higher than the control and a large giant rats tail grass soil seed bank (Fig 4.3 and 4.5) was maintained. Giant rats tail grass remained the dominant species (Fig 4.23 and 4.25).

At the Gympie site, the fertiliser treatment responded differently. The giant rats tail grass basal area was reduced substantially below the control (Fig 4.7), with plant density (Fig 4.14) and its proportion of the pasture (Fig 4.20) also being reduced. This difference between Gympie and the other two sites was due to rhodes grass being present throughout the Gympie site. The rhodes grass responded to reduced grazing and fertiliser by growing tall and increasing its contribution to the pasture (section 4.4.4.1) smothering the giant rats tail grass. At Kilcoy the associated species (couch, paspalum and carpet grass) were short species, and the giant rats tail grass grew tall, shaded and almost eliminated them (section 4.4.4.2). Edroma (1981) found that taller grasses can overgrow and shade out the shorter species to the point of exclusion. At the Foxtail Flats site there were few other species to respond and compete with the giant rats tail grass.

At the Gympie and Kilcoy sites, the fertiliser treatment maintained a good ground cover (section 4.4.6) and subsequently, few giant rats tail grass seedlings emerged (Fig 4.27 and 4.28). At the Foxtail Flats site the fertiliser treatment was slashed and raked prior to the spring 1998 fertiliser being applied. The exposed bare areas between the plant tussocks (Fig 4.32) resulted in the emergence of many giant rats tail grass seedlings (Fig 4.29). This flush of emergence was unexpected as the slash/rake treatment in the previous year at Foxtail Flats resulted in only 14 seedlings/m^2 emerging and none establishing (Fig 4.18). The low number of emerged seedlings and low ground cover (approximately 50%) for the slash/rake treatment indicated that root competition was more important than above ground competition (Cook 1979) and that slashing the fertiliser treatment with its vigorous tussocks would not induce a large flush of seedlings. However, as discussed in the previous fire treatment section (section 4.5.3), this expectation did not take into account the relatively wet season of 1998/99 and its impact on the balance between root and shoot competition and the large soil seed bank in the fertiliser treatment (Fig 4.5).

Heavy dressings of nitrogen have reduced the incidence of giant rats tail grass in highly competitive star grass (*Cynodon nlemfuensis*) pastures in Africa, similar to the response at the Gympie site, but fertilisation at the required level was not economic (Rodel & Scheerhoorn 1976; Parkin *et al.* 1980). The relatively high rate of fertiliser applied in the current experiment is also unlikely to be adopted commercially, especially since the response achieved at the Gympie site probably occurred only because grazing was controlled and the rhodes grass was not selectively grazed. It would be unlikely that a grazier would outlay resources applying fertiliser and not utilise the pasture heavily to maximise the economic return from the investment.

Fertiliser application has a role in maintaining pastures in a competitive state, while preventing giant rats tail grass seedling emergence. When combined with a tall, robust species like rhodes grass and appropriate grazing management, fertilisers can enable these grasses to out-compete and kill some giant rats tail grass plants. However, care must be taken as giant rats tail grass does respond to fertiliser, by producing large amounts of seed and can out-compete shorter species.

4.5.5 Wick wiping treatment

Wick wiping is designed to selectively kill taller, ungrazed, unpalatable weeds without damaging the palatable (grazed down) pasture, while using less chemical than broadacre spraying, less labour than spot spraying and is cheaper than either broadacre or spot spraying (Campbell & Nicol 1998).

Wick wiping with herbicide three times in two years steadily reduced the basal area of giant rats tail grass (Fig 4.7, 4.10 and 4.12). After the first wick wipe treatment, even though the basal area was reduced, giant rats tail grass plant density (Fig 4.14, and 4.16 and 4.18) was not reduced (some tillers killed but not the whole tussock). Therefore, it would be expected that with only one wipe and no follow-up, giant rats tail grass would recover quickly to original levels. This has been the experience of some landholders (G. Elphinstone *pers. com.).*

After the second wick wipe, plant density started to decline, and this continued following the third wipe at the Gympie and Kilcoy sites. At Foxtail Flats, giant rats tail grass plant density increased after the third wipe, due to the establishment of seedlings in bare areas (Fig 4.32), following the decomposition of previously damaged plants. In this case, few other shorter species were present to replace the wiped plants. The wick wipe treatment at the Gympie and Kilcoy sites had few giant rats tail grass seedlings emerge, as other species were present below the wick wiper height (section 4.4.4), so ground cover was maintained (section 4.4.6) providing competition.

It is essential that good, competitive and preferably stoloniferous species are present within a giant rats tail grass infested pasture for the wick wiping strategy to be successful. The unwiped competitive species can invade bare areas created by the death of giant rats tail grass plants, provide competition and prevent seedling establishment. If no competitive species are initially present in the pasture, they should be established before starting a wick-wiping program.

A wick wiping program of 3 wipes in 2 years as trialled here substantially reduced the amount of giant rats tail grass in a pasture, but was unlikely to eliminate giant rats tail grass from the pasture. Many small, scattered giant rats tail grass plants were still present throughout the pasture and were likely to increase, especially under selective grazing. One or even two wick wipes is of no benefit for giant rats tail grass control.

Incorporation of regular maintenance wick wiping into the pasture management system has the potential to maintain giant rats tail grass at low abundance in a pasture, once the initial weed infestation has been reduced. It is expected that pastures maintained in a healthy competitive condition (ie. not overgrazed) would require fewer maintenance wipes, as a similar grass (giant parramatta grass) did not increase in well-managed pastures (Betts 1989). One problem with this strategy is that the pasture will always be a potential source of seed contamination for uninfested areas. Also, if grazing management is poor or wick wiping stopped, the abundance of giant rats tail grass can increase quickly from the surviving plants.

4.5.6 Selective herbicide treatment

The selective herbicide treatment was successful at Gympie and Kilcoy, as giant rats tail grass basal area (Fig 4.7 and 4.10), plant density (Fig 4.14 and 4.16) and proportion of biomass present in the pasture (Fig 4.20 and 4.23) were reduced substantially and maintained at low levels. This contrasted with the Foxtail Flats site where the basal area (Fig 4.12) and plant density (Fig 4.18) were initially reduced, but plant density subsequently increased.

The different response was probably due to the presence of other stoloniferous pasture species at the Gympie and Kilcoy sites. They were able to colonise areas left by the dead giant rats tail grass. These other grasses maintained plot cover (section 4.4.6) and competition thus preventing seedling establishment (Fig 4.27 and 4.28). At Foxtail Flats, the native upright grasses increased (Fig 4.25), but there were still bare areas created in spring 1998 (Fig 4.32), when the dead plant material (mulch) decomposed. These areas were not quickly colonised, so provided an opportunity for seedlings to emerge (Fig 4.29) and establish (Fig 4.18). Betts (1989) described a similar situation where an application of herbicide to a giant parramatta grass infested area that had few herbicide tolerant grasses, resulted in an initial reduction of giant parramatta grass, which was followed by an increase in subsequent years.

For a selective herbicide strategy to be successful a vigorous, competitive and preferably stoloniferous plant species not substantially affected by the selective herbicide needs to be widespread in the pasture (Betts 1989). These plant species can spread and replace the dead plants, as gaps are created in the pasture sward. If bare areas are created, giant rats tail grass will re-establish from the soil seed bank. The importance of minimising bare areas highlights the necessity for good pasture management.

The selective herbicide treatment at Gympie and Kilcoy was applied by locating and painting individual giant rats tail grass tussocks with a non-selective herbicide, essentially conducting a precise spot spraying application. Difficulties were encountered in finding small plants in the pasture and some were missed. Spot spraying is unlikely to be successful and economically feasible because of the difficulties in locating giant rats tail grass plants at the paddock scale.

The reduction in competition from the death of nearby mature tussocks, resulted in the initially missed giant rats tail grass plants quickly increasing in size and proportion of the pasture (Fig 4.20 and 4.23), even though the plant density remained low (Fig 4.14 and 4.16). An effective broadacre selective herbicide may have killed these small plants.

Overall, the selective treatment was one of the most effective treatments. The extension of this treatment into a commercial control strategy is hindered by a limited number of selective herbicides that kill giant rats tail grass but do not harm desirable pasture plants. Flupropanate herbicides can be used with some pasture types and are the only option available at present. Further research should be conducted into selective herbicides and into plant species that may be tolerant of the presently available herbicides.

4.5.7 Unselective herbicide treatment

Broadacre glyphosate herbicide application resulted in a relatively good kill, substantially reducing giant rats tail grass plant density at Gympie and Foxtail Flats (Fig 4.14 and 4.18). The kill was not as effective at Kilcoy (Fig 4.16), due to rain falling shortly after the initial application. Glyphosate also killed most of the species growing between the giant rats tail grass tussocks.

Once the dead plant material broke down, bare areas were created (Fig 4.31 and 4.32) resulting in the emergence of many giant rats tail grass seedlings (Fig 4.28 and 4.29). These seedlings thrived in the low competition conditions. At the Gympie site, rhodes grass appeared relatively tolerant of glyphosate and although affected by the herbicide, recovered and spread rapidly across many plots providing competition by maintaining ground cover, thus limiting the number of giant rats tail grass seedlings that emerged (Fig 4.27). Glyphosate at the rates used in this experiment appeared to selective kill giant rats tail grass when rhodes grass was present. The use of glyphosate as a selective herbicide in combination with rhodes grass and other pasture species (eg. *Paspalum nicorae*) should be investigated further.

Over-spraying when spot spraying or broadacre application with an unselective herbicide creates of bare areas. These bare areas will allow giant rats tail grass seedlings to establish from the soil seed bank, potentially increasing the giant rats tail grass population. Betts (1989) found that bare areas were created when using herbicides that kill all pasture species in a giant parramatta grass infestation. This allowed rapid re-invasion from the soil seed bank. This is supported by Campbell (1998) who found that a herbicide treatment applied alone results in reinfestation by serrated tussock from the soil seed bank.

Cook & Ratcliffe (1992) killed native pasture with herbicide and found that the lowered pasture competition allowed oversown pasture species to establish, whereas without this disturbance subsequent recruitment was limited. This work led to the development of technology where herbicide bands were used to reduce pasture competition to aid the establishment of sown pasture. Herbicide bands or patches would allow giant rats tail grass to establish from the soil seed bank. This highlights the importance of not over-spraying when spot spraying.

Herbicide control alone will never bring about permanent control of a weed (Green 1956) and broadacre application of an unselective herbicide in an attempt to control giant rats tail grass is futile in most circumstances, unless used as a pre-treatment to cultivation and sowing a pasture or fodder crop.

4.5.8 Cultivation treatment

As expected, large numbers of giant rats tail grass seedlings emerged in the cultivation treatment during the experiment (Fig 4.27, 4.28 and 4.29), probably due to reduced competition and soil disturbance (Froud-Williams *et al.* 1984; Betts 1989). Even though large numbers of seedlings emerged, the soil seed bank was not fully depleted after 2 years and 8 cultivations (Fig 4.2, 4.4 and 4.6), although the response varied between sites. Seedlings were still emerging towards the end of the experiment, with the number of giant rats tail grass plants establishing between the final cultivation and the final charting of permanent quadrats (3-4 months) being equivalent to the initial plant density (Fig 4.15, 4.17 and 4.19). Providing good conditions for giant rats tail grass seed germination will not induce the whole soil seed bank to germinate at once and so does not predispose the seedlings to either pre- (herbicides) or post-emergent (eg. recultivation, herbicides) control. This lack of a 'one-off' seedling flush has implications for the use of pre-emergent herbicides, which usually only kill germinating seed or emerging seedlings and not 'ungerminated' seed. Most pre-emergent herbicides would have dissipated from the soil long before all the seeds in the soil seed bank had germinated.

The soil seed bank data for the cultivation treatment (Fig 4.2, 4.4 and 4.6) were difficult to interpret. At the Gympie and Kilcoy sites the soil seed bank appeared to increase between the initial sampling and the following spring. Possible reasons for the increase may be sampling error and soil seed bank variability (Champness 1949). After cultivation began, the same soil surface area was sampled, but core depth was increased from 5cm to 10cm. The deeper cores may have sampled a substantial reservoir of seed lower in the soil profile. However, this is unlikely as only about 6% of the giant rats tail grass soil seed bank is contained in the 2.5-5cm deep soil layer (Vogler 2002). Therefore, there is unlikely to be a large amount of seed below this depth. The other reason for the possible increase in seed bank size is that a large amount of seed was transported into the plots. There are many seed transport vectors (Bray *et al.* 1998b), although most are not likely to be significant in this situation. The most likely transport vector would be wind. Vogler (2002) investigated the distance giant rats tail grass seed is transported via wind from an infestation. He found that the majority of seed fell within 1.2m of the infestation, with a few seeds reaching 2-3m. My plots had a 1m border surrounding the area where the soil seed banks were sampled and therefore the area where most seed would fall from neighbouring areas was not sampled.

By the following spring (1998) the soil seed bank appeared to be declining, and this trend continued until the end of the experiment at the Gympie and Kilcoy sites. This reduction further dispelled the possibility that a large amount of seed was being transported into the cultivation plots. The soil seed bank in the cultivation treatment at the Foxtail Flats site remained fairly stable throughout the experiment, indicating a long-lived soil seed bank.

This experiment has shown that frequent cultivation over long periods (up to 2 years) will not remove the giant rats tail grass soil seed bank. This finding is supported by Bourdot & Hurrell (1992), who found that a two-year cropping program with cultivation to prevent seeding of *Stipa neesiana* would be unlikely to deplete the soil seed bank sufficiently to provide adequate control of this weed.

Weed seed burial and subsequent movement of seed back to the surface with cultivation has the potential to be an important issue with giant rats tail grass, due to its long-lived soil seed banks (Andrews 1995a; Andrews *et al.* 1996; Vogler 2002). The disturbance created by recultivation or pasture renovation may bring the dormant buried seeds back to the surface, where exposure to light and temperature fluctuation may break the dormancy and allow the seeds to germinate and establish (Wesson & Wareing 1969b). In some cases it may be preferable to avoid soil disturbance (Graham & Hutchings 1988), as a giant rats tail grass soil seed bank may be present even though giant rats tail grass plants are not apparent in the pasture sward, due to seed transport or an earlier weed control program.

The cultivation treatment was not cultivated for 3-4 months prior to the final sampling, after being cultivated for 2 years. The giant rats tail grass plant density at the final sampling was similar to the initial plant density (Fig 4.15, 4.17 and 4.19). Therefore, if the treatment was left to regrow, the giant rats tail grass plant density could be similar if not higher than the original plant density. To compound the problem, the good pasture species that were present initially were almost eliminated by the cultivation. Sowing a competitive pasture species following cultivation is therefore essential to provide effective control.

Cultivation by itself is not a control option for giant rats tail grass, but will be an essential part of some control strategies, such as the fodder pre-cropping and pasture replanting control strategy (McIntosh *et al*. 1999). Long periods of frequent cultivation do not appear to be advantageous, as some other treatments including the competitive pasture treatments (rhodes, rhodes/bisset and bisset) often had a similar or smaller soil seed banks after two years and would have provided some grazing income during the intervening period. A long period of continuous cultivation would also increase the risk of soil erosion and soil structure degradation, especially on marginally arable pasture soils.

4.5.9 Competitive species treatments

Sowing or developing a competitive pasture sward will be an integral part of any control strategy that is to provide long-term control of giant rats tail grass. Sowing competitive species has been part of control programs for many pasture weeds including serrated tussock (Campbell 1960a) and giant parramatta grass (Betts 1989).

At Gympie, 6 months after sowing, giant rats tail grass plant density was low (Fig 4.15), although seedlings had emerged between sowing and prior to charting (Fig 4.27), but the competitive pasture established well and appeared to out-compete and kill the small giant rats tail grass seedlings. Campbell (1960a) found that serrated tussock seedlings established along with the pasture species in an improved seedbed, but 70-94% were killed by pasture competition if it was spelled from grazing for 12 months.

At Kilcoy and Foxtail Flats the competitive pastures did not establish as vigorously and giant rats tail grass density after sowing was higher than the original plant density (Fig 4.17 and 4.19). The bisset treatment at Kilcoy established relatively slowly (Fig 4.31) and many giant rats tail grass plants established, grew, matured and quickly flowered (22 inflorescences/m^2 in June 1998). By comparison, the rhodes grass in the rhodes treatment at Kilcoy established more vigorously and covered the ground relatively quickly. The rhodes treatment still contained many giant rats tail grass plants (Fig 4.17), but they remained small beneath the rhodes sward and produced few inflorescences (0.5 inflorescences/m^2 in June 1998). Once the competitive pasture treatments established, few new giant rats tail grass seedlings emerged (Fig 4.28).

Without prior control of the soil seed bank, giant rats tail grass seedlings will emerge with the sown pasture and even though the plants are small, they are persistent and once established will withstand highly competitive conditions (also see Chapter 6). These giant rats tail grass plants would probably increase in size once the pasture was opened up by drought and over-grazing. Further investigations are needed to determine how to remove giant rats tail grass plants from sown pasture, as there are currently only a limited range of selective herbicides and small giant rats tail grass plants are difficult to locate and identify for spot spraying or chipping-out.

The competitive species treatments appear to have minimised the giant rats tail grass infestation at the Gympie site. Rhodes grass and Bisset did not appear to be as competitive at the other sites, so other pasture species should be evaluated for competitive ability against giant rats tail grass (see Chapter 5). Other pasture species may be better adapted to other locations, soil types and management situations. Conservative grazing management will be important in maintaining complete ground cover (Campbell 1960a) to prevent reinfestation of sown pastures.

4.5.10 Farmer management treatment

The farmer management treatment was outside the exclosure, so plots could not be randomly allocated within the experimental blocks containing the rest of the plots. Therefore, the farmer management treatment was not part of a valid experimental design and comparisons between the farmer management treatment and other treatments should be treated with caution.

At the Gympie site the farmer management plots were subjected to high grazing pressure outside the exclosure. Therefore, the farmer management treatment was assumed to differ from the control in the grazing pressure applied. No other manipulations were applied. The basal area of giant rats tail grass in the farmer management treatment increased substantially during the experiment (Fig 4.9) and other species such as the palatable rhodes grass remained as a small proportion of the sward (Fig 4.22). This contrasted with the control inside the exclosure, where giant rats tail grass basal area was generally maintained, while rhodes grass became a larger proportion of the sward biomass. The original giant rats tail grass plants in the farmer management treatment grew larger (increased basal area) during the experiment, probably because they were not grazed and competition from the heavily-grazed palatable species (eg. rhodes grass, carpet grass) was minimised (Anderson & Briske 1995; Lungu *et al.* 1995; Moretto & Distel 1997). Edroma (1981) found that selective clipping (simulated selective grazing) resulted in reduced production of the clipped plants, placing them at a competitive disadvantage. In the mixed species pasture they studied, this meant that the palatable species (eg. *Themeda triandra*) were adversely affected by grazing, while the less palatable tussocky grasses (eg. giant rats tail grass) increased because they remained ungrazed (Edroma 1981).

Inflorescence number and seed production were high in the farmer management treatment at the Gympie site (Fig 4.37), even though many inflorescences were partly grazed. Cattle were observed grazing inflorescences containing ripe seed, so the seed production was probably an underestimate for the farmer management treatment. Many viable giant rats tail grass seeds are excreted in cattle manure and could be transported to uninfested areas (Bray *et al.* 1998a).

The farmer management treatment at the Foxtail Flats site was exposed to relatively light grazing pressure and maintained similar basal area and plant density patterns to the control throughout the experiment (data not presented). The farmer management treatment at the Kilcoy site was wick wiped and grazed moderately and was similar to the wick wipe treatment with a reduction in giant rats tail grass basal area and plant density (data not presented).

Grazing giant rats tail grass infested pasture at moderate to high stocking rates can increase the giant rats tail grass problem due to the other species being selectively grazed. This statement is supported by Betts (1989) who found that cattle tend not to eat unpalatable giant parramatta grass and preferentially selected other pasture species. This resulted in the area between the giant parramatta grass tussocks being overgrazed, which reduced the ability of these species to compete with the giant parramatta grass.

4.6 *Conclusion*

Maintaining pastures in a healthy competitive state with good ground cover will limit the establishment of giant rats tail grass plants. Any bare areas will allow giant rats tail grass seedlings to establish from the substantial, long-lived soil seed bank. Once giant rats tail grass plants are established they are tolerant of most common agronomic manipulations and are difficult to remove without the use of targeted intensive practices such as herbicides.

Nearly all manipulations trialled highlighted the importance of a good competitive pasture being present to maintain ground cover, while targeting the giant rats tail grass plants. Without a competitive pasture species being present and able to compete (ie. not selectively grazed) any giant rats tail grass control attempt will be futile.

The use of fire should be treated with caution due to interactions between ground cover and seasonal conditions that may encourage dominance of giant rats tail grass. However, it may be useful for reducing the soil seed bank as a pre-treatment for a control strategy. Slashing, cultivation and broadacre application of an unselective herbicide are by themselves, little benefit for giant rats tail grass control and are likely to have negative outcomes, unless used as part of a pre-treatment for a comprehensive control strategy. Fertiliser application can increase the severity of a giant rats tail grass infestation if suitable pasture species and pasture management are not addressed. A wick wiping strategy of 3 wipes over 2 years reduced the amount of giant rats tail grass in the pasture, however many small plants were still present. Wick wiping on its own is unlikely to eliminate the weed and additional control measures will be required. Spot spraying is unlikely to be successful due to the difficulty in locating small giant rats tail grass plants at the paddock scale.

The most successful treatment trialled for giant rats tail grass control was the selective herbicide treatment. However, the companion pasture species present and the availability of a suitable herbicide require careful consideration.

Outcomes from this experiment have highlighted the need for further research into:

- The competitive ability of giant rats tail grass seedlings particularly in relation to shoot and root competition and seasonal interactions (addressed in Chapter 6).
- Finding "new" selective herbicides or selective herbicide strategies using glyphosate and glyphosate tolerant species (not addressed in this thesis).
- Investigation of fire as a pre-treatment for herbicide application (not addressed in this thesis).
- Identification and evaluation of a range of competitive pasture species for use as part of giant rats tail grass control strategies (addressed in Chapter 5).

CHAPTER 5 Evaluation of competitive sown pasture species for use in giant rats tail grass infested areas

5.1 *Summary*

Giant rats tail grass control strategies require sown pasture species that provide high levels of plant competition under grazing to prevent seedling establishment from the soil seed bank.

A pasture species evaluation trial was conducted at 4 giant rats tail grass invaded sites in south-east Queensland. At each site a small plot trial (10-20 m^2/plot) evaluated the 14 most likely pasture accessions for that site, whilst an adaptation trial (1 m^2/plot) evaluated unregistered accessions, other potential accessions not included in the small plot trial and accessions requiring planting by runners. The accessions were assessed on their ease of establishment, pasture cover and aggressiveness over two years following sowing. Plant density of giant rats tail grass, other volunteer grasses and broad-leaf weeds were also assessed.

Giant rats tail grass emerged regardless of the pasture accession planted. Some giant rats tail grass plants remained in the plots even after 2 years and following a wick wiping with herbicide. Therefore, control strategies should incorporate techniques that reduce the giant rats tail grass soil seed bank prior to sowing and should remove giant rats tail grass plants that do establish.

After two years evaluation, the stoloniferous or rhizomatous grasses Callide rhodes grass, Keppel indian bluegrass, Bisset bluegrass, *Paspalum nicorae* CPI 27707 (brunswick grass), Floren bluegrass, Whittet kikuyu, Tully koronivia grass, Competidor bahia grass and Basilisk signal grass showed the most potential for use in giant rats tail grass control strategies at one or more sites. Other pasture accessions that demonstrated some potential in the adaptation trial at one or more sites include *Digitaria didactyla* (swazi grass-runners), Nemkat rhodes grass, Medway indian bluegrass, Hatch bluegrass and pangola grass (runners).

5.2 *Introduction*

Giant rats tail grass (*Sporobolus pyramidalis*) is a competitive, unpalatable, perennial grass invading pastures along the east coast of Queensland and northern New South Wales (Delaney 1991). This grass weed is growing in many coastal and sub-coastal areas suitable for sown pasture establishment. In these areas, sown pastures are likely to be an integral part of giant rats tail grass control strategies.

Preliminary results from the management manipulations experiment (Chapter 4, in late 1997), general observation and work on giant parramatta grass *(Sporobolus fertilis)* (Andrews 1995a; Andrews *et al.* 1996) indicated that pasture competition was crucial in preventing the emergence and establishment of *Sporobolus* seedlings. Sown pastures can provide high pasture competition to limit weed establishment and growth (Campbell 1960a) and planting sown pastures is part of an integrated control program for many weeds (eg. Campbell 1960a; Betts 1989; Campbell 1998; Benz *et al.* 1999). In fact, vigorous sown pasture is regarded as the best barrier against the invasive, unpalatable, perennial grass serrated tussock (*Nassella trichotoma*) (Green 1956), which belongs to a similar plant functional group as giant rats tail grass.

Planting sown pastures is an important part of a number of integrated giant rats tail grass control and prevention strategies, which include:

1. Preventing giant rats tail grass invasion by developing highly competitive pastures in areas at risk of being contaminated with giant rats tail grass seed (eg. pastures located near current infestations, cattle quarantine paddocks).
2. Giant rats tail grass control using the fodder pre-crop and pasture replanting, as now described in the "Giant rats tail grass best practice manual" (McIntosh *et al.* 1999).
3. Giant rats tail grass control using direct pasture replacement.

The giant rats tail grass control strategies for current infestations (Strategies 2 and 3 above) can be used in arable and semi-arable country and consist of provisions to:

- Kill the giant rats tail grass invaded pasture.
- Reduce or control the large giant rats tail grass soil seed bank.
- Plant a competitive, sown pasture.

Selecting the appropriate pasture species for planting is an important part of these weed control strategies (Robinson & Whalley 1988).

Prior to this work, a number of pasture species had been recommended for use in giant rats tail grass control strategies (DNR 1998). This list had been devised from past experience in landholder's paddocks and the outcomes of demonstration trials. There had been little formal ranking or assessment of these species for competitive ability against giant rats tail grass, although some informal rating had occurred at Mackay and Bundaberg (H. Bishop & J. Wright *pers. com.*).

In this experiment, 14 'best-bet' sown pasture species were evaluated at 4 sites in south-east Queensland for their competitiveness and potential for use in a giant rats tail grass control program. These species were chosen, according to the following important attributes.

- Likely to be well adapted to the environment.
- Vigorous at some stage during pasture re-establishment.
- Preferably stoloniferous or rhizomatous (growth habit).
- Deemed to be palatable.

5.2.1 The importance of plant growth habit

Growth habit and vigour at different stages during establishment are likely to be crucial in the success of a pasture species as part of a giant rats tail grass control strategy. Different pasture species show distinctive differences in their growth habits. Callide rhodes grass (*Chloris gayana*) and Bisset bluegrass (*Bothriochloa insculpta*) will be used to demonstrate the importance of considering different growth habits.

Callide rhodes grass has high seedling vigour and establishes quickly (Blacket *et al.* 1996), covering the ground via vigorous coarse stolons (O'Reilly & Cameron 1992) and producing a dense body of tall feed. However, after 3-4 years the available nitrogen level of unfertilised pasture can fall and the rhodes grass pasture can 'open-up' and decline. This has implications when sown into a giant rats tail grass infested area. The quick establishment will limit the establishment of giant rats tail grass seedlings and would probably suppress the growth of giant rats tail grass seedlings that do establish.

However, as the Callide rhodes pasture declines, the suppressed giant rats tail grass plants are likely to develop and gaps in the pasture would allow more giant rats tail grass seedlings to establish from the long-lived soil seed bank (Andrews 1995a; Andrews *et al.* 1996; Vogler 2002; Chapter 4).

By comparison, Bisset bluegrass has a reputation for being slow to establish, but is highly stoloniferous (Blacket *et al.* 1996) and forms a dense sward. However, large numbers of giant rats tail grass seedlings are likely to establish in the prepared seedbed during Bisset's slow establishment period. Once Bisset has established, it forms a dense stoloniferous sward in coastal Queensland and provides good long-term competitive cover under grazing. Bisset bluegrass is also adapted to lower soil fertility than most sown pasture grasses and can persist after soil nitrogen levels have fallen below those required for persistence of other sown grasses (O'Reilly & Cameron 1992). Therefore, if established giant rats tail grass plants can be selectively removed from the new Bisset pasture using a selective herbicide or with a selective application technique (eg. wick wiping), Bisset could be an integral part of a successful long-term giant rats tail grass control strategy.

A strategy being trialled commercially (and trialled in the management manipulations experiment - Chapter 4) as a 'best-bet' option is to sow Callide and Bisset together, to take advantage of the good traits of both these species. Callide provides quick early cover and then, as it declines, the Bisset takes over to continue providing good cover.

5.2.2 Common pasture plant growth forms

The pasture accessions assessed in the trial have been categorised into four growth forms; tussock grasses, stoloniferous grasses, rhizomatous grasses and legumes.

Tussocky erect grasses, for example *Setaria* spp., are less likely to provide good ground cover with grazing and therefore are unlikely to inhibit giant rats tail grass establishment. The tussock type grasses being trialled in this experiment (3 or 4 per site) originate from a distinct base, but have a prostrate form (Hatch creeping bluegrass and Nixon sabi grass are strongly prostrate). Tussock type grasses rely on seed production, germination and establishment to fill in areas of low plant density. When overgrazed these grasses are often eaten back to their base, leaving gaps between tussocks that provide an opportunity for giant rats tail grass to establish.

Stoloniferous grasses are generally regarded as the 'best-bet' option for giant rats tail grass control. When overgrazed these species are eaten down, but generally maintain a ground cover of intertwined stolons that inhibit giant rats tail grass establishment. Additionally, the stolons invade bare areas reducing pasture gaps and the potential for weed establishment. Seven or eight stoloniferous grasses were evaluated at each site in this trial.

Rhizomatous grasses have the main stems underground protected from grazing. These grasses may provide good long-term competition under heavy grazing. Some rhizomatous *Paspalum* spp. have the potential to be highly competitive against giant rats tail grass, but there are some concerns that these grasses may become environmental weeds. Two highly palatable lines were evaluated in this trial.

Legumes are generally regarded as not being competitive enough for use in giant rats tail grass control, because the accompanying grasses are usually sown at high rates to provide high early competition. However, two legumes were evaluated. Amarillo forage peanut (*Arachis pintoi)* is also a stoloniferous plant that can provide good ground cover in the long-term. Wynn cassia (*Chamaecrista rotundifolia*) is a vigorous annual that may provide good competition for short periods (B. Cook *pers. com.).* Legumes may also allow the use of a wider range of selective herbicides (i.e. selectively remove grasses) to remove giant rats tail grass. Legumes can improve the nitrogen status in the soil, which may favour the companion grasses more than giant rats tail grass. The legumes were sown by themselves in this trial and not in combination with sown grasses. This allowed the competitive ability of the legumes to be evaluated, without the confounding effect of separating the competitive ability of sown grasses.

5.2.3 Experiment objectives

The overall objective of the experiment was to evaluate potentially competitive sown pasture species for use as part of an overall giant rats tail grass control strategy. This main objective was achieved by addressing 3 sub-objectives.

1. Evaluate the competitive ability of establishing sown pasture accessions and their ability to suppress giant rats tail grass seedlings following sowing.
2. Assess the competitiveness of established sown pasture plants, against newly established giant rats tail grass plants.
3. Evaluate the ability of an established competitive pasture sward to prevent further establishment of giant rats tail grass from the soil seed bank.

5.3 *Materials and methods*

I conducted two experiments at each of four sites:

1. **Small plot trial** (10-20m^2 per plot), from which data were collected to address the objectives. This trial contained the 14 'best-bet' accessions for use in giant rats tail grass control strategies at a particular site. Generally only one accession from each species was included at each site.
2. **Adaptation trial**, planted as a mini sward (1m^2 per plot). The adaptation trial included unregistered 'potential' species, accessions with little seed available, accessions requiring vegetative planting and some accessions similar to those included in the small plot trial. The adaptation trial highlighted accessions that might be worthy of further evaluation in the future.

The four sites were established in south-east Queensland at Gympie, Kilcoy, Foxtail Flats and Gayndah (see Site descriptions in section 3.1). The trial sites were located on established giant rats tail grass infestations and therefore had a substantial giant rats tail grass soil seed bank to provide competition for the sown pasture accessions.

5.3.1 Experimental design

In the small plot trial, sown pasture accessions were planted in rectangular plots 10-20m^2 (Gympie - 5x4m, Kilcoy and Foxtail Flats - 5x3m, Gayndah - 5x2m) in a randomised complete block design with three blocks. There was no unsown lane between neighbouring plots. Fourteen pasture accessions that were expected to be the most competitive at each site were sown (Table 5.1). One plot in each block was left unsown (Control). The control treatment allowed giant rats tail grass to establish from the soil seed bank without competition from the sown accessions, although other volunteer/weed species were present. The control plot also demonstrated the detrimental effect of patchy sown seed distribution and/or no pasture establishment. Sowing rates were high and set as described later (Section 5.3.2.3 and Table 5.1).

Table 5.1 Sown pasture accessions evaluated for use in giant rats tail grass control strategies in south-east Queensland in plots 15-20m^2.

Accessions are grouped on plant growth form, with an 'x' indicating the sites where sown. The sowing rate and percentage live seed (in brackets) from germination tests are also presented.

Species name	Accession/cultivar (common name)	Evaluation site				Sowing rate kg/ha
		Gympie	Kilcoy	Foxtail	Gayndah	
Tussock type species						
Bothriochloa bladhii	forest bluegrass (native)	x	x	x	x	16 (1)
Bothriochloa insculpta #	Hatch (creeping bluegrass)				x	16 (9)
Digitaria eriantha subsp. eriantha	Premier (digit grass)	x	x	x	x	8 (33)
Urochloa mosambicensis #	Nixon (sabi grass)	x	x	x	x	8.8 (1)*
Stoloniferous species						
Bothriochloa pertusa	Keppel (indian bluegrass)	x	x	x		16 (6)
Bothriochloa pertusa	Dawson (indian bluegrass)				x	16 (6)
Bothriochloa insculpta	Bisset (creeping bluegrass)	x	x	x	x	8 (28)
Brachiaria decumbens	Basilisk (signal grass)	x	x	x	x	13.2 (28)
Brachiaria humidicola	Tully (koronivia grass)	x	x	x	x	8 (15)
Chloris gayana	Callide (rhodes grass)	x	x	x	x	8 (25)
Dichanthium aristatum	Floren (bluegrass)	x	x	x	x	8 (82)
Digitaria milanjiana	Jarra (digit grass)	x	x	x		8 (88)
Digitaria milanjiana	Strickland (digit grass)				x	16 (3)
Rhizomatus species						
Paspalum nicorae	CPI27707(brunswick grass)	x	x	x	x	8 (72)
Paspalum notatum	Competidor (bahia grass)	x	x	x	x	8 (67)
Pennisetum clandestinum	Whittet (kikuyu)	x	x			4.4 (79)
Legume species						
Arachis pintoi	Amarillo (pinto forage peanut)	x	x	x		32 (35)
Chamaecrista rotundifolia	Wynn (roundleaf cassia)			x	x	8 (43)

* germination test used was probably not appropriate for this accession.

The growth form of Hatch and Nixon is probably half-way between a tussock and stoloniferous growth form.

The adaptation trial consisted of mini plots (2 x 0.5m = 1m^2). The plots were arranged in a randomised complete block design with three blocks. This adaptation trial was situated beside the small plot trial (within 3m). The plots were arranged in rows with the short 0.5m side touching the neighbouring plot. There was a 0.5m wide unsown lane between each row of plots. Eight or nine accessions were sown at each site (Table 5.2).

Table 5.2 Sown pasture accessions evaluated in an adaptation trial (plots 1m^2) as possibilities for use in giant rats tail grass control strategies in south-east Queensland.
Accessions are grouped on plant growth form, with an 'x' indicating the sites where sown. The sowing rate and percentage live seed (in brackets) from germination tests are also presented.

Species name	Accession/cultivar (common name)	Evaluation site				Sowing rate kg/ha
		Gympie	Kilcoy	Foxtail	Gayndah	
Tussock type species						
Bothriochloa bladhii	Swann (forest bluegrass)				x	16 (12)
Bothriochloa insculpta #	Hatch (creeping bluegrass)	x	x	x		16 (9)
Dichanthium annulatum	CPI 106146 (sheda bluegrass)	x	x	x	x	8 (57)
Dichanthium caricosum #	CPI 84719 (nadi bluegrass)	x				13.2 (33)
Stoloniferous species						
Bothriochloa insculpta	CPI 69517 (creeping bluegrass)	x	x	x	x	8 (36)
Bothriochloa pertusa	Medway (indian bluegrass)	x	x	x	x	16 (1)
Chloris gayana	Nemkat (rhodes grass)	x	x	x	x	8 (55)
Digitaria didactyla	CPI 40639 (Swazi grass-seed)	x				8 (7)
Digitaria didactyla	(Swazi grass-runners)	x	x	x	x	runners
Digitaria eriantha ssp. pentzii	(Pangola grass)			x		runners
Digitaria eriantha	supplied by J.Wright			x	x	runners
Urochloa mosambicensis	Saraji (creeping sabi grass)	x	x	x	x	8.8 (41)
Legume species						
Chamaecrista rotundifolia	Wynn (roundleaf cassia)		x			8 (43)

The growth form is probably half-way between a tussock and stoloniferous growth form.

5.3.2 Ground preparation, sowing and management

A direct pasture replacement strategy was used to sow the pastures. Therefore, although the existing giant rats tail grass plants were killed, there was limited control of the soil seed bank. To meet the objectives of the experiment, the potential for good pasture establishment by each sown accession needed to be assured. 'Best-bet' planting practices were followed to give the sown accession the best chance to establish and compete with giant rats tail grass.

5.3.2.1 Seed-bed preparation

The sites were sprayed with glyphosate (3-4L glyphosate/ha) to kill the infested pasture. The pasture was allowed to brown-off, burnt and then cultivated in at least two directions using a chisel type plough. Approximately 2 months later, the site was rotary hoed to produce a reasonably fine seedbed. Three to four weeks after rotary hoeing the site was sprayed again (3L glyphosate/ha) to kill emerged weed seedlings. The sites were pegged and sown later that day.

5.3.2.2 Sowing technique

The pasture seeds were sown into dry soil by mixing the exact amount of seed for the plot with a few handfuls of sawdust and then sprinkling the mixture evenly over the plot. The soil surface was then raked with metal hand rakes to mix the seed into the soil surface. The whole site was then rolled to improve the soil-seed contact.

The pasture species requiring planting of runners (eg. pangola grass) were planted in a continuous single 2m row down the centre of the adaptation trial plots.

The sites were sown at Gympie, Kilcoy and Gayndah in October 1997 and at Foxtail Flats in November 1997 and allowed to establish on natural rainfall (Fig 3.1, 3.2, 3.3 and 3.4)

5.3.2.3 Sowing rates

The pasture accessions were sown at high rates. The recommended sowing rate in giant rats tail grass infested areas is double or triple the standard sowing rate (DNR 1998; McIntosh *et al.* 1999). The viability of the seed for each accession was tested prior to planting by placing seed on moist filter paper in a petri dish and incubating on an alternating temperature/light cycle (35^{o}C day and 20^{o}C night) over 2 weeks. Sowing rates were adjusted to 4 times the standard rate if seed appeared to have poor viability (<10%), otherwise double the highest recommended sowing rate was used (see Table 5.1 and 5.2 for actual sowing rates and percentage live seed).

5.3.2.4 Fertiliser application

Superphosphate was applied at sowing, at a rate of 20kg P/ha (superphosphate also contains S and Ca). No nitrogen was applied at sowing. Nitrogen (100kg N/ha as Nitram) was applied on one occasion after most of the plots were deemed to have established at each site, ~3 months after sowing.

5.3.2.5 Pasture management

The new pastures were protected from grazing until they were established (4-5 months after sowing). The sites were grazed periodically by leaving the site gate open and allowing cattle access from the adjoining paddock. The gate was closed again when the sown pasture accessions were generally eaten down. There was some selectivity of grazing between pasture species.

The plots were slashed to knock down rank material at Kilcoy and Gayndah in January 1999. The Gympie, Kilcoy and Foxtail Flats sites were wick wiped (0.5L glyphosate/1L of water) in March 1999. The Foxtail Flats site was accidentally burnt in July 1999.

5.3.3 Sampling

Soil seed banks were sampled immediately prior to sowing, to determine the number of viable giant rats tail grass seeds in the soil seed bank. Five cores (5cm diameter to a depth of 10cm) were taken from each block in the small plot trial. The germinable seed bank method was used to determine the size of the giant rats tail grass soil seed bank (see section 3.2.2.4).

Pasture sampling was conducted 2-3 months after sowing, with another 2-3 sampling occasions over a two-year period. The Gayndah site was only sampled twice. Sampling of the small plot trial was conducted by assessing ten small quadrats (18.5x20cm = 0.037m^2) in each plot. Two operators moved along two lengthwise transects assessing five quadrats each. The edges of the plot were avoided. Data recorded were:

1. Plant counts, divided into 4 categories:
   - Sown accession plants and/or their rooted down stolons/rhizomes.
   - Giant rats tail grass plants.
   - Other grass weeds - included weedy and 'volunteer' grasses that were not sown.
   - Broad-leafed plants/weeds.

   If greater than 10 plants in any category were counted per quadrat (generally only occurred in fine, highly stoloniferous accessions eg. Keppel), it was recorded as 10 plants.
2. The ground covered by the sown pasture accession and the total ground cover of the quadrat (percent).
3. An aggressiveness rating was also given to the sown accession in each quadrat. The aggressiveness rating was used to give an indication of how the sown accession was spreading and covering the ground. Aggressive plants are likely to compete more strongly against giant rats tail grass. The rating categories were:
   - Rating 1 - small seedlings present, not really established or not vigorous.
   - Rating 2 - established seedlings or plants growing but not spreading or covering ground quickly.
   - Rating 3 - established plants, slow-medium spread with stolons or other method.
   - Rating 4 - established plants, spreading out and covering ground quickly, but not a dense mat (Callide rhodes was used as a standard).

- Rating 5 - established plants, spreading out and covering ground quickly, creating a thick inter-woven mat.

If a sown pasture accession was between rating categories it was given, for example, a rating of 3.5. If no sown accession was recorded in a quadrat, no aggressiveness rating or sown pasture cover was recorded. In the control treatment, giant rats tail grass plants were evaluated for the aggressiveness rating and pasture cover.

In the adaptation trial, the accessions were assessed visually as to whether they demonstrated persistence and aggressive behaviour, which would indicate that they should be evaluated further, for use in giant rats tail grass control strategies. Three quadrats per plot were also assessed for sown pasture cover two years after sowing.

5.3.4 Data processing and statistical analysis

Plant density for a particular category in each plot was the sum of plants counted during quadrat sampling and converted to plants/m^2. Sown pasture cover was the average of all quadrats for a plot. Total cover was the average of all quadrats for a plot. The aggressiveness rating was an average of the quadrats in a plot, but quadrats with no aggressiveness rating (ie. no sown pasture plants in quadrat) were not included in the calculation.

Data for the small plot trial were analysed using analysis of variance at each sampling date at each site. Statistical differences are $P<0.05$. Plant density data were cube root transformed (transformation=$(\text{density} + 1)^{0.3333}$) for analysis and back-transformed for presentation. Sown pasture cover, total cover and aggressiveness rating data were not transformed for analysis. Statistical differences are presented for the sown pasture density, giant rats tail grass density and sown pasture cover datasets.

Accessions from the adaptation trial that demonstrated persistence and aggressive behaviour are listed for each site. The sown pasture cover assessed two years after sowing was averaged across all plots for each sown pasture accession. No statistical analysis of these data was conducted.

5.4 *Results*

Generally there were significant differences among sown pasture accessions for most data sets. However there were large overlaps between groups of accessions that were not significantly different. The accessions have been ranked in the results tables based on the percent cover of the sown pasture accession. The data are presented on an individual site basis for the small plot trial and all sites combined for the adaptation trial.

5.4.1 Gympie site

The giant rats tail grass soil seed bank at the Gympie site was 3089 ± 1080 seeds/m^2 at sowing. The trial was sampled 4 times: 2, 6, 16 and 25 months after sowing in October 1997. The site was grazed periodically from ~5 months after sowing and wick wiped 17 months after sowing (March 1999).

The stoloniferous grasses Keppel, Callide and Bisset had a high plant density and high pasture cover two months after sowing and they were still persisting strongly 2 years later (Table 5.3). These three grasses were generally regarded as being aggressive, spreading rapidly with stolons. The stoloniferous grasses Basilisk and Floren also produced swards with good pasture cover (>75%) 6 months after sowing, while Tully had good pasture cover (>90%) 16 months after sowing. The rhizomatous brunswick grass was relatively slow establishing but produced a good pasture sward (88% cover) two years after sowing. Jarra and Premier demonstrated some vigour soon after sowing but failed to persist.

Giant rats tail grass was present in all plots soon after sowing (no significant difference between plots of sown accessions) and was still present 2 years later (Table 5.3), even though the plots had been wick wiped once. The control had a significantly higher density of giant rats tail grass plants at 16 months after sowing (18.4 plants/m^2) compared to the best long-term pasture species identified above. Although variable, there was generally less giant rats tail grass, grass weeds and broad-leafed weeds in the plots with a high sown pasture cover. Total pasture cover was high (>95%) for all plots

16months after sowing. The aggressiveness rating showed a similar ranking of accessions to the sown pasture cover.

Forest bluegrass established poorly (Table 5.3), probably due to poor quality seed. Establishment and sward development of Whittet kikuyu was poor even though a patch of kikuyu pasture was growing within 100m of the site.

5.4.2 Kilcoy site

The giant rats tail grass soil seed bank at the Kilcoy site was 3871 ± 636 seeds/m^2 at time of sowing. The Kilcoy site was sampled three times: 2, 16 and 25 months after sowing in October 1997. Grazing at this site was limited by the availability of drinking water until 13 months after sowing. The pasture grew fairly tall and rank during this lightly grazed period. Between 13 and 25 months after sowing, the site was periodically grazed. The site was slashed 15 months after sowing and wick wiped 17 months after sowing.

The stoloniferous grasses Callide and Whittet had the highest pasture cover 2 years after sowing (Table 5.4), although Whittet was slow to develop a good pasture cover (only 45% cover 16 months after sowing). Bisset, Keppel, Jarra, Nixon demonstrated some vigour soon after sowing, but subsequently declined. Tully, Basilisk and brunswick grass were a substantial component of the sward in their plots 2 years after sowing (45-65% cover).

Large numbers of giant rats tail grass plants were present 2 months after sowing (average 50 plants/m^2, no significant difference between accessions) (Table 5.4). This number had declined by 16 months after sowing (mean 13 plants/m^2) and accessions with a high sown pasture cover generally had a lower density of giant rats tail grass plants. By 25 months after sowing and following a wick wiping, there was no significant difference in giant rats tail grass density between accessions (average 11 plants/m^2), probably due to high variability between replicate plots.

Table 5.3 Summarised data from the competitive species evaluation small plot trial at Gympie. The trial was sown in October 1997. The accessions are sorted on sown pasture cover. The aggressiveness rating and sown pasture cover in the control treatment was given for giant rats tail grass. Values within datasets that are followed by the same letter are not significantly different (P>0.05).

Gympie December 1997 - 2 months after sowing										
Accession	**sown pasture**		**GRT**		**grass#**	**bl weed**	**aggress**	**cover %**		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	**rating***	sown pasture		total
Keppel	140.9	a	2.8	n.s.	4.2	26.8	5.0	69	a	78
Bisset	63.0	cd	4.5		3.2	13.6	4.2	44	b	51
Jarra	87.1	bc	4.2		6.4	25.6	3.5	41	bc	46
Callide	74.4	cd	7.5		2.2	35.1	3.8	40	bc	52
Floren	70.2	cd	8.9		1.8	37.8	2.6	30	cd	43
Premier	130.8	ab	4.1		3.0	23.7	2.0	23	de	29
Whittet	49.8	de	12.1		2.5	26.8	2.9	15	ef	29
brunswick grass	55.4	cde	6.0	n.s.	2.3	41.4	2.3	13	efg	29
Nixon	22.4	f	8.3		1.8	33.1	2.9	13	efg	27
Basilisk	30.6	ef	6.3		1.2	18.0	2.9	13	efg	24
Competidor	56.5	cde	7.2		1.2	30.9	2.4	12	efg	29
Amarillo	8.4	g	8.5		2.2	52.7	2.9	9	fg	38
Tully	16.4	fg	4.3		4.8	74.4	3.2	6	fg	42
Control	n/a	-	11.0		2.2	66.3	1.9	2	g	32
forest bluegrass	6.4	g	7.4	n.s.	8.9	46.6	2.1	1	g	31

Gympie April 1998 - 6 months after sowing										
Accession	**sown pasture**		**GRT**		**grass#**	**bl weed**	**aggress**	**cover %**		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	**rating***	sown pasture		total
Keppel	271.3	a	2.2	defgh	3.2	4.1	5.0	100	a	100
Bisset	167.4	bc	1.1	fgh	0.7	3.7	4.9	100	a	100
Callide	114.7	cd	1.6	efgh	0.0	12.7	4.3	96	ab	96
Basilisk	66.7	ef	5.3	cdef	7.3	5.3	3.8	90	abc	95
Premier	87.7	de	0.0	h	12.7	8.1	2.7	79	abc	89
Jarra	183.9	bc	6.8	bcde	8.3	3.2	3.7	77	bc	82
Floren	81.4	de	0.7	gh	1.6	22.4	3.6	76	bc	81
Nixon	39.1	fg	7.7	abcd	6.4	14.5	3.4	69	c	77
Competidor	65.6	ef	13.4	abc	15.1	17.9	2.8	39	d	65
Tully	41.0	fg	7.5	abcd	23.3	35.4	2.8	25	de	55
brunswick grass	75.2	de	4.9	cdefg	19.4	16.7	2.6	22	de	61
Amarillo	28.2	gh	11.1	abc	11.6	41.1	2.6	14	ef	47
Whittet	15.7	h	18.0	a	28.5	15.1	2.5	12	ef	67
Control	n/a	-	14.8	ab	33.4	50.5	2.4	8	ef	44
forest bluegrass	0.0	I	12.5	abc	60.7	19.5	0.0	0	f	62

GRT – giant rats tail grass # grass weeds bl weed – broad-leaf weeds * aggressiveness rating

n.s. - no significant difference.

Table 5.3 continued.

Gympie February 1999 - 16 months after sowing										
Accession	**sown pasture**		**GRT**		**grass#**	**bl weed**	**aggress**	**cover %**		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	**rating***	sown pasture		total
Bisset	90.9	b	0.0	f	0.0	0.7	4.2	100	a	100
Callide	68.0	bc	0.0	f	0.0	0.0	3.9	100	a	100
Basilisk	50.2	cd	2.8	e	6.0	0.0	3.7	100	a	100
Keppel	159.2	a	3.6	de	2.8	0.7	4.3	95	a	100
Tully	37.6	de	6.8	cde	11.7	4.1	3.6	93	a	100
Nixon	49.0	cd	5.6	de	1.9	6.8	3.5	90	ab	99
Floren	67.0	bc	2.8	e	2.6	1.1	4.0	88	ab	100
Competidor	77.1	bc	7.2	bcde	6.6	3.6	3.2	70	bc	98
Control	n/a	-	18.4	a	31.6	15.6	2.6	60	c	99
Premier	47.7	cd	4.3	de	21.9	3.7	2.7	53	c	96
brunswick grass	68.4	bc	2.8	e	27.2	1.6	3.4	50	c	100
Amarillo	16.1	f	17.4	a	20.3	8.2	2.7	20	d	100
Jarra	22.5	ef	7.8	bcd	25.4	15.5	2.4	19	d	95
forest bluegrass	0.0	g	12.5	abc	48.5	6.9	0.9	9	d	100
Whittet	11.7	f	14.3	ab	37.7	5.3	2.7	5	d	100

Gympie November 1999 - 25 months after sowing										
Accession	**sown pasture**		**GRT**		**grass#**	**bl weed**	**aggress**	**cover %**		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	**rating***	sown pasture		total
Callide	113.8	abc	2.8	ef	0.0	4.1	4.0	95	a	99
Keppel	176.8	a	1.6	f	5.4	14.0	4.5	93	ab	100
brunswick grass	174.9	a	4.3	cdef	12.3	5.4	4.2	88	abc	99
Floren	126.0	ab	2.8	ef	2.9	12.1	3.9	87	abc	100
Bisset	71.0	cd	2.8	ef	10.0	11.3	3.9	79	abc	97
Basilisk	72.6	cd	3.6	def	19.6	3.2	3.6	78	bc	99
Tully	81.6	bcd	4.5	cdef	10.5	4.1	3.9	76	c	99
Competidor	131.8	ab	8.1	abcd	4.5	2.8	3.8	75	c	100
Amarillo	54.1	a	13.4	a	34.7	6.1	3.1	51	d	99
Control	n/a	-	14.7	a	61.9	6.0	3.0	42	de	98
Nixon	25.6	e	8.3	abc	37.6	20.8	2.9	28	ef	90
Whittet	17.2	ef	14.6	a	32.8	5.3	3.0	19	fg	99
Premier	23.9	e	6.8	bcde	62.9	20.2	2.8	16	fgh	97
Jarra	6.4	f	8.9	abc	73.9	24.7	2.4	4	gh	97
forest bluegrass	0.0	g	10.0	ab	112.1	6.8	0.0	0	h	98

GRT – giant rats tail grass   # grass weeds   bl weed – broad-leaf weeds   * aggressiveness rating

Table 5.4 Summarised data from the competitive species evaluation small plot trial at Kilcoy. The trial was sown in October 1997 and sampled on 3 dates. The accessions are sorted on sown pasture cover. The aggressiveness rating and sown pasture cover in the control treatment was given for giant rats tail grass. Values within datasets that are followed by the same letter are not significantly different (P>0.05).

Kilcoy December 1997 - 2 months after sowing

Accession	sown pasture plants/m^2		GRT plants/m^2		grass# plants/m^2	bl weed plants/m^2	aggress rating*	cover % sown pasture		cover % total
Callide	56.2	bc	41.2	n.s.	1.1	17.4	4.4	90	a	91
Bisset	47.1	bcd	52.8		11.3	21.6	4.8	88	ab	95
Keppel	92.7	a	31.7		11.7	20.6	4.9	85	ab	96
Jarra	66.5	ab	52.5		4.1	24.0	3.6	73	bc	83
Nixon	23.3	e	41.4		4.9	27.5	4.0	66	cd	75
Floren	73.0	ab	47.7		9.6	17.4	3.0	51	de	71
Premier	90.3	a	31.1		2.8	19.3	2.6	48	e	61
Basilisk	35.1	cde	49.7	n.s.	11.1	22.4	3.7	42	ef	75
brunswick grass	93.3	a	59.8		1.6	13.0	3.0	42	ef	70
Competidor	53.2	bc	43.3		5.9	13.4	3.0	35	efg	57
Whittet	31.0	de	34.4		12.6	20.0	3.4	28	fg	67
control	n/a	-	81.9		11.4	24.6	2.4	23	gh	50
Tully	28.6	de	80.6		13.0	20.4	3.8	23	gh	74
Amarillo	7.5	f	74.9		23.1	34.5	3.0	9	hi	58
forest bluegrass	3.7	f	45.2	n.s.	19.6	23.0	1.5	2	I	64

Kilcoy February 1999 - 16 months after sowing

Accession	sown pasture plants/m^2		GRT plants/m^2		grass# plants/m^2	bl weed plants/m^2	aggress rating*	cover % sown pasture		cover % total
Basilisk	63.2	bc	9.2	cde	1.6	0.0	3.6	100	a	100
Callide	70.3	b	0.7	f	0.0	0.0	4.0	99	a	100
Floren	70.3	b	6.0	de	4.8	0.0	3.6	95	a	100
Bisset	67.1	b	3.0	ef	2.2	1.1	3.9	93	a	100
Keppel	122.4	a	8.9	cde	6.1	2.8	4.2	89	ab	100
Tully	55.2	bcd	11.8	bcd	4.5	1.1	3.4	80	ab	95
control	n/a	-	18.6	abc	19.1	3.2	2.6	62	bc	100
Nixon	34.4	def	17.4	abc	12.7	1.6	3.1	61	bc	96
brunswick grass	55.3	bcd	17.1	abc	6.6	2.8	3.2	59	bc	100
Whittet	55.7	bcd	15.9	abc	5.4	1.6	3.1	45	cd	98
Competidor	38.0	cde	24.9	ab	3.6	0.0	3.2	34	cd	100
Premier	18.9	f	21.1	ab	15.9	11.8	2.7	28	de	100
Amarillo	20.3	ef	26.4	a	18.0	0.7	2.7	18	de	100
Jarra	26.3	ef	24.1	ab	32.4	1.6	2.4	16	de	98
forest bluegrass	0.0	g	14.6	abcd	15.8	3.0	0.8	2	e	100

Kilcoy November 1999 - 25 months after sowing

Accession	sown pasture plants/m^2		GRT plants/m^2		grass# plants/m^2	bl weed plants/m^2	aggress rating*	cover % sown pasture		cover % total
Callide	75.9	ab	0.7	n.s.	0.0	5.5	3.9	86	a	100
Whittet	110.8	a	20.3		21.3	4.9	3.8	82	ab	99
Tully	54.4	bc	10.1		46.4	13.5	3.5	62	bc	100
Basilisk	58.3	bc	1.6		48.8	13.8	3.5	61	bc	100
brunswick grass	58.5	bc	10.2		53.0	26.4	3.3	47	cd	100
Keppel	53.5	bc	11.7		78.9	20.2	3.6	39	d	99
Floren	46.6	bc	8.3		76.3	8.1	3.1	35	de	100
Bisset	32.0	cd	11.8	n.s.	83.8	31.4	3.3	35	de	100
Amarillo	32.5	cd	7.8		60.4	12.6	2.9	29	def	100
control	n/a	-	17.0		90.8	9.6	2.9	17	efg	100
Nixon	15.7	de	12.5		53.7	23.9	2.8	14	efg	100
Competidor	11.4	e	25.3		45.5	41.5	2.7	9	fg	100
Premier	9.8	e	29.5		100.8	45.2	2.7	9	fg	99
Jarra	5.5	e	8.1		120.3	41.8	1.7	3	g	100
forest bluegrass	0.0	f	20.5	n.s.	74.7	19.1	0.0	0	g	98

GRT – giant rats tail grass # grass weeds bl weed – broad-leaf weeds * aggressiveness rating
n.s. - no significant difference.

5.4.3 Foxtail Flats site

The giant rats tail grass soil seed bank at the Foxtail Flats site was 747 ± 327 seeds/m^2 at time of sowing, much lower than at Gympie and Kilcoy. The Foxtail Flats site was sampled 4 times: 2, 10, 15 and 24 months after sowing in November 1997. The site was grazed periodically from ~4 months after sowing, wick wiped with herbicide 16 months after sowing and accidentally burnt 20 months after sowing.

Soon after sowing the stoloniferous grass Callide developed a high sown pasture cover, which persisted for the next 2 years (Table 5.5). The legume Amarillo and the rhizomatous brunswick grass had a low pasture cover 2 months after sowing (11% and 21% cover respectively), however by 15 months after sowing they had developed a good pasture cover (>80% cover). Keppel, Tully, Competidor and Basilisk were substantial components of the sward 2 years after sowing (>59% cover), while Bisset, Jarra and Premier demonstrated some initial vigour but subsequently declined 2 years after sowing.

Giant rats tail grass plants emerged in all plots with no significant difference between accessions 2 months after sowing (Table 5.5). Callide had the lowest giant rats tail grass density, which was maintained over the following 2 years. Between the last two sampling dates, the majority of accessions increased in giant rats tail grass plant density, possibly in response to the unplanned fire 20 months after sowing. This fire reduced pasture cover in nearly all plots between 15 and 24 months after sowing.

Table 5.5 Summarised data from the competitive species evaluation small plot trial at Foxtail Flats. The trial was sown in November 1997. The accessions are sorted on sown pasture cover. The aggressiveness rating and sown pasture cover in the control treatment was given for giant rats tail grass. Values within datasets that are followed by the same letter are not significantly different (P>0.05).

Foxtail Flats January 1998 - 2 months after sowing										
Accession	sown pasture		GRT		grass#	bl weed	aggress	cover %		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	rating*	sown pasture		total
Callide	66.1	d	3.2	n.s.	4.1	24.3	4.0	64	a	67
Jarra	100.8	bc	12.7		12.0	39.2	3.6	50	ab	61
Keppel	306.1	a	6.1		5.3	28.1	4.0	47	b	58
Premier	118.0	b	6.8		3.6	39.9	2.5	43	b	50
Wynn	74.0	cd	14.3		5.9	26.7	3.4	41	b	57
Bisset	53.5	d	10.7		4.8	82.4	4.1	34	bc	66
Nixon	24.7	e	11.0		3.2	67.1	3.6	34	bc	57
Basilisk	20.6	e	9.8	n.s.	3.6	58.8	3.6	24	cd	46
Floren	135.2	b	9.6		9.0	54.9	2.7	22	cde	43
brunswick grass	67.0	d	22.0		10.5	54.7	2.5	21	cde	48
Amarillo	6.1	f	5.2		12.1	58.2	3.0	11	def	53
Competidor	30.2	e	10.2		6.0	70.6	2.6	11	def	45
Tully	7.1	f	16.6		8.9	74.0	2.9	6	ef	47
control	n/a	-	9.6		3.7	66.9	2.3	3	f	43
forest bluegrass	7.1	f	12.0	n.s.	12.1	54.9	1.4	2	f	41

Foxtail Flats September 1998 - 10 months after sowing										
Accession	sown pasture		GRT		grass#	bl weed	aggress	cover %		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	rating*	sown pasture		total
Callide	108.9	bc	0.0	g	0.0	1.6	4.2	98	a	98
Basilisk	51.3	e	9.1	cdef	0.7	3.2	3.5	97	a	99
Bisset	137.6	b	7.3	ef	1.6	5.1	4.8	96	a	98
Jarra	50.7	e	8.1	def	1.6	1.1	3.0	96	a	99
Keppel	225.3	a	12.9	abcde	0.0	2.3	4.7	91	a	92
Premier	62.5	de	4.2	f	4.1	8.9	2.7	71	b	91
Nixon	29.8	f	11.7	abcde	2.8	21.0	3.0	70	b	89
Tully	49.6	ef	15.7	abcd	4.5	8.5	3.1	62	bc	90
Competidor	63.6	de	16.6	abc	8.1	12.7	2.9	60	bc	92
Floren	79.3	cd	15.0	abcde	3.6	24.7	3.2	60	bc	76
brunswick grass	123.1	b	19.4	ab	4.8	4.5	2.9	54	bcd	92
Wynn	69.3	de	10.1	bcdef	2.8	8.5	3.0	47	cde	62
Amarillo	64.7	de	16.4	abcd	3.2	26.8	3.0	37	de	73
control	n/a	-	19.9	a	6.0	38.6	2.7	30	e	59
forest bluegrass	1.1	g	19.5	a	33.1	19.7	0.7	0	f	85

GRT – giant rats tail grass # grass weeds bl weed – broad-leaf weeds * aggressiveness rating
n.s. - no significant difference.

Table 5.5 continued.

Foxtail Flats February 1999 - 15 months after sowing										
Accession	sown pasture		GRT		grass#	bl weed	aggress	cover %		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	rating*	sown pasture		total
Callide	125.9	b	1.6	e	0.0	3.2	3.7	91	a	92
Keppel	219.4	a	12.0	abcd	0.0	9.8	4.6	89	ab	96
Amarillo	76.5	de	15.5	abcd	2.8	5.9	3.9	87	ab	98
Wynn	76.1	de	23.2	a	5.9	8.9	4.0	87	ab	99
control	n/a	-	21.1	ab	7.3	43.1	3.0	85	ab	94
Bisset	118.2	bc	8.1	d	1.1	4.9	4.0	81	ab	97
brunswick grass	205.7	a	14.6	abcd	1.1	12.3	4.4	80	ab	100
Floren	107.3	bcd	18.4	abc	3.0	17.1	3.8	75	abc	97
Premier	83.2	cd	11.0	bcd	8.9	8.3	3.1	66	bcd	81
Basilisk	52.8	e	12.7	abcd	1.1	4.5	3.5	55	cde	90
Tully	53.2	e	16.3	abcd	4.5	10.3	3.3	54	cde	92
Competidor	97.6	bcd	12.5	abcd	3.6	8.9	3.5	50	def	95
Jarra	71.9	de	9.0	cd	3.0	16.3	3.0	35	ef	74
Nixon	29.5	f	8.3	d	3.7	21.9	3.1	30	f	89
forest bluegrass	1.6	g	20.3	ab	34.7	25.6	1.3	4	g	98

Foxtail Flats Noveber 1999 - 24 months after sowing										
Accession	sown pasture		GRT		grass#	bl weed	aggress	cover %		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	rating*	sown pasture		total
Amarillo	140.8	ab	11.7	f	4.8	35.9	4.0	93	a	98
brunswick grass	203.6	a	16.8	ef	0.7	69.0	3.6	78	ab	84
Callide	161.9	ab	0.0	g	1.6	30.5	3.8	74	bc	75
Keppel	155.0	ab	14.3	f	3.7	44.6	3.8	62	bcd	76
Tully	128.6	bc	23.1	cdef	11.0	46.7	3.7	61	bcd	69
Competidor	145.2	ab	21.9	def	5.4	46.6	3.6	60	cd	71
Basilisk	71.1	de	15.4	ef	7.1	63.2	3.4	59	cd	63
Premier	84.1	cde	15.7	ef	14.4	49.9	2.8	46	de	63
control	n/a	-	59.9	ab	33.8	102.7	2.8	33	ef	52
Floren	46.1	e	36.6	bcde	22.7	104.7	2.7	25	fg	67
Jarra	59.5	e	28.1	cdef	21.4	148.9	2.5	20	fgh	61
Wynn	119.0	bcd	43.3	abcd	23.9	89.6	1.9	15	ghi	62
Nixon	10.3	f	72.5	a	21.1	155.0	2.7	10	ghi	68
Bisset	12.9	f	41.7	abcd	37.4	130.7	3.0	7	hi	61
forest bluegrass	4.8	f	50.0	abc	27.2	112.8	1.7	2	I	57

GRT – giant rats tail grass # grass weeds bl weed – broad-leaf weeds * aggressiveness rating

5.4.4 Gaydah site

The giant rats tail grass soil seed bank at the Gayndah site was 679 ± 59 seeds/m^2 prior to sowing, similar to the Foxtail Flats site. Relatively dry conditions followed sowing in October 1997 (Fig 3.4). The Gayndah site was sampled twice: 3 and 16 months after sowing. The site was only grazed twice and was slashed 15 months after sowing.

The stoloniferous grasses Dawson, Floren, Bisset and Callide and the prostrate tussock grass Hatch had the highest pasture cover 3 and 16 months after sowing (Table 5.6). Nixon, Premier and Strickland were a substantial part of their plots 16 months after sowing (>55% cover).

No giant rats tail grass plants were identified within the trial site 3 months after sowing and only a few giant rats tail grass plants had established within the trial site 16 months after sowing (Table 5.6). The reason for the low numbers of giant rats tail grass plants is unclear and may be a factor of low rainfall and a relatively small initial soil seed bank size. Meanwhile, volunteer grass and broad-leaf weeds established densely in treatments with low pasture cover.

Table 5.6 Summarised data from the competitive species evaluation small plot trial at Gayndah. The trial was sown in October 1997 and sampled on 2 dates. The accessions are sorted on sown pasture cover. The aggressiveness rating and sown pasture cover in the control treatment was given for giant rats tail grass. Values within datasets that are followed by the same letter are not significantly different (P>0.05).

Gayndah January 1998 - 3 months after sowing

Accession	sown pasture		GRT		grass#	bl weed	aggress	cover %		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	rating*	sown pasture		total
Dawson	121.2	a	0	n.s.	0.0	13.4	4.2	38	a	43
Hatch	71.1	abc	0		3.6	11.7	4.1	32	ab	39
Callide	39.2	cd	0		1.1	9.2	3.9	30	b	34
Floren	77.8	abc	0		0.0	19.4	2.8	26	bc	28
Bisset	25.3	d	0		0.7	10.1	3.9	25	bcd	32
Wynn	51.4	bcd	0		1.6	16.6	3.0	19	cde	27
Nixon	25.0	d	0		0.0	6.0	3.0	19	cde	29
Strickland	68.5	abc	0	n.s.	0.0	6.6	2.8	18	de	25
Premier	84.8	ab	0		0.7	11.4	2.2	12	ef	21
Basilisk	4.1	e	0		0.7	8.7	3.0	9	fg	20
Tully	4.3	e	0		1.1	6.8	2.8	5	fg	22
forest bluegrass	4.3	e	0		1.6	9.8	2.3	3	g	21
Competidor	3.0	e	0		0.7	10.2	1.3	3	g	25
brunswick grass	4.1	e	0		2.2	8.5	1.2	2	g	21
control	n/a	-	0	n.s.	2.2	16.3	0.0	0	g	20

Gayndah February 1999 - 16 months after sowing

Accession	sown pasture		GRT		grass#	bl weed	aggress	cover %		
	plants/m^2		plants/m^2		plants/m^2	plants/m^2	rating*	sown pasture		total
Dawson	277.8	a	0.0	n.s.	0.0	0.0	5.0	100	a	100
Hatch	78.6	bc	0.0		0.0	0.0	3.9	100	a	100
Floren	69.3	bc	0.0		1.9	0.0	3.5	100	a	100
Bisset	114.6	b	0.9		0.7	0.0	4.2	100	a	100
Callide	101.8	b	0.0		0.0	0.0	3.7	96	a	99
Nixon	46.4	c	0.0		7.2	10.1	3.5	74	b	79
Premier	70.7	bc	0.0		3.2	4.1	2.8	64	bc	64
Strickland	75.7	bc	0.0	n.s.	4.1	0.0	2.8	56	c	58
Basilisk	21.1	de	0.0		49.8	17.0	2.9	41	d	57
Tully	42.3	cd	0.0		93.6	21.1	3.1	24	e	76
Wynn	76.6	bc	0.0		53.6	5.9	2.4	20	e	61
brunswick grass	12.3	ef	0.9		108.8	74.0	3.1	7	f	50
Competidor	4.6	fg	0.9		130.3	32.5	2.9	4	f	59
forest bluegrass	1.6	g	0.0		172.0	9.8	2.3	2	f	69
control	n/a	-	0.0	n.s.	172.9	43.1	n/a	0	f	62

GRT – giant rats tail grass # grass weeds bl weed – broad-leaf weeds * aggressiveness rating
n.s. – no significant difference

5.4.5 Adaptation trial

The adaptation trial was designed to highlight other species/accessions that pasture specialists believed may demonstrate some potential for use as part of a giant rats tail grass control strategy. Accessions with good sown pasture cover that appeared to be competitive and had persisted for two years after sowing at each site are identified in Table 5.7. These species were stoloniferous and aggressive, invading beyond their plots and forming almost mono-specific stands with few giant rats tail grass plants.

The other accessions in the adaptation trial either; did not establish, did not persist or did not appear to be competitive.

Table 5.7 Sown pasture cover of pasture accessions identified in the adaptation trial to be competitive, persistent and with good sown pasture cover two years after sowing at each of four sites.

Pasture accession	Sown pasture cover %			
	Gympie	Kilcoy	Foxtail Flats	Gayndah
Digitaria didactyla (swazi grass runners)	100	100		
Nemkat rhodes grass	79	100	39	73
Medway indian bluegrass	77			77
Hatch creeping bluegrass	63			100#
Dichanthium annulatum (CPI 106146)	65			
Dichanthium caricosum (CPI 84719)	61			
Pangola (runners)			64	
Bothriochloa insculpta (CPI 69517)				99
Digitaria eriantha (runners) supplied by J.Wright			84	

measured in the small plot trial at this site.

5.5 *Discussion*

The overall objective of the experiment was to evaluate potentially competitive sown pasture accessions for use as part of giant rats tail grass control strategies. This experiment has allowed various pasture accessions to be recommended for south-east Queensland and helped identify some of the attributes which should be considered when choosing a sown pasture accession.

The discussion has been split into four sections:

- The competitive ability of sown pasture accessions for giant rats tail grass suppression.
- Attributes required by a sown pasture accessions for giant rats tail grass control.
- Choosing a sown pasture accession for use in a giant rats tail grass control program at a particular site.
- Sowing techniques, pasture and grazing management.

5.5.1 The competitive ability of sown pasture accessions for giant rats tail grass suppression

The main objective, to evaluate potentially competitive sown pasture species for use as part of giant rats tail grass control strategies, was to be achieved by addressing 3 sub-objectives. Each sub-objective will be discussed separately.

5.5.1.1 Sub-objective 1: Evaluate the competitive ability of establishing sown pasture accessions and their ability to suppress giant rats tail grass seedlings following sowing.

There was no significant difference in giant rats tail grass plant density amongst newly sown pasture accessions at any site 2-3 months after sowing (1st sampling). This indicates that it does not matter which pasture accession is sown into soil containing a giant rats tail grass soil seed bank, some giant rats tail grass seedlings will establish, without some other practice to control the soil seed bank (eg. pre-emergent herbicide application). Giant rats tail grass density was generally higher in the control and sown pasture accessions with low seedling density and/or vigour (eg. Tully at Kilcoy and Foxtail Flats sites), while giant rats tail grass density was generally lower in the faster establishing accessions (eg. Premier and Keppel at Kilcoy, Gympie and Foxtail Flats sites). Fast establishment of the sown pasture accessions is of some benefit in reducing giant rats tail grass establishment from sowing, although some giant rats tail grass seedlings will still establish. These seedlings must be controlled.

This experiment has highlighted the importance of trying to reduce and/or control the giant rats tail grass soil seed bank prior to sowing pastures to reduce the number of giant rats tail grass seedlings that do establish. The fodder pre-cropping (with a pre-emergent herbicide) and pasture replanting strategy (McIntosh *et al.* 1999) has been one of the most successful giant rats tail grass control strategies undertaken on commercial properties (G. Elphinstone *pers. com.*). This control strategy reduces the soil seed bank in the fodder pre-cropping phase, prior to replanting the sown pasture.

The control strategy of direct pasture replacement of giant rats tail grass infested pasture will not be successful unless selective herbicides for giant rats tail grass control (pre- or post-emergent) that are compatible with the sown pasture accessions become available. Some sown pasture accessions are tolerant of particular herbicides. For example, signal grass (*Brachiaria decumbens*) has a high degree of tolerance to the pre-emergence herbicide atrazine (Hawton 1976) and an established sward of Callide rhodes grass is relatively tolerant of glyphosate (section 4.5.7). The rate-selective herbicide, flupropanate, also has potential for use with newly sown pastures, although further field testing is required.

One observation, which was not expressed in the data, was that giant rats tail grass plants in the faster establishing accessions (eg. Callide, Bisset at Gympie and Kilcoy) grew slower, remained small and flowered later than in the slower establishing accessions (eg. Tully, brunswick grass), this was also observed in the management manipulations experiment (section 4.5.9). The faster establishing pastures were competing for resources, restricting the growth of giant rats tail grass. The density of giant rats tail grass seedlings two months after sowing was not closely related to the soil seed bank size. Seasonal conditions seemed to also play an important part in determining the initial density of giant rats tail grass seedlings, independent of the vigour of the competing newly sown pasture accessions.

5.5.1.2 Sub-objective 2: Assess the competitiveness of established sown pasture plants, against newly established giant rats tail grass plants.

The experimental design assumed that even though some giant rats tail grass seedlings would probably establish initially, the sown pasture accessions would still have the opportunity to develop an 'established' pasture sward which could be used to test sub-objectives 2 and 3. However, the slower establishing accessions probably had reduced potential for good sward establishment due to high weed competition. The low competitive conditions in the slower establishing accessions allowed the giant rats tail grass plants to grow vigorously. Subsequently, the large giant rats tail grass plants were competing strongly for resources, further reducing growth and development of the sown accessions. Therefore, the competitive environment in a particular sward is a function of the accession, giant rats tail grass, other grasses and broad-leaf weeds and not the sown accession only.

The density of giant rats tail grass plants appeared to decline with time in some sown pasture accessions. Giant rats tail grass density in the Callide rhodes plots fell from 7.5 plants/m^2 two months after sowing to 3 plants/m^2 two years later at Gympie, 41 plants/m^2 to 1 plant/m^2 at Kilcoy and 3.2 plants/m^2 to no (sampled) plants/m^2 at Foxtail Flats. Bisset and Basilisk reduced giant rats tail grass density at Gympie and Kilcoy respectively. The reduction of giant rats tail grass density with Callide and Bisset is supported by results from the management manipulations experiment (see Gympie site, Fig 4.27; 12.5 seedlings/m^2 emerged and Fig 4.15; <2 plants/m^2 established). However, the reduction in plant density may be a function of plant size. Fast establishing accessions were able to limit giant rats tail grass seedling size (discussed section 5.5.1.1) and therefore had a greater chance of killing the small plants. Slower establishing accessions allowed the giant rats tail plants to grow larger. Therefore these accessions had a reduced likelihood of being able to out-compete the well-established giant rats tail grass plants. A formal competition experiment would be required to investigate these subtleties.

Pasture management probably played an important role in the reduction of giant rats tail grass density. At Kilcoy, grazing was limited in the first year. Therefore all plots produced a large bulk, which probably contributed to the drop in giant rats tail grass between December 1997 (mean 51 plants/m^2) and February 1999 (mean 15 plants/m^2) (Table 5.4), although there were still many giant rats tail grass plants in the plots.

The giant rats tail grass density in some accessions remained relatively stable (eg. Competidor at Gympie and brunswick grass at Foxtail Flats). Therefore it could be assumed that these pasture swards (mix of accession and giant rats tail grass) were not out-competing the established giant rats tail grass plants, but were preventing further giant rats tail grass seedling establishment.

Results of this trial indicate that it is unlikely that a sown pasture sward will out-compete well-established giant rats tail grass plants. In the management manipulations experiment (section 4.5.4) only fertilised, relatively lightly grazed rhodes grass at the Gympie site, was able to smother and kill giant rats tail grass tussocks (fertiliser treatment; Fig 4.14 and 4.7). Small giant rats tail grass plants can survive intense competition from surrounding pasture (Chapter 4 and 6) and these plants will always pose a threat of 'coming-away', once the pasture is weakened (eg. by drought and/or selective grazing). The surviving giant rats tail grass plants, although slowed by sward competition, will produce some seed, thus maintaining a giant rats tail grass soil seed bank. Broadacre herbicides will be required to remove these giant rats tail grass plants from the pasture. Sown pasture accessions that are less susceptible than giant rats tail grass to a particular herbicide or herbicide application technique (eg. wick wiping) will have an advantage over other accessions for use in giant rats tail grass control strategies. The combination of sown pasture accession and selective removal of weed plants that do establish is likely to be the basis of a successful integrated weed management system (Benz *et al.* 1999).

5.5.1.3 Sub-objective 3: Evaluate the ability of an established competitive pasture sward to prevent further establishment of giant rats tail grass from the soil seed bank.

Giant rats tail grass density increased over time in some sown accession treatments, for example, Bisset, Nixon, Jarra, Premier and Wynn at Foxtail Flats and Amarillo at Gympie (prior to wick wiping). Giant rats tail grass density tended to increase in treatments that had a reducing pasture and total cover (ie. pasture was 'opening-up'). Sown pasture accessions that did not 'open-up' with time and seasonal conditions (eg. Callide) did not have an increase in giant rats tail grass density.

Due to the sampling methods used, it is impossible to tell if there was a turn over in the giant rats tail grass population, with some of the initially recorded plants dying and being replaced by new seedlings. Results from Chapter 4 and Chapter 6 show that when there is a high total cover, few giant rats tail grass seedlings establish. Therefore, sown pastures that quickly cover the ground and maintain the cover throughout the year will minimise giant rats tail grass establishment. Pasture accessions that 'open-up' creating bare areas during the year or over time (eg. Wynn, Jarra and Nixon at Foxtail Flats) are likely to allow many giant rats tail grass seedlings to establish. Some stoloniferous or rhizomatous accessions that produce a grazing-tolerant, dense ground-covering sward (eg. brunswick grass, Keppel and Tully) will minimize giant rats tail grass establishment. These grasses could be used successfully in areas at risk of giant rats tail grass invasion, such as pastures located near current infestations and cattle quarantine paddocks.

5.5.2 Attributes required by sown pasture accessions for giant rats tail grass control

The accessions sown in this experiment were selected on a number of attributes that were likely to be beneficial for success against giant rats tail grass. The attributes were:

- Likely to be well adapted to the environment.
- Vigorous at some stage during pasture re-establishment.
- Preferably stoloniferous or rhizomatous.
- Deemed to be palatable.

Experience gained during my evaluation has expanded the list of attributes required. The attributes I would aspire to seeing in a sown pasture accession at a site are:

1. Well-adapted to the environmental conditions and soil type.
2. Palatable, productive and perennial.
3. Stoloniferous or rhizomatous growth habit.
4. Resistant to over-grazing.
5. Fast establishing.
6. Provide competition year round (does not 'open-up' in late winter/spring).
7. Maintains competitiveness as soil fertility declines.
8. Cheap seed (economical to sow at high rates).
9. Tolerant of pre- and/or post-emergent herbicides, that are effective against giant rats tail grass.
10. Little seed production once established (low weed risk).

If a sown pasture accession does not contain the majority of the above attributes it is unlikely to be successful as part of a giant rats tail grass control program that is based on grazing pasture as the land-use.

Some of the attributes appear contradictory, for example cheap seed and little seed production (low weed risk). Good seed production and therefore cheap seed was an important attribute selected for in earlier pasture selection and evaluation work (Cameron 1977). Future selection or development of cultivars will need to be assessed against modified selection criteria. The emphasis has changed in pasture selection due to environmental concerns and increasing importance being placed on maintaining native vegetation communities free of exotic species. Cameron (1977) stated, when discussing selection of pasture plants for the dry tropics, that "the majority of the plants eventually selected will need to be very well adapted, with a high ability to naturalise and spread from minimal establishment techniques and possibly widely spaced points of introduction". This ability to naturalise and spread is the same trait required by a successful weed. Therefore, if a particular pasture plant becomes regarded as a weed, it has a key attribute to be a successful weed.

Most pasture plants have the potential to become weeds somewhere and some past introductions have become regarded as serious weeds (Low 1997). In the future, I believe the environmental community will be unlikely to support the release of pasture plants that have a high potential to invade outside the sown paddock. Ideally, some of the weediness characteristics need to be removed from pasture plants. Stoloniferous and rhizomatous species do not necessarily require seed to be produced to persist. These plants mostly spread asexually under grazed conditions. Future sown pasture research will need to focus on breeding or genetic modification to minimize seed production once the plant is sown in a paddock, but still produce seed in seed crops, so seed is cheap to purchase. Another option is to develop easy, reliable and cost-effective technology to plant infertile species vegetatively. Accessions to consider here include the stoloniferous accessions, pangola grass and swazi grass.

The high sowing rates used in this experiment would probably not be economically viable on a commercial grazing enterprise due to the high cost of the pasture seed. The sowing rates may be refined with further trials, however, good establishment of the sown pasture still must be ensured. Additionally, because the pasture needs to be grazed conservatively to maintain ground cover, financial return from grazing to recover sowing costs may be difficult.

Some attributes for a particular sown accession may change and become more important in the future (eg. Item 9 - Tolerant of pre-emergent and post-emergent herbicides, that are lethal to giant rats tail grass). At present there are only a few situations where herbicides can be used selectively to remove giant rats tail grass with minimal damage to the sown pasture accession (eg. flupropanate with a number of species; Callide rhodes grass is relatively tolerant of 3L glyphosate/ha–see section 4.5.7). In the future, herbicides may be found that are lethal to giant rats tail grass but not to a particular sown pasture accession. Therefore this sown pasture accession will have an imcreased likelihood of success in a giant rats tail grass control program.

Planting a combination of accessions with complementary attributes may be successful. For example, sowing Premier in combination with brunswick grass may provide good giant rats tail grass control at the Gympie site. Premier will establish fast, providing early competition to limit giant rats tail grass establishment, while the brunswick grass establishes slowly. Then, as the Premier starts to decline the brunswick grass would probably increase, producing a competitive, grazing resistant, rhizomatous sward for long-term suppression of the giant rats tail grass soil seed bank. The sowing of a combination of accessions with compatible attributes needs to be further assessed under commercial conditions. A mix of Callide and Bisset was trialled as one of the competitive species treatments in the management manipulations experiment (rhodes/bisset treatment). This treatment was generally not significantly different from the straight rhodes grass treatment. The trial did not run long enough to determine whether Bisset would assume dominance over Callide as soil fertility declined, however, Bisset appeared to be struggling to compete with the Callide and was <2% of the sward, two years after sowing at two of the three sites.

5.5.3 Choosing a sown pasture accession for use in a giant rats tail grass control program at a particular site

For a sown pasture accession to be commercially successful in a giant rats tail grass control program, it will need to possess the majority of the attributes listed in the previous section. Individual sown pasture accessions can be chosen against the attributes needed for a particular site using a simple rating system (see Table 5.8 for an assessment for the Gympie site). This rating system is subjective and requires knowledge of how various pasture accessions perform at different locations under various management systems. The rating system highlights pasture accessions that do or don’t meet the majority of the attributes, allowing any deficiencies to be addressed.

Table 5.8 An evaluation of sown pasture accessions, rated against the attributes required for success as part of a giant rats tail grass control strategy for the Gympie site.

Planting a combination of accessions with compatible attributes may improve the assessment compared to an accession rated individually eg. Premier and brunswick grass. The higher the total score, the better an accession meets the attributes list, however any deficiencies need to be identified and addressed. Ratings[@] and Attributes[#] are listed below the table.

Pasture accession	Attribute [#]									
	Adapt	3P	Habit	Graze	Estab	Comp	Low fert	Cheap seed	Herbi	Low Weed	Total
Callide	2	2	2	1	2	2	0	2	2	0	15
Bisset	2	2	2	2	1	2	2	1	0	0	14
Keppel	2	1	2	2	2	2	2	1	0	0	14
brunswick	2	2	2	2	0	2	2	0	2	0	14
Floren	2	2	1	2	1	2	1	1	1	1	14
Tully	2	1	2	2	0	2	2	1	0	1	13
Competidor	2	1	2	2	0	2	2	0	2	0	13
Amarillo	2	1	2	1	0	1	2	0	2	2	13
Basilisk	2	2	1	1	1	1	1	1	1	1	12
Whittet	1	2	2	1	0	1	1	0	0	1	9
Nixon	1	1	1	1	1	0	1	1	1	1	9
Jarra	1	1	1	0	2	0	0	1	0	2	8
Premier	1	1	0	0	2	1	1	1	0	1	8
Premier plus brunswick	2	2	2	2	2	2	2	1	2	0	17

@ Rating: 0 = does not meet the attribute
1 = partly meets the attribute
2 = meets the attribute

Attribute:

Adapt	Well adapted to the environmental conditions and soil type.
3P	Palatable, productive and perennial.
Habit	Stoloniferous or rhizomatous growth habit.
Graze	Resistant to over-grazing.
Estab	Fast establishing.
Comp	Provides competition year round (does not open up in late winter/spring).
Low fert	Maintains competitiveness as soil fertility declines.
Cheap seed	Cheap seed (economical to sow at high rates).
Herbi	Compatible with pre- and post-emergent herbicides that are effective against giant rats tail grass.
Low weed	Low weed risk, little seed production once established.

As an example, slow establishment in Tully or brunswick grass is identified as a concern due to the expected establishment of large numbers of giant rats tail grass seedlings from the soil seed bank following sowing. Options required to be part of a successful control strategy using these pasture accessions include:

- Fodder pre-cropping to minimise the soil seed bank prior to sowing the pasture.
- Identify a selective pre-emergent herbicide that will persist until the pasture accession has established a good ground cover.
- Identify a selective post-emergent herbicide to control establishing giant rats tail grass seedlings (will be required anyway).
- Consider sowing in combination with a faster establishing accession.

At each site, some of the evaluated sown pasture accessions were well adapted and had potential for use in giant rats tail grass control strategies (Table 5.9). Only two cultivars of the one species, Callide and Nemkat rhodes grass, were expected to be good at all sites, both being adapted to a wide range of soil types and rainfall amounts. The broad adaptation of Callide was also found in an evaluation trial of many introduced pasture species across 8 sites in Queensland (Middleton 1996).

The three higher rainfall sites (Gympie, Kilcoy and Foxtail Flats) each had four of the best performing accessions (Callide, brunswick grass, Basilisk and Tully) highly rated. Tully and Basilisk were previously found to be adapted to high rainfall sites in Queensland, particularly in the wet tropics (Loch 1977; McIvor *et al.* 1982; Middleton 1996).

The two clay soil sites (Gympie and Gayndah) had Callide and three bluegrass species, *Bothriochloa pertusa* (Keppel, Dawson and Medway), *B. aristatum* (Floren) and *B. insculpta* (Bisset and Hatch) in common as successful competitors. Bisset, Hatch and Floren have previously been found to be high yielding with good survival on clay soils across Queensland (Middleton 1996). Keppel also performed well at the Foxtail Flats site, although not at Kilcoy after two years. *Bothriochloa pertusa* (eg. Keppel) had been found previously to establish and spread on a wide range of soils, but was lower yielding than the 'best' accessions at 8 sites across Queensland (Middleton 1996).

Table 5.9 List of the best sown pasture accessions for use in giant rats tail grass control programs at each of four sites in south-east Queensland, following two years of evaluation.

The accessions marked with a * were good in the adaptation trial and would probably be good for use in giant rats tail grass control strategies, but require further testing or technology for widespread use (eg. planting runners).

Sown pasture accession	Gympie	Kilcoy	Foxtail Flats	Gayndah
Callide	x	x	x	x
Nemkat*	x	x	x	x
Keppel	x		x	
Medway*	x			x
Dawson				x
brunswick grass	x	x	x	
Bisset	x			x
Hatch*	x			x
Floren	x			x
Basilisk	x	x	x	
Tully	x	x	x	
swazi grass* (runners)	x	x		
Whittet		x		
Competidor			x	
*Dichanthium annulatum** CPI 106146	x			
*Bothriochloa insculpta** CPI 9517				x
Pangola* (runners)			x	
Amarillo			x	
*Digitaria eriantha** (supplied by J.Wright –runners)			x	

The two *Paspalum* accessions (*P. nicorae* CPI 27707 - brunswick grass and Competidor) were relatively slow to establish, but may have potential under different management systems, that selectively remove taller species following sown pasture establishment. At the higher rainfall sites, the *Paspalum* accessions had a high frequency, but being shorter and slow to establish they were under the overhanging canopy of large giant rats tail grass plants. These accessions formed a reasonably tight sward between the giant rats tail grass tussocks. Therefore, if the giant rats tail grass plants were removed, further establishment of giant rats tail grass would be less likely. From field observation, it appears that these two accessions may be relatively tolerant to glyphosate and flupropanate herbicides. An effective broadacre herbicide application may remove the giant rats tail grass plants and allow the tight sward of these two accessions to close up and prevent further giant rats tail grass establishment. Further research and field trials should be conducted into the tolerance or susceptibility of these two accessions to glyphosate and flupropanate.

Whittet kikuyu was well-rated at Kilcoy, producing a dense ground cover, although it was relatively slow to establish. Whittet did not establish well under the management conditions at the Gympie site, even though there were areas of established kikuyu pasture within 100m of the trial site. The use of specific establishment methods for Whittet (involving slashing and fertilising) may have improved its success at Gympie.

A couple of accessions established well, but then declined, notably Jarra and Premier. Jarra was in the top four accessions at the three higher rainfall sites at the first sampling 2-3 months after sowing. However, two years later it had declined and was one of the least persistent grasses. However, Jarra and Premier may have a role for sowing in combination with slow establishing but more persistent accessions. Jarra and Premier establish quickly, covering the ground, but then as they ‘open-up’ they may allow slower establishing accessions to ‘come-away’. The decline of Jarra and Premier highlights the need for long-term evaluation of pasture accessions. If the trial had only been evaluated for 12-18 months, accessions like Jarra may have been considered to be quick-establishing and persistent. These trial plots will be monitored periodically, to follow other changes that may occur over time.

As expected, the legumes were not competitive enough against giant rats tail grass when sown on their own. The two legumes evaluated did appear to be well-adapted and persistent. Amarillo was good at Foxtail Flats and Gympie and still persisting at Kilcoy after 2 years. Wynn was persisting at Foxtail Flats and Gayndah after 2 years, although it was seasonal in its vigour, as Wynn dies back during winter. Both legumes tested did not appear to be overly palatable, with little evidence of grazing throughout the evaluation. Amarillo exhibited a high tolerance of pasture competition even when overshadowed by large giant rats tail grass plants. This ability indicates that it may be a legume that can be planted with competitive grasses sown at high rates to limit giant rats tail grass establishment. The Amarillo would probably be slow to develop ground coverage, but it will persist and should increase as soil fertility declines.

Conservative grazing management to limit giant rats tail grass establishment from the soil seed bank will be needed for many years to ensure that a large bulk of pasture is always present and that ground cover is maintained. This type of management would not be conducive to the good establishment and persistence of most legumes. A successful pasture system will eventually require nitrogen fertiliser input or a legume component. The legume component could be over-sown after the giant rats tail grass soil seed bank has been depleted, which may take up to 10 years (Vogler 2002). The other possible role of legumes is that they may allow use of a wider range of selective herbicides. Selective herbicides (eg. Spinaker) that kill grass but not legumes may allow selective removal of giant rats tail grass over a number of years. A grass can then be over-sown at a later date, once the giant rats tail grass soil seed bank has been depleted.

Sown pasture accessions that have potential for use in giant rats tail grass control programs, are available for most areas of south-east Queensland. In other areas of Queensland, well-adapted sown pastures that exhibit the majority of the attributes required for such success may not be available. Future sown pasture selection may be needed for these locations. However, well-managed native pastures have demonstrated a capacity to resist giant rats tail grass invasion (Chapter 6). Therefore, in some areas a suitable sown pasture accession may not be required.

5.5.4 Sowing techniques, pasture and grazing management

5.5.4.1 Sowing technique

The ground preparation and sowing technique needs to ensure that the pasture has the best chance of quick establishment. Pasture accessions that were slow to establish, generally had more giant rats tail grass plants establishing, and these giant rats tail grass plants grew quickly and competed strongly against the sown pasture.

Without a selective herbicide (either pre- or-post emergent) to remove giant rats tail grass, the direct pasture replacement method as used in this experiment, is not an ideal approach. Fodder pre-cropping (McIntosh *et al.* 1999) should be used if possible to reduce the giant rats tail grass soil seed bank prior to sowing the pasture. All giant rats tail grass seeds will not be removed from the long-lived soil seed bank, but the number will be reduced, therefore reducing potential competition against the sown pasture and the demand for follow-up control.

5.5.4.2 Pasture and grazing management

Pastures sown for giant rats tail grass control will need to be managed conservatively, to ensure the pasture does not 'open-up' for many years. Once bare soil is exposed, many giant rats tail grass seedlings will emerge (section 4.5) and establish from the long-lived soil seed bank (Vogler 2002).

Sown pastures have been used successfully for serrated tussock (*Nassella trichotoma*) control in New South Wales. However, when establishing new pastures for serrated tussock control, it is recommended that the pasture be spelled for the first year (Campbell 1960a). This period of spelling was believed to constitute the most important step in the eradication of serrated tussock and that complete ground cover in an improved pasture was necessary to prevent tussock re-infestation. Removal of re-infesting tussocks was still required each year.

Giant rats tail grass plants will establish with a sown pasture. These plants must be removed. At present there are limited chemical options for removing giant rats tail grass plants selectively from a sown pasture. More research should be conducted to identify herbicides or herbicide application techniques that selectively control giant rats tail grass.

5.6 *Conclusion*

Well-adapted and competitive sown pasture species are available for use in giant rats tail grass control programs in south-east Queensland. A list of attributes required by a sown pasture accession in a giant rats tail grass control program has been developed through the experience gained in this study. If a sown pasture accession does not exhibit the majority of these ten attributes, it is unlikely to be successful as part of a giant rats tail grass control program.

It cannot be over-emphasised that some giant rats tail grass plants will establish with the newly sown pasture. They must be controlled by other means. Strategies to reduce the giant rats tail grass soil seed bank prior to sowing will be crucial for success, especially if the best-adapted sown pasture accession is slow establishing, but has good, long-term competitive ability.

Established giant rats tail grass plants are unlikely to be out-competed by the sown pasture. Therefore, identification of techniques to remove giant rats tail grass plants that do establish is an important part of a control strategy. New selective herbicides (or selective application techniques) are needed for individual sown pasture accessions as part of an integrated weed management program for giant rats tail grass.

CHAPTER 6 Competition experiment demonstrates native pasture in sub-coastal Queensland can resist invasion of giant rats tail grass

6.1 *Summary*

Substantial vegetation gaps (1.2x1.2m) or smaller gaps with above-average rainfall allowed giant rats tail grass to invade healthy native pasture in sub-coastal Queensland, however without canopy gaps, giant rats tail grass seedling establishment was prevented.

Giant rats tail grass has already invaded 200 000ha of pasture land in Queensland and has the potential to invade 105Mha. Previous work has indicated that giant rats tail grass seedlings may be sensitive to pasture competition. However, the ease with which this weed can invade, establish and reproduce in competition with native pasture in drier sub-coastal regions (600-800 mm/yr) has been unclear.

An investigation was conducted to assess the competitive ability of giant rats tail grass to establish from seed and compete as a seedling within a mature native pasture. Pasture shoot and root competition were manipulated by cutting canopy gaps, inserting root exclusion tubes and simulating above-average rainfall conditions.

Healthy native pasture in the southern speargrass zone of Queensland prevented invasion and establishment of giant rats tail grass, even during periods of above-average rainfall. However, weed control and containment strategies should focus on minimizing the formation of pasture canopy gaps, particularly where giant rats tail grass seed has already been or is likely to be incorporated into the soil seed bank.

6.2 *Introduction*

6.2.1 Giant rats tail grass is a problem for land managers

The unpalatable pasture weed, giant rats tail grass (*Sporobolus pyramidalis*), has invaded 200 000ha of pasture-land in Queensland. However, this is only a small proportion of the potential distribution of 105Mha or 60% of Queensland predicted by eco-climatic modelling (NRM 2001). The current wide geographical distribution of isolated outbreaks of this perennial tussock-grass on a range of soil types, climate zones and pasture types leaves little doubt that this weed has the potential to grow across its predicted potential distribution.

Giant rats tail grass infestations reduce the sustainability of rural enterprises. Landholder experience suggests that, when pastures are infested with giant rats tail grass, carrying capacity can be reduced by up to 80% in dense infestations, livestock can take up to 12 months longer to reach target weights (NRM 2001) and property values can be halved (G. Graham *pers. com.).* Biodiversity of the ground layer vegetation is also potentially reduced by dense infestations (NRM 2001).

6.2.2 Practical weed control strategies and additional knowledge are required

The development of practical weed control and containment strategies is imperative, due to the large potential losses associated with the continuing invasion and spread of giant rats tail grass. These control strategies should be targeted and require an understanding of the life cycle and competitive ability of this weed and particularly identification of any weaknesses within its life cycle.

The ability of native pasture to resist invasion of giant rats tail grass in the drier sub-coastal zones is largely unknown. Most current giant rats tail grass infestations are on land that receives greater than 900 mm/yr rainfall and fewer infestations occur in the sub-coastal zone with 600-800 mm/yr rainfall. Two theories could account for this difference. The first theory is that many infestations began with the sowing of pasture species adapted to the higher rainfall zone. Giant rats tail grass was a contaminant of this pasture seed and less of this seed was planted in the drier zone. The second theory postulates that giant rats tail grass is simply not adapted to and can not compete in the drier sub-coastal environment and is a therefore a high rainfall zone weed. This second theory is possibly flawed, as a number of infestations currently exist in the drier sub-coastal zone of Queensland (eg. Middlemount, Bauhinia, Monto and Gayndah). However, little is known about the ability of giant rats tail grass to invade and reproduce in competition with native pasture in the drier sub-coastal zone.

6.2.3 Pasture competition and vegetation gaps may be the key to giant rats tail grass seedling establishment

The process of pasture competition may have a significant role in the successful seedling establishment of giant rats tail grass. Previous testing of pasture management techniques (in the >900 mm/yr rainfall zone, Chapter 4) such as burning, fertilizer application and cultivation, has produced conflicting responses in terms of giant rats tail grass seedling establishment. The annual spring fire treatment, which had reduced ground cover after the burn, had few seedlings establish in one year with average rainfall, whereas many seedlings established after a further fire in the following wet year (Fig 4.14, 4.16 and 4.18). In other treatments that maintained a high level of pasture cover, few seedlings established in either year, whereas in the cultivated treatments (little pasture cover or root competition), many seedlings emerged in both years. This work indicated that reduced pasture competition has a significant role in the establishment of giant rats tail grass seedlings, not just in respect to pasture cover and root competition, but also in regard to seasonal conditions, particularly in wetter than average periods.

Plant competition can be a potent force to influence the success or failure of plant establishment (Cook *et al.* 1993). Vegetation gaps can be an obvious physical gap in the canopy or a less obvious area of reduced plant competition, for example due to the recent death of a nearby plant within the pasture sward. Vegetation gaps increase access to limiting resources such as nutrients, light (amount and quality) and water

(Cook *et al.* 1993), and can have a substantially different temperature regime (Tothill 1969; Thompson & Grime 1983). The increased availability of resources in vegetation gaps provides a superior opportunity for many species to germinate and subsequently grow, survive and reproduce (eg. Harper 1977; Goldberg & Werner 1983; Snaydon & Howe 1986; Specht & Clifford 1991; Panetta & Wardle 1992; Cook *et al.* 1993; Bullock *et al.* 1994; Hook *et al.* 1994; Aguilera & Lauenroth 1995; Bullock *et al.* 1995; Morgan 1997; Moretto & Distel 1998; Morgan 1998; King & Grace 2000).

The need for vegetation gaps to achieve establishment of new plants is reduced if resources are supplied in excess of the requirements of the existing vegetation, thus minimising competition effects (Cook 1985). Additional water supplied by above-average rainfall or irrigation would probably increase the emergence, growth and survival of seedlings in the absence of other confounding factors (eg. disease). The highly variable rainfall in Queensland may provide sporadic opportunities for giant rats tail grass seedling establishment, even in dry zones.

6.2.4 Shoot and root competition difference and implications for pasture management techniques and seedling establishment

Pasture competition can be divided into shoot and root competition (Donald 1958). Shoot competition can regulate light (amount and quality) and temperature (level and fluctuations) resources. Shoot competition (above-ground) is manipulated via vegetation gaps and canopy density. Burning, slashing, some herbicides and heavy grazing tend to reduce shoot competition in the short-term, whereas fertilising, spelling and irrigation tend to increase pasture growth and bulk, thus increasing shoot competition. By comparison, root competition (below-ground) can limit the availability of nutrient and moisture resources (Cook *et al.* 1993). However, root competition is difficult to manipulate without killing plants by using chemicals or cultivation.

Both root and shoot competition around a plant are reduced by a deterioration of vigour in neighbouring plants or by increasing the size of vegetation gaps. Regular burning, slashing and heavy-grazing can reduce plant vigour over time, by reducing leaf area for photosynthesis and a run-down of plant reserves. However, in general, one-off or irregular burning, slashing and grazing reduces shoot competition, but has only a relatively small effect on root competition (Cook *et al.* 1993).

The relative importance of shoot and root competition in limiting giant rats tail grass seedling establishment will determine the invasion success during typical management operations (eg. fire) and seasonal influences (eg. low pasture cover at end of the dry-season). Weeds that require reduced shoot competition, but are not greatly limited by root competition, would be difficult to contain under Queensland's typical management and seasonal conditions, where livestock are continually grazed during long dry seasons substantially reducing canopy cover.

6.2.5 The experiments

Three experiments were conducted with the following objective: To investigate the process of pasture competition and to determine its role in preventing the establishment of giant rats tail grass in a sub-coastal, native pasture in Queensland.

Artificially created canopy gaps (Morgan 1997) and root exclusion tubes (Cook & Ratcliff 1984) altered the intensity of pasture shoot and root competition, and supplementary irrigation simulated above-average rainfall conditions. Both seed and transplants of giant rats tail grass were used in the experiments. Seedling emergence, establishment, growth, survival and reproduction were recorded.

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6.3 *Materials and methods*

6.3.1 Experimental design

This investigation consisted of three experiments, which were analysed separately.

Experiment 1: *The effect of pasture canopy gaps and root competition on the survival, growth and reproduction of giant rats tail grass transplanted as seedlings, receiving above-average (~1000mm) rainfall per year.*
Giant rats tail grass seedlings/transplants were planted in plots, which had 1 of 5 canopy gap sizes, plus or minus a root exclusion tube. The experiment was irrigated.

Experiment 2: *The effect of canopy gaps and root competition on the emergence, establishment, survival, growth and reproduction of giant rats tail grass sown as seed, receiving above-average (~1000mm) rainfall per year.*
Giant rats tail grass seed was sown in plots, which had 1 of 5 canopy gap sizes, plus or minus a root exclusion tube. The experiment was irrigated.

Experiment 3*: The effect of canopy gaps on the emergence, establishment, survival, growth and reproduction of giant rats tail grass sown as seed, receiving natural (~700mm) rainfall per year.*
Giant rats tail grass seeds were sown in plots, which had 1 of 5 canopy gap levels (and no root exclusion tube). The experiment received only natural rainfall (Gayndah 1998).

The experiments were conducted at the Gayndah site (see site description – section 3.1.4) in a native pasture dominated by *Bothriochloa bladhii* (forest bluegrass) and *Heteropogon contortus* (black spear grass), growing on a fertile slightly-cracking, brown clay. The pasture had been ungrazed for approximately two years beforehand. Canopy height was approximately 50-60cm. The experiments were planted on 5 February 1998 and ran eleven months, with the final sampling on 12 January 1999.

Experiments 1 and 2 were combined into the same randomised block experimental design with four blocks arranged parallel to the direction of movement of a travelling irrigator. Treatments were a factorial of planted seedlings (Experiment 1) or sown seed

(Experiment 2), plus or minus a root exclusion tube and five levels of canopy gap size. The treatments were randomly allocated to plots within each block. The plot size for all experiments was 2x2m.

Experiment 3 was a randomised block design and was located ~6m away from Experiments 1 and 2. Treatments were five levels of canopy gap size. Plots were arranged in a row across the slope, with the four blocks arranged down the gentle slope (1-2%).

6.3.2 Creating canopy gaps and installing root exclusion tubes

The three experiments had five canopy gap sizes: no gap, 15x15, 30x30, 60x60 and 120x120cm. The square canopy gaps were cut in the centre of the 2x2m plots by permanently locating an appropriately sized quadrat and carefully removing all plant material, minimising soil disturbance. Plant regrowth within the quadrat was sprayed with glyphosate (low pressure application to avoid non-target damage) or hand weeded. Canopy gap edges were trimmed at each sampling date (every 2 weeks initially) or as required. Thus, each plot had a minimum 80cm wide border between neighbouring canopy gaps (ie. between two neighbouring 120x120cm canopy gaps).

Root exclusion tubes were made from sheet steel, rolled and welded to form a tube, 28.5cm diameter and 20cm deep. The tubes were pushed approximately 19cm into moist soil, around the 10x10cm area to be sown in the centre of each plot. The size of the tubes was influenced by the experiences of Cook & Ratcliff (1984), who used 7.5 or 10cm diameter tubes. Larger tubes were used in this experiment because the plants were expected to grow larger than theirs and for a longer period. The tubes were pushed 19cm into the soil since Cook & Ratcliff (1984) found that the zone of major root activity for a similar native pasture was 10-15cm deep. Note: in some 15x15cm canopy gap treatments with a root exclusion tube (28.5cm diameter), plants were removed from the zone (4-7cm wide) just outside the canopy gap because they were rooted inside the tube. It is believed, that this had minimal impact on shoot competition applied, due to the intermeshing canopies of surrounding plants leaning toward the canopy gap and the limited number of plots that had plants of a substantial size in this zone.

A 10x10cm wire quadrat marking the area to be sown was pegged in the centre of each tube, canopy gap or plot (for the no gap treatments).

6.3.3 Planting giant rats tail grass seedlings (Experiment 1)

Seedlings were grown from seed that were collected near the experimental site nine months prior to sowing and had approximately 90% viability. The seedlings were grown in disposable, plastic drinking cups that had sloping sides and were approximately 6cm diameter at the top. Drainage holes were punched in the bottom and the cups filled with sterilised (methyl bromide fumigated) sandy loam soil. A number of seeds were sown in each cup, but emerged seedlings were thinned to one healthy seedling per cup. They were grown for approximately 6 weeks in a plant house prior to transplanting. The seedlings were 8-10cm high, with minimal tillering and approximately 5-7 leaves each. No fertiliser was applied to the seedlings. Three healthy seedlings were planted in each plot by removing three soil cores (5cm diameter and approximately 7cm deep) with a soil sampler, within the central 10x10cm area. The seedlings were planted in the holes and watered in with approximately 350ml of water per plot. The soil was moist from natural rainfall at planting. Thus, twelve seedlings were planted per treatment (3 seedlings/plot x 4 blocks).

Morgan (1997) used one seedling per plot, but very few survived, which made data analysis difficult. Hence, I increased the numbers planted per plot.

6.3.4 Sowing giant rats tail grass seed (Experiment 2 and 3)

The same seedlot was used as in Experiment 1. Seed dormancy should have been negligible at time of sowing (Vogler 2002). Fifty giant rats tail grass seeds were sown in the 10x10cm quadrat in the centre of each plot. Fifty seeds (5000 seeds/m^2) were used because it was approximately the average soil seed bank size for the Gympie, Kilcoy and Foxtail Flats research sites in early 1997 (Chapter 4, section 4.4.1). The seeds were sown by scoring the soil surface to a depth of 3-5mm and sprinkling on the seeds.

6.3.5 Contrasting rainfall regimes were created by supplementing natural rainfall with irrigation

Soil moisture was likely to be the major limiting factor for giant rats tail grass germination, seedling emergence, growth and survival, with or without pasture competition. Two rainfall/moisture regimes were imposed:

1. Natural rainfall at the Gayndah site for that year (Experiment 3), historical average of 708 mm/yr.
2. Simulated above-average rainfall (Experiments 1 and 2), aiming for 1000 mm/yr.

Simulated above-average rainfall strategy

Above-average rainfall was simulated by using a travelling irrigator to top up natural rainfall at the Gayndah site to approximately 1000 mm/yr. Historical mean and median monthly rainfall at the wetter Gympie township (Willcocks & Young 1991) was used as a guide to determine when irrigation was required. The Gympie township rainfall distribution was used to ensure the simulated above-average rainfall treatment at Gayndah had a realistic rainfall distribution pattern for a higher rainfall region. The Gympie township is approximately 110km south-east of the Gayndah site. If early in the last week of each month, the weather forecast was for dry conditions and the experiments had not received the required monthly rainfall, they were irrigated to increase the total moisture applied to between the mean and median monthly rainfall of Gympie township.

Rainfall regimes

The total natural rainfall at Gayndah from February 1998 until January 1999 was 741mm (Figure 6.1), which was slightly higher than the 708 mm/yr long-term average annual rainfall for the Gayndah site. The above-average rainfall regime (Experiments 1 and 2) received 170mm of supplementary irrigation, over three low rainfall months (March, June and July 1998), to bring the total to 911 mm/yr. This total was slightly less than the desired 1000 mm/yr, but the difference was mainly due to the small amount of rain received in January 1999 at the end of the experiment.

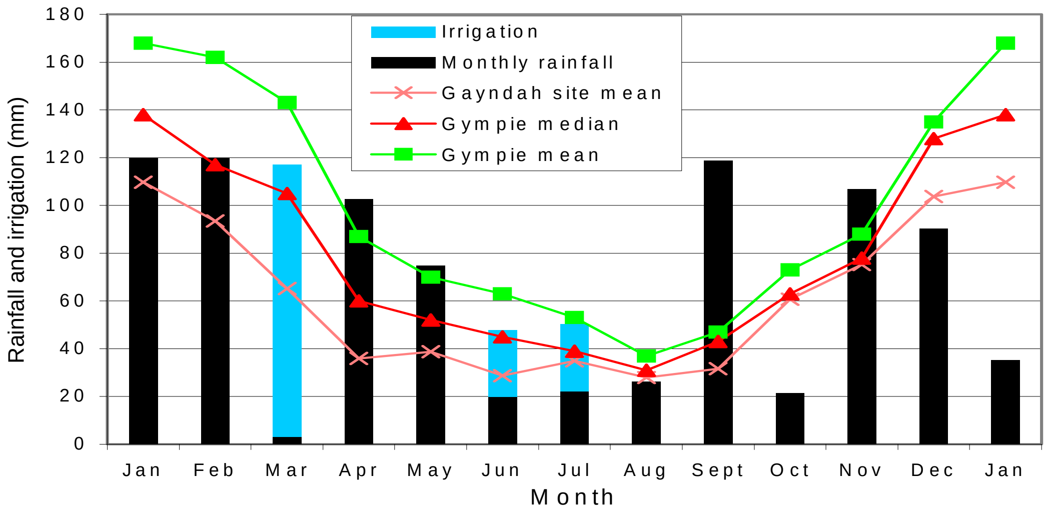

Figure 6.1 Monthly rainfall and supplementary irrigation, from January 1998 to January 1999 at the Gayndah site, compared to Gympie township median and mean monthly rainfall (Willcocks & Young 1991) and the Gayndah site mean monthly rainfall (J. Kirk *pers. com.*).

6.3.6 Sampling

Data from the experiments were recorded approximately every 2 weeks from sowing (February 1998) until September 1998 and then monthly until November 1998 with a final sampling in January 1999.

In Experiment 1, the three transplanted seedlings in each plot were individually identified (using different coloured ribbon) and monitored separately throughout the experiment. A number of measurements were taken on these plants.

- Plant height was measured from the soil surface to the tip of the tallest green leaf or inflorescence when the plant was pulled straight up. If the leaf tip was dead, height was measured to the tallest green part of the leaf. If the plant had tall inflorescences that had shed all of their seed, height was measured to the tip of the tallest inflorescence with branches still attached.
- The number of tillers per plant was counted every 2 weeks until May 1998 and every 4 to 8 weeks thereafter.

- The number of days from planting the seedling until the first inflorescence emerged was recorded for each plant. The inflorescence was considered emerged once the tip of the inflorescence emerged from the flag leaf sheath. The date for emergence was recorded as the sampling date, therefore all inflorescences which emerged since the last sampling date were recorded as emerging at the current sampling date.
- The cumulative number of emerged inflorescences per plant was recorded at each sampling.
- Basal area of the tussocks was measured in January 1999 (final sampling), by measuring the basal diameter in two perpendicular directions and calculating the area of a circle.

In Experiments 2 and 3, the number of giant rats tail grass seedlings in each plot was counted at each sampling date. Up to 8 seedlings were permanently identified (using different coloured ribbon) and the same plant measurements as Experiment 1 (listed above) were recorded for these plants. If one of the 8 plants died it was recorded as dead and another plant (if present) was permanently identified and measured thereafter in its place.

Gravimetric surface soil moisture content was measured periodically in one block in Experiments 1 and 2. A 2cm diameter, 0-7cm deep soil core was taken approximately 10cm from the centre of the plot. Care was taken to minimise soil disturbance and the holes were back filled with local soil.

Photosynthetically active radiation (PAR) was measured in the centre of each canopy gap on 8 April 1998 (minimal cloud cover) at 2.00pm and 4.00pm. Measurements were taken using a modified 100cm line sensor (LI-191SB, Li-Cor Inc., Lincoln, Nebraska, USA). To sample only the centre of each gap, 90cm of the sensor was blacked out leaving only 10cm exposed at one end. The exposed part of the sensor was placed in the centre of the gap approximately 5cm above the soil surface. Values were multiplied by 10 to correct for blacking out 90% of the sensor. Measurements were also taken above the pasture canopy at a height of ~60cm.

6.3.7 Data manipulation and statistical analysis

All data sets were converted to 1 value per plot (measurements for up to 8 plants were averaged) and if appropriate, transformed prior to statistical analysis. In Experiment 1 (planted seedlings) few plants died (few missing values) and the data were statistically analysed using the analysis of variance technique. In Experiments 2 and 3 (sown seed) many plots had no seedlings surviving (many missing values), therefore statistical analysis was not conducted on some datasets, although trends are still evident from the presented data. In some datasets, for example tiller number/plant in Experiment 2, the data presented are the average of plots with plants present. Plots with no plants were ignored for this parameter. The error bars presented on graphs are least significant difference (LSD) values at the 5% level.

Plant height was statistically analysed at each sampling date for Experiment 1. In Experiments 2 and 3, the presented data is an average of plots with seedlings.

Tiller number was the average number of tillers per plant in each plot including the main shoot. Two datasets were produced from the tiller number data. Rate of tiller production (the tiller number increased relatively linearly with time) and the tiller number at each sampling date. In Experiments 2 and 3, the data are presented as an average of plots with seedlings.

The number of days from planting the seedlings (Experiment 1) or sowing seed (Experiments 2 and 3) until the first inflorescence emerged per plot (not plant) was analysed. Plots with no inflorescences had the days to flower treated as a missing value. The cumulative inflorescence number was the sum of all inflorescences that emerged per plot (not plant) for the duration of the experiment. Plots with no inflorescences were included in the analysis (as 0). The data was square root transformed (square root data = $(\text{inflorescence number}+0.5)^{0.5}$) prior to analysis. Values in the text are back transformed means.

Basal area was calculated per plot. The basal area of each plant was calculated by averaging the two basal diameters and then calculating the area of a circle for that diameter. The individual plant basal areas were summed for each plot. In Experiments 2 and 3, the data are presented as an average of plots with plants.

Plant number data recorded in Experiment 2 were square root transformed prior to statistical analysis. Values presented in the text are back transformed means. Plots with no plants were included in the analysis. In Experiment 3, the plant number data were square root transformed and are an average of all plots.

6.4 *Results*

6.4.1 Photosynthetically active radiation (PAR)

The amount of incident photosynthetically active radiation (PAR) received in the centre of the vegetation gaps increased with increasing gap size (Fig 6.2).

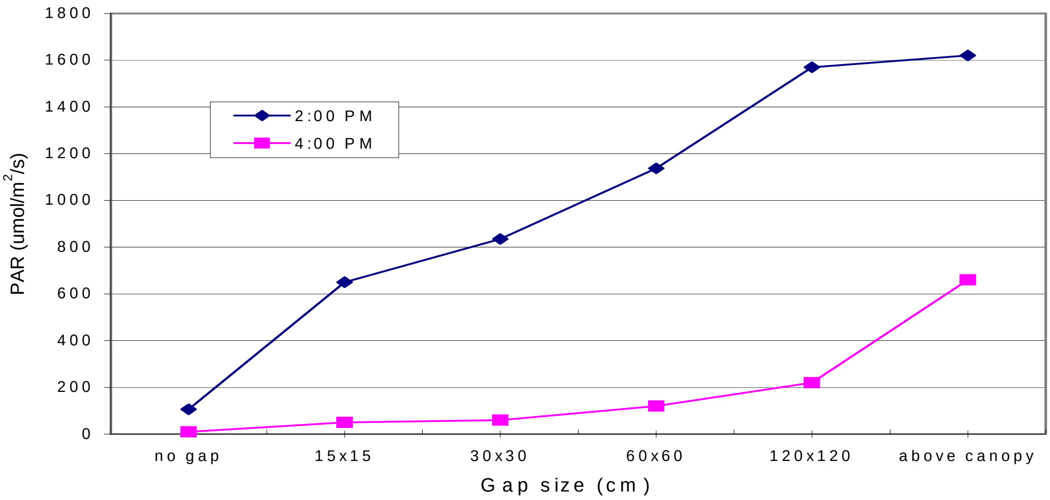

Figure 6.2 Photosynthetically active radiation (PAR) 5cm above the soil surface in a range of artificially created canopy gap sizes in a native pasture and above the pasture canopy (~60cm) at 2:00pm and 4:00pm on the 8th April 1998 at the Gayndah site.

The largest gap size (120x120cm) received a similar amount of radiation as existed above the canopy during the middle of the day (2pm). The no canopy gap treatment received only a small percentage of above-canopy radiation (6%), even during the middle of the day.

6.4.2 Rainfall and soil moisture

The experiment experienced a dry period during late February and March following sowing in early February (Fig 6.3). Many giant rats tail grass seedlings that initially emerged (Experiment 2) died prior to supplementary irrigation being applied at the end of March.

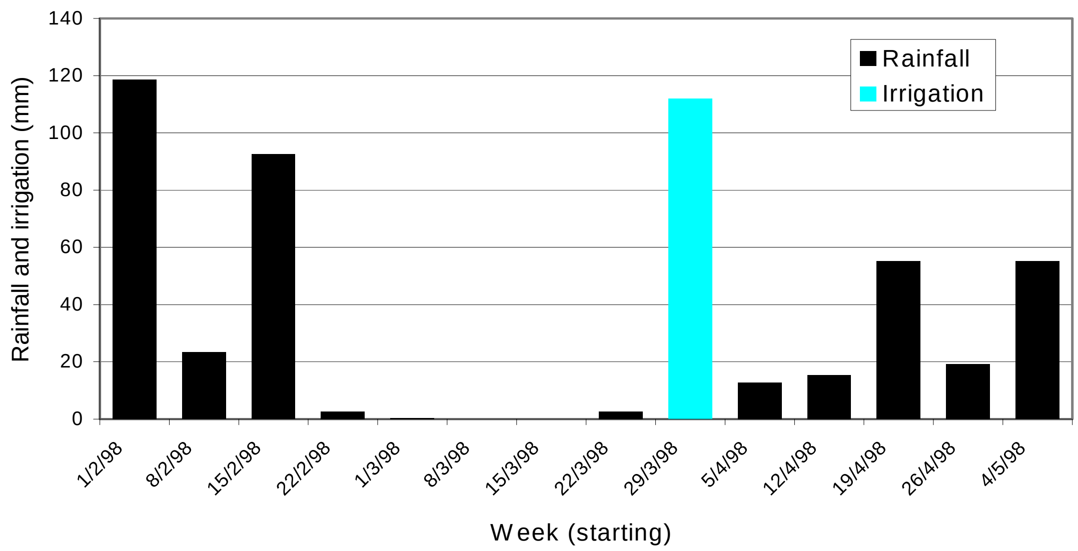

Figure 6.3 Weekly rainfall and supplementary irrigation during the first 3 months of the experiment. Seed was sown and seedlings planted on 5-6 February 1998, following rain earlier in the week.

The surface soil moisture content (0-7cm) was measured in 10 plots on three occasions in the first 2 months of Experiments 1 and 2, and near the end of Experiment 2. These data were not spatially replicated (only 1 block sampled), therefore care needs to be taken when using them to explain seedling survival.

Near the start of Experiment 2 (sown seed), treatments with a root exclusion tube had a higher surface (0-7cm) soil moisture content than treatments without a root exclusion tube (Fig 6.4a, 6.4b and 6.4c), except in the largest canopy gap size (120x120cm), where the soil moisture content was similar between tube treatments. The treatment with a root exclusion tube and no canopy gap had the highest soil moisture content. Soil moisture content generally decreased with increasing gap size probably due to greater radiation interception (Fig 6.2) and more air movement in the larger canopy gap sizes increasing evaporation from the soil surface.

Towards the end of the experiment there was little effect on surface soil moisture content from the installation of root exclusion tubes for all gap sizes (Fig 6.4d, 6.4e and 6.4f), although surface soil at the centre of the larger gap sizes tended to be slightly drier.

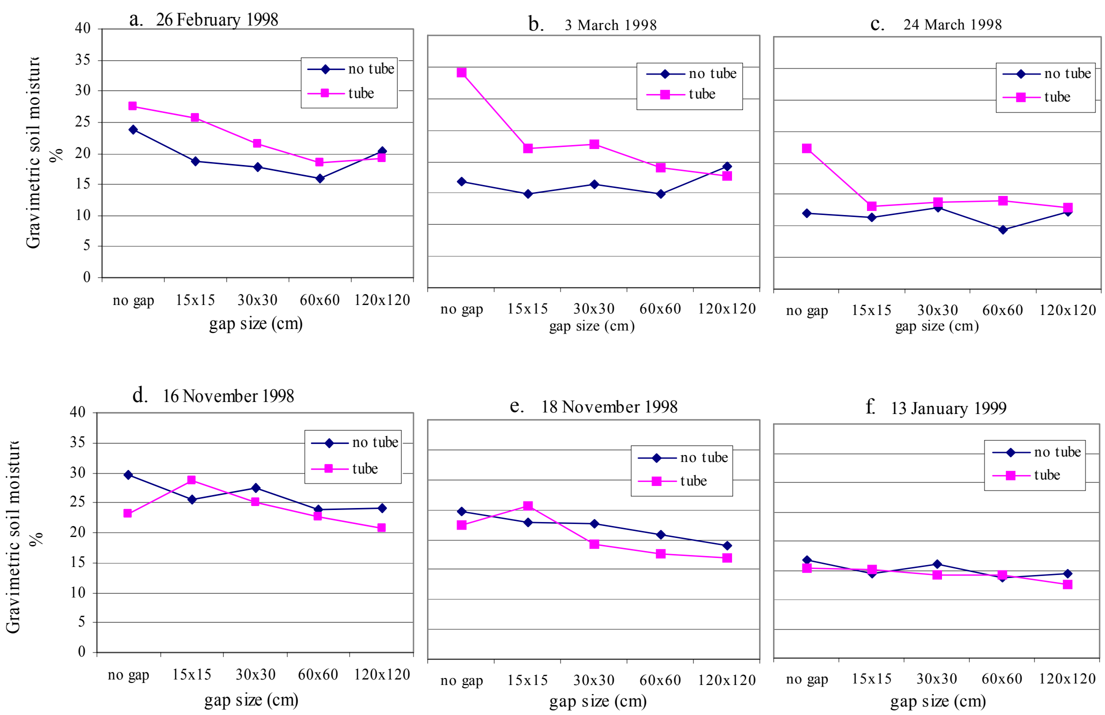

Figure 6.4 Gravimetric soil moisture content of surface soil (0-7cm) in each treatment for one block in Experiment 2 (sown seed) for three dates near the start of the experiment (a, b, c) and 3 dates near the end of the experiment (d, e, f).

Near the start of Experiment 1 (planted seedlings), the surface soil moisture content for treatments with no gap and 15x15cm canopy gap sizes were much higher with a root exclusion tube than for those without a tube (Fig 6.5a and 6.5b). This difference was not apparent after a long dry period (Fig 6.5c). The tube treatments had similar surface soil moisture contents with either a 60x60 or 120x120cm canopy gap size.

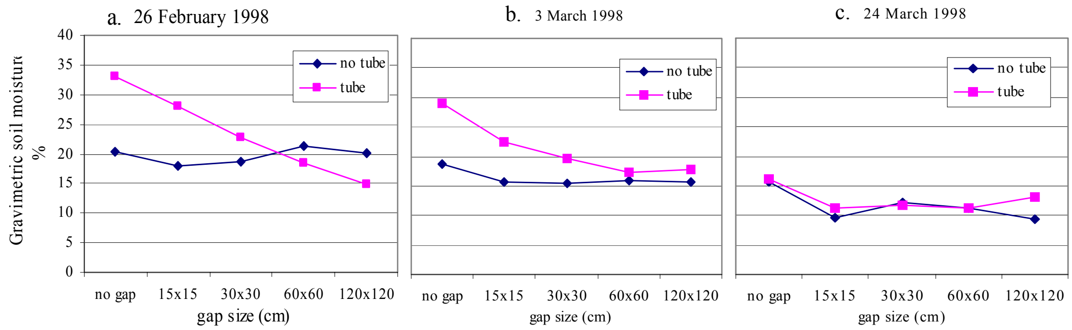

Figure 6.5 Gravimetric surface soil moisture content (0-7cm) in each treatment for one block in Experiment 1 (planted seedlings) for 3 dates (a, b, c) near the start of the experiment.

6.4.3 Plant measurements for Experiment 1: planted seedlings

6.4.3.1 Plant number

Three seedlings were planted per plot, 12 seedlings per treatment, with a total of 120 seedlings planted in the experiment. Only seven seedlings died out of the 120 seedlings (94% survival), all were planted without a root exclusion tube. Three of these seedlings died in the no canopy gap (highest plant competition) and four in the 15x15cm canopy gap. Six of these seedlings died within two months of planting during the dry period in March 1998 (Fig 6.3).

6.4.3.2 Plant height

There were small but significant treatment differences in plant height at the first two sampling dates (Fig 6.6). The no canopy gap and small gap size seedlings grew taller than those in the larger gaps. One month after planting the seedlings, this pattern remained, but there were no significant differences. Then from mid May 1998 until the end of the experiment, the plants in the 120x120cm gap were significantly taller than the plants in all the other gap sizes, except the 60x60cm gap at a couple of dates. Also from May 1998 onwards, the no gap treatment plants were shorter than those in all other gap sizes. Over the same period, the 15x15cm gap size plants were the second tallest until September 1998, whereafter the 60x60cm gap became the second tallest until the end of the experiment.

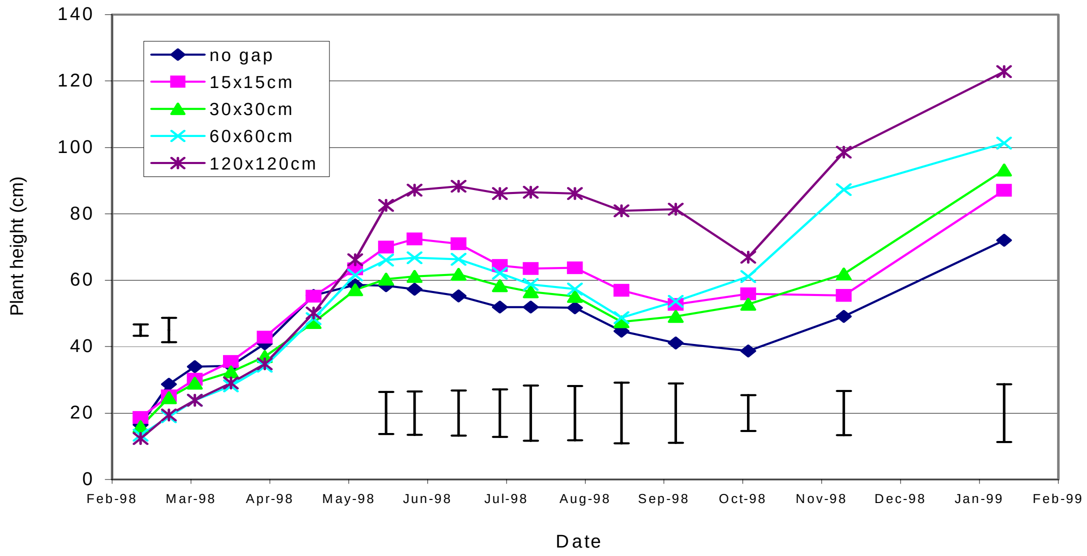

Figure 6.6 The height (cm) of giant rats tail grass plants after planting as small giant rats tail grass seedlings on 5 February 1998 into five different canopy gap sizes.
Error bars are LSD at the 5% level. There was no significant difference between treatments for sampling dates without a corresponding error bar.

Plants surrounded by a root exclusion tube were significantly taller than those growing without a root exclusion tube from mid March 1998 until September 1998 (76cm vs. 53cm at 1 July 1998) (Fig 6.7). The no tube treatments became significantly taller at the final sampling in January 1999 (102cm vs. 88cm).

There was a significant interaction between gap size and tube treatment on plant height from mid April 1998 until July 1998, due to the plants in the 15x15cm gap size responding more (growing taller) with a root tube present than those plants from the other gap sizes (Fig 6.8a). Between October 1998 and January 1999, there was another interaction between gap size and tube treatment, with the no gap and 15x15cm gap plants growing taller with a root exclusion tube present, while the plants in the 60x60cm and 120x120cm gap sizes were shorter where a root tube was present (Fig 6.8b). This interaction pattern was recurring in other plant attribute datasets in these experiments and was probably linked to soil resources being limited by the root exclusion tube where the plants were able to grow large (Cook & Ratcliff 1984).

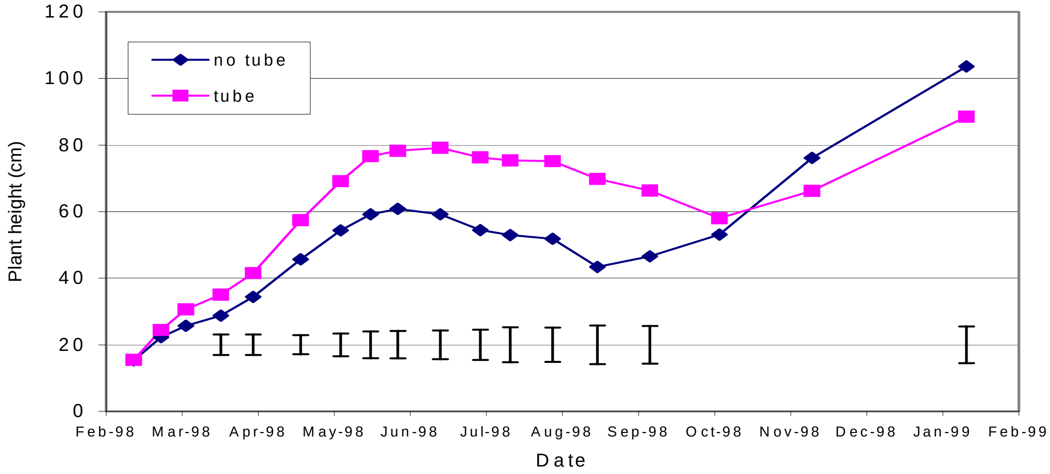

Figure 6.7 The height of giant rats tail grass plants after planting as small giant rats tail grass seedlings on 5 February 1998, with and without a root exclusion tube.
Error bars are LSD at the 5% level. There was no significant difference between treatments for sampling dates without a corresponding error bar.

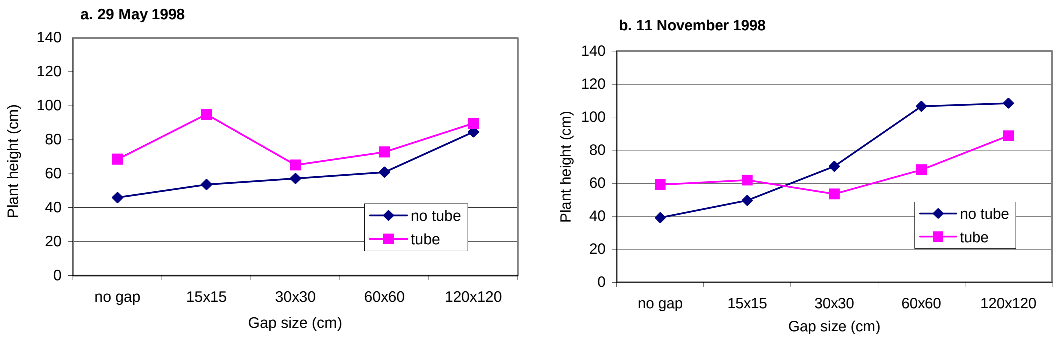

Figure 6.8 Interaction between gap size and tube treatment for plant height at two dates a. 29 May 1998 and b. 11 November 1998, following planting of small giant rats tail grass seedlings on 5 February 1998.

6.4.3.3 Tiller number and rate of tiller production

Tiller number was the average number of tillers per plant in each plot. The tiller number data formed two datasets; rate of tiller production and the tiller number at each sampling date.

There were significant differences between gap sizes in the rate of tiller production, with the rate increasing with gap size (Fig 6.9). Plants in the 120x120 and 60x60cm gap sizes were similar (0.11 tillers/day) and had a significantly higher rate of tiller production than those growing in the smaller gap sizes. The no gap treatment plants had a significantly lower rate of tiller production (0.05 tillers/day) than those with a 30x30cm gap size (0.08 tillers/day).

There was a significant interaction between gap size and root tube treatment for rate of tiller production (Fig 6.9). The rate of tiller production for the no gap and 15x15cm gap size treatments was lower with no root tube, whereas the rate in the 60x60 and 120x120cm gap size treatments was higher with no root tube. The presence of a root exclusion tube meant that the rate of tiller production was virtually unaffected by canopy gap size, i.e. no shoot competition effect. Due to the interaction there was no overall significant difference between tube treatments.

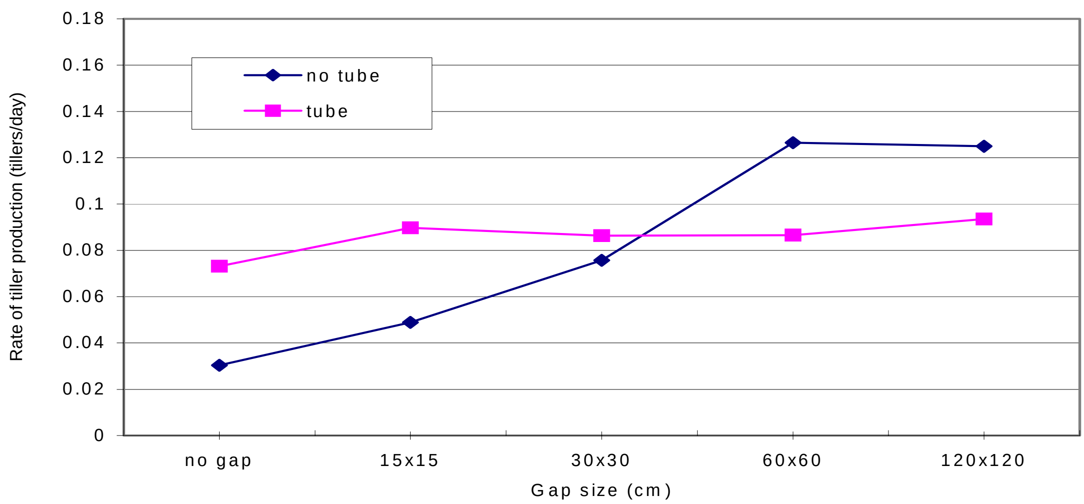

Figure 6.9 Interaction between canopy gap size and root exclusion tube presence on the mean rate of tiller production between February 1998 and January 1999, following planting of small giant rats tail grass seedlings on 5 February 1998.

The tiller number data when analysed at each sampling date had significant differences between gap sizes following the initial sampling. From mid-April 1998, tiller number increased with gap size (Fig 6.10). At the final sampling, plant tiller numbers in a 60x60cm gap were similar to those in the 120x120cm gap size treatment. Plants in the 15x15 and 30x30cm gap sizes had similar tiller numbers, while plants in the no gap treatment had significantly lower tiller numbers than the other treatments throughout the experiment.

Plants encircled by a root tube had significantly higher numbers of tillers per plant at most sampling dates compared to the no root tube treatments. However there was a significant interaction between gap size and tube treatment from April 1998 onwards (similar to Fig 6.9).

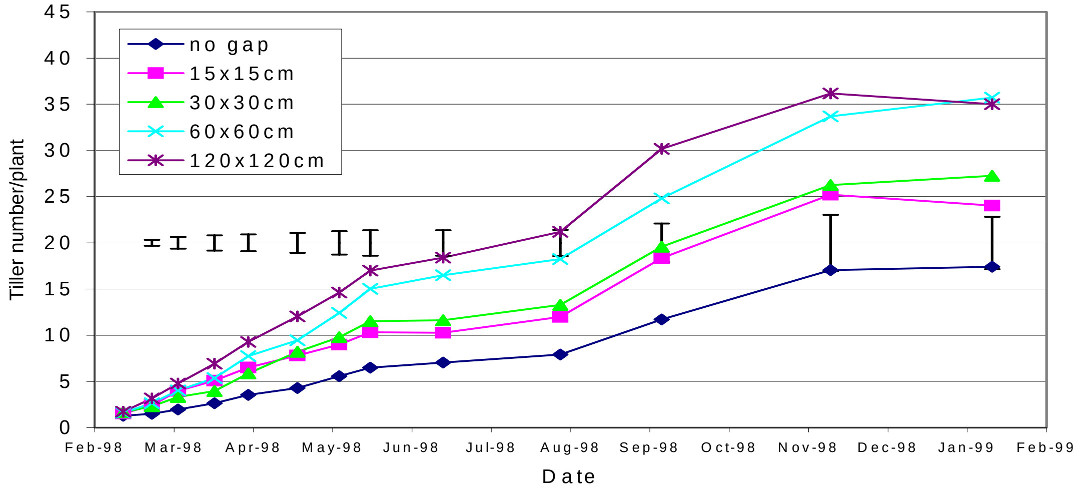

Figure 6.10 Change in tiller number per plant over time following the planting of small giant rats tail grass seedlings into different sized canopy gaps.
Error bars are LSD at the 5% level. There was no significant difference between treatments for sampling dates without a corresponding error bar.

6.4.3.4 Basal area

Giant rats tail grass basal area was measured at the final sampling in January 1999 for the planted seedlings. There were significant differences in basal area amongst canopy gap sizes, with basal area increasing with gap size (Fig 6.11). The 120x120cm gap size had significantly the highest basal area per plot (197cm^2), followed by the 60x60cm gap size (164cm^2), which was significantly higher than all the smaller gap sizes. The 30x30cm (91cm^2) and 15x15cm (75cm^2) gap sizes were not significantly different from each other. The no gap treatment (41cm^2) had significantly the lowest basal area per plot of all treatments.

Basal area was not significantly different between root exclusion tube treatments. However there was a significant interaction between gap size and root tube treatment (Fig 6.11). The use of 28cm diameter root exclusion tubes driven 19cm into the ground restricted the growth in basal area of plants in large canopy gaps (60x60 and 120x120cm), but with smaller canopy gaps the root exclusion tubes enhanced plant basal area at the time of final sampling, 11 months after planting the seedlings.

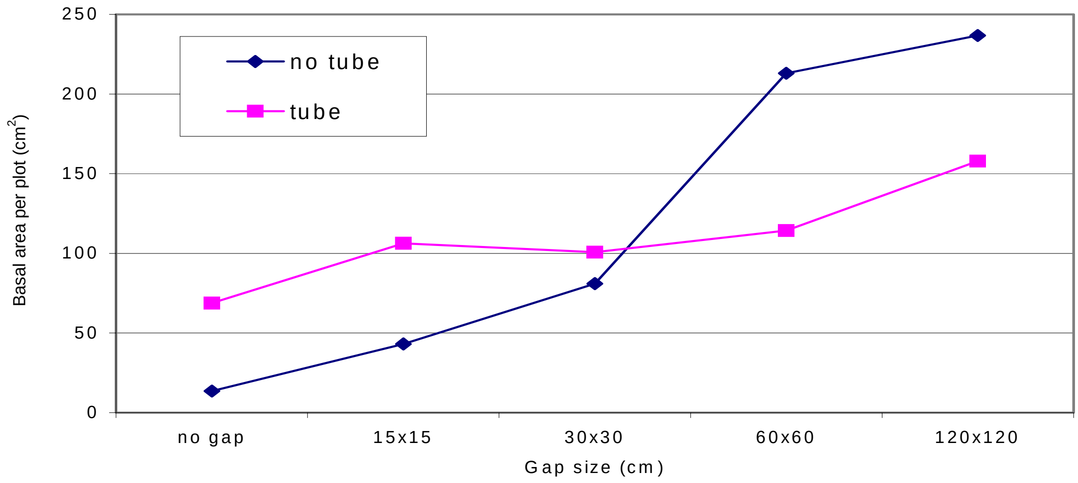

Figure 6.11 Interaction between the presence of root exclusion tubes and canopy gap size on the basal area of giant rats tail grass per plot in January 1999, 11 months after planting seedlings.

6.4.3.5 Time until first inflorescence emerged and cumulative inflorescence number

The number of days from transplanting the seedlings until the first inflorescence emerged was recorded for each plot (not plant). With full competition (no root exclusion tube and no canopy gap) only 1 plot (of 4) flowered (Table 6.1), while with reduced root competition (a root tube and no gap treatment) or reduced shoot competition (no tube and 15x15cm gap) 3 plots flowered within 11 months. In all the other treatments the 4 plots contained plants that flowered within 11 months of planting.

Even though the data were quite variable, the plants within larger gap sizes generally flowered earlier than those within smaller gap sizes and plants growing without a root exclusion tube took longer to flower than when a root tube was present. Only plants in the largest gap size (120x120cm) flowered within 3 months of being transplanted prior to winter.

Table 6.1 Time until the first inflorescence emerged and cumulative inflorescence number per plot (over 11 months) following giant rats tail grass being planted as seedlings into different canopy gap sizes, plus or minus a root exclusion tube.
Means followed by a different letter are significantly different (P<0.05) within each dataset. The number in brackets is the number of plots that flowered if less than 4.

Gap size (cm)	Time until inflorescence emergence (days)			Cumulative inflorescence number per plot		
	mean	no tube	tube	mean	no tube	tube
no gap	271 b	361 (1)	181 (3)	1.0 d	0.4 (1)	1.7 (3)
15x15	295 b	345 (3)	246	2.6 cd	2.6 (3)	2.6
30x30	257 b	300	215	5.5 c	7.8	3.6
60x60	198 ab	206	190	19.2 b	33.1	9.0
120x120	89 a	89	89	29.6 a	46.5	16.4
mean		260 a	184 b		12.8 a	5.8 b

Gap size, tube treatment and gap size by tube treatment interaction were statistically significant for the cumulative inflorescence number per plot. Inflorescence numbers increased with increasing gap size (Table 6.1), and plants growing without a root exclusion tube in the larger gap sizes had significantly greater inflorescence numbers than those in treatments with a root exclusion tube.

6.4.4 Plant measurements for Experiment 2: sown seed

Data analysis was difficult, because following the initial seedling flush in February/early March 1998, only 21 of 40 plots contained giant rats tail grass plants (many missing values). Therefore, only the plant number data have been statistically analysed. The other datasets, although not statistically analysed, show trends within the presented data, although care must be taken when comparing specific differences. Datasets (for example tiller number/plant) are an average of plots with plants present. Plots with no surviving plants were not included in the calculation.

6.4.4.1 Plant number

Seedling number increased quickly following sowing then decreased rapidly (Fig 6.12 and 6.13), as many seedlings died during a dry period in March 1998 (Fig 6.3). Plant numbers then remained static from the end of April 1998 for the rest of the experiment. In the no canopy gap and no root exclusion tube treatment (full competition), no giant rats tail grass seedlings survived (Table 6.2), while the 15x15 and 30x30cm gap size treatments with no root exclusion tube had only one plot (out of 4) containing plants from April 1998. Only the 15x15cm and 120x120cm gap sizes with a root exclusion tube had seedlings in all plots.

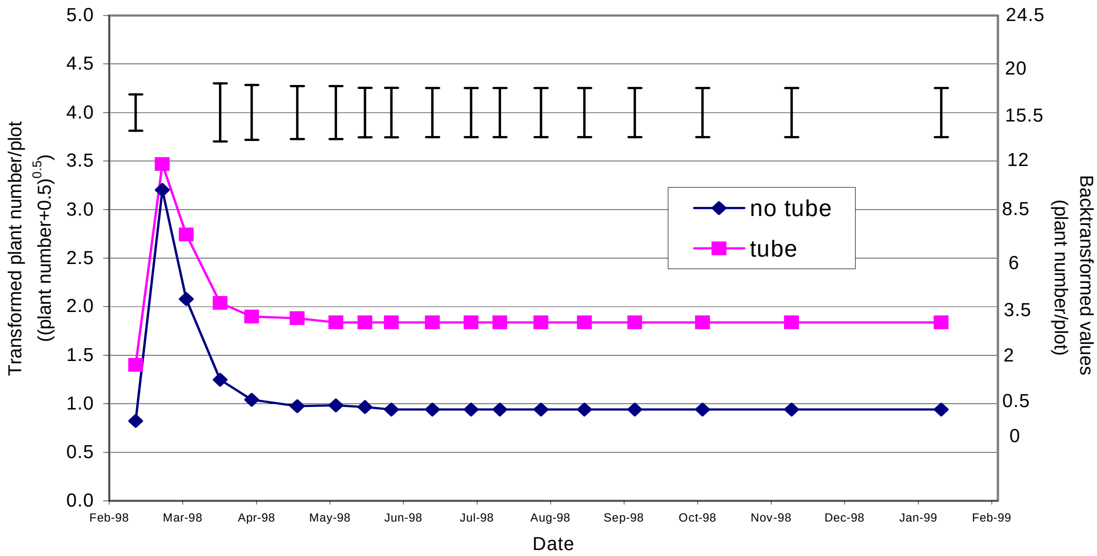

Figure 6.12 Giant rats tail grass plant number per plot following 50 seeds being sown into a native pasture, with and without a root exclusion tube.

The data is square root transformed ((plant number+0.5)$^{0.5}$) and the right y-axis contains back transformed values. Error bars are LSD at the 5% level. There was no significant difference between treatments for sampling dates without a corresponding error bar.

There was a significant difference due to root tube treatment at the initial sampling date (6 days after sowing) and from 19 March 1998 (42 days after sowing) to the end of the experiment (Fig 6.12), with fewer plants where there was no root exclusion tube. Maximum plant numbers approximately 3 weeks after sowing were 9.8 plants/plot without a root tube and 11.5 plants/plot with a root tube (from 50 seeds sown). Plant numbers following the initial emergence event fell to 2.9 plants/plot with a root tube installed and 0.4 plants/plot in the absence of a root tube. Little additional giant rats tail grass emergence was recorded after the initial emergence event.

Table 6.2 Number of plots (out of 4) containing giant rats tail grass plants and the total number of plants surviving in each treatment in April 1998 two months after sowing seed into different canopy gap sizes, plus or minus a root exclusion tube, and total plant number in each treatment in January 1999 (11 months after sowing).
These plants contributed to the plant attribute data (eg. plant height, tiller number and basal area) that was generally the average of plants in that treatment.

Gap size (cm)	Number of plots with plants 1 April 1998		Total plant number/treatment 1 April 1998		Total plant number/treatment 12 January 1999	
	no tube	tube	no tube	tube	no tube	tube
no gap	0	2	0	11	0	8
15x15	1	4	4	21	4	19
30x30	1	3	5	23	1	23
60x60	2	2	3	19	2	16
120x120	2	4	4	11	4	11

There was a significant difference in plant number amongst the gap size treatments at the first two sampling dates (Fig 6.13). At the first sampling date (6 days after sowing) the no gap treatment had the highest seedling number (3.8 plants/plot) followed by the 15x15cm gap treatment (1.2 plants/plot). The 30x30, 60x60 and 120x120cm gaps had virtually no seedlings at the first sampling. At the second sampling (~3 weeks after sowing) the no gap treatment had the lowest plant number (4.7 plants/plot), with the 120x120cm gap the next lowest at 10 plants/plot. The 30x30cm gap had the highest mean plant number at this time with 14.6 plants/plot. The plant number in all gap sizes then declined, levelling out 7-8 weeks after sowing (end of March 1998) and following irrigation. The no gap treatment then had the lowest plant number (0.6 plants/plot) and the 30x30cm gap size the highest (2 plants/plot) with no significant difference between canopy gap sizes.

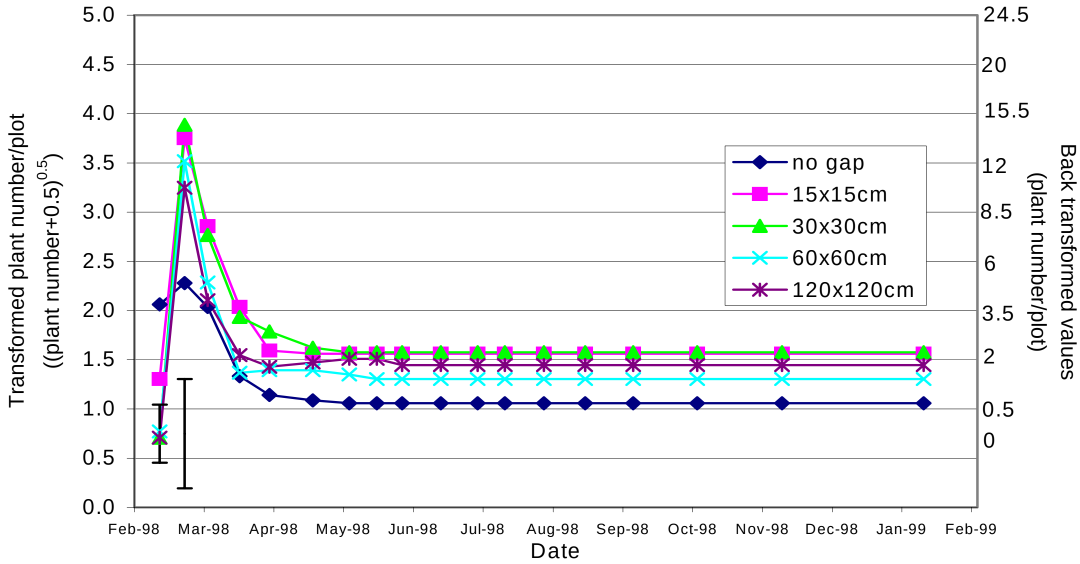

Figure 6.13 The effect of canopy gap size on giant rats tail grass plant numbers after 50 seeds were sown into 5 canopy gap sizes in a native pasture.

The data is square root transformed ((plant number+0.5)$^{0.5}$) and the right y-axis contains back transformed values. Error bars are LSD at the 5% level. There was no significant difference between treatments for sampling dates without a corresponding error bar.

6.4.4.2 Plant height

The height of giant rats tail grass seedlings that emerged in the field has not been statistically analysed but trends are still apparent. Plants in the 15x15 and 30x30cm gap sizes were tallest between mid March and mid June 1998 (Fig 6.14), although much shorter than those seedlings transplanted into gaps in Experiment 1 (Fig 6.6). Plants in the 120x120cm gap size then became tallest for the rest of the experiment. From November 1998 (9 months after sowing), plant height increased with increased canopy gap size. The planted seedlings (Experiment 1) had similar heights from November 1998 (Fig 6.6). Plants in treatments with a root exclusion tube were taller than treatments without a tube throughout the experiment, except for the 120x120cm gap size from October 1998 and the 30x30cm gap size at the final sampling (data not shown).

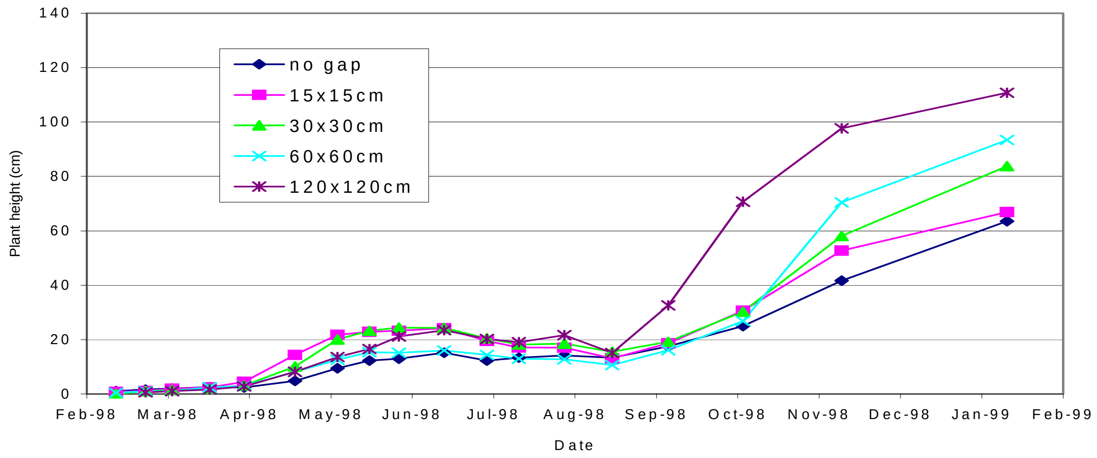

Figure 6.14 Plant height of giant rats tail grass plants emerging in the field after being sown as seed into different sized canopy gaps.

Data are an average of plots with seedlings.

6.4.4.3 Tiller number and rate of tiller production

The tiller number data for Experiment 2 have not been statistically analysed, however it does indicate that tiller numbers were similar for all gap sizes from sowing until mid April (Fig 6.15). At this time, plants growing in the 120x120cm gap size had the greatest tiller number and those plants with no canopy gap had the fewest tillers. This difference widened over time with the mid sized gaps similar, until those in the 60x60cm gap size tillered rapidly in spring and resembled those in the 120x120cm gap size treatment.

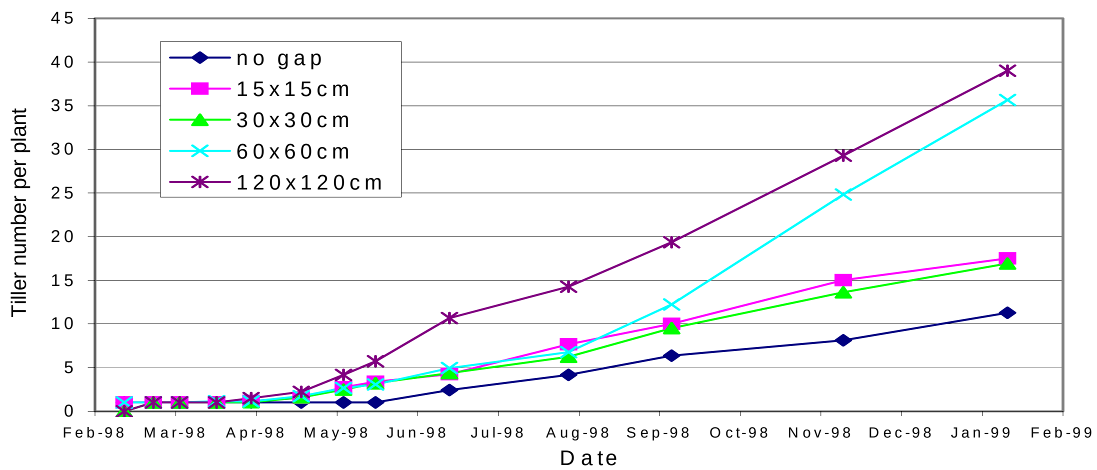

Figure 6.15 Tiller number per giant rats tail grass plant following emergence in the field from seed sown into different sized canopy gaps.

Data are an average of plots with plants.

There was no difference in tiller number between root tube treatments until November 1998 (data not presented). From then on, the no tube treatments had a consistently higher tiller number.

The mean rate of tiller production over 11 months generally increased with increasing canopy gap size (Fig 6.16). The presence of a root exclusion tube increased the rate of tiller production for the no gap and 15x15cm canopy gap treatments, but decreased the rate of tiller production in the three larger canopy gap size treatments.

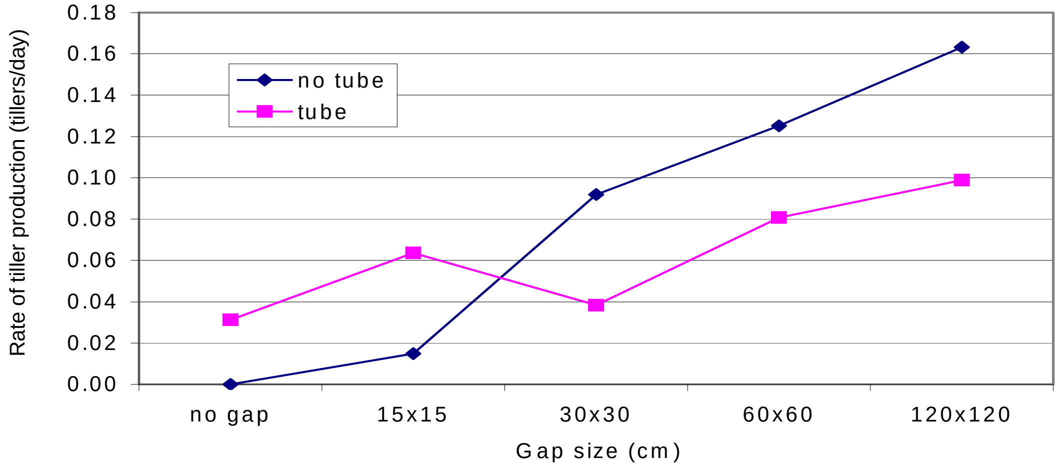

Figure 6.16 Interaction between canopy gap size and root exclusion tube presence on the mean rate of tiller production of giant rats tail grass plants, sown as seed in February 1998 and grown until January 1999.

6.4.4.4 Basal area

Except for the 120x120cm gap size, the root exclusion tube treatments produced a larger basal area than treatments without a tube (Fig 6.17). The 15x15cm and 30x30cm gap sizes with a root exclusion tube had 8 times and 2.5 times greater basal area respectively in January 1999 (11 months after sowing), than the same gap sizes growing without a root exclusion tube.

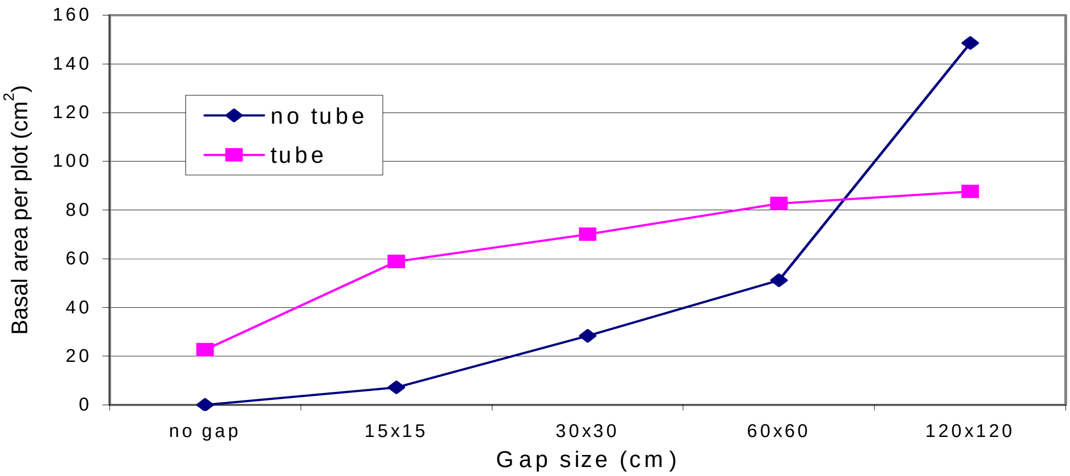

Figure 6.17 The effect of root exclusion tube presence and canopy gap size on the total basal area of giant rats tail grass per plot at January 1999, 11 months after sowing seed into native pasture.

6.4.4.5 Time until the first inflorescence emerged and cumulative inflorescence number

Giant rats tail grass plants sown as seed and without a root exclusion tube only produced inflorescences by January 1999 in the 60x60 and 120x120cm gap sizes (Table 6.3), while plants growing with a root exclusion tube produced some inflorescences in each gap size. However, more inflorescences were produced without a root exclusion tube for the 120x120cm gap size. The number of days to inflorescence emergence decreased with increasing gap size. None of the plots flowered for the first time until the following spring (7 months after sowing).

Table 6.3 Time until first inflorescence emerged and cumulative inflorescence number (over 11 months) per plot following giant rats tail grass being sown as seed into different canopy gap sizes, plus or minus a root exclusion tube.

Gap size (cm)	Time until inflorescence emergence (days)		Cumulative inflorescence number per plot	
	no tube	tube	no tube	tube
no gap	no plants	342	no plants	1.0
15x15	no flower	301	0	2.3
30x30	no flower	288	0	5.3
60x60	342	262	4.0	8.5
120x120	243	222	33.0	11.0

6.4.5 Plant measurements for Experiment 3: sown seed without supplementary irrigation

6.4.5.1 Plant number

Only a low number of giant rats tail grass seedlings survived under natural rainfall following the initial emergence event and subsequent death of most seedlings (Fig 6.18). This was almost certainly because of the low rainfall period in March 1998 (Fig 6.3) shortly after seedling emergence. By the end of the experiment only the 120x120cm gap size (no root exclusion tubes were used in this experiment) contained giant rats tail grass plants (3.7 plants/plot), with each of the four replicate plots containing plants. The no gap treatment had few seedlings in the initial seedling flush (0.5 plants/plot), while the other gap sizes had approximately 8 plants/plot emerging from the 50 seeds sown.

The final plant number in the 120x120cm gap size without supplementary irrigation (3.7 plants/plot) was surprisingly greater than that in the equivalent treatment receiving supplementary irrigation in Experiment 2 (0.8 plants/plot).

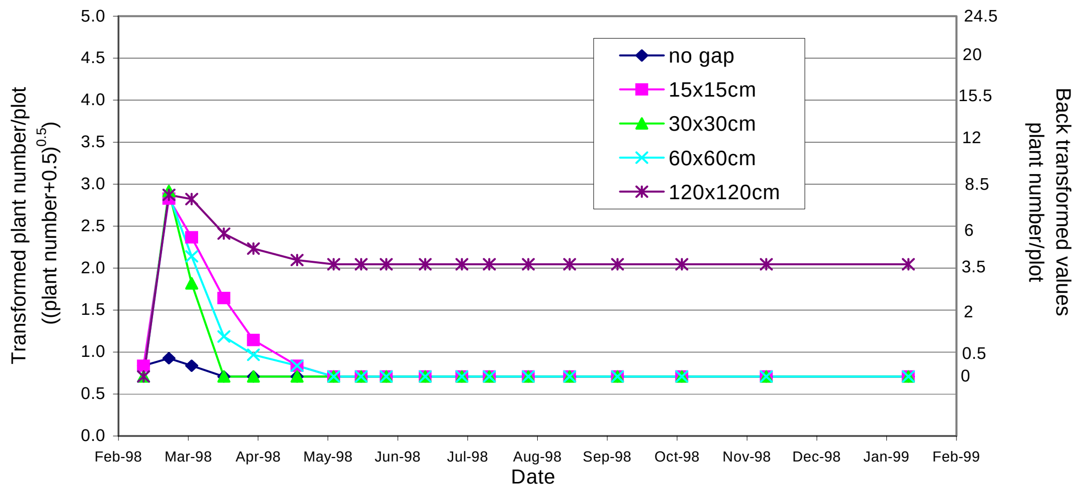

Figure 6.18 Plant number per plot after 50 giant rats tail grass seeds were sown into various canopy gap sizes in a native pasture receiving only natural rainfall at Gayndah.
The data is square root transformed ($(\text{plant number}+0.5)^{0.5}$) and the right y-axis contains back transformed values. No statistical analysis has been conducted.

6.4.5.2 Plant height, rate of tiller production and tiller number

The plant height and tiller number data are presented for plants in the 120x120cm gap size without a root tube and natural rainfall (Fig 6.19). The average rate of tiller production for the 120x120cm gap size treatment was 0.07 tillers per day, compared to 0.16 tillers per day in the equivalent treatment receiving some supplementary irrigation in Experiment 2 (Fig 6.16).

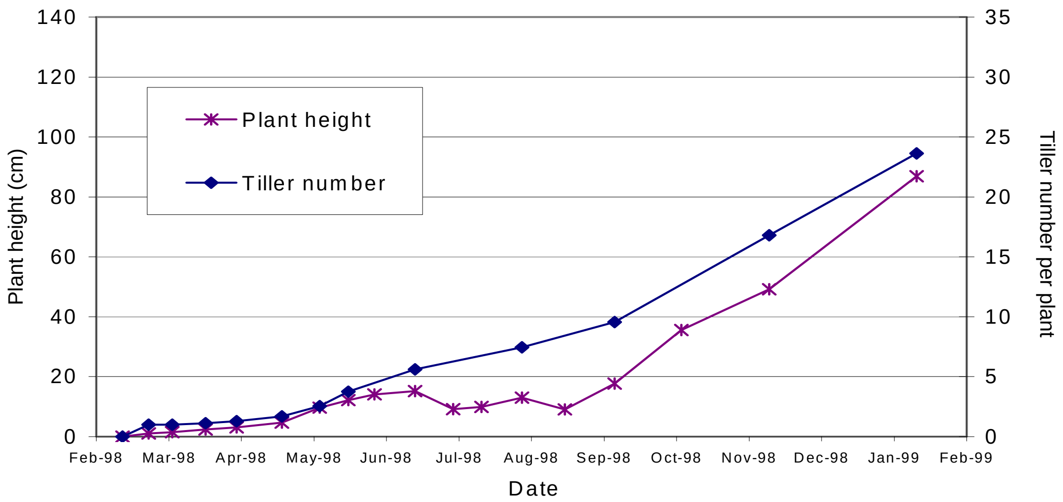

Figure 6.19 Mean giant rats tail grass plant height and tiller number for the 120x120cm canopy gap size after emerging from seed and growing on natural rainfall only.

6.4.5.3 Basal area, time to first inflorescence emergence and cumulative inflorescence number

The average basal area per plot for the 120x120cm canopy gap size without a root exclusion tube was 19.5cm^2 at the final sampling date, compared to 150cm^2 in Experiment 2 with supplementary irrigation. The cumulative inflorescence number for the 120x120cm canopy gap size was 11 inflorescences/plot, while the time to first inflorescence emergence per plot was 254 days, similar to Experiment 2 (243 days) for the equivalent treatment receiving supplementary irrigation.

6.5 *Discussion*

Giant rats tail grass emergence, early seedling survival, growth, and reproduction were sensitive to competition from the surrounding pasture and above-average rainfall. Survival of 6 to 8 week old giant rats tail grass seedlings was insensitive to competition from the surrounding pasture. Shoot (above-ground) and root (below-ground) competition exerted by an established pasture were both important in suppressing invading giant rats tail grass propagules. Artificially created canopy gaps and root exclusion tubes were useful in separating the impacts of root and shoot competition.

6.5.1 Gap size and root exclusion tube treatments modify environment

The two environmental factors measured in relation to the applied treatments were surface soil moisture (0-7cm) and photosynthetically active radiation (light) quantity. Soil nutrient availability, soil temperature and light quality (all not measured) are also likely to affect seedling establishment and growth, but soil moisture was expected to be the dominant factor in this drier sub-coastal region (Cook 1980b; Cook *et al.* 1993).

6.5.1.1 Soil moisture dynamics and root competition

It was expected that the root exclusion tubes would eliminate root competition from surrounding vegetation and allow more soil resources for seed germination and growth of giant rats tail grass seedlings. As expected, the treatments with a root exclusion tube generally had a higher surface soil moisture content (0-7cm) than treatments without a root tube early in the experiment, except in the 120x120cm gap size where both tube treatments were similar (Fig 6.4a,b,c and 6.5a,b,c). The higher soil moisture content with a root tube indicates that roots from the surrounding vegetation were probably extracting soil moisture from within the smaller gap sizes in the absence of a root tube. The similar soil moisture content in the 120x120cm gap size with or without a root tube suggests that roots from the surrounding vegetation do not reach the centre of this gap size. Therefore, it could be assumed that there is negligible root competition from surrounding vegetation in the centre of the 120x120cm gap size soon after canopy gap formation.

The surface soil (0-30cm) in small canopy gaps was expected to have a higher root density (root competition) from the surrounding vegetation compared to the centre of larger gaps (Hook *et al.* 1994). All other factors being equal, higher root density should equate to a greater capacity for extraction of soil water for transpiration, leading to smaller gaps being drier, while treatments with similar low root densities (eg. absence of roots in the root tube treatments) should have similar soil moisture contents regardless of the gap size treatments. However, this was not the case. Soil moisture generally decreased with increasing gap size (Fig 6.4 and 6.5), indicating that soil surface evaporation (influenced by ground cover and exposure - sun and wind) along with soil moisture extraction by roots (root competition) determine the soil moisture dynamics within vegetation gaps. Surprisingly, the soil moisture data, do not explain the increased plant size in the larger gap sizes (Fig 6.10 and 6.15), as there does not seem to be greater moisture resources available within these larger gaps.

Soil moisture in this experiment was sampled as a 0-7cm deep core, with the soil moisture an average over this depth. This sampling method did not enable the moisture distribution down the soil profile to be described. However, soon after a rainfall or irrigation event the soil surface in the 120x120cm gap size was observed to be dry and would be expected to have a substantial moisture gradient down the profile, whereas under the cover of the pasture canopy in the no gap treatment, the soil surface remained moist for longer. This observation is supported by other studies (eg. Panetta & Wardle 1992; Morgan 1997). In native mesic grasslands, soil surface moisture (0-2.5cm) was found to decrease with increased canopy gap size (Morgan 1997), whereas another study found no difference due to gap size in soil moisture in the deeper 2-5cm zone (Goldberg & Werner 1983). The difference in the duration the soil surface remained wet would have implications for seed germination and seedling emergence (Silcock 1973; 1980; Panetta & Wardle 1992). This may be why, in the no gap and 15x15cm gap size more seedlings had emerged seven days after sowing (1st sampling) compared to the larger gap sizes (Fig 6.13).

Towards the end of the experiment (Fig 6.4d,e,f), there were no differences in soil moisture between the root tube treatments, although the soil moisture still decreased with increased gap size. This decrease, apart from greater soil surface evaporation, may also be due to larger plants growing in the large canopy gaps (Fig 6.10 and 6.15) extracting more soil moisture and drying the soil more rapidly.

6.5.1.2 Photosynthetically active radiation quantity

The amount of photosynthetically active radiation (PAR) 5cm above the soil surface increased with increasing gap size (Fig 6.2), which was also found by Goldberg & Werner (1983) and Morgan (1997). Over time, PAR also increased with plant size (Fig 6.10 and 6.15) in this experiment. The no gap treatment received only 6% of above-canopy PAR, while the largest gap size (120x120cm) received 95% of above-canopy PAR near the middle of the day (2:00pm). The increase in plant size with the increase in PAR suggests that competition for light may play an important role in plant growth. However, this conflicts with Cook (1980b) who suggested that the relatively sparse open nature of a similar native pasture canopy (*Heteropogon contortus* pasture) and that of many other native pastures in Australia, limits the importance of competition for light.

The increased incidence of PAR potentially reaching and heating the soil surface in the larger gaps sizes would enhance soil surface evaporation, providing a justifiable mechanism for the observed soil moisture decrease with increasing gap size.

6.5.1.3 Other environmental factors

Doubt over the importance of light competition (Cook 1980b) and the marginally lower soil moisture in larger gaps (Fig 6.4 and 6.5) not preventing increased plant growth in larger gap sizes (Fig 6.10 and 6.15) indicates that competition for other growth limiting resources may control plant growth, for example soil nitrogen (Cook 1980b; Cook *et al.* 1993). In other work, addition of soil nutrients, usually in association with irrigation (reduced water limitation), enhanced seedling establishment and growth at various levels of competition (Cook & Ratcliff 1984; 1985).

Changes in light quality and soil temperature were not measured in this experiment, but may also contribute to the success of seedling emergence. Light quality may be altered with small gap sizes, with the red:far red ratio being reduced after passing through the canopy, reducing or inhibiting seed germination (Taylorson & Borthwick 1969). Also temperature and daily temperature range play a role in the germination of some plant species (Thompson & Grime 1983). Fresh giant rats tail grass seed are often dormant and require certain temperature, daily temperature fluctuations and light quality for germination, although these requirements are reduced as the seed ages (Vogler 2002) and should not have been a factor limiting the germination of the seed used in this experiment (10 months old).

6.5.2 Effect of shoot and root competition on sown seed and planted seedlings

The experimental design makes it difficult to fully separate the effects of shoot and root competition. Most natural canopy gaps are likely to be influenced by a variation in root density rather than the presence or absence of roots, as root density is expected to decrease with increased distance from surrounding plants (Hook *et al.* 1994). Therefore small gaps (eg. 15x15cm) are likely to have a high root density throughout the canopy gap (assuming the surrounding plant bases are located near the side of the canopy gap), compared to larger canopy gaps (eg. 120x120cm) where the root density is likely to be low in the centre of the gap. This hypothesis is supported by the soil moisture data (Fig 6.4 and 6.5) where the difference in soil moisture content between the root tube treatments generally decreased with increasing gap size. Small canopy gaps are expected to experience reduced shoot competition, while large canopy gaps are expected to have both shoot and root competition reduced at their centre.

In this experiment, increasing canopy gap size increased giant rats tail grass tiller numbers, plant height, basal area and eventually inflorescence numbers, while the time until the first inflorescence emerged decreased. Eliminating root competition using root exclusion tubes increased seedling emergence and early survival, plant height, tiller number and decreased the time until the first inflorescence emerged, however this trend was reversed for larger gap sizes later in the experiment (discussed later in section 6.5.4).

Plant establishment can be divided into two phases within a plant's life cycle, germination and emergence followed by seedling growth and survival (Cook 1980b). The three experiments conducted in this trial addressed these phases. Experiment 1 (planted seedlings) addressed the growth and survival phase, while Experiments 2 and 3 (sown seed) addressed both the germination and emergence phase and then the growth and survival phase.

6.5.2.1 Seed germination and emergence

Emergence of giant rats tail grass seedlings was unaffected by canopy gap size (Fig 6.13 and 6.18), except in the no gap treatment which had reduced emergence. The seedlings in the no gap and to a lesser extent the 15x15cm gap size emerged faster than in the other gap sizes (Figure 6.13), especially with a root exclusion tube present (Fig 6.12). The faster emergence may have been due to the soil surface remaining wetter for longer under the pasture canopy (Fig 6.4 a,b,c), whereas in the larger gap sizes the soil surface appeared drier and possibly slowed emergence. In the no gap treatment, even though seedling emergence was faster, the total number of seedlings was reduced, which could be attributed to the light conditions. Vogler (2002) found that light quantity and quality affected germination of freshly harvested giant rats tail grass seed, with reduced germination in darkness and in green light (reduced red:far red ratio), but after 6 months the innate dormancy and light requirements were reduced. It is unlikely that light requirements were a major factor in this experiment as the seed was 10 months old at sowing.

The presence of a root exclusion tube did not significantly increase the number of seedlings that emerged (Fig 6.12), however it did significantly improve early seedling survival thereafter.

6.5.2.2 Seedling growth and survival

Competition between the established vegetation and establishing seedlings for nutrients and moisture is recognized as the major factors limiting seedling growth and survival (Cook 1980b).

Seedling survival

Many giant rats tail grass seedlings died following the initial seedling emergence event (Fig 6.12, 6.13 and 6.18). Other workers have also found that pasture seedling survival is low (eg. McIvor & Gardner 1981; Cook 1984). The few weeks after seedling emergence is regarded as the critical period of radicle entry into the soil and early root development (Plummer 1943; Campbell & Swain 1973a; 1973b) and, combined with the production of early adventitious roots (Silcock 1980; Aguilera & Lauenroth 1993; Hook *et al.* 1994; Aguilera & Lauenroth 1995) strongly influences establishment success. In this experiment, the plant population stabilised approximately 8 weeks after sowing, with few seedlings dying thereafter.

Seedling number and survival of other tussock grasses have been recorded to increase with increasing gap size (Aguilera & Lauenroth 1993; Moretto & Distel 1998). This was not the case in this experiment, where gap size did not significantly influence plant number and survival when seed was sown and supplementary irrigation applied (Fig 6.13). However, in the no canopy gap and no root exclusion tube treatment (full competition), no seedlings survived (Table 6.2) and when seed was sown under natural rainfall conditions (Experiment 3), seedlings only survived in the largest canopy gap size (120x120cm) (Figure 6.18).

The presence of a root exclusion tube had no effect on the initial seedling numbers (3 weeks after sowing), but had a large effect on the number that survived thereafter (Fig 6.12 and Table 6.2), with treatments without a root tube present having a significantly lower number of seedlings surviving (0.4 plants/plot), compared to when a root exclusion tube was present (2.9 plants/plot). Root exclusion tubes also increased seedling survival of *Bouteloua gracilis* (Aguilera & Lauenroth 1993), which can be attributed to a reduction in the competing root density and the rate at which soil water was depleted (Hook *et al.* 1994). Once the giant rats tail grass seedling number stabilised, approximately 8 weeks after sowing, few seedlings died thereafter, with no subsequent effect of gap size and root tube treatment on plant survival.

The 8-10cm high, untillered, transplanted seedlings (Experiment 1) had a much greater survival (94% survival) compared to the survival of seedlings that emerged from seed (Figure 6.12 and 6.13). Howe & Snaydon (1986) found that transplanted ramets had a much higher survival than seedlings (emerged from seed) for four grass species planted into an established ryegrass sward. This difference in survival was attributed by them to the large initial difference in plant size between seedlings and ramets, and hence a difference in competitive ability. The high plant survival rate found in Experiment 1 (planted seedlings) is consistent with the results found in the sown seed experiments (Experiments 2 and 3), where 8 weeks old seedlings had a high survival rate thereafter, possibly due to the amount of early root development reached by that age (Plummer 1943).

Weaver (1930) found that tillering in all species they studied began simultaneously with the development of the secondary root system (usually 3 to 6 weeks after germination), coinciding with increased likelihood of establishment and survival. The tillering of transplanted seedlings began soon after transplanting (Fig 6.10), while tillering of seedlings sown as seed (Fig 6.15 and 6.19) began 8-9 weeks after sowing, coinciding with the stabilisation of the plant numbers (Fig 6.12, 6.13 and 6.18).

Seedling growth

Plant height and tiller number were measured to follow plant growth non-destructively, because competition from established plants was expected to affect these two growth attributes (Rhodes 1968a). Giant rats tail grass seedlings in the no gap and 15x15cm gap sizes were slightly taller than in the larger gap sizes in the first two months of the experiment (Fig 6.6). The plants in the 15x15cm gap size remained the second tallest treatment for seven months, but the no gap treatment became the shortest treatment, which was probably related to its lack of production of inflorescences (Table 6.1). Approximately nine months after planting seedlings or sowing seed, plant height increased with increasing gap size thereafter.

Tiller number, the other growth attribute measured, increased linearly with time and for most of the experiment tiller number increased with increasing gap size (Fig 6.10 and

6.15). Weaver (1930) and Rhodes (1968a) found that tiller production in temperate pasture species was generally more severely affected by competitive stress than other vegetative characters, with higher competition delaying or prohibiting tillering.

Under full competition, the growth of giant rats tail grass seedlings was slow (Fig 6.10 and 6.15), but few seedlings died. Chippindale (1932; 1948) also found that small grass seedlings of four species were suppressed (remaining small for >10 months) under high root and shoot competition without dying. Chippindale (1932) found that the suppressed seedlings later grew and flowered, following a reduction in competition for both nutrients and light. Most of the giant rats tail grass seedlings suppressed in this experiment (although not tested) would be expected to grow and flower following a reduction in competition from surrounding plants. The reduction in competition may be caused by selective grazing or following dry periods where the surrounding plants are weakened. Giant rats tail grass seedlings have demonstrated tolerance of very dry conditions compared to the seedlings of other grass species (Vogler 2002), and established plant survival appears high under drought conditions (eg. Foxtail Flats site in 1997 – Fig 3.3 and 4.18). This adaptation would provide a survival advantage over other species within a mixed sward.

6.5.2.3 Reproduction

The time to first inflorescence emergence was shorter, while the cumulative inflorescence number was greater for the larger gap size treatments (Table 6.1 and 6.3). Also, the no root competition (tube present) treatments flowered earlier than corresponding gap sizes with root competition present, except at the largest gap size where the results were inconsistent. Similar results were found by Morgan (1997) when investigating gap sizes on the flowering of *Rutidosis leptorrhynchoides*, where flowering was restricted to the largest gap sizes (30x30, 50x50 and 100x100cm), with most flowers occurring in the 100x100cm gap size.

One unexpected response was that in the larger gap sizes, the no root tube treatments had a higher cumulative inflorescence number than with a root tube present (Table 6.1 and 6.3). This response was probably due to the root exclusion tube limiting the rooting volume (Cook & Ratcliff 1984; Cook 1985; Snaydon & Howe 1986) and therefore available resources (eg. water and nutrients) for inflorescence production.

6.5.3 Root or shoot competition, which is most important?

There is a lot of evidence to suggest that root competition is more important than shoot competition in grasslands (eg. Donald 1958; King 1971; Cook 1979; Remison & Snaydon 1980; Snaydon & Howe 1986; Stone *et al.* 1998). However, this experiment showed that under these conditions, a combination of root and shoot competition was important, although root competition was probably more important.

No strong evidence was found to suggest soil moisture was the main factor in root competition (except possibly at seedling emergence), so the other major factor was most likely competition for nutrients and in particular nitrogen; however this not investigated in these experiments. Cook & Ratcliff (1984; 1985) found that root competition for nutrients was the primary limiting factor for green panic (*Panicum maximum* var. *trichoglume*) in experiments that received some supplementary irrigation, as did Experiments 1 and 2. Snaydon & Howe (1986) also concluded that below ground competition was most important for preventing invasion of weedy grasses into perennial ryegrass pastures, with nitrogen the most limiting resource.

These experiments provide evidence that competition for light is important for seedling growth in healthy sub-coastal native pastures that lack gaps or have only small gaps. The effect of light competition was probably most pronounced between the no gap and 15x15cm gap size. There would be relatively little difference in root competition levels between these two gap sizes, yet factors like basal area (Fig 6.11) and rate of tiller production (Fig 6.8) were higher in the 15x15cm gap size, in the presence or absence of root competition. Maximum seedling number during the initial seedling emergence event (Fig 6.13 and 6.18) was also higher in the 15x15cm gap size compared to the no gap treatment. Light competition probably has its greatest role in limiting seedling emergence and although light competition may slow some growth processes, giant rats tail grass seedling survival was high once they reached 8-9 weeks of age.

6.5.4 Limitations of using root tubes in competition experiments

The presence of a root exclusion tube had a positive effect on giant rats tail grass seedling survival (Fig 6.12) and early growth (increased height and tiller number). However, as the plants grew larger, particularly in the larger canopy gap sizes, the growth and reproduction of plants in treatments with a root exclusion tube was slowed (Fig 6.9, 6.11, 6.16; Table 6.1 and 6.3), while treatments without a root exclusion tube grew comparatively fast, larger and produced more inflorescences. The apparent negative impact of the root exclusion tube was probably due to the rooting volume being limited (Cook & Ratcliff 1984; Cook 1985; Snaydon & Howe 1986), therefore limiting access to soil resources (eg. moisture and nutrients/nitrogen). A couple of giant rats tail grass plants growing within root exclusion tubes were excavated at the end of the experiment. The roots were dense throughout the soil within the tube and resembled a root-bound pot plant. Some roots had extended deeper than the root tube depth (19cm). The giant rats tail grass plants without a root tube were almost impossible to pull out by hand and the roots extended over a greater surface area than the surface area of a root tube.

Cook & Ratcliff (1984) recognised that root exclusion tubes restricted root distribution and would limit the duration over which useful data could be obtained from such experiments, especially when studying tropical species that develop relatively large basal areas. Cook (1985) found the presence of a 10cm diameter root exclusion tube limited the growth (tiller number) of large green panic seedlings after 42 days. Snaydon & Howe (1986) also found that the presence of below-ground tubes restricted root distribution and hence nutrient uptake, reducing seedling growth. In the current experiment a large tropical grass was investigated over 11 months. Therefore, a root tube diameter of 28.5cm was used, which had approximately 8 times the surface area of the 10cm diameter tubes used by Cook & Ratcliff (1984). The larger tubes probably had little restrictive effect for the first few months, but the constraints provided by the tubes became noticeable with time as plants increased in size, especially in the large canopy gap sizes.

Even though there are constraints with root exclusion tubes restricting root distribution of the test plants, my experiment supports the claim by Cook & Ratcliff (1984), that the technique should be well-suited to studying the importance of above and below-ground competition during such processes as weed invasion into pasture. Using root exclusion tubes in the field should more closely approximate reality than competition experiments conducted in pots in a glasshouse.

It is difficult to suggest how this technique can be improved, as larger tubes will interfere with surrounding plants especially if small canopy gap sizes are to be included in the experimental design. Larger diameter tubes could possibly be used in larger gap sizes, as the plants are often larger and therefore the most restricted, but this would complicate the experiment with changes in rooting volume and therefore changes in available resources such as nutrients. The other possibility is to reduce the length of the experiment. However, establishment experiments must be continued for a sufficient length of time to enable a true picture of survival to be gained. This would involve monitoring plants for up to 12 months, or at least until the start of the second growing season (Cook 1980b). For a robust species like giant rats tail grass, reducing the length of this competition experiment would not have been critical. However, for a species with a lower survival following secondary root development or an investigation of survival in harsher environments (eg. drier), information on survival into the second season or until the first flowering would be important.

6.5.5 Rainfall amount and its interaction with seedling establishment

Amount of rainfall and weather conditions during establishment will play a role in giant rats tail grass establishment success. Few giant rats tail grass seedlings established at the Gayndah site in 1998 under natural rainfall conditions except in the largest canopy gap size (120x120cm) (Fig 6.18). However, some seedlings established in most gaps under simulated above-average rainfall conditions, except in the highest competition treatment (no canopy gap, no root exclusion tube). Unusually wet conditions occur occasionally and may make recruitment possible in small openings (Hook *et al.* 1994). This study has shown that once the giant rats tail grass seedlings reach 8-9 weeks of age, they are able to survive highly competitive conditions and have the potential to survive average and below-average rainfall years.

The fire treatment in the management manipulations experiment (Chapter 4) highlights the importance of rainfall amount in conjunction with gap size. During average rainfall years, few giant rats tail grass seedlings emerged in the fire treatment even though bare ground was exposed between tussock bases (canopy gaps) following the fire (Fig 4.14, 4.16 and 4.18). In an above-average rainfall year, many seedlings emerged and established in an apparently similar environment of a recently burnt pasture.

6.5.6 Implications for management

Grazing and vegetation management which form gaps in a pasture can encourage the establishment of unpalatable grasses (Moretto & Distel 1998), including giant rats tail grass. Once a giant rats tail grass seedling has developed a secondary root system it will survive high competition. Therefore, the competition only needs to be reduced once for a relatively short period, eg. the end of the dry season/beginning of the wet season, for giant rats tail grass to establish, if seeds are present in the soil seed bank. It is difficult not to create these low competition periods especially with the highly variable seasonal rainfall experienced in Queensland. This highlights the importance of preventing the initial introduction of giant rats tail grass seed into a pasture soil seed bank by any seed transport vectors (Bray *et al.* 1999).

Pasture renovation when a pasture is contaminated with giant rats tail grass seed is risky, as the renovation will create gaps/microsites that would allow the giant rats tail grass seedlings to establish from the soil seed bank before the desirable grasses are able to recover and provide substantial competition.

Herbicide application will create gaps of low competition, potentially allowing many giant rats tail grass seedlings to emerge from the soil seed bank, as occurred in the management manipulations experiment (unselective, wick wipe and selective treatments, Fig 4.27, 4.28 and 4.29). If spot spraying is undertaken with non-selective herbicides (eg. glyphosate), only the actual giant rats tail grass tussock should be sprayed, to allow the surrounding pasture species to quickly invade the gap created by the death of the sprayed plant. This is likely to prevent the emergence and establishment of giant rats tail grass seedlings, as strong pasture competition would be maintained. Herbicide bands have been used successfully to create pasture gaps (reducing pasture competition) to aid sown pasture legume establishment (Cook *et al.* 1993). However, if weed seed is present, then weed establishment would also be likely.

Maintaining pastures in a healthy, competitive state with few gaps will restrict giant rats tail grass emergence, survival and growth.

6.5.7 Conclusion

Root and shoot competition provided by a good competitive pasture, resulted in the emergence of few giant rats tail grass seedlings, none of which survived. Seedlings exposed to full pasture competition grew more slowly and flowered less than seedlings growing in canopy gaps. Although, giant rats tail grass seedlings subjected to full competition were less vigorous, they were not dying and would probably ‘come-away’ once the pasture was opened up by drought, over-grazing or other injudicious management practices. Above-average rainfall conditions will also improve the likelihood of giant rats tail grass establishment.

These experiments support the conclusion that a pasture only needs to be ‘opened-up’ once (even for a short period), in the presence of viable giant rats tail grass seed, for giant rats tail grass seedlings to establish and survive. Therefore preventing giant rats tail grass seeds entering a pasture and good pasture management to keep the pasture in a healthy, competitive state are essential to prevent invasion.

CHAPTER 7 General discussion

The work reported in this thesis has substantially increased knowledge about the life cycle stages and transitions for the unpalatable pasture weed giant rats tail grass (*Sporobolus pyramidalis*). Several weaknesses have been identified within the life cycle. In addition the thesis has highlighted many strengths within the life cycle, which enable giant rats tail grass to be a successful pasture weed in Australia. This knowledge can be used to help design effective giant rats tail grass management strategies that target the weaknesses while avoiding or minimising the impact of the strengths of this weed.

7.1 *Giant rats tail grass life cycle*

The ability of a plant to complete its life cycle drives its survival and success as a species in a particular ecosystem (Harper 1977). In weed control/management the objective is to inhibit the completion of a life cycle stage and therefore "break" the life cycle and success of the weed. The previous three experimental chapters have detailed experiments that investigated the impacts of various management-controlled factors on the ability of giant rats tail grass to complete its life cycle. Each of the life cycle stages and transitions (see Fig 2.1 for a life cycle diagram) will be discussed separately, highlighting any weaknesses that could be targeted or strengths that should be avoided or addressed as part of giant rats tail grass control/management strategies.

7.1.1 Soil seed bank

Giant rats tail grass soil seed banks are large and generally ranged between 1000 and 10000 seeds/m^2 (see Fig 4.1, 4.3 and 4.5), although some individual plots recorded much higher values (up to 30000 seeds/m^2). These high seed numbers correspond to the giant rats tail grass soil seed bank size measured by Andrews (1995a) 900-7300 seeds/m^2 and Vogler (2002) 1500-10500 seeds/m^2. The large soil seed bank size is also a feature of a range of other exotic, perennial, unpalatable grassy weeds, for example, chilean needle grass (*Stipa neesiana*) had soil seed banks of 4000-18000 seeds/m^2

(Bourdot & Hurrell 1992), giant parramatta grass (*Sporobolus fertilis*) had soil seed banks of 1650–21300 seeds/m^2 (Andrews *et al.* 1996), while serrated tussock has soil seed banks up to 44000 and 75000 seeds/m^2 (Healy 1945; Joubert 1984). In contrast, perennial, native grasses in Queensland often do not have large soil seed banks, for example, purple wiregrass (*Aristida ramosa*) often has less than 50 seeds/m^2 (Campbell 1996) and the palatable black speargrass (*Heteropogon contortus*) had only 60 seeds/m^2 in north Queensland (McIvor 1987). This substantial difference in soil seed bank size would give the exotic weeds a significant ecological advantage.

No treatments tested eliminated the giant rats tail grass soil seed bank in 2 years. Soil seed banks, appeared to be slowly declining in treatments where seed production was limited or reduced (eg. cultivation treatment at Gympie and some herbicide treatments Fig 4.1 and 4.2). The fire treatment was the only treatment that quickly affected the soil seed bank size, with pre-burn seed banks higher than post-burn seed banks (Fig 4.1, 4.3 and 4.5), but the reduction in soil seed bank size ranged between 10-90%. Vogler (2002) also reported variable reductions in giant rats tail grass soil seed bank size with fire (0-60% reduction). However, even though a high percentage of seed may be killed by fire, many viable seeds remained in the soil seed bank and during the following year with no other intervention, the post-burn soil seed bank levels were generally replenished to pre-burn levels as the giant rats tail grass plants recovered, flowered and produced more seed (see fire treatment at Gympie, Fig 4.1, 4.34 and 4.37).

Giant rats tail grass seeds appear to be long-lived in the soil. Treatments that had low inflorescence densities and low expected seed input to the soil seed bank over 2 years, eg. cultivation, herbicide and rhodes grass treatments (section 4.4.7), still had many giant rats tail grass seeds remaining in the soil seed bank, and if the ground cover was low, many seedlings were still emerging at the end of the 2 years experimental period (see cultivation treatment at Kilcoy Fig 4.17, 4.28 and 4.31). Andrews (1995a) found that the viability of buried *Sporobolus* seed after one year ranged between 51-71%, with an estimated time of 7-14 years for soil seed banks to decline to 1%. Vogler (2002) had similar results with 57% of buried giant rats tail grass seed remaining viable after 3years leading to a prediction of 8 years for viability to reach 1%. Other grasses can also have long-lived soil seed banks. Buried *Sorghum halepense* (johnson grass) seeds had 48% viability after 5.5 years (Egley & Chandler 1983), while serrated tussock had small quantities of seed surviving in the soil seed bank for 13 years (Campbell & Vere 1995) and possibly up to 20 years (Taylor 1987). By comparison the soil seed banks of the native purple wiregrass and black speargrass are relatively short-lived, with few seeds remaining in the soil seed bank after 1year (Campbell 1996).

The potential longevity of the soil seed bank is determined by the inherent viability of seeds (generally >90% viability for fresh giant rats tail grass seed) and dormancy mechanisms that prevent germination (Garwood 1989). The period of seed dormancy is considered one of the single greatest factors contributing to the seriousness of a weed (Chepil 1946 cited by Roberts & Feast 1973b). In laboratory studies, the innate dormancy mechanisms of giant rats tail grass have been overcome by temperature alternations and light (Andrews 1995a; Andrews *et al.* 1997; Vogler 2002), which are largely controlled in the field by gap size or pasture cover (Tothill 1969; Thompson & Grime 1983; Cook *et al.* 1993). Results from the field experiments reported in this thesis support this finding. Although germination itself was not measured, most new giant rats tail grass seedlings were identified in treatments with reduced ground cover (eg. cultivation and fire treatments, section 4.4.5 and 4.4.6) or within poorly established sown pasture accessions (Table 5.3, 5.4 and 5.5).

The large, persistent soil seed bank of giant rats tail grass is one of the strengths of this weedy plant. There appears to be no easy way to quickly remove the soil seed bank with management, although a fire prior to other control techniques (eg. cultivation or herbicide application) may reduce the soil seed bank size substantially. However, many viable seeds will still remain with potential to reinfest the pasture for many years. Any soil that is moved from a giant rats tail grass infested area, eg. in mud on machinery or cattle hooves, is likely to contain many giant rats tail grass seeds that will contaminate uninfested areas. Managing the long-lived soil seed bank and associated seedling emergence will be an important consideration within successful giant rats tail grass control strategies.

7.1.2 Seedling emergence and establishment

Germination and the early stages of seedling development are hazardous periods in the early life cycle of plants (Plummer 1943; Solbrig 1980), although seedling growth and survival rather than seed germination have been found to be the major limiting factors in seedling establishment in some situations (Cook 1984). Once a plant that is adapted to a site has lived through the seedling stage, it can be expected to endure the fluctuations of that environment (Plummer 1943).

Giant rats tail grass seedling emergence and establishment was sensitive to root and shoot competition, as manipulated by canopy cover and pasture gaps. Few giant rats tail grass seedlings emerged and survived long enough to be counted, if there was a dense pasture canopy cover (eg. the control and fertiliser treatments at Gympie and Kilcoy, section 4.4.5 and 4.4.6; no canopy gap treatment, Fig 6.13 and 6.18), but once the pasture was 'opened-up' by disturbance (eg. herbicide application, Fig 4.28 and 4.29; cutting artificial canopy gaps, Fig 6.13 and 6.18), many giant rats tail grass seedlings emerged. Even though a high percentage of seedlings may die soon after emergence, large numbers of seedlings still survive.

Seasonal conditions, particularly wet years, appeared to have a large impact on seedling emergence and establishment, especially once canopy cover (shoot competition) was reduced (eg. fire treatment, section 4.4.5). Successful establishment was probably related to the modification of the water balance in relation to level of competition (both root and shoot) imposed by surrounding plants. Hook *et al.* (1994) found that unusually wet conditions may make seedling recruitment possible in small openings (high competition), in which competition for water would usually be restrictive. When above –average rainfall conditions were simulated in Chapter 6, giant rats tail grass seedlings were able to establish in much smaller canopy gaps than in treatments that only received natural or close to long-term average rainfall (Fig 6.13 and 6.18)

Giant rats tail grass germination and emergence can occur at any time of the year, although most emergence occurs in late spring, summer and early autumn (Vogler 2002), which is similar to the serrated tussock (Healy 1945). This means there is no "safe" period when the pasture can be 'opened-up' (eg. by pasture renovation and for sowing pastures) that avoids giant rats tail grass emergence. To minimise emergence, pasture disturbance should be undertaken preferably during winter, late autumn and early spring. Conversely, if giant rats tail grass emergence is to be maximised (eg. in attempting to reduce the soil seed bank) the pasture should be cultivated during late spring, summer and early autumn. However, giant rats tail grass seeds in the soil seed bank do not all germinate at once and therefore the soil seed bank will not be entirely depleted.

Following giant rats tail grass seedling emergence, the seedlings appear to establish quickly, becoming resistant to high pasture competition as pasture cover increases (eg. following a fire and sowing pasture species). When we transplanted 6-week-old, 8-10cm high, untillered giant rats tail grass seedlings into a range of pasture gap sizes, 94% survived (section 6.4.3.1). Rhodes (1968b) suggested that the rate and extent of nodal root (adventitious root) production is closely associated with seedling competitive ability. Adventitious roots are often produced simultaneously with tillering (Weaver 1930). Giant rats tail grass tillering began 8-9 weeks after sowing seed in the competition experiment (Fig 6.15), whereafter seedling survival was very high (Fig 6.12 and 6.13), with no subsequent impact on survival of the various levels of competition imposed.

The sensitivity of emergence and early seedling survival to pasture canopy cover and competition may be a potential weakness in the life cycle of giant rats tail grass. There appears to be an opportunity to exploit this weakness using pasture management to minimise giant rats tail grass emergence and establishment. However, pasture management to maximise canopy cover and competition would be difficult on commercial properties, particularly as there is only a small time window when pastures can be ‘opened-up’, before giant rats tail grass seedlings become resistant to competition.

7.1.3 Seedling growth, development and survival

Giant rats tail grass seedlings appear tough and able to survive high levels of competition from surrounding plants. In only a few cases, did the numbers of seedlings/small plants drop substantially following the early establishment phase. In these cases, extreme levels of plant competition were imposed, for example the rhodes and bisset treatments at Gympie where many giant rats tail grass seedlings emerged with the sown pasture (12 seedlings/m^2, Fig 4.27), but the sown pasture quickly formed a dense canopy (Fig 4.30). Over the following 7 months, most of the giant rats tail grass seedlings disappeared with <1 seedlings/m^2 remaining (Fig 4.15).

Generally giant rats tail grass seedlings/small plants appear to be able to remain small within a pasture sward for long periods of time. This ability to survive with slow or imperceptible seedling growth due to competition has been described by Chippindale (1932; 1948). Chippindale (1932) found that small seedlings of four British pasture grasses were suppressed (remaining small for >10 months) under high root and shoot competition but did not die. These seedlings later grew and flowered following reduction in competition for both nutrients and light. Simpson *et al*. (1989) also describe a similar situation of inhibited seedlings using the term ‘seedling bank’ to describe this phenomenon. When the environmental conditions improved (eg. increased light or moisture) the inhibition was removed enabling the seedlings to develop into mature plants.

The rhodes treatment at Kilcoy is an example of the development of a ‘seedling bank’. Many giant rats tail grass seedlings established with the sown rhodes grass (Fig 4.17) and most were still present 18 months after sowing. Meanwhile, the giant rats tail grass basal area remained very low (Fig 4.11) and few inflorescences were produced (section 4.4.7.2), indicating the plants were not growing. It would be expected that if the rhodes pasture was ‘opened-up’ by drought, overgrazing or soil fertility decline, these giant rats tail grass seedlings would respond quickly and develop into mature plants. The selective herbicide treatment at Gympie demonstrates the ability of small giant rats tail grass plants to develop quickly once competition is reduced. In the selective treatment some small giant rats tail plants were missed during manual application of the herbicide (Fig 4.14). Following the reduction in pasture competition with removal of most of the surrounding mature giant rats tail grass plants, the missed seedlings/small plants appeared to grow relatively quickly and produced many inflorescences (Fig 4.7 and 4.34).

Giant rats tail grass seedlings can develop into reproductive plants relatively quickly, rapidly completing the life cycle. Field grown seedlings growing under relatively low competitive stress (in a 120x120cm canopy gap size) flowered in 3-4 months, with time to inflorescence emergence increasing under higher levels of competitive stress (Table 6.1).

One observation that was not expressed in the presented data is that two or more giant rats tail grass seedlings can grow together and form what appears to be a single tussock. Therefore, a giant rats tail grass tussock may be comprised of a number of individual plants with no actual connection between the plants. This occurrence may be one reason why only spraying one side of a tussock or only wiping part of a tussock (such as when wick wiping in one direction) with a translocatable herbicide (eg. glyphosate) only kills part of the tussock, while the rest remains healthy (G. Elphinstone *pers. com*.).

The tough, persistent seedlings of giant rats tail grass (after tillering has commenced) are a strength in the life cycle of this weed.

7.1.4 Mature flowering plants

Mature giant rats tail grass plants are long-lived. Some giant rats tail grass plants were monitored for 4 years without exhibiting signs of old age (eg. unexplained decline in tussock health), therefore the lifespan of plants could be >10 years. Many giant rats tail grass tussocks broke up into smaller segments, especially with disturbance, a phenomenon that has also been noted in the native grass *Aristida ramosa* (Orr *et al*. 1997). These segments appear separate from each other, but in a good season can grow back together, reforming a single tussock. The giant rats tail grass plants are tough, withstanding fire, slashing, grazing and high levels of plant competition. These findings are also supported by the work of Fianu (1978) who studied pastures containing giant rats tail grass in Ghana. Only the fertiliser treatment at Gympie appeared to result in the death of giant rats tail grass plants (Fig 4.14) through intense competition exerted by the fertilised rhodes grass.

Rodel & Scheerhoorn (1976) also found that high levels of fertiliser (>350kg N/ha) in combination with star grass (*Cynodon nlemfuensis* cv No2) reduced the amount of giant rats tail grass in the pasture. However, the high levels of fertiliser required are unlikely to be considered economic for livestock production. The fertiliser should be applied in combination with an aggressive, vigorous pasture species and appropriate grazing management practices. Otherwise, giant rats tail grass will respond to the fertiliser, outcompete the other pasture species and completely dominate the sward as occurred at Kilcoy and Foxtail Flats (Fig 4.23 and 4.25).

The rate of basal area increase (tillering) in grasses corresponds to the rate of growth and extent of the root system (Weaver 1930). High levels of competition can slow the rate of tillering (Fig 6.9 and 6.16) and basal area increase (eg. rhodes treatment at Gympie and Kilcoy, Fig 4.8 and 4.11). Therefore, treatments with low competitive ability (eg. bisset treatment at Kilcoy and Foxtail Flats, 4.11 and 4.13) allowed giant rats tail grass seedlings to tiller profusely and become well-established. These established giant rats tail grass plants then appear to exert high levels of competition on other species, suppressing them and assuming dominance. This has implications for slow establishing pasture species and pastures rundown by drought or overgrazing and may explain why the giant rats tail grass population on commercial properties appears to "explode" following dry periods (G. Elphinstone *pers. com.*).

Giant rats tail grass is sensitive to some herbicides eg. glyphosate and flupropanate (DNR 1998). Giant rats tail grass control may be achieved if these herbicides can be used to selectively remove giant rats tail grass plants from the pasture, while maintaining a competitive pasture sward.

The leaf blades of giant rats tail grass are tough and difficult for cattle to graze. A preliminary investigation into the leaf strength of giant rats tail grass (data not presented) indicated that it took over 2.5 times the force to break a giant rats tail grass leaf blade compared to a rhodes grass leaf blade. This difference in leaf strength would explain why giant rats tail grass is relatively unpalatable for cattle. This difference in palatability leads to selective grazing of the more palatable species, providing an advantage for the unpalatable giant rats tail grass (Anderson & Briske 1995; Moretto & Distel 1997).

The long-lived, unpalatable giant rats tail grass tussocks that are tolerant of most agronomic manipulations, together with the long-lived soil seed bank mean that giant rats tail grass will be persistent and difficult to eradicate from a pasture.

7.1.5 Seed production

Giant rats tail grass infestations can produce large numbers of inflorescences (Fig 4.34, 4.35 and 4.36), and large numbers of seed (Fig 4.37, 4.38 and 4.39). Some treatments contained up to 150 inflorescences/m^2 and produced over 80000 seeds/m^2 in one season at Foxtail Flats (Fig 4.39). The successful pasture weed serrated tussock also produces large amounts of seed (93000 seeds/m^2, Campbell 1960b). The seed production of giant rats tail grass can be reduced in highly competitive pastures, although it is unlikely to be eliminated.

Giant rats tail grass tends to produce some inflorescences throughout the year (DNR 1998), but the majority appear in summer and autumn. Unfortunately, giant rats tail grass does not have a 'one-off' flowering event as is found in some other weedy grasses. For example, grader grass (*Themeda quadrivalvis*) flowers in response to day-length (Kleinschmidt & Johnson 1977). Hence, it is susceptible to a single strategic slashing, which can greatly reduce seed production and eventually lead to a decline in the soil seed bank.

Compared to the high seed production (up to 80000 seeds/m^2) the giant rats tail grass soil seed bank is comparatively small (1000-10000 seeds/m^2). Many seeds are lost between seed shed and incorporation into the soil seed bank. The fate of these seeds is largely unknown. Williams (1984) also found that the chances of seeds of most species becoming incorporated into the long-term soil seed bank were small. However, giant tail grass plants under conditions of low competitive stress have the potential to quickly develop a large, long-lived soil seed bank.

Seed dispersal, although not investigated in this thesis, is also a strength in the life cycle of giant rats tail grass. The seeds become sticky when wet (Guerin 1899 cited by Toole 1941; Jacobs & McClay 1993) and can become attached to any surface brushing the pasture, including livestock and machinery. These seeds later fall off, but can be transported large distances (Bray *et al.* 1998b; 1999). Cattle also eat the seedheads and can excrete large amounts of seed (Bray *et al.* 1998a). One weakness in the seed dispersal of giant rats tail grass is that many of the vectors are under human control and can be managed eg. livestock and vehicle movement (Bray *et al.* 1998b; 1999).

However, seed transport in fast flowing water and by native and feral animals is difficult to prevent.

The large seed production and effective seed dispersal mechanisms of giant rats tail grass, also add to the imposing strengths of this weed.

7.2 *Summary of weaknesses and strengths within the life cycle of giant rats tail grass*

Giant rats tail grass appears to have some weaknesses within its life cycle that could be targeted within giant rats tail grass management strategies (Fig 7.1). The identified weaknesses were:

- Seed germination and early seedling establishment are sensitive to competition. Therefore if pastures are maintained in a healthy competitive state with a high level of canopy cover, few giant rats tail grass seedlings are likely to establish.
- A fire event can remove a significant proportion of the soil seed bank (variable, 10 to 90%).
- Giant rats tail grass is sensitive to some herbicides. Therefore if a pasture species tolerant of flupropanate or standard rates of glyphosate are introduced into a pasture, giant rats tail grass may be selectively removed.
- Some seed transport vectors are under human control and can be managed.

Giant rats tail grass, as expected, has many strengths within its life cycle (Fig 7.1) which need to be addressed and if possible avoided in giant rats tail grass control/management strategies. The strengths identified include:

- High seed production (up to 80000 seeds/m^2).
- Large (1000-10000 seeds/m^2), long-lived (~8 years) soil seed bank, which is difficult to deplete.
- Ability to exploit areas and periods of reduced plant competition in the pasture to germinate, emerge, establish and grow (eg. above-average rainfall, disturbance).
- Competition tolerant seedlings once they start tillering at approximately 8 weeks old.

- Unpalatable, long-lived mature plants, resistant to high pasture competition and most cultural practices eg. slashing, burning, grazing and fertilising.

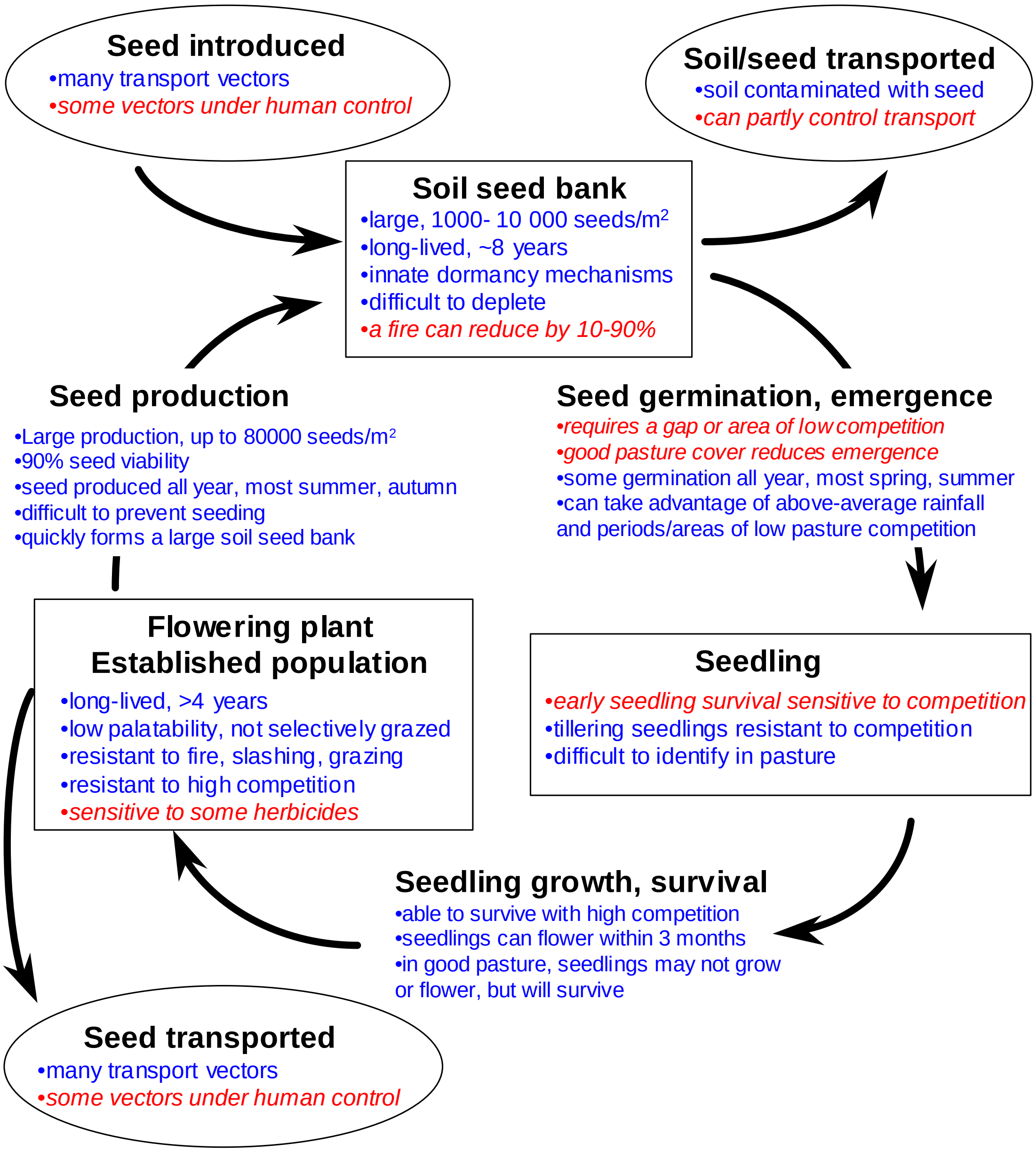

Figure 7.1 Life cycle diagram for the unpalatable pasture weed giant rats tail grass, highlighting the strengths (in blue) and *weaknesses* (in red, italics) within the life cycle. These weaknesses have potential to be targeted within giant rats tail grass control strategies, while the strengths need to be addressed or avoided.

7.3 *Future research*

Further research is required in an attempt to enhance our ability to manage the troublesome weed giant rats tail grass.

Research should be conducted into finding "new" selective herbicides that are compatible with sown and/or native pasture grasses. The ability to selectively remove established giant rats tail grass plants with minimal damage to the surrounding pasture will be an important part of a control/management strategy. Grazing management practices will probably also require modification to maintain the pasture in a healthy, competitive state throughout the year to limit re-establishment from the soil seed bank.

To reduce the competitiveness of giant rats tail grass, the potential for biological control should be thoroughly investigated. Organisms may be available that will target some of the strengths of giant rats tail grass, eg. seed production and plant longevity, which may tip the competitive balance in favour of other pasture species.

Economic control/management strategies also need to be devised for extensive properties particularly in hilly or wooded terrain, where good grazing control and isolated plant control are difficult.

7.4 *Conclusion*

Maintaining pastures in a healthy, competitive state with a good canopy cover will limit the establishment of giant rats tail grass plants. However, once giant rats tail grass plants are established they are difficult to remove without the use of herbicides and any bare areas created will allow more seedlings to establish from the large, long-lived soil seed bank.

This research has clarified the many strengths in the life cycle of giant rats tail grass that make it a successful weed in Queensland pastures. However a few weaknesses were also identified (Fig 7.1). Giant rats tail grass control/management strategies will need to take into account these weaknesses and strengths to achieve success. The presence of a healthy competitive pasture will be the cornerstone of any control/management strategy, without which the strategy will fail.

Due to the difficulty in controlling an established giant rats tail grass infestation, significant resources should be directed into property hygiene strategies that prevent seed transport into uninfested areas.

CHAPTER 8 References

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