THE IMPACT OF ANNUAL GRASSES AND GRASS REMOVAL WITH HERBICIDES ON CARRY-OVER OF TAKE-ALL (*GAEUMANNOMYCES GRAMINIS* var. *TRITICI*)

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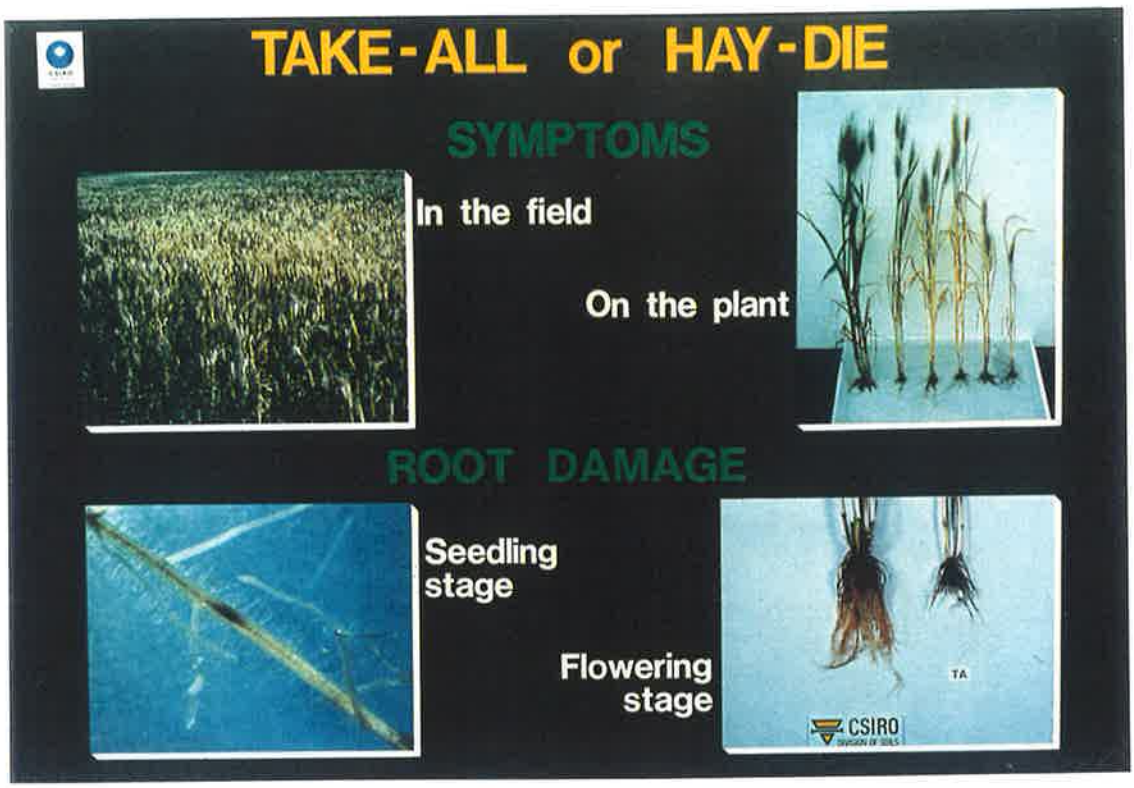

Plate 1.1 The "take-all" story (photo compiled by Dr A. D. Rovira)

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ABSTRACT

This thesis reports on research data from seven field experiments, two pot trials and two surveys. This work was aimed at providing information on control measures against *Gaeumannomyces graminis* var. *tritici* (abbreviated to Ggt) in annual pastures across southern Australia. Most data presented in this thesis comes from research using conditions and materials as close to field situations as possible (natural Ggt inoculum, mixed swards of grass genera and field based trials).

Four field experiments assessed the impact of timing of herbicides applied to naturally regenerating annual pastures for the ability to reduce Ggt carry-over and to reduce the incidence of take-all on wheat sown the following season. I found that the impact of timing of herbicide application depended on a distinction between "lower rainfall" (<350 mm annual rainfall) and "higher rainfall" (>450 mm annual rainfall) districts. Ggt carry-over would normally be reduced in 'lower rainfall" districts if herbicides are applied by the end of June, but in "higher rainfall" districts herbicide applications could occur as late as mid July to control Ggt. The impact of variation in timing of rainfall patterns, as well as herbicide application on the control of Ggt are also discussed.

Additional experiments examined the ability of grass genera to host and carry over Ggt. Three field experiments (using either natural or artificial Ggt inoculum) showed that Ggt infection on wheat roots was most severe when sown in soil which previously supported *Hordeum* spp., with *Bromus* and *Vulpia* spp. being moderate carriers and *Lolium rigidum* least able to carry Ggt. This was confirmed by two surveys of pasture sites across Victoria and South Australia.

However, in two pot experiments, significant variation between *Lolium rigidum* genotypes in ability to carry over Ggt was found, with the variation ranging in Experiment 1 from 12.5% to 70.6% seminal root infection on following wheat, and 8.5% to 37.8% in Experiment 2.

The following recommendations have arisen from my research.

1. Farmers should remove grasses early in the growing season; late June in "lower-rainfall environments" (<350 mm annual rainfall), and mid July in "higher-rainfall" environments (>450 mm annual rainfall). In addition, the success of grass removal for the control of Ggt will vary from season to season. Farmers should approach each season mindful of the possibility that in some seasons grass removal may not be required or may not have the desired effect of reducing Ggt, due to a season that does not allow the build-up of Ggt, due to reduced rainfall, or a late break season that significantly reduces the time available for break-down of Ggt infected material.

2. Farmers should consider their choice of herbicides in terms of the speed with which herbicides kill grasses, as this can affect the length of time that remains for microbial activity to break down any Ggt-infected material, therefore reducing control of Ggt.

3. Farmers should pay particular attention to the removal of *Hordeum* spp., but also to *Bromus* and *Vulpia* spp.. More than 165 *Hordeum* spp. plants per m^2 will result in significantly increased levels of Ggt carry-over. *Lolium rigidum* is essentially a "low host" genus, but farmers should be aware that there are genotypes of *Lolium rigidum* that are very effective hosts of Ggt and able to cause significant levels of Ggt infection on subsequently sown wheat.

DECLARATION

I HEREBY DECLARE that the work presented in this thesis has been carried out by myself and does not incorporate any material previously submitted for another degree in any University. To the best of my knowledge it does not include any material previously written or published by another person, except where due reference is made in the text.

I am willing to make this thesis available for photocopy and loan for the purposes of study and further research.

Richard J Inwood

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This Thesis is dedicated to the memory of my grandmother, Eva and to my parents, Annette and Dick, who have been consistent supporters, never doubting and always encouraging. Without their love and support (in so many ways) throughout my education, subsequent career and my personal life, I would have been significantly worse off.

CHAPTER 1

INTRODUCTION, LITERATURE REVIEW AND AIMS

1.1. Introduction

The disease, "take-all", caused by the fungus *Gaeumannomyces graminis* (Sacc.) Arx and Olivier var. *tritici* Walker, hereafter abbreviated to Ggt, was first referred to in 1852 in South Australia (Anon. 1868) and by the 1870's, research and publications concerning this fungus had begun to appear. Reports of losses from wheat crops as a result of "take-all" (the colloquial name given to cereals infected with Ggt) became common in the 1920's and 1930's, especially on the lighter soil types typical of the Mallee environments in southern Australia (Samuel 1923; Carne and Campbell 1924; Fish 1927; Garrett 1934). In the same period, the first cases of take-all were reported from U.S.A. and the U.K.. Since the 1970's, Korea and China have been added to the list of countries that suffer from this disease. Today, take-all is one of the most significant diseases of cereals and is found in all cereal growing countries of the world (Chambers 1964; Nilsson 1969; Garrett 1981).

The following review, which draws on information presented in 85 papers, relates to take-all in agricultural areas across southern Australia, with particular reference to the impact of Ggt infection on yields of wheat following annual pastures.

Pastures are an important part of rotational dry land farming across southern Australia, with approximately 28 million ha of self regenerating annual pastures (Carter 1981; Reuter *et al.* 1993), based on either *Trifolium* spp. or *Medicago* spp. (medics), contributing to increased availability of soil nitrogen, additional organic matter and improved soil structure. Annual

grasses such as *Hordeum* spp., *Bromus* spp., *Vulpia* spp. and *Lolium rigidum* Gaud. are consistently found in these pastures and it is accepted that Ggt-infected debris from annual pasture grasses is an effective and significant cause of Ggt infection in subsequent cereal crops, particularly wheat (Nilsson 1969; Walker 1975; MacNish and Nicholas 1987; Rovira 1990; Inwood 1995).

1.2 Literature review

1.2.1 Ggt infection

Deacon (1981) describes Ggt as highly invasive, with infection hyphae that extend from runner hyphae, which penetrate the cortex, endodermis and finally the stele of the wheat root. The phloem is colonised and destroyed, restricting supply of photosynthate to roots below the infection point, resulting in senescence. The xylem is more slowly colonised but rarely completely destroyed; however, a brown discolouration will occur (Plate 1.2 and 1.3) with a subsequent reduction in upward flow of water (Deacon 1981). Plant top symptoms include stunting and premature ripening of grain, often occurring in patches, resulting in reduced grain yield. Grain yield losses of up to 60% can occur in severely infected crops (Jones 1984; King 1984; Rovira 1990) However, in many situations, grain yield reduction of up to 20% can occur, even when there are few leaf symptoms.

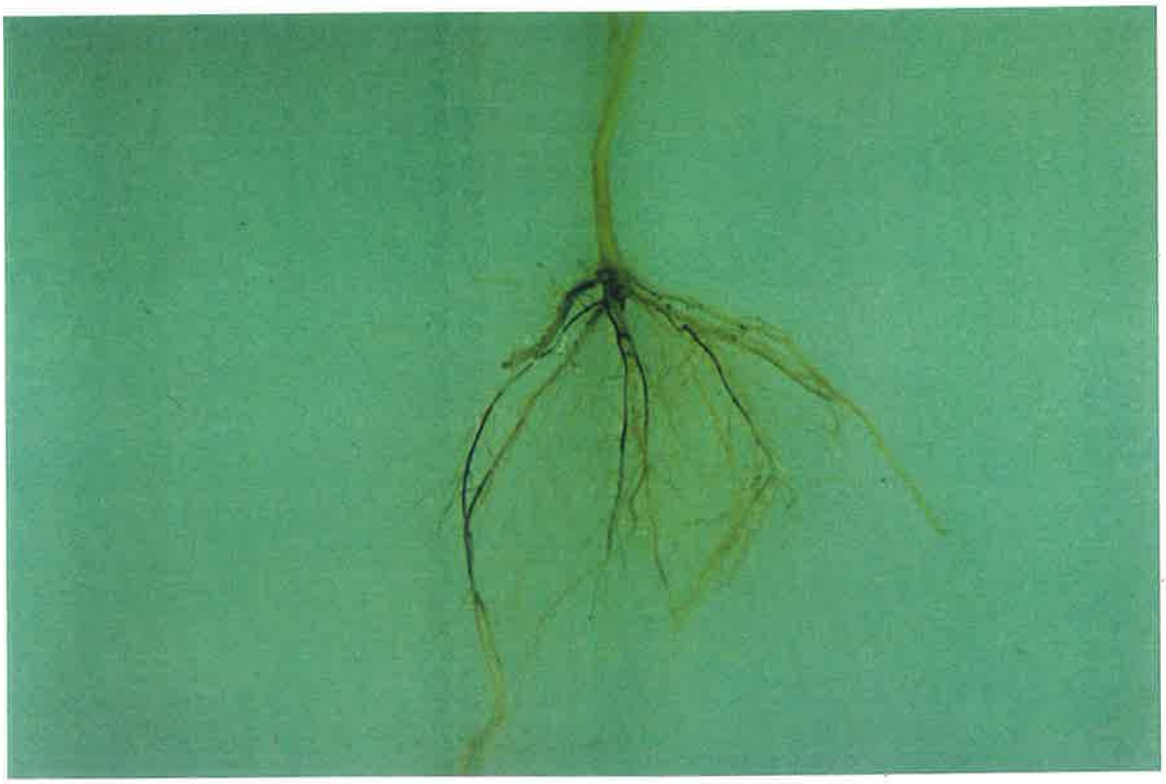

Plate 1.2 **Showing Ggt lesions on wheat roots**

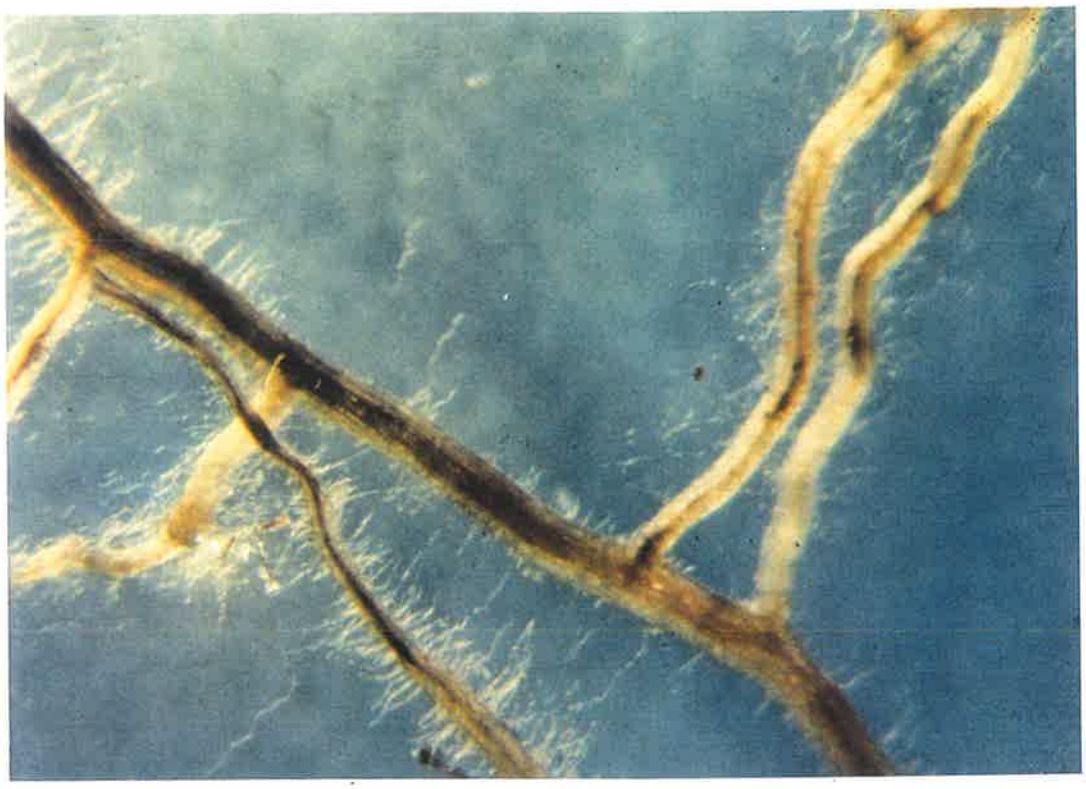

Plate 1.3 **Showing Ggt lesions in a close-up view, with characteristic invasion of conducting tissue**

1.2.2 Economic importance of Ggt

Brennan and Murray (1988) assessed the economic impact of wheat diseases in Australia and found that Ggt caused the highest annual losses, ahead of *Septoria tritici* blotch, Cereal Cyst Nematode, black point and yellow spot. In 1988, the estimated cost of wheat yield reductions as a direct result of Ggt infection across Australia, was $81 million (Brennan 1988), with the bulk of this occurring in southern Australia (Murray 1987). With the inclusion of other susceptible cereals (barley and triticale) this financial loss would be greater.

1.2.3 Control of Ggt - Role of grasses

Ggt survives saprophytically over summer as hyphae in infected host residues, particularly annual grass debris from pastures (Adam 1951; Chambers and Flentje 1968; Deacon 1981; Shipton 1981), and grows from this material onto the roots of susceptible plants.

Current control methods rely on the poor saprophytic survival of Ggt in the absence of a suitable host (Garrett 1947; Garrett 1956). Thus the use of non-host crops (pulses, oil seeds and oats) result in a reduction in Ggt inoculum surviving in the soil (Brooks 1965; Speakman *et al.* 1978; MacNish 1985). This is particularly so for farmers operating in agricultural environments with sufficient annual rainfall (>350 mm) for grain legumes (pulses). Areas with less than 350 mm annual rainfall are generally unable to grow grain legumes and therefore have greater difficulty in controlling Ggt, but long fallows, oats or decreased grass densities in their pastures, through increased fertiliser applications and heavy grazing, was used to reduce Ggt (Griffiths 1933; Kollmorgen *et al.* 1983).

As early as 1955 there were reports in the New Zealand literature of selective herbicides being assessed for the ability to reduce *Hordeum* densities in clover pastures (Lynch 1955; Merry 1959). Australian researchers continued this research (Campbell 1961; Squires 1963; Cuthbertson 1965), although the concept of manipulating pastures to achieve a dominance of low-host grass species e.g. *Lolium rigidum*, instead of the typical dominance of high-host grass species such as barley grass, was not new (Griffiths 1933). During the 1960's, the focus of pasture research appeared to be on increasing nitrogen fixation, reducing weed competition for water and nutrients, minimising grass seed damage to livestock, and reducing the need for subsequent herbicide use in cereals, rather than control of take-all.

Grass removal from pastures for the purpose of root disease control was evaluated in the 1980's when a number of researchers reported reduced take-all incidence and improved grain yields following a reduction in the grass component of previous pastures (Venn 1983; King 1984; MacNish and Nicholas 1987; Rovira 1990; Stephenson 1993).Yield increases following grass removal from pastures may be due to a number of factors other than disease control, e.g. increased nitrogen fixation, reduction in grass weeds in the crop year, allowing more timely sowing of the crop and the adoption of direct drilling techniques (Ladd 1981; Jones 1984).

In southern Australia the manipulation of botanical composition of annual pastures is achieved either by grazing (Carter 1990a) or by use of selective or non-selective herbicides. Research by Leys (1988, 1990, 1991a, 1991b), has assessed the impact of a number of herbicides on various grass genera (particularly *Vulpia* spp.), and subsequent production of pasture legumes (*Medicago* spp. and subterranean clover). He reported that grass selective herbicides such as Fusilade®, Sertin® and Verdict® effectively removed most grasses except for *Vulpia* spp.,

which could be controlled by the addition of Simazine®. Non-selective herbicides such as, Gramoxone® and Roundup® could also be used.

Leys found that the use of grass selective herbicides led to an increase in pasture legume dominance and an increase in nitrogen fixation, but that, the use of non-selective herbicides, depending on the growth stage of the pasture legume, would often cause significant damage to the pasture legume, leading to a potential reduction in nitrogen fixation,. The work of Leys confirms earlier research by Campbell (1961), Cuthbertson (1965), Barrett (1973) and Thorn and Perry (1983).

In addition to killing grasses, the timing of herbicide application impacts on the effectiveness of Ggt control. The timing of the herbicide applications to control Ggt is related to the time available for microbial breakdown of infected root material while soil is moist (Zogg 1969; MacNish and Dodman 1973; Thorn and Perry 1983; Cotterill and Sivasithamparam (1986); Macleod and MacNish 1989). However, Leys (1990) points out that there is limited research regarding the length of the grass-free period required to significantly reduce carry-over of Ggt. This factor is important when considering the timing and efficacy of herbicide sprays in relation to annual rainfall. Higher rainfall environments will have a longer period when the soil is sufficiently moist and warm, and thus conducive to microbial breakdown compared to a low rainfall environment.

1.2.4 Carry-over of Ggt on different grasses

In southern Australia, there are four common annual pasture grasses, *Hordeum* spp., *Bromus* spp., *Vulpia* spp. and *Lolium rigidum.* Of the four grass species, *Lolium rigidum* is the only sown species., with the other grasses being volunteers. It is generally accepted that *Hordeum* is the most common grass in pastures with *Lolium rigidum* and *Bromus* spp. being more widespread than *Vulpia* spp. (Donald 1970).

Comment has been made in the literature regarding the suspected relative importance of grass species on carry-over of Ggt. However, very little field based research has been conducted on this topic. Most reports are based on field observations (Griffiths 1933; Sims 1961; Banyer 1966) or based on controlled-environment experiments using artificial inoculum, artificially infected sods and straws of grass species or pure swards of grass genera (Chambers 1971; Kidd 1995).

The early field observations by Griffiths (1933), in the South Australian Mallee area following the 1932-33 season in which take-all was widespread, showed that *Hordeum* spp. were badly infected and appeared to have the ability to spread take-all. This was similar for *Bromus* spp. and possibly *Vulpia* spp. He also reported that *Lolium rigidum* tended to have a controlling influence on take-all. Sims *et al.* (1961), reported on a field survey of 76 wheat crops in 1958 from the Victorian mallee, and found that 75 % of 45 crops, which had been sown after a fallow containing *Hordeum* spp, developed more than 5% white heads (indicative of Ggt infection), compared to 23% of 31 crops, which had been sown after fallows without *Hordeum* spp. An earlier paper by Sims (1958), based on plot trials, reported that wheat

following a *Lolium rigidum*/Barrel medic ley, had 0.3% white heads compared to 10.7% following a volunteer *Hordeum* spp. ley. In a review of 'Root and Foot Rot Diseases' by Butler (1960), there are reports of papers by Osborne (1924) and Anon. (1937), in which there is the suggestion that *Lolium rigidum* is not immune to Ggt.

Chambers and Flentje (1968), who conducted field trials in South Australia with naturally infected residues of various grass species, found that high carry-over levels of Ggt occurred on *Hordeum* and *Bromus* spp., but not on *Lolium rigidum* and *Vulpia* spp. Subsequent work by Chambers (1971), using artificially-infected sods of grass species, measured higher survival of Ggt following *Bromus gussonii* Parl. and *Hordeum* spp,. moderate survival on *Lolium perenne* L., *Bromus mollis* L. and least survival following *Vulpia myuros* (L.) Gmel. Shipton (1981) also reported highest Ggt survival on *Bromus gussonii* and *Hordeum* spp, and least survival on *Lolium rigidum* and *Vulpia myuros*. During experiments with Ggt isolates taken from *Lolium rigidum*, Dewan and Sivasithamparam (1990) found that Ggt isolates taken from *Lolium rigidum* caused significantly more root rot and plant mortality to wheat than to *Lolium rigidum* plants, indicating that *Lolium rigidum* appeared to have some degree of resistance to Ggt.

The general consensus from the above authors is that that carry-over of Ggt is highest after *Hordeum* spp. and *Bromus* spp, with some question about the relative importance of *Vulpia* spp. as a host and that typically, carry-over of Ggt following *Lolium rigidum* would be least.

However, Macleod and MacNish (1989) and Kidd (1995) reported that *Lolium rigidum* is equal to *Hordeum* spp. in carry-over ability but experimental data is not provided to support

this statement. Kidd also provided evidence that *Lolium rigidum* carried over Ggt but this work involved extremely high levels of natural inoculum, such that the natural defence mechanisms of the *Lolium rigidum* plant may have been overwhelmed.

It has been suggested that the effectiveness of a grass genus to carry over Ggt is altered by the physical characters of the straw, chemical exudates, rate of decomposition and the grass density (Chambers and Flentje 1968; Chambers 1971). Research results presented in this thesis involve an additional possibility, that genetic variation (genotypes) within grass genera (particularly *Lolium rigidum*) as a possible cause of variability in the findings on the Ggt hosting ability within a single grass genus.

The research for this thesis involves experiments using conditions and materials as close to field conditions as possible, (natural Ggt inoculum, mixed swards of grass genera and field based trials) and incorporates seed of grasses from Western Australia, South Australia and Victoria. In addition, throughout this thesis, the term "carry-over of Ggt" will indicate the ability of Ggt to survive and subsequently infect new roots of wheat from the original source of infected material.

A significant factor concerning subsequent carry-over of Ggt, is the density of grasses in annual pasture. Research from Western Australia estimates that Ggt infection in subsequent cereal crops increased by 5% for every additional 100 kg of grass dry matter in a pasture preceding wheat (MacNish and Nicholas 1987; Macleod and MacNish 1989). Again from Western Australia, Cotterill and Sivasithamparam (1988a) reported maximum levels of Ggt carry-over once the proportion of grass exceeded 20% of a pasture. In contrast, earlier work by Kollmorgen *et al.* (1983) reported that disease incidence and severity were not significantly

increased by the presence of grasses (*Lolium rigidum* and *Hordeum* spp.) in a medic pasture, although the authors acknowledged that this result was difficult to explain.

1.3 Aims of Thesis

This thesis has five primary aims, as follows:

(1) To assess the impact of grass removal from pastures with herbicides on levels of Ggt disease on the roots of subsequent wheat plants.

(2) To determine the impact of timing of herbicide application (both selective and non-selective herbicides) on the level of take-all and subsequent yield of wheat.

(3) To conduct a field survey of levels of Ggt carried-over on crowns of different grass genera.

(4) To compare the ability of four common annual pasture grass genera in southern Australian pastures to carry-over Ggt and subsequently infect wheat roots.

(5) To determine if differences exist within selections of *Lolium rigidum* in the ability to carry Ggt.

CHAPTER 2

THE IMPACT OF REMOVAL OF ANNUAL GRASSES FROM PASTURES, WITH SELECTIVE AND NON-SELECTIVE HERBICIDES, ON CARRY-OVER OF *GAEUMANNOMYCES GRAMINIS* var. *TRITICI* AND GRAIN YIELDS OF A FOLLOWING WHEAT CROP

2.1 Introduction

Pastures dominant in *Trifolium* or *Medicago* spp. are valuable in farming systems of southern Australia (Carter 1981; Jones 1984; Reeves 1987) and well managed legume dominant pastures contribute to nitrogen fixation and soil organic matter, and provide grazing for livestock (Ellington 1979; Ladd 1981, 1986; Thorn and Perry 1983; Dufey 1986). In addition, low grass pastures increase legume seed set, decrease seed injury to sheep and sheep related products (Little *et al.* 1993) and facilitate in minimum tillage systems (Thorn and Perry 1983; Jones 1984).

However, annual grasses are frequently a major component of annual pastures in southern Australia. These grasses, *Hordeum* spp., *Bromus* spp., *Vulpia* spp. and *Lolium rigidum*, are known to host Ggt and have the potential to produce significant infection in subsequently sown cereals (Chambers and Flentje 1968; Nilsson 1969; Cotterill and Sivasithamparam 1988a, 1988b, 1988c; Kidd 1995).

Generally, the farming community is aware that the primary measure for control of Ggt is through grass-free, non-host crops, particularly grain legumes (pulses) sown prior to cereals (Griffiths 1982; MacNish 1985; Rovira 1990). However, in agricultural areas with low annual rainfall (below 350 mm), cultivation of grain legumes can be unreliable and uneconomic, leaving the pasture phase as the primary target for control of cereal root diseases (King 1984).

In southern Australia, pasture manipulation with herbicides was first trialed in the early 1960's with the release of the non-selective herbicide Gramoxone®. This chemical successfully decreased seed set of annual grasses, but at this time no assessment was made on its influence on carry-over of Ggt (Jones 1984).

Barrett *et al.* (1973) continued the assessment of Gramoxone® by measuring the impact of application times and rates on subterranean clover (hereafter abbreviated to sub-clover) densities. He reported that sub-clover densities increased with all applications of Gramoxone®, but that the earliest applications (June/July) gave additional increases in sub-clover densities, compared to the later applications.

Assessment of the ability of herbicides which selectively controlled grasses to control Ggt began in the early 1980's when Venn (1983) conducted studies in South Australia on the use of a selective herbicide, code named PP009 (Fluazifop), subsequently released as Fusilade®. He found that Fusilade®, applied at either 0.5 or 1.0 kg /ha, on July 23, 1980, decreased grass composition from 73% (predominantly *Hordeum* spp.) to 28% and increased medic (cv. Harbinger) from 27% to 72%. Importantly, wheat yields increased from 0.55 t/ha (untreated) to 0.87 t/ha (0.5 kg Fusilade /ha) and 1.17 t/ha (1.0 kg Fusilade /ha.), due to a reduction in carry-over of Ggt (Venn 1983).

Concurrent to the work of Venn, research in Western Australia on a range of herbicides including Fusilade®, showed increased clover composition and a decline in grass density. In addition, this research indicated that removal of grasses must occur "early" to allow time for the decomposition of grass debris infected with Ggt prior to the drying out of the soil (Thorn

1983), but gave no clear indication of what "early" meant in terms of a recommended date for herbicide application.

In the search for parameters with which to measure and predict the likely carry-over levels of Ggt infection, Macleod and MacNish (1989) related the efficacy of herbicide application to grass dry matter yield and subsequent carry-over of Ggt. They found that Ggt infection of a subsequent wheat crop increased by 5% for every additional 100 kg /ha of grass dry matter present at the time of spraying the grass. They also agreed with comments by Thorn and Perry (1983) regarding the need for early grass removal to ensure decomposition of material infected with Ggt, suggesting that herbicides should be applied by "about the six leaf stage of the clover/medic plant" (Macleod and MacNish 1989). Recent work by Kidd (1995) reported reductions in carry-over of Ggt with applications of herbicides ranging from 5-14 June to July 23-27.

Timing of grass removal is a significant question that has not yet been critically examined. The aim of the research described in this section, was to examine (1) the effects of timing of herbicide applications to a grassy annual pasture, repeated over several seasons and rainfall environments, on the level of take-all and yield of wheat, (2) the effects of a range of selective and non-selective herbicides and mixtures of these herbicides on take-all and wheat yields and (3) the rates of these herbicides that efficiently remove the four most common annual grasses in annual pastures, viz, *Hordeum* spp., *Bromus* spp., *Vulpia* spp. and *Lolium rigidum*.

2.2 Experimental procedure

Four randomised complete block experiments were conducted on two field sites over the years 1989 - 1991. The two field sites were chosen to represent the two major soils used for cropping in south eastern Australia, viz. red brown earth (fine loam mixed calcic rhodoxeralf, identified in the Northcote Key (Northcote 1971) as Dr 2.3, with a pH of 5.6 (in Ca Cl_2) and an average annual rainfall, 496 mm) at Kapunda (34° 21′ S, 138° 55′ E), and a calcareous sandy loam (calcic xerosol), identified in the Northcote Key as Gc 1.12 with a pH of 8.1 (in Ca Cl_2) with an average annual rainfall of 335 mm) at Palmer (34° 51′ S, 139° 10′ E). The individual field plot size was 50m long by 2m wide, with four replicates (Plates 2.1 and 2.2).

Both selective and non-selective herbicides were used with application dates ranging from mid June to early November. Herbicides were mixed on the basis of applying the equivalent of 100 l of water per hectare and applied through XR Teejet (8002VB) nozzles mounted on a four wheel All Terrain Vehicle with a 2 m boom mounted on the rear.

Table 2.1 Herbicides used in experiments at Kapunda and Palmer

Herbicide	Active ingredients
Gramoxone®	200 g a.i./l Paraquat
Fusilade®	212 g a.i./l Fluazifop
Simazine®	500 g a.i./l Simazine*
Roundup®	300 g a.i./l Glyphosate

* Mixed with either Fusilade® or Gramoxone®
All herbicides were mixed with 250 ml of Agral 600 wetter per 100 l water

Table 2.2 Herbicides used and the rates and timing of applications for Experiment 1 - Kapunda 1989

Treatments	Application date	Herbicide rate
Control		
Gramoxone®	26/7/89	1.5 l/ha
Fusilade®	26/7/89	0.5 l/ha
Fusilade®	9/8/89	0.5 l/ha
Fusilade®	24/8/89	0.5 l/ha
Fusilade®	7/9/89	0.5 l/ha
Fusilade®	20/9/89	0.5 l/ha
Fusilade®	4/10/89	0.5 l/ha
Roundup®	3/11/89	0.4 l/ha
Gramoxone® (Spraytop)	8/11/89	0.5 l/ha

During the conduct of Experiment 1, it was noticed that Fusilade® (grass selective herbicide) was not killing *Vulpia* spp. and that numbers of this species were increasing following removal of other grasses. As a consequence, from Experiment 2 onwards, Simazine was incorporated into mixtures of both selective and non-selective herbicides to control *Vulpia* spp..

Table 2.3 Herbicides used and the rates and timing of applications for Experiment 2 - Kapunda 1990

Treatments	Application date	Herbicide rate
Control		
Gramoxone®	3/8/90	1.5 l/ha
Fusilade ®	3/8/90	0.5 l/ha
Fusilade®/Simazine®	3/8/90	0.5 / 1.0 l/ha
Gramoxone®/Simazine®	3/8/90	0.3 /1.0 l/ha
Fusilade®/Simazine®	17/8/90	0.5 / 1.0 l/ha
Gramoxone®/Simazine®	17/8/90	0.3 /1.0 l/ha
Fusilade®/Simazine®	7/9/90	0.5 / 1.0 l/ha
Fusilade®/Simazine®	28/9/90	0.5 / 1.0 l/ha
Gramoxone® (Spraytop)	15/10/90	0.5 l/ha

Table 2.4 Herbicides used and the rates and timing of applications for Experiment 3 - Kapunda 1991

Treatments	Application date	Herbicide rate
Control		
Gramoxone®/Simazine®	28/6/91	0.3 /1.0 l/ha
Fusilade®/Simazine®	28/6/91	0.5 / 1.0 l/ha
Fusilade®	28/6/91	0.5 l/ha
Fusilade®/Simazine®	11/7/91	0.5 / 1.0 l/ha
Fusilade®/Simazine®	24/7/91	0.5 / 1.0 l/ha
Fusilade®/Simazine®	9/8/91	0.5 / 1.0 l/ha
Gramoxone® (Spraytop)	25/10/91	0.5 l/ha

Table 2.5 Herbicides used and the rates and timing of applications for Experiment 4 - Palmer 1991

Treatments	Application date	Herbicide rate
Control		
Gramoxone®/Simazine®	27/6/91	0.3 /1.0 l/ha
Fusilade®/Simazine®	27/6/91	0.5 / 1.0 l/ha
Fusilade®/Simazine®	10/7/91	0.5 / 1.0 l/ha
Fusilade®/Simazine®	26/7/91	0.5 / 1.0 l/ha
Fusilade®/Simazine®	9/8/91	0.5 / 1.0 l/ha
Fusilade®/Simazine®	28/8/91	0.5 / 1.0 l/ha
Gramoxone® (Spraytop)	25/10/91	0.5 l/ha

Pasture botanical composition was measured following herbicide applications to determine the percentage population of each grass species and the percent bare ground using the Levy Point Quadrat method (Levy and Madden 1933).

Soil was collected from all experiments during the summer following herbicide application, for assessment of levels of Ggt by soil bioassay. A soil sampler (see Fig 2.1 page 18) was used to collect a bulk soil sample of 5-8 kg. Soil was taken from the top 5 cm of each plot and there were four replicate plots per treatment. Four wheat seeds were sown into each of three replicate plastic pots (diameter of 90 mm and volume of 500 cc) representing each plot, each with 500 g of unsieved moistened soil. Soil moisture was maintained at 15% of soil air dried

weight. After four weeks growth at 15 deg. C, wheat plants were washed free of soil and the percent incidence of seminal roots with Ggt lesions was recorded.

In the autumn following herbicide spraying, wheat (cv Spear) was sown, after 1-2 cultivations, using a 10 row tyned drill with row spacings of 15 cm. Eight weeks after emergence, twenty wheat plants per plot were sampled from each of the four replicates and Ggt infection of the roots was assessed. At maturity all plots were mechanically harvested and wheat grain yield expressed as tonnes /ha.

Statistical analyses was carried out with an Analysis of Variance being applied to all data.

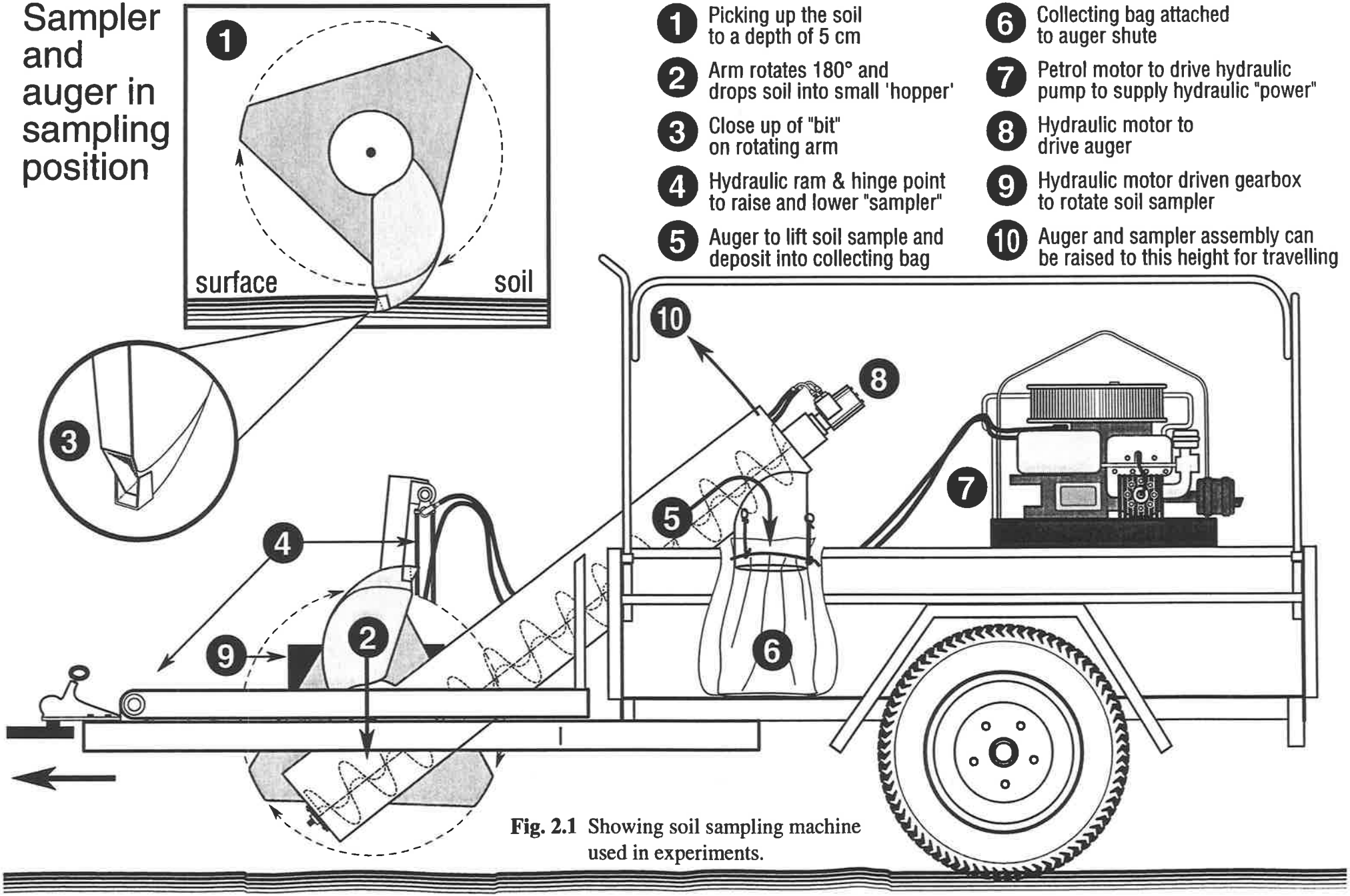

Fig. 2.1 Showing soil sampling machine used in experiments.

2.3 Results

Pasture composition:

Experiments 1, 2, and 3 were assessed for the impact of herbicide type, and rate and timing of herbicide application on pasture composition. Herbicides applied before the 20 September, in Experiment 1 and by 7 September, in Experiment 2, increased density of *Trifolium* spp. and decreased density of grass spp., compared to the untreated controls (Tables 2.6 and 2.8). Pasture composition in Experiment 3 also showed significant increases in density of *Trifolium* spp. and a decrease in grasses for herbicide treatments applied up to 24 July (Table 2.10)

Soil bioassay for Ggt:

In Experiment 1, only the earliest application of Gramoxone® and Fusilade®, 26 July, significantly reduced Ggt carry-over, which subsequently infected the seminal roots of wheat (8% and 21% respectively), compared to the non-treated control (38%), (Table 2.7). In Experiment 2, Ggt carry-over was significantly reduced by the first applications of Fusilade/Simazine® and Gramoxone/Simazine® mixtures on 3 August, and the second application of Gramoxone/Simazine® on 17 August (15%, 8% and 15% respectively), compared to the untreated control (32%) (Table 2.9).

In Experiment 3, all herbicides and herbicide mixtures, (except spraytop treatment) applied between the 28 June and 9 August, significantly reduced carry-over of Ggt from 44% (untreated control) to 15% or less (Table 2.11). At Palmer, a low rainfall site, the earliest

treatment of Gramoxone/Simazine® on 27 June, significantly reduced carry-over of Ggt from 28% (control) to 12%. A result which I cannot explain is the significant increase in Ggt carry-over measured following the 9 August Fusilade/Simazine® application, where Ggt carry-over increased from 28% (control) to 43%.

Disease assessment on wheat roots in following season:

In Experiment 1, there were no differences in Ggt infection on wheat roots. This was not the case in all other Experiments. In Experiment 2, seminal wheat root ratings of the untreated controls were high (58%) but these levels were significantly reduced after herbicide applications of Gramoxone®and Gramoxone/Simazine®, applied on the 3 August , (37% and 22% respectively) (Table 2.9). This was also the case in Experiment 3, where all herbicides and herbicide mixtures applied by the 9 August decreased Ggt infection on wheat roots from 15% to less than 5% seminal root infection (Table 2.11).

A result difficult to explain is the spraytopping treatment in Experiment 3 (25 October) which also significantly decreased Ggt infection on wheat roots. In Experiment 4, Gramoxone/Simazine® applied at the earliest date (27 June) and Fusilade /Simazine® applied on 27 June and 10 July, significantly decreased levels of Ggt infection on wheat roots (26%, 19% and 23% respectively) compared to the control (41%) (Table 2.12).

Wheat yield:

Treatments gave no differences in wheat yield in Experiments 1 or 3 (Tables 2.7 and 2.11). However, increases of up to 0.85 t/ha were measured in Experiment 2, with significant increases occurring in all treatments (except Fusilade® applied 2 November) (Table 2.9). Compared to the untreated control (1.0 t/ha), wheat yields were more than doubled in three treatments of Experiment 4: Gramoxone/Simazine®, 27 June (2.07 t/ha), and Fusilade/Simazine®, 27 June and 10 July, (2.01 and 2.38 t/ha respectively) (Table 2.12).

Table 2.6 Effects of herbicides and timing of applications on percentage pasture composition - Experiment 1, Kapunda 1989

Treatments	Application date	Herbicide rate	Percent overlapping cover		
			Sub-clover	Grass	Other spp. +B.G.~
Control			42	53	5
Gramoxone®	26/7/89	1.5 l/ha	60*	5*	35*
Fusilade®	26/7/89	0.5 l/ha	77*	8*	15*
Fusilade®	14/8/89	0.5 l/ha	82*	8*	10
Fusilade®	24/8/89	0.5 l/ha	84*	12*	4
Fusilade®	7/9/89	0.5 l/ha	84*	7*	9
Fusilade®	20/9/89	0.5 l/ha	79*	16*	5
Fusilade®	5/10/89	0.5 l/ha	56	41	3
Roundup®	3/11/89	0.4 l/ha	47	47	6
Gramoxone® (Spraytop)	3/11/89	0.5 l/ha	40	56	4
* significantly different from control		l.s.d (P<0.05)	15	13	7

~ Bare ground

Table 2.7 Effects of herbicides and timing of applications on levels of Ggt infection on wheat roots and wheat yield Experiment 1, Kapunda 1989/90

Treatments	Application date	Herbicide rate	Soil bioassay (12/1/90)	Wheat root ratings (12/9/90)	Grain yield (t/ha)
Control			38.0	39.0	2.86
Gramoxone®	26/7/89	1.5 l/ha	8.0*	32.0	2.89
Fusilade®	26/7/89	0.5 l/ha	21.0*	29.0	2.89
Fusilade®	14/8/89	0.5 l/ha	41.0	35.0	3.03
Fusilade®	24/8/89	0.5 l/ha	40.0	41.0	2.80
Fusilade®	7/9/89	0.5 l/ha	51.0	46.0	2.90
Fusilade®	20/9/89	0.5 l/ha	37.0	38.0	2.95
Fusilade®	5/10/89	0.5 l/ha	35.0	49.0	2.85
Roundup®	3/11/89	0.4 l/ha	36.0	48.0	2.76
Gramoxone® (Spraytop)	3/11/89	0.5 l/ha	40.0	36.0	2.84
* Significantly different from control		l.s.d (P<0.05)	16.2	n.s	n.s

Wheat crop sown 10/7/90

Table 2.8 Effects of herbicides and timing of applications on pasture composition - Experiment 2, Kapunda 1990

			Percent overlapping cover		
Treatments	Application date	Herbicide rate	Sub-clover	Grass	Other spp. + B.G.~
Control			39	58	3
Gramoxone®	3/8/90	1.5 l/ha	69*	22*	9
Fusilade ®	3/8/90	0.5 l/ha	50*	43*	7
Fusilade®/Simazine®	3/8/90	0.5 / 1.0 l/ha	89*	5*	6
Gramoxone®/Simazine®	3/8/90	0.3 /1.0 l/ha	89*	4*	7
Fusilade®/Simazine®	17/8/90	0.5 / 1.0 l/ha	81*	14*	5
Gramoxone®/Simazine®	17/8/90	0.3 /1.0 l/ha	81*	13*	6
Fusilade®/Simazine®	7/9/90	0.5 / 1.0 l/ha	70*	26*	4
Fusilade®/Simazine®	28/9/90	0.5 / 1.0 l/ha	48	51	1
Fusilade®	2/11/90	0.5 l/ha	46	51	3
Gramoxone® (Spraytop)	2/11/90	0.5 l/ha	45	53	2
* significantly different from control		l.s.d (P<0.05)	11	11	n.s

~ Bare ground

Table 2.9 Effects of herbicides and timing of applications on levels of Ggt infection on wheat roots and wheat yields - Experiment 2, Kapunda 1990/91

Treatments	Application date	Herbicide rate	Soil bioassay (18/5/91)	Wheat root ratings (18/8/91)	Grain yield (t/ha)
Control			32.0	58.0	4.20
Gramoxone®	3/8/90	1.5 l/ha	17.0	37.0*	4.62*
Fusilade ®	3/8/90	0.5 l/ha	17.0	51.0	4.75*
Fusilade®/Simazine®	3/8/90	0.5 / 1.0 l/ha	15.0*	49.0	5.05*
Gramoxone®/Simazine®	3/8/90	0.3 /1.0 l/ha	8.0*	22.0*	4.91*
Fusilade®/Simazine®	17/8/90	0.5 / 1.0 l/ha	21.0	45.0	5.01*
Gramoxone®/Simazine®	17/8/90	0.3 /1.0 l/ha	15.0*	47.0	5.00*
Fusilade®/Simazine®	6/9/90	0.5 / 1.0 l/ha	35.0	48.0	4.80*
Fusilade®/Simazine®	28/9/90	0.5 / 1.0 l/ha	28.0	61.0	5.13*
Fusilade®	2/11/90	0.5 l/ha	32.0	55.0	4.22
Gramoxone® (Spraytop)	2/11/90	0.5 l/ha	24.0	51.0	4.74*
* Significantly different from control		l.s.d (P<0.05)	16.5	17.1	0.30

Wheat crop sown 12/6/91

Table 2.10 Effects of herbicides and timing of applications on pasture composition - Experiment 3, Kapunda 1991

			Percent overlapping cover		
Treatments	Application date	Herbicide rate	Sub-clover	Grass	Other spp. + B.G.~
Control			21	38	41
Gramoxone®/Simazine®	28/6/91	0.3 /1.0 l/ha	49*	0*	51
Fusilade®/Simazine®	28/6/91	0.5 / 1.0 l/ha	55*	2*	43
Fusilade®	28/6/91	0.5 l/ha	48*	9*	43
Fusilade®/Simazine®	11/7/91	0.5 / 1.0 l/ha	50*	0*	50
Fusilade®/Simazine®	24/7/91	0.5 / 1.0 l/ha	42	13*	45
Fusilade®/Simazine®	9/8/91	0.5 / 1.0 l/ha	30	33	37
Gramoxone® (Spraytop)	25/10/91	0.5 l/ha	24	42	34
* significantly different from control		l.s.d (P<0.05)	22	11	n.s

~ Bare ground

Table 2.11 Effects of herbicides and timing of applications on levels of Ggt on wheat roots and wheat yield - Experiment 3, Kapunda 1991/92

Treatments	Application Date	Herbicide rate	Soil bioassay (18/2/92)	Wheat root ratings (29/7/92)	Grain yield (t/ha)
Control			44.0	15.0	2.79
Gramoxone®/Simazine®	28/6/91	0.3 /1.0 l/ha	2.0*	0.0*	3.49
Fusilade®/Simazine®	28/6/91	0.5 / 1.0 l/ha	3.0*	2.0*	3.27
Fusilade®	28/6/91	0.5 l/ha	7.0*	2.0*	3.51
Fusilade®/Simazine®	11/7/91	0.5 / 1.0 l/ha	5.0*	4.0*	2.99
Fusilade®/Simazine®	24/7/91	0.5 / 1.0 l/ha	10.0*	5.0*	2.99
Fusilade®/Simazine®	9/8/91	0.5 / 1.0 l/ha	15.0*	2.0*	3.16
Gramoxone® (Spraytop)	25/10/91	0.5 l/ha	33.0	6.0*	2.91
* significantly different from control		l.s.d (P< 0.05)	13	7.0	n.s

Wheat crop sown 30/5/92

Table 2.12 Effects of herbicide and timing of applications on levels of Ggt on wheat roots and wheat yield - Experiment 4, Palmer 1991

Treatments	Application date	Herbicide rate	Soil bioassay (18/3/92)	Wheat root rating (21/7/92)	Grain yield (t/ha)
Control			28.0	41.0	1.0
Gramoxone®/Simazine®	27/6/91	0.3 /1.0 l/ha	12.0*	26.0*	2.07*
Fusilade®/Simazine®	27/6/91	0.5 / 1.0 l/ha	21.0	19.0*	2.01*
Fusilade®/Simazine®	10/7/91	0.5 / 1.0 l/ha	30.0	23.0*	2.38*
Fusilade®/Simazine®	26/7/91	0.5 / 1.0 l/ha	29.0	31.0	1.60
Fusilade®/Simazine®	9/8/91	0.5 / 1.0 l/ha	43.0*	42.0	1.64
Fusilade®/Simazine®	28/8/91	0.5 / 1.0 l/ha	40.0	44.0	1.24
Gramoxone® (Spraytop)	25/10/91	0.5 l/ha	26.0	29.0	1.11
* Significantly different from control		l.s.d (P<0.05)	14	14	0.64

Wheat crop sown 30/5/92

Note, pasture composition counts were not done on this experiment

Plate 2.1 **Showing effects of grass removal at Kapunda Experiment site 1992**

Plate 2.2 **Showing effects of grass removal and the cages used for pasture monitoring at Kapunda Experiment site 1993**

2.4 Discussion

Experiments presented in this chapter point to the importance of reducing the levels of self-sown grasses (typically >40%) to achieve significant reductions in Ggt carry-over. This is shown in Experiment 1 where a significant reduction in Ggt carry-over (measured by soil bioassay) was recorded only when the residual grass component was reduced to 8% or less (compared to untreated control with 53% grass), using Fusilade® or Gramoxone® applied on 26 July.

A similar result was obtained in Experiment 2, with Fusilade/Simazine® and Gramoxone/Simazine® applied on 3 August, and Gramoxone/Simazine® applied 17 August, which reduced grasses from 58% to 13% grass. In Experiment 3, a number of herbicides and mixtures applied up to the 24 July, reduced grass numbers from 38% grass to 13% residual grass.

In Experiment 4 (Palmer), pasture composition was not measured, but visual assessment of the pasture clearly showed that only the earliest Gramoxone®/Simazine® treatment (27 June) reduced grass densities to negligible levels (<5%), which subsequently showed a significant reduction in Ggt carry-over. All other treatments had high residual levels of grasses (>20%) and did not reduce subsequent carry-over of Ggt.

Data presented here generally agrees with work by Cotterill and Sivasithamparam (1988a) who reported that the maximum levels of Ggt inoculum were present in a pasture with a composition of 80% sub-clover and 20% grass. However, measurements of Ggt infection on a

wheat crop sown subsequent to the experiment indicated that 40% grass composition (in the previous pasture) was necessary to significantly increase carry-over of Ggt in comparison to a pure sub-clover stand. Their data is based on one field experiment, and thus only relates to the conditions of that season, so it is conceivable that in a year more conducive to the development of Ggt, a smaller proportion of grass could have maintained a high enough level of Ggt to cause significant Ggt infection in the subsequent wheat crop.

Data presented here indicates that in some years Ggt carry-over increased with 8% residual grass but in other years 15% grass could be tolerated. Thus it appears that seasonal conditions can have a major impact on the level of grass required in a pasture for a significant carry-over of Ggt. I have also shown that grass removal must occur early to achieve significant reductions in carry-over of Ggt. The effect of the season is probably related to differences in the length of time that the soil is sufficiently moist for microbial activity and subsequent break down rates of Ggt infected debris. These results indicate that the success of grass removal for the control of Ggt will vary between seasons; for example, in a season with a late break, there may be insufficient time for microbial breakdown of grass root debris, making the application of herbicide for this purpose redundant.

In addition, there were treatments in Experiments 1, 2, and 3 which significantly reduced grass densities, yet carry-over levels of Ggt are not affected, indicating that a number of additional factors affect the impact of grass control on carry-over of Ggt. In Experiments 1 and 2, all Fusilade® and Fusilade®/Simazine® treatments failed to reduce levels of Ggt, probably because Fusilade takes up to four weeks longer than Gramoxone to kill grasses, allowing less time, within the growing season, for microbial action on roots carrying take-all.

An additional problem with selective herbicides such as Fusilade®, is that some grass species, notably *Vulpia* spp, are not killed and can host the Ggt fungus allowing significant carry-over. The addition of Simazine® to selective herbicides controls *Vulpia* spp.

In a comparison of herbicide timing and subsequent Ggt carry-over between Experiments 3 (450 mm annual rainfall) and 4 (335 mm annual rainfall), it appears that rainfall can impact on the required timing of herbicide application. In both experiments, herbicides were applied on essentially the same day, yet in Experiment 4 (low rainfall site), only the two earliest application dates (27 June and 10 July) significantly reduced Ggt carry-over. This contrasts with Experiment 3 (high rainfall site), where herbicides applied up to 9 August reduced Ggt carry-over.

This observation suggests that in low rainfall environments herbicides need to be applied earlier than in higher rainfall environments. This finding agrees with work by Kidd (1995) who conducted an experiment on a 400 mm annual rainfall site, and measured significant reductions in carry-over of Ggt only when herbicides were applied by 14 June. The reason for this is not fully understood but is thought to relate to the length of time in which the soil is sufficiently moist for microbial activity to break down Ggt-infected material (MacNish and Dodman 1973; Garrett 1981; Thorn 1983; Macleod and MacNish 1989). In low rainfall environments soil is moist for less time, thus necessitating earlier death of grasses.

Data from Experiment 3 also suggests that in some areas (higher rainfall sites), late applications of herbicides (1st week in August), can still achieve significant reductions in

carry-over of Ggt. The probable reason for this result in 1991, is the longer than normal growing season extending the opportunity for microbial breakdown of infected material.

Other than in Experiment 4 (low rainfall site), the relationship between Ggt carry-over and yield was not consistent. In only one out of three years (Experiment 2) was there a relationship between Ggt carry-over measured and subsequent grain yield, even though significant reductions in Ggt carry-over were measured (by either soil bioassay or wheat root rating). This suggests that other influences were impacting on yield, possibly the presence of *Microdocium bollei* (Sprague) de Hoog and Hermanides-Nijhof, which has been reported as a biological control organism (Kirk and Deacon 1987), but these factors are largely unexplored in Australian agricultural environments. Mr D. K. Roget (pers. comm.), has carried out studies on the same site as one of my experiments (Kapunda site) over 14 years and found that the effect of Ggt infection on grain yield has been unpredictable. This then supports the notion of other influences impacting on grain yield in Experiments 1 and 3.

CHAPTER 3

VARIATION IN THE ABILITY OF COMMON ANNUAL PASTURE GRASSES TO CARRY OVER *GAEUMANNOMYCES GRAMINIS* var. *TRITICI*

3.1 General introduction

Early research examining the relative importance of various grass genera on carry-over of Ggt reported on field observations of disease levels in wheat following pastures dominant in common grass genera (Samuel 1923; Carne and Campbell 1924; Griffiths 1933; Garrett 1934; Chambers 1960). Most reports commented on the significant yield losses of wheat following pastures dominant in *Hordeum* spp., with *Bromus* and *Vulpia* spp. also considered likely to contribute to Ggt infection in a subsequent crop. Reports were less consistent on the role of *Lolium rigidum* with a number of reports suggesting low levels of Ggt infection in wheat crops following pastures dominant in *Lolium rigidum* and some workers suggesting that *Lolium rigidum* may have some resistance to Ggt (Griffiths 1933; Sims 1958; Banyer 1966). However, other reports suggest that *Lolium rigidum* may be a significant host (Osborn 1924; Anon. 1937; Chambers and Flentje 1967).

A permanent rotation trial at the Mallee Research Station, Walpeup, Victoria, (Sims *et al.* 1961) was assessed for symptoms of Ggt infection in the wheat phase which was then related back to the previous cropping history. With deadheads used as a measure of Ggt infection, it was found that deadheads were highest in wheat that followed pastures dominant in *Hordeum* spp. compared to wheat following a barrel medic/*Lolium rigidum* ley. No assessments of pasture composition or other grass genera was given so it is difficult to reliably attribute these Ggt results to just the grasses mentioned in the paper.

A field experiment conducted at Esperance, Western Australia, in which a pasture carrying Ggt was oversown with pure swards of grasses showed that Ggt was carried over at a high level on *Hordeum* and *Bromus* spp., but not on *Vulpia* spp. or *Lolium rigidum* and that subsequent yields of wheat reflected this Ggt carry-over (Chambers and Flentje 1968). Also, in Western Australia, Macleod and McNish (1989) stated that *H. leporinum* was found to be the most susceptible grass followed closely by *Lolium rigidum* and *Vulpia* spp. with *Bromus* spp. being least susceptible but no research results were provided to support this statement.

Given the lack of specific field-based research on the relative importance of various annual grass genera to host Ggt, surveys of a wide range of pasture sites in South Australia and Victoria were made to determine the role of common annual pasture grasses in the carry-over of Ggt. The surveys were designed to: (i) measure Ggt carry-over occurring on different grass genera in annual pastures in South Australia and Victoria and (ii) quantify the contribution of individual genera to the carry-over of Ggt.

3.2 Survey of Ggt carry-over on grass genera in annual pastures

3.2.1 Introduction

Previous research on the role of grass genera in annual pastures and carry-over of Ggt has relied on site-specific and season-specific data or observations from field sites (Cass Smith 1960; Sims *et al.* 1961) or experimental procedures using artificial inoculum in pure sown swards of grass genera. Data presented in this section is based on a broad survey of sites with mixes of grass genera over a range of environments to assess the carry-over potential of annual grasses under natural environment and soil type conditions.

Four grass genera, *Hordeum* spp., *Bromus* spp., *Vulpia* spp., and *Lolium rigidum* were targeted in this study as these are the most widespread pasture grasses in cereal-growing districts of southern Australia.

3.2.2 Experimental Procedure

Sampling sites were selected on the basis that these: (i) had a minimum of two target grass genera, (ii) had been in pasture for one or two years and (iii) were in a pasture-crop rotation. In Survey 1 (1990/91), 581 grass crowns were assessed in a sample of 9 pasture sites in South Australia (Fig. 3.1a). In Survey 2, (1993/94), 843 crowns were assessed in a sample of 10 sites in South Australia and the two composite sites in Victoria (Fig. 3.1b). Five sites chosen in Victoria had too few crowns of some grass genera for comparisons to be valid, so these were grouped into two composite sites on the basis of similarity of soil and paddock history.

Grass crown and bulk soil sampling procedure: During summer, crowns were collected across each pasture paddock at 15-20 sample points. At each sample point, all crowns in 0.3 m^2 were collected by spade to a depth of approximately 5 cm. Soil was also collected from each sample point to a depth of approximately 5 cm for assessment of a background level of Ggt in the soil (see Soil Bioassay method, page 34).

Crown bioassay: Soil was shaken from the crowns and roots trimmed to 1 cm. The weight of each grass crown was recorded. The crowns were placed in free draining seedling punnets, with 6 compartments of 50 cc capacity. Washed sand was placed in the bottom third of the compartments, the crown was placed on this and covered with 2 cm of washed sand. Three wheat seeds (cv. Spear) were placed on this layer and covered with a further 2 cm of washed

sand. Punnets were placed on a bed of moist sand and kept in a growth cabinet at 15^0 C with 12 hours of light per day (Plate. 3.1).

The punnets were watered with sterile water every four days during the first two weeks. At 10 days, wheat plants were thinned to one plant per compartment. After two weeks, sterile water mixed with a 10% strength nutrient solution (Hoagland and Arnon 1950) was used for watering. The wheat plants were harvested after four week's growth and their roots were assessed for Ggt infection (see assessment of Ggt infection) (Plates 3.2 and 3.3).

Soil bioassay: A sub-sample of 300 g of the soil sampled from each site was placed on 100 g of washed sand in a 500 ml pot. Five wheat grains (cv. Spear) were sown at 1 cm below the soil surface, and the soil moistened to 15% soil moisture (based on the weight of air dried soil), and maintained at this level by regular watering to weight. The pots were placed in a 15^0C water bath in a glasshouse. One week after emergence, the plants were thinned to three plants per pot and harvested after four week's growth and the roots assessed for Ggt infection (see assessment of Ggt infection).

Assessment of Ggt infection: Seminal roots of each wheat plant were assessed for the characteristic discolouration of the stele indicating the presence of Ggt. The number of seminal roots infected was calculated as a percentage of the total number of seminal roots per plant.

Identification of grass genera assessed in the surveys: Apart from *Lolium rigidum*, grasses assessed in the surveys were identified to the level of genus from the above-ground material attached to the crowns. Crowns of *Hordeum* spp. were found to be the most prevalent genus

sampled in both Surveys. There were 488 crowns of *Hordeum spp.*, followed by *Lolium rigidum*, with 360 crowns, *Bromus spp.* with 277 crowns and *Vulpia* spp. with 299 crowns.

Statistical Analysis : In Survey 1, there were unequal numbers of crowns of each grass genus examined at each site and so it was necessary to weight the observations by the inverse of the number of crowns sampled to give equal emphasis at each site. No replication was used. Analysis of variance was used to compare the sites and the grass genera.

In Survey 2, 24 crowns per grass genus were randomly selected from the total pool of crowns sampled. This number was then separated into groups of 6 crowns (1 punnet) giving 4 replicates. A generalised linear model was fitted. The number of infected crowns was modelled using a generalised linear model which gave estimates of the Ggt infection rates for each grass both at each site and across all sites.

SURVEY 1. Summer of 1990-91

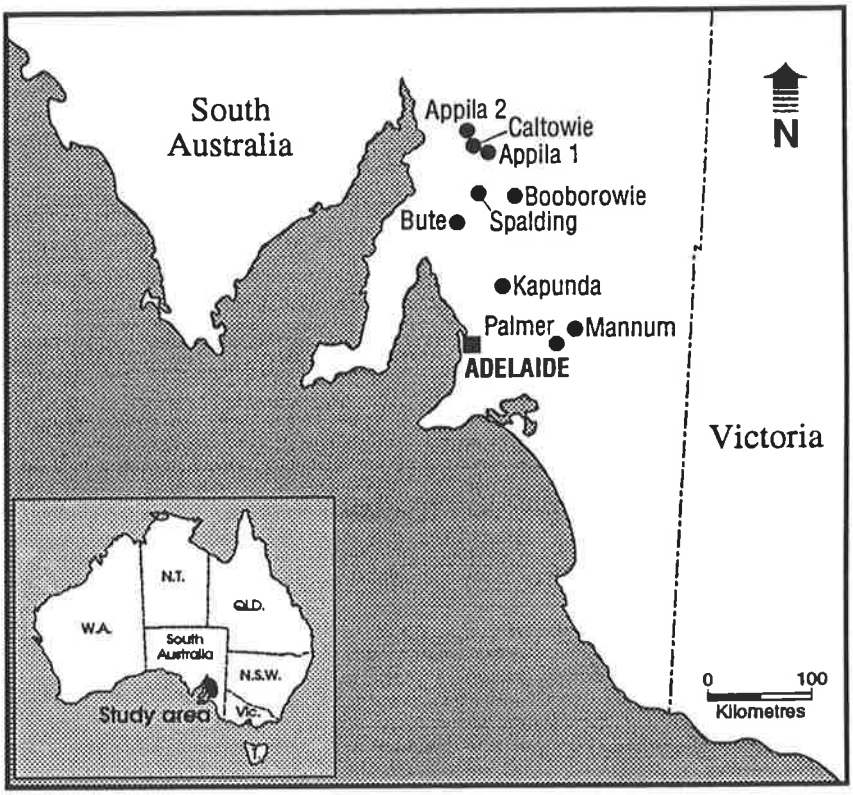

Figure 3.1a.

SURVEY 2. Summer of 1993-94

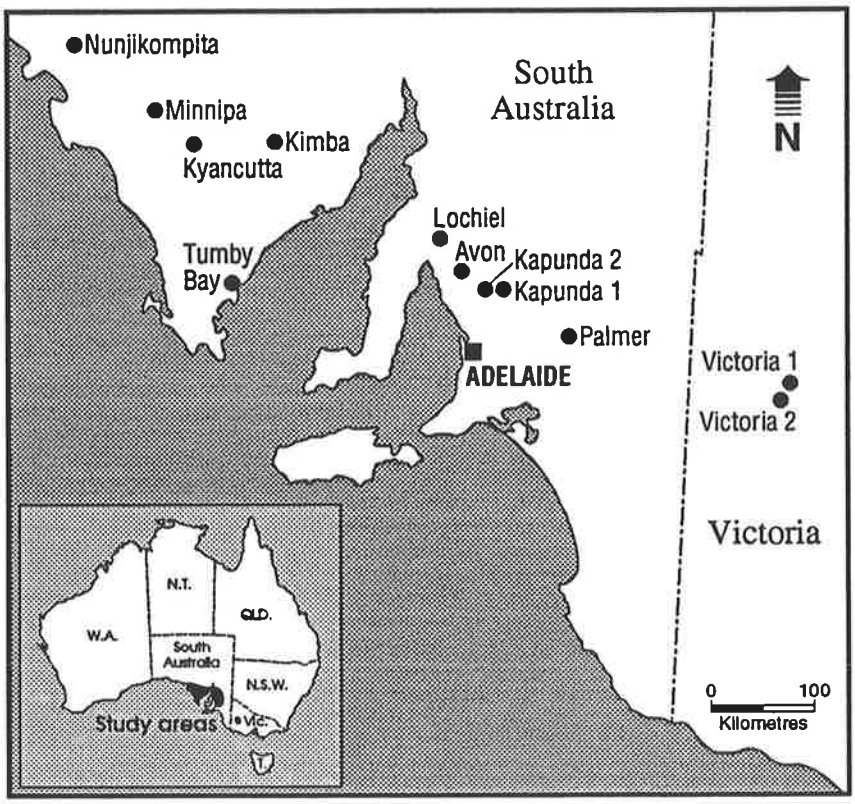

Figure 3.1b.

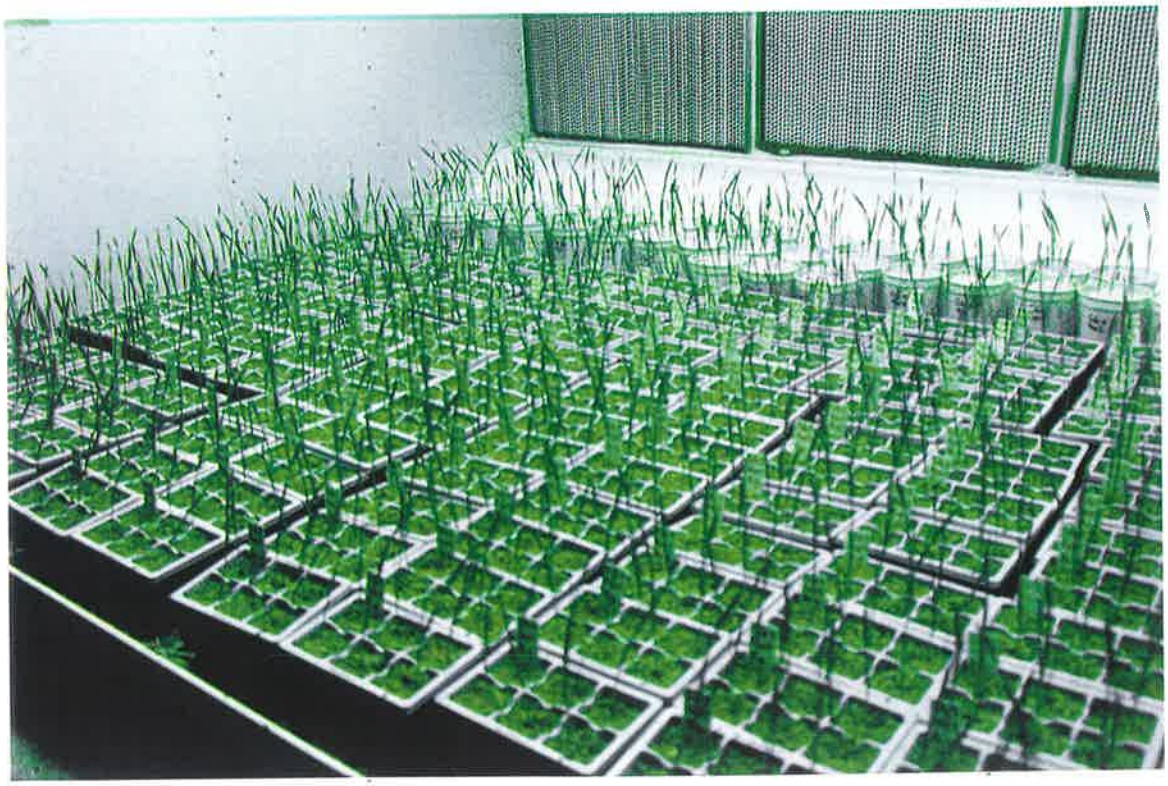

Plate 3.1 **Showing wheat growing in punnets used for bioassay of grass crowns collected in Surveys 1 and 2**

Plate 3.2 Showing wheat shoots and roots which have grown over crowns of various grass genera collected in Surveys 1 and 2

Plate 3.3 Showing close-up view of wheat roots growing over a grass crown

3.2.3 Results

Soil bioassay: Soil bioassay data (Table 3.1) indicate wide variation between sample sites in levels of Ggt surviving in the sample years of 1990/91 and 1993/94.

Crown bioassay: The levels of Ggt infection on wheat roots grown over crowns of various grass genera showed that there were significant differences, both between sites sampled and grass genera in the carry-over levels of Ggt in both surveys (Table 3.2). In Survey 1, where there were significant differences between grass genera in the level of Ggt carry-over infection arising from grass crowns, *Hordeum* spp. were highest or equal highest in 7 out of 8 sites. At only one site (Booborowie) was Ggt infection from *Hordeum* spp. lower than another grass genus (*Vulpia* spp.). In Survey 2, carry-over was highest or equal highest with *Hordeum* spp. in 4 out of 7 sites. There were no sites that contained a grass species that had significantly greater levels of Ggt carry-over than *Hordeum* spp..

Ggt carry-over on *Bromus spp.* varied greatly between Surveys. In Survey 1, *Bromus* spp. carried less Ggt than other genera, except at the Mannum site, where it was equal highest with *Hordeum* spp. At three sites in Survey 2 (Kyancutta, Nonjikompita and Victoria (b)), Ggt carry-over levels on *Bromus* spp. were higher than with *Lolium rigidum,* and at two sites (Victoria (b) and Palmer), higher compared to *Vulpia* spp. (Table 3.2).

Vulpia spp. carried over the highest level of Ggt at the Booborowie site in Survey 1, but this was the only occasion in both Surveys (Table 3.2) that *Vulpia* spp. were so prominent.
Ggt carry-over following *Lolium rigidum* was lowest (or not significantly different from the lowest) at three sites in Survey 1 and at 6 sites in Survey 2. Overall, *Lolium rigidum* was least

able to carry over Ggt and subsequently infect wheat roots (5.9% seminal root infection), in comparison to *Hordeum* spp. which was most able to carry over Ggt (13.2 % seminal root infection). *Bromus* spp. and *Vulpia* spp. were intermediate in ability to carry over Ggt with 9.6% and 7.2% seminal root infection respectively, (Table 3.2).

Table 3.1 Soil bioassay for Ggt infection on wheat roots after 4 weeks growth in soil taken from crown sampling points

Ggt infection on wheat roots (% seminal root infection per plant)			
Survey 1 (1990/91)		Survey 2 (1993/94)	
Sites		Sites	
Appila (a)	10.0	Avon	1.0
Appila (b)	17.8	Kapunda (a)	0.0
Booborowie	6.7	Kapunda (b)	10.0
Bute	4.4	Kimba	18.3
Caltowie	31.3	Kyancutta	24.4
Kapunda	84.4	Locheal	0.0
Mannum	19.9	Minnipa	11.1
Palmer	6.7	Nunjikompita	0.0
Spalding	4.4	Palmer	2.7
		Tumby Bay	4.0
		Victoria (a)	11.4
		Victoria (b)	57.5
Mean	20.6		
		Mean	11.7

Table 3.2 Ggt infection on roots of wheat sown over the crowns of four grass genera collected in two surveys of pasture sites in South Australia and Victoria

	Seminal root infection (%, +/- s.e)			
	Lolium rigidum	*Bromus spp.*	*Vulpia spp.*	*Hordeum spp.*
Survey 1 (1990-91)				
Sites:				
Appila (a)	8.8 (3.2)	3.9 (2.3)	~	8.6 (5.5)
Appila (b)	1.6 (1.0)	~	~	29.7 (13.2)
Booborowie	16.6 (6.2)	16.0 (5.7)	33.6 (3.8)	8.8 (3.3)
Bute	5.0 (3.5)	2.5 (2.5)	~	32.5 (18.9)
Caltowie	8.0 (3.8)	~	5.0 (3.0)	17.3 (3.5)
Kapunda	~	5.0 (2.2)	1.2 (0.1)	9.2 (3.6)
Mannum	~	15.7 (15.7)	3.1 (3.1)	17.3 (9.3)
Palmer	7.9 (6.1)	0.0	0.0	10.7 (9.9)
Spalding	0.7 (0.7)	5.1 (3.2)	11.4 (4.1)	16.7 (9.2)
Mean	6.7 (2.1)	7.9 (2.0)	9.4 (1.9)	17.2 (1.8)
Survey 2 (1993-94)				
Sites:				
Avon	7.5 (4.8)	~	~	15.0 (6.4)
Kapunda (a)	1.7 (1.7)	~	1.7 (1.2)	0.9 (0.9)
Kapunda (b)	~	~	11.3 (4.1)	8.5 (3.7)
Kimba	18.3(7.6)	~	~	13.5 (5.5)
Kyancutta	2.4 (2.4)	12.5 (6.4)	~	7.9 (4.6)
Lochiel	0.0 (0.0)	~	~	2.6 (2.6)
Minnipa	0.9 (0.9)	5.4 (3.2)	~	15.2 (6.2)
Nunjikompita	0.0	1.7 (1.3)	~	0.4 (0.4)
Palmer	~	8.2 (4.5)	1.7 (1.2)	3.9 (2.2)
Tumby Bay	16.3 (5.4)	~	~	12.9 (4.6)
Victoria (a)	0.0	0.8 (0.8)	0.9 (0.9)	4.2 (3.4)
Victoria (b)	7.5 (3.0)	30.4 (8.5)	8.3 (4.5)	28.3 (6.0)
Mean	5.0 (1.4)	11.3 (1.8)	4.9 (2.0)	9.1 (1.2)
Mean of Survey 1 and 2	5.9	9.6	7.2	13.2

~ = Grass species not present

Relationship between Soil bioassay and Crown bioassay: In Survey 2 there was a significant relationship between the level of Ggt measured in a soil bioassay using bulk soil collected at each site (Table 3.1) and the level of Ggt infection measured on the crowns of *Hordeum* spp. and *Bromus* spp. at each site (Table 3.3). There was no relationship in Survey 1.

Table 3.3 Relationship between the level of Ggt infection measured on wheat grown in a soil bioassay and the level of Ggt infection measured on wheat grown over crowns of grass genera

	Survey 1				Survey 2			
	slope	s.e.	t	r^2	slope	s.e.	t	r^2
Hordeum spp.	- 0.093	0.127	-0.73	n.s.	0.395	0.096	4.13	0.572*
Bromus spp.	- 0.0064	0.096	-0.07	n.s.	0.493	0.076	6.53	0.874**
Lolium rigidum	- 0.015	0.242	-0.06	n.s.	0.090	0.125	0.72	n.s.
Vulpia spp.	- 0.140	0.177	-0.177	n.s.	0.098	0.101	0.97	n.s.

* P< 0.05, ** P< 0.01
n.s. - Not significant

Effects of crown weight on carry-over levels of Ggt: In Survey 1, *Hordeum* spp. crowns were significantly heavier than *Bromus* spp. or *Lolium rigidum* crowns, all of which were heavier than crowns of *Vulpia* spp. and in Survey 2, *Hordeum* spp were significantly heavier than crowns of *Vulpia* spp. (Table 3.4). The key result from Table 3.4 is that there is a significant positive relationship between crown size and Ggt infection for *Hordeum* spp.. There is no relationship between crown size and Ggt infection for any other genus tested.

Table 3.4 Estimates of effects of crown weight on Ggt infection of wheat grown over crowns of grasses

	Survey 1				Survey 2			
	Crown weight (mg)	Slope	t		Crown weight (mg)	Slope	t	
Hordeum spp.	59.8 (4.0)	0.0037 (0.0009)	4.05	**	111.4 (8.3)	0.0012 (0.0003)	3.51	**
Bromus spp.	36.1 (4.5)	- 0.0078 (0.0036)	-2.16	n.s	121.4 (12.4)	0.0013 (0.0007)	1.87	n.s
Lolium rigidum	32.6 (4.5)	- 0.0044 (0.0025)	-1.79	n.s	116.4 (9.4)	0.0013 (0.0006)	2.22	n.s
Vulpia spp.	23.8 (4.3)	- 0.0040 (0.0029)	1.73	n.s	83.9 (14.1)	- 0.0013 (0.0017)	-0.76	n.s

In Survey 1, crowns of *Hordeum* spp. and *Vulpia* spp. weighing more than 100 mg carried over significantly greater levels of Ggt compared to crowns which weighed less than 20 mg. In Survey 2, *Lolium rigidum* crowns of 100-200 mg carried more disease than crowns weighing less than 20 mg. (Figs 3.2 and 3.3).

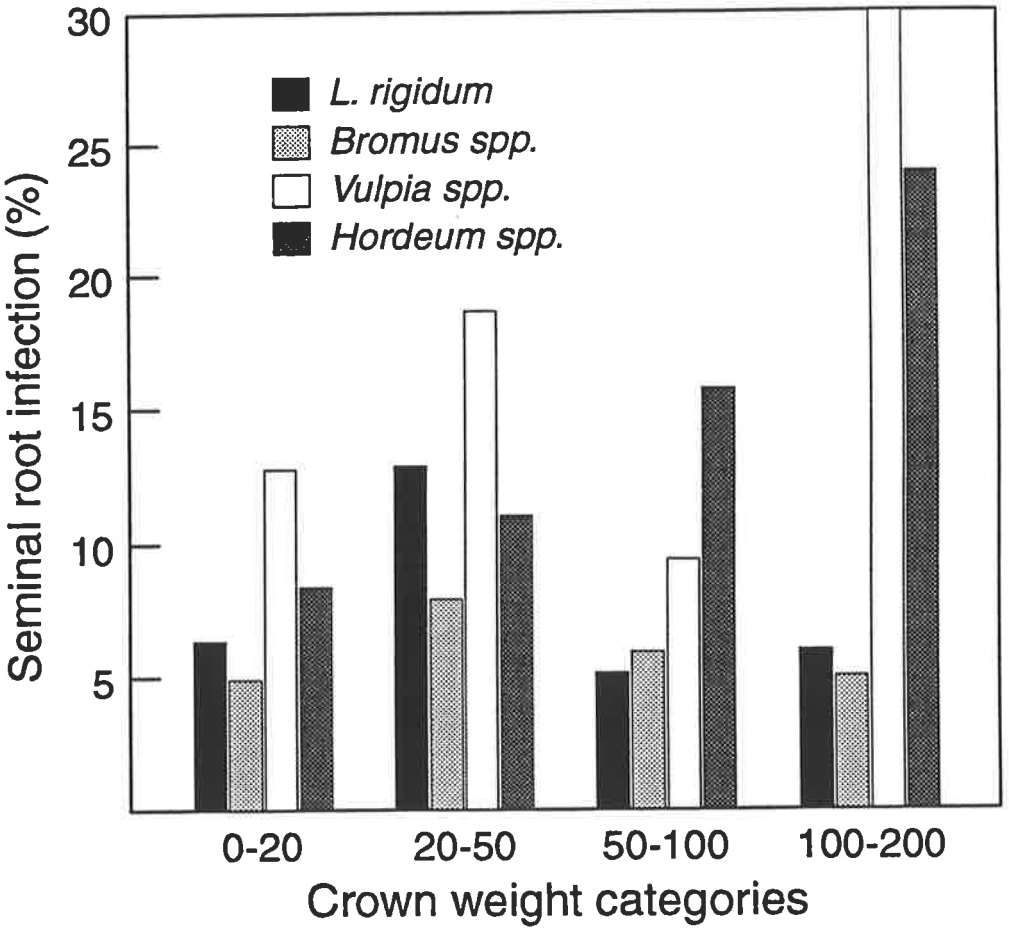

Figure 3.2 Survey 1: Ggt infection on wheat roots grown over a range of crown weight categories (Data on per plant basis).

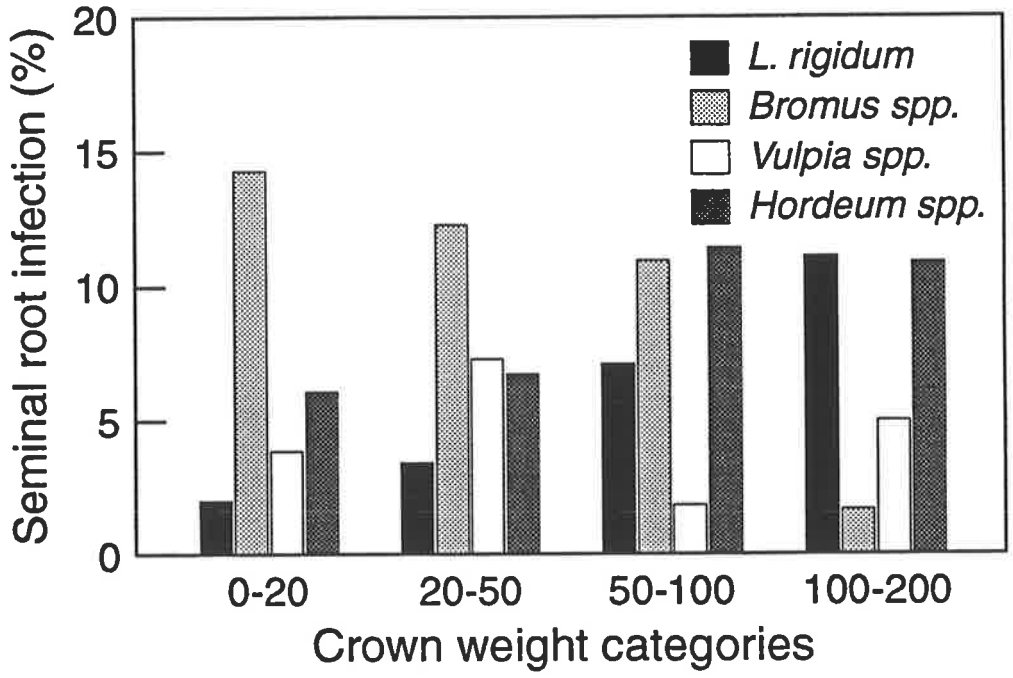

Figure 3.3 Survey 2: Ggt infection on wheat roots grown over a range of crown weight categories (Data on per plant basis).

3.2.4 Discussion - Surveys 1 and 2

This study is the most extensive undertaken in Australia, covering 21 field sites over a distance of some 1500 km between the most eastern and western sites. The results indicate that although all grass genera (*Lolium rigidum, Bromus* spp., *Hordeum* spp. and *Vulpia* spp.), hosted Ggt, there were significant differences between the genera.

Hordeum spp. carried the most Ggt in Survey 1 and was equal highest with *Bromus* spp. in Survey 2. *Bromus* spp. and *Vulpia* spp. crowns generally carried less disease than *Hordeum* spp. with *Lolium rigidum* least able to carry-over Ggt as shown in both surveys. There were a small number of sites where the Ggt infection of the various grasses did not follow these trends.

The changing of order of the ability of grass genera to carry over Ggt, demonstrated by previously reported work and these bio-assay results, suggests that a number of factors impact on the ability of grasses to host and carry-over Ggt. These factors may include, moisture and fertility differences between sites, genetic variation within selections of grass genera resulting in a range of resistance or susceptibility to Ggt infection (R. Inwood - unpublished data), variation in Ggt pathotypes found between sample sites (Harvey 1994), seasonal conditions affecting growth of the fungus and differences between genus crown size, which could affect the rate of decomposition of grass crowns and subsequent survival of Ggt inoculum over summer (Chambers and Flentje 1968; Chambers 1971; Hornby 1975).

Results from these surveys are consistent with those of Macleod and MacNish (1989) who reported that *Hordeum* spp. was the most susceptible common grass (and therefore most able

to carry over Ggt), but differ in that they reported *Bromus* spp. as being less susceptible than *Vulpia* spp. and *Lolium rigidum*. In the data presented here, *Bromus* spp. are clearly able to carry-over greater levels of Ggt than *Lolium rigidum,* and is similar in this ability to *Vulpia* spp.

The finding that *Lolium rigidum* is least able to carry-over Ggt and subsequently infect wheat roots is consistent with Australian field-based research on Ggt persistence on various grass genera (Cass Smith 1960; Sims *et al.* 1961; Banyer 1966; Chambers and Flentje 1968).

In Survey 2, the level of Ggt disease measured on the crowns of *Hordeum* and *Bromus* spp., was representative of disease measured in the soil in the immediate vicinity of these crowns, but this was not the case in Survey 1. Conceivably, significant levels of Ggt infection were present at sites in Survey 1, but the disease may have occurred on roots below the crowns, so that the immediate vicinity of these crowns had low levels of Ggt infection.

Previous research which investigating the impact of crown size on carry-over of Ggt has shown that large crowns represent a large food reserve for the pathogen and can be expected to house more mycelium of the fungus able to initiate subsequent infection (Wilkinson and Cook 1985). Infectivity of propagules decreased as they aged and decomposed, but usually the larger fragments remained infectious longer (Hornby 1975). This was apparent in this present study when crown weight data for both surveys were analysed across all grass genera. However, when an analysis was carried out on the individual grass genera, these findings only applied to *Hordeum* spp. and were inconsistent for other grass genera.

Lester (1981) commented on the "dearth of control measures other than rotation", but results presented here point to the potential of encouraging dominance of *Lolium rigidum* in pastures in preference to *Hordeum* spp. or *Bromus* spp. and *Vulpia* spp., as a possible means of minimising persistence of Ggt from the pasture phase to the cereal phase.

3.3 Impact of sown swards of different grass genera on subsequent Ggt infection of wheat roots

3.3.1 Introduction

The following series of experiments were designed to examine the ability of the four common grass genera to carry over Ggt in both pure (1991 Experiment) and mixed swards (1992 Experiment), using natural and artificial Ggt inoculum.

3.3.2 Experimental Procedure - 1991

Hordeum spp., *Bromus* spp. *Vulpia* spp. and *Lolium rigidum* were sown in pure swards, at 1650, 930, 10 000 and 2000 seeds per sq m respectively. These densities were selected to approximate those found in grassy pastures. A bare ground treatment (control) was also included. Ggt inoculum (Ggt 500) on dead ryegrass seed was used at three rates; 0, 3150 (6.3 g) and 6300 (12.6 g) propagules per m^2, the inoculum was distributed evenly at a depth of 5 cm. Plots of 1 m^2 were established at two sites; at Kapunda, on a Red Brown Earth soil with 495 mm annual rainfall and at Avon on a calcareous sandy loam, typical of "the Mallee", with 335 mm annual rainfall. Plots were set up in a Randomised Complete Block design with four replicates.

Plots at Kapunda were maintained pure with regular weeding (Plates 3.4(a) and 3.4(b)). At Avon, plots had volunteer *Lolium rigidum* which meant that the plots were actually a mixture of the sown grass and this volunteer *Lolium rigidum* (Table 3.5).

Grasses grew for the full season. Over summer, 5 random samples of soil were taken by shovel from each plot, to a depth of 5 cm, and bioassayed for Ggt as outlined earlier in this Chapter (page 34). In the autumn following the "opening rains", wheat (cv. Spear) was direct-drilled over the plots and 10 wheat plants per plot were sampled at 8 weeks and assessed for Ggt infection on the basis of percent seminal root showing characteristic discolouration of the stele.

Statistical analysis was by analysis of variance.

Plate 3.4 (a) Showing layout of field experiment at Kapunda

Plate 3.4 (b) Showing close-up view of pure swards of grasses at Kapunda experiment site

3.3.3 Results

At both sites, *Lolium rigidum* and *Vulpia* spp. carried the least Ggt with less infection on roots of wheat sown in the following year compared to *Hordeum* spp. and *Bromus* spp. Grain yield were highest following *Lolium rigidum* and *Vulpia* spp.. This was the case in both pure sown sward or mixed sward situations. Ggt infection levels were higher at the Avon site.

At the Avon site (Table 3.6), an increase in Ggt carry-over was measured in all treatments at low and high inoculum levels, compared to the zero level. In-addition, there was a distinction between low and high inoculum levels and subsequent Ggt carry-over for *Lolium rigidum* and the Bare ground treatment (which was invaded by volunteer *Lolium rigidum*), compared to the zero level of inoculum.

The bare treatment at Avon effectively became a comparison between a pure sward of naturally occurring (volunteer) *Lolium rigidum* and a mixture of volunteer and sown *Lolium rigidum* selections. Measurement of Ggt infection on wheat roots showed that the mixture of volunteer and sown *Lolium rigidum* was less able to subsequently infect wheat roots than a pure stand of volunteer *Lolium rigidum*. This points to possible differences between populations (genotypes) of *Lolium rigidum* in the ability to host and carry-over the Ggt fungus.

At the Kapunda site (Table 3.7), Ggt carry-over after *Hordeum, Bromus spp.* and the Bare ground treatment, increased at the low inoculum level compared to the zero level, but there

was little distinction in carry-over levels between low or high inoculum levels. In contrast, there was no significant effect of inoculum rate for *Lolium rigidum* and *Vulpia* spp.

The "bare" ground treatment (fallow) at Kapunda gave the least carry-over of Ggt, demonstrating that this fungus is not maintained in soil without a host.

Table 3.5 Grass genera content of plots at Avon, based on a duplicate assessment of percent area of cover of genera or bare ground

Treatment	Ggt inoculum level	Genera in plot (%)				
		Hordeum spp.	*Bromus* spp.	*Vulpia* spp.	*Lolium rigidum*	Bare
Hordeum	0	79.3	0.0	0.0	10.0	10.7
Hordeum	Low	23.8	0.0	0.0	46.2	30.0
Hordeum	High	17.5	0.0	0.0	30.0	52.5
Bromus	0	1.2	52.5	0.0	36.3	10.0
Bromus	Low	0.0	26.3	0.0	43.7	30.0
Bromus	High	2.5	28.8	0.0	43.7	25.0
Vulpia	0	5.0	1.3	46.3	37.4	10.0
Vulpia	Low	0.0	0.0	50.0	38.7	11.3
Vulpia	High	1.3	0.0	51.3	36.1	11.3
L. rigidum	0	5.0	0.0	0.0	62.5	32.5
L. rigidum	Low	3.8	0.0	0.0	58.7	37.5
L. rigidum	High	1.3	0.0	0.0	52.4	46.3
Bare	0	6.3	2.5	0.0	70.0	21.2
Bare	Low	5.0	3.8	0.0	65.0	26.2
Bare	High	6.3	0.0	0.0	66.3	27.4
L.S.D (P = 0.05)		9.0	7.6	10.4	19.7	19.4

Table 3.6 Impact of pure grass swards mixed with volunteer *Lolium rigidum* on subsequent Ggt infection of wheat roots and grain yield at Avon

Treatment	Ggt inoculum level	Soil bioassay (% seminal root infection)	Mean	Plant assessment (% seminal root infection)	Mean	Grain yield (g/m^2)	Mean
Hordeum spp.+	0	9.1		8.2		219	
	Low	55.2	43.0	72.5	50.2	125	165
	High	64.7		69.9		151	
Bromus spp.+	0	0.0		14.4		254	
	Low	85.7	51.2	80.3	56.2	90	184
	high	68.0		73.6		206	
Vulpia spp.+	0	6.0		6.9		314	
	Low	60.2	41.5	33.4	27.2	281	296
	High	58.3		41.3		290	
Lolium rigidum+	0	2.5		2.2		350	
	Low	47.8	33.2	13.6	18.3	280	300
	High	49.2		38.9		269	
Bare ground+~	0	5.8		5.6		380	
	Low	56.8	42.5	28.8	30.1	310	347
	High	64.7		55.9		350	
L.S.D (P= 0.05)		13.1		11.6		38.5	

+ invaded by volunteer *Lolium rigidum*

~ although this treatment was intended to be maintained free of all vegetation, this was not possible due to invasion by volunteer *Lolium rigidum*

Table 3.7 Impact of sown swards of grass genera on subsequent Ggt infection of wheat roots and grain yield at Kapunda

Treatment	Ggt inoculum level	Soil bioassay (% seminal root infection)	Mean	Plant assessment (% seminal root infection)	Mean	Grain yield (g/m^2)	Mean
Hordeum spp.	0	17.5		29.1		256	
	Low	69.2	51.6	24.2	29.3	254	266
	High	68.0		34.4		287	
Bromus spp.	0	3.8		9.1		271	
	Low	71.7	43.3	31.3	24.4	250	279
	High	54.2		32.7		313	
Vulpia spp.	0	3.8		3.5		476	
	Low	4.6	5.2	3.2	3.4	446	447
	High	7.1		3.4		416	
Lolium rigidum	0	3.8		1.4		341	
	Low	7.3	6.9	1.3	4.4	350	330
	High	9.6		10.4		294	
Bare ground	0	5.0		5.8		350	
	Low	25.2	15.8	13.7	8.6	309	334
	High	17.0		6.3		341	
L.S.D (P= 0.05)		10.1		9.4		34	

This data is discussed in-conjunction with the next section (3.4) which reports on the "Impact of sown swards of mixed grass genera on subsequent Ggt infection of wheat roots".

3.4 Impact of sown swards of mixed grass genera and medic on subsequent Ggt infection of wheat roots

3.4.1 Introduction

Previous research on the role of grass genera and carry-over of Ggt has been conducted in controlled experiments using pure sown swards of grasses often using artificial inoculum sources or have been observations of mixed genera with little experimental procedure. While these techniques have produced some valuable data, the weakness of these approaches is that it is rare that grass genera occur in pure swards and also in the field observations there is a lack of experimental control. This next experiment seeks to assess the validity of the concept first mooted by Garrett (1934) of replacing "high host" grass genera with " low host" genera.

3.4.2 Experimental Procedure - 1992

During 1992, a field site at Palmer, South Australia, was selected for its negligible background level of Ggt (due to a previously sown vetch crop). A soil bioassay subsequently confirmed zero levels of Ggt. Palmer (34° 51′ S, 139° 10′ E) is in a low rainfall environment with a calcareous sandy loam (calcic xerosol), identified in the Northcote Key as Gc 1.12 with a pH of 8.1 (in water) and an average annual rainfall of 335 mm. P.V.C. cylinders with a cross sectional area of 0.075 m^2 were pressed 12 cm into the ground, leaving 3 cm exposed above the soil surface to minimise an influx of local grass seeds.

Hordeum spp., *Vulpia* spp. and *Lolium rigidum* were sown in either pure swards or mixed swards of 70% grass with 30% medic. The percentage of grass or medic sown was calculated on the 100% rate of what would "normally" be expected in a naturally-occurring pasture (see page 49). The number of seeds for each grass or medic for a 100% sward are: 120 seeds (1.3

g) *Hordeum* spp., 700 seeds (0.15 g) *Vulpia* spp., 140 seeds (0.3 g) *Lolium rigidum* and 960 seeds of Paraggio medic (2.5 g). Also included, for comparison of the threshold of "high host" genera, was a treatment of 60 % *Lolium rigidum* mixed with 30 % medic and either 5 or 10 % *Hordeum* spp. (based on 700 seeds /m^2).

Natural Ggt inoculum (Plate 3.5), was collected from a site known to have high levels of Ggt infected wheat roots and ground to a uniform size range of between 2 and 5 mm. Cylinders with added Ggt inoculum treatments had 10 g of inoculum banded at a depth of 5 cm and the 5 cm of surface soil replaced. All seeds were sown in late April, at 1 cm depth and the grasses grown to maturity. In the following season, 15 wheat seeds (cv. Spear) were sown in mid April 1993. Soil (1 kg) was taken from each cylinder during the summer periods of 1992, 1993 and 1994 and bioassayed for Ggt, with two replicates for each cylinder, in the manner previously described. There were four cylinders per treatment.

3.4.3 Results

Table 3.8 Soil bioassay results of treatments involving both pure and mixed sown swards of grass genera using natural inoculum of Ggt.

Pasture composition within cylinder (%)			Soil bioassay (% seminal root infection on wheat roots)		
			Soil collection time for bioassay		
Medic	Grass genera	Inoculum	2/12/92	18/2/93	4/1/94
0	0	-	1.7	1.6	0.0
0	0	+	15.8	1.1	8.0
100	0	-	0.0	0.0	0.0
100	0	+	4.2	1.0	0.0
0	100 *Vulpia* spp.	-	0.0	0.0	0.0
0	100 *Vulpia* spp.	+	25.0	1.0	7.2
0	100 *Hordeum* spp.	-	55.7	44.7	65.0
0	100 *Hordeum* spp.	+	85.4	41.5	20.3
0	100 *Lolium rigidum*	-	0.0	0.0	0.0
0	100 *Lolium rigidum*	+	4.8	0.0	0.0
30	70 *Vulpia* spp.	-	16.0	1.0	1.3
30	70 *Vulpia* spp.	+	29.9	0.0	0.0
30	70 *Hordeum* spp.	-	59.1	33.3	71.3
30	70 *Hordeum* spp.	+	77.3	40.9	49.2
30	70 *Lolium rigidum*	-	6.7	0.0	0.0
30	70 *Lolium rigidum*	+	6.9	2.7	1.7
30	60 *Lolium rigidum* and 10*Hordeum* spp.	-	0.0	0.0	0.0
30	60 *Lolium rigidum* and 10*Hordeum* spp.	+	42.5	2.3	18.0
30	60 *Lolium rigidum* and 5*Hordeum* spp.~	-	8.3	0.0	2.5
30	60 *Lolium rigidum* and 5*Hordeum* spp.~	+	20.1	6.3	8.0
L.S.D (p=0.05)			33.0	17.4	17.3

~ Where 5% *Hordeum* spp. was used, the total cylinder density was 95% with the remaining 5% of area being bare ground.

In year one, only the treatments with high numbers of *Hordeum* spp. (100% or 70% pasture composition) had significant disease levels and these disease levels were maintained over the three years of the trial. Swards comprising 70% *Vulpia* spp. gave elevated levels of Ggt infection but this was not sustained over successive summers. *Lolium rigidum* was never a significant carrier of Ggt (Table 3.8).

The impact of added Ggt inoculum varied between grasses. With the addition of natural Ggt inoculum, significantly higher levels of infection occurred on wheat roots grown after *Hordeum* spp. and *Vulpia* spp. but not with *Lolium rigidum*. There were indications that, with added natural inoculum, 10% *Hordeum* spp. was sufficient to cause significant increases in Ggt infection on roots of the following wheat plants.

The addition of 30% medic had no influence on the development or carry-over of Ggt.

Plate 3.5 Showing natural Ggt inoculum used in Experiments

3.4.4 Discussion - experiments from sections 3.3 and 3.4, involving pure and mixed sown swards of grass genera

The results from both pure sown swards and mixed sown sward treatments, showed that *Hordeum* spp. is most able to carry over Ggt, subsequently infecting wheat roots, but also that the fungus persists best on this genus. This data confirms the view that *Hordeum* spp. is the main contributor to the overall Ggt carry-over burden of pastures.

Vulpia spp. and *Lolium rigidum* in pure swards (Kapunda trial site) had a low carry-over capability, but at the Avon trial site, where both treatments were invaded by volunteer *Lolium rigidum*, Ggt carry-over levels were increased. This result strongly suggests that Ggt carry-over in these treatments was due to the indigenous *Lolium rigidum* and not the sown *Vulpia* spp. or *Lolium rigidum*. Nonetheless, in comparison to *Hordeum* spp. and *Bromus* spp., both *Vulpia* spp. and *Lolium rigidum* were less able to maintain these infection levels into the following year.

There is a clear contrast between *Hordeum* spp. and *Lolium rigidum* in the ability to build-up, maintain and carry over Ggt. Wheat sown after *Lolium rigidum* had low levels of infection (4.8% seminal root infection) and the infection levels did not persist into subsequent years (less than 1% seminal root infection after 24 months). In comparison, *Hordeum* spp. increased levels of Ggt from 15.8% seminal root infection (untreated control) to 85.4% and after 12 months the levels of Ggt (measured by soil bioassay) was 41.5% and after 24 months was 20.3%.

This result supports the findings of many authors and anecdotal farmer evidence across southern Australia. However recent work by Kidd (1995) reported levels of Ggt infection on wheat roots following *Lolium rigidum*, equal to or greater than following *Hordeum* spp. There are two possible explanations for these findings of Kidd. First, the rates of natural inoculum used by Kidd were approximately 20 times higher than rates of natural inoculum used in my experiments at Palmer and, as Kidd mentions, these rates may have overwhelmed the natural defence mechanisms of *Lolium rigidum.* Secondly, the genotype of *Lolium rigidum* used may be less able to resist Ggt than other genotypes of *Lolium rigidum*.

My experiments using natural Ggt inoculum with *Hordeum* spp. mixed with other grass genera and a pasture legume indicated that a grass density of 10% of *Hordeum* spp. was sufficient to significantly increase carry-over of Ggt. This level of grass equates to 165 plants per square metre.

Although it is not strictly possible to compare my data with other research, it is interesting to note that Cotterill and Sivasithamparam (1988a) reported significant increases in carry-over of Ggt once the proportion of grass exceeded 20% of the total pasture. This figures is relatively low and tends to support the concept that only a small proportion of grass can be tolerated in a pasture to avoid build-up and carry-over of Ggt, especially if the dominant pasture grass comprises *Hordeum* spp..

Data presented here demonstrate conclusively the concept proposed by Griffiths (1933), that Ggt carry-over can be significantly reduced by increasing the proportion of "low host" genera (*Lolium rigidum*), and minimising the proportion of "high host" genera.

The question of variability of genotypes within *Lolium rigidum*, in susceptibility to Ggt, is examined in Chapter 4.

CHAPTER 4

ABILITY OF *LOLIUM RIGIDUM* GENOTYPES TO CARRY OVER *GAEUMANNOMYCES GRAMINIS* var. *TRITICI*

4.1 Introduction

Across southern Australia, annual grasses are hosts of the fungus *Gaeumannomyces graminis* var. *tritici* Walker (Ggt) (Nilsson 1969). However, differences exist between the different grass genera in their ability to carry over Ggt (Sutton 1911; Samuel 1923; Fish 1927; Griffiths 1933; Garrett 1934; Anon 1933-6; White 1947; Sims *et al.* 1961; Banyer 1966; Chambers and Flentje 1968). Of particular interest are reports suggesting variable carry-over of Ggt on *Lolium rigidum.*

This part of the thesis research was undertaken because there is no published information on the variation in Ggt resistance between genotypes of *Lolium rigidum*. For the purposes of this study, "genotypes" of *Lolium rigidum* are defined as populations sampled from areas at least 10 kilometres apart, although the sampling distance was generally several hundred kilometres apart.

Research results presented in Chapter 3, which are based on two surveys of pasture sites across South Australia and Victoria, provide evidence of significant variation in Ggt carry-over on *Lolium rigidum* crowns, with a range of 0-18% seminal root infection on wheat grown over crowns of *Lolium rigidum*. Also reported in Chapter 3 was the contrast between volunteer and sown (introduced) populations of *Lolium rigidum*, in the differing ability to carry-over Ggt. In addition, there have also been reports from farmers and farm advisers working around Eyre Peninsula (South

Australia) and Western Australia, of high Ggt infection in wheat crops following pastures dominant in *Lolium rigidum*.

Lolium rigidum is a wind-pollinated species that out-crosses with other species (*L. perenne* and *L. multiflorum*). In addition, cross breeding occurs between the resultant hybrids causing a continuum of genetic variation on almost every character (Kloot 1983). This property is significant as it could lead to a range of resistances to Ggt in different genotypes of *Lolium rigidum*.

This study was planned to test the hypothesis that genotypes of *Lolium rigidum* vary in their ability to host Ggt and subsequently infect wheat plants. Genotypes of *Lolium rigidum* were grown from seed collected across southern Australia.

4.2 Experimental Procedure

Two pot experiments were established (Experiment 1, 1992 and Experiment 2, 1993) using genotypes of *Lolium rigidum* grown from seed collected from agricultural areas across Victoria, South Australia and Western Australia. The seed was provided from collections held by Melbourne University and the South Australian Research and Development Institute.

Soil used for pot experiments: Soil was collected from the same field used for earlier studies on Ggt at Palmer South Australia. The soil is a fine mixed thermic Typic Natrixeralfs and described as a Red Brown Earth (Great soil group) (Stace *et al.* 1968), Dr 4.13 (Principal Profile Form) (Northcote *et al.* 1975).

The soil used in both experiments was bioassayed for Ggt, when the main experiment was established, to determine Ggt infectivity on wheat (see soil bioassay method on page 68).

Experimental design: Two identical experiments were conducted 1 year apart (October 1992 and October 1993). Both experiments were established as a Randomised Complete Block Design with four replicates.

Statistical analyses: The Spearman rank correlation between the rankings of the percent infection means for each of the two experiments was calculated for those *Lolium rigidum* genotypes common to both experiments.

Percent infection data from *Lolium rigidum* genotypes common to both experiments (S 1 - 14, bare and wheat) were transformed on the basis of natural log + 1 and a two-way analysis of variance applied. Where data from all genotypes in both experiments were combined, an unbalanced two-way analysis of variance was applied with the distribution improved with the following transformation; log [(% root infection + 5) / (100 - % root infection + 5)]. The analysis of variance structure included the main effects of genotype and year and their interaction. The interaction indicates whether or not the trend in percent infection values for the genotypes is similar for both years.

Main pot experiment: Identical experiments (Experiments 1 and 2) were set up with 2.8 kg of unsieved soil placed in 3 l plastic buckets. Ten seeds of each *Lolium rigidum* genotype were sown at a depth of 3 cm and the soil wet with de-ionised water to 15 % soil moisture, based on air dry weight. Polythene beads were added to the surface of the soil to minimise moisture evaporation and the pots placed in a constant temperature water bath at 15^0 C for three months. Plants were thinned to 8 per pot at 6 weeks of growth. The plants were clipped twice during this period to simulate grazing. Pots were watered to weight twice weekly.

After three months growth, watering ceased and *Lolium rigidum* plant tops were removed. Pots were left in the water bath at 15^0 C for a further four weeks and then the soil surface was disturbed to a depth of 5 cm and 8 wheat seeds were sown at a depth of 3 cm. Soil was maintained at 15 % soil moisture by watering to weight twice weekly. After 6 week's growth, the wheat roots were washed free of soil and assessed for Ggt. Assessment of Ggt was based on the percentage of seminal roots showing lesions with the characteristic blackening of the stele.

Soil bioassay: Prior to each pot experiment, four sub-samples of 400 g of soil (collected from the top 5 cm of the soil surface, by spade) was assessed for the back-ground level of Ggt. Soil was placed in a 500 ml pot and five wheat seeds (cv. Spear) were sown and water added to give a 15 % moisture level, based on air dried weight, and maintained at this level by regular watering to weight. The pots were placed in a 15^0 C water bath in a glasshouse. One week after emergence, wheat plants were

thinned to three per pot and harvested after four week's growth and the roots assessed for Ggt infection as described on the previous page.

4.3 Results

Experiment 1 (Genotypes S 1 - 25): Ggt infection on wheat sown, subsequent to the growth of the genotypes, varied significantly (P< 0.027) with disease levels ranging from 12.5 % to 70.6 % seminal root infection. In comparison, wheat sown after three months of bare soil was 8.8 %, compared to wheat following wheat which was 67.1% (Table 4.1).

Table 4.1 Ggt infection on wheat grown over crowns of *Lolium rigidum* genotypes, Experiment 1, 1992

L. rigidum genotypes (S)	State of origin	Seminal root infection (%)	Transformed data (Natural log + 1)
Bare		8.8	2.190
S1	Victoria	12.5	2.075
S2	Victoria	12.9	2.367
S3	Victoria	15.3	2.532
S4	Victoria	17.4	2.868
S5	Victoria	18.0	2.901
S6	Victoria	22.0	3.048
S7	Victoria	23.4	2.896
S8	South Australia	23.8	3.035
S9	Victoria	23.9	3.153
S10	South Australia	24.8	2.834
S11	Victoria	28.4	3.671
S12	Western Australia	30.6	4.165
S13	South Australia	42.4	3.231
S14	South Australia	70.6	3.056
S15	Western Australia	14.7	2.397
S16	South Australia	16.8	3.136
S17	Western Australia	28.1	2.362
S18	South Australia	41.7	2.232
S19	South Australia	31.7	2.852
S20	Western Australia	30.3	3.249
S21	South Australia	27.3	3.083
S22	Western Australia	22.8	3.601
S23	Victoria	23.3	3.394
S24	Victoria	13.5	3.302
S25	Victoria	19.2	3.427
Wheat		67.1	4.20
Mean (Bare + Wheat + S1-S25)		26.3	3.009
s.e.d.		10.6	0.581
Significance, P = 0.027			

Note: Soil bioassay of soil used in Experiment 1 gave 63 % seminal root infection (natural level of Ggt)

Experiment 2 (Genotypes S 1 -14 and S 26 - 34): Disease incidence on wheat following *Lolium rigidum* was again significantly affected (P< 0.007) by the preceding *Lolium rigidum* genotype with disease levels ranging from 1.5 % to 38 % seminal root infection. The Ggt infection on wheat following three months of bare soil was 1.5 % infection compared to wheat following wheat which was 67.0% (Table 4.2).

Table 4.2 Ggt infection on wheat grown over crowns of *Lolium rigidum* genotypes Experiment 2, 1993

L. rigidum genotypes (S)	State of origin	Seminal root infection (%)	Transformed data (Natural log + 1)
Bare		1.5	0.79
S1	Victoria	8.5	1.44
S2	Victoria	13.0	2.43
S3	Victoria	1.5	0.68
S4	Victoria	16.8	2.72
S5	Victoria	19.5	2.29
S6	Victoria	25.5	3.14
S7	Victoria	21.0	2.70
S8	South Australia	12.0	2.55
S9	Victoria	19.5	2.70
S10	South Australia	16.3	2.30
S11	Victoria	11.9	2.23
S12	Western Australia	26.0	2.89
S13	South Australia	37.8	3.55
S14	South Australia	29.5	3.02
S26	Victoria	16.0	2.06
S27	Victoria	14.5	2.63
S28	Victoria	7.0	1.21
S29	Victoria	18.0	2.18
S30	South Australia	11.5	1.72
S31	South Australia	5.5	1.39
S32	South Australia	38.1	3.34
S33	South Australia	29.5	3.15
S34	South Australia	13.0	2.06
Wheat		67.0	4.00
Mean (Bare + Wheat + S1-14 + S26-S34)		19.2	2.37
s.e.d.		12.8	0.805
Significance P = 0.007			

Note: Soil bioassay of soil used in Experiment 2 gave 9 % seminal root infection (natural level of Ggt)

Experiment 1 and 2 (Genotypes S1 - 14): The interaction between genotype and year was not significant (P> 0.05), indicating that the trend in Ggt infection levels following *Lolium rigidum* genotypes were similar in both experiments. Thus, each genotype mean can be averaged across both experiments and compared. Genotypes were significantly different in ability to carry-over Ggt and infect wheat roots (P< 0.001) (Table 4.3).

In addition, there was a significant correlation between the percent infection rankings of the genotypes in both experiments (P < 0.002), as indicated by the Spearman rank correlation coefficient of 0.74 (Table 4.3). This indicates a high level of consistency in the rankings of the relative ability of *Lolium rigidum* genotypes to carry-over Ggt.

Infection means for each genotype were significantly different between experiments. In Experiment 1 mean infection levels (27.6) were higher than those in Experiment 2 (20.4) (P = 0.001) (Table 4.3).

The level of carry-over of Ggt on *Lolium rigidum* genotypes and subsequent infection levels on wheat was also assessed on the basis of State of origin of the seed. No significant differences between samples from the different States was found (P< 0.05) (analysis not shown).

Table 4.3 Combined analysis of Ggt infection on wheat grown over crowns of *Lolium rigidum* genotypes common to Experiments 1 and 2

L. rigidum genotypes (S)	State of origin	Seminal root infection (%) (on wheat roots) Exp 1	Exp 2	mean	Log mean Exp 1 and 2	Rank of % infection Exp 1	Exp 2
Bare		8.8	1.5	5.2	1.492	1	1.5
S1	Victoria	12.5	8.5	10.5	1.760	2	3
S2	Victoria	12.9	13.0	7.0	2.401	3	6
S3	Victoria	15.3	1.5	8.4	1.663	4	1.5
S4	Victoria	17.4	16.8	17.1	2.793	5	8
S5	Victoria	18.0	19.5	10.3	2.802	6	9.5
S6	Victoria	22.0	25.5	23.8	3.092	7	12
S7	Victoria	23.4	21.0	22.2	2.796	8	11
S8	South Australia	23.8	12.0	17.9	2.792	9	5
S9	Victoria	23.9	19.5	21.7	2.928	10	9.5
S10	South Australia	24.8	16.3	20.6	2.640	11	7
S11	Victoria	28.4	11.9	20.2	2.863	12	4
S12	Western Australia	30.6	26.0	28.3	3.612	13	13
S13	South Australia	42.4	37.8	40.1	3.592	14	15
Wheat	(cv. Spear)	67.1	67.0	67.1	4.099	15	16
S14	South Australia	70.6	29.5	50.1	2.763	16	14
Spearmen rank correlation							0.74
Significance							P<0.002
Mean (Bare + Wheat + S1 - S14)		27.6	20.4	l.s.d = 0.858			
Significance (Natural log + 1)		P = 0.019	P = <0.001				

Combined analysis of Experiments 1 and 2 (Bare + Wheat + S1 - S14), (Natural log + 1)

Lolium rigidum genotype	P < 0.001
Experiment (1992)	P < 0.001
Lolium rigidum genotype Experiment	P < 0.661 N.S

Combined analysis of experiment 1 and 2; log [(% root infection + 5) / (100 - % root infection + 5)]

Lolium rigidum genotype	P < 0.001
Experiment (1993)	P < 0.006
Lolium rigidum genotype Experiment	P < 0.690 N.S

4.4 Discussion

While total resistance by *Lolium rigidum* to Ggt infection cannot be claimed, data presented here show significant variation in Ggt infection occurring on wheat roots grown over crowns of different genotypes of *Lolium rigidum*. Of particular interest are *Lolium rigidum* genotypes 1, 2, 3, 28 and 31, which consistently caused less disease on subsequently-sown wheat. In comparison, there were also genotypes that had a considerable ability to infect wheat roots, viz, 12, 13, 14, 18 and 32.

In Experiment 1, under high levels of natural Ggt inoculum, the *Lolium rigidum* genotype most able to carry Ggt carried over Ggt at levels equal to wheat. However, at low levels of natural inoculum in Experiment 2 the *Lolium rigidum* genotype most able to carry-over Ggt, only carried half that of wheat.

This range of infection confirms the difficulty in predicting Ggt infection levels in wheat sown after a pasture dominated by *Lolium rigidum*. This is supported by observations in the field by Agricultural Advisers and farmers on Eyre Peninsula (South Australia) and in Western Australia, who have reported high levels of Ggt infection on wheat following pastures dominant in *Lolium rigidum*.

While it is true that, in comparison to other common annual grasses, *Lolium rigidum* is generally less able to cause infection to a subsequent wheat crop, these pot trials show that there are populations of *Lolium rigidum* that have a considerable ability to carry over Ggt onto wheat.

It is interesting to note that although the soil bioassay results of the Palmer soils used in the two experiments (1992 and 1993) showed large differences in seminal root infection, viz, 63 % and 9 % (Experiments 1 and 2 respectively), the magnitude of mean infection on wheat for each experiment, while significant (26.3 % and 19.2 % seminal root infection for Experiments 1 and 2 respectively) was not as large as expected from the soil bioassay results.

A consistent theme through this chapter is the variation between genotypes in ability to carry-over Ggt. The mechanisms involved in this variability are not clear. Recent research into the molecular taxonomy and population biology of *G. graminis* may provide some insights into this differential carry over of Ggt inoculum. By using DNA probes and primers which differentiate the three varieties of *G. graminis* (ie. Ggt, Gga and Ggg), Harvey (1993) was able to show that pathogen populations which were isolated from or had a recent exposure to oats contained high frequencies of Gga, whereas populations exposed to wheat were dominated by either Gga or Ggt. Similarly, Hollins and Scott (1990) and O'Dell (1992) were able to identify isolates of Ggt which differed in their ability to parasitise cereal rye, and that these rye pathotypes were found to co-exist in wheat crops. These studies indicate that if the host genotype can exert intense selection upon the *G. graminis* pathogen population, rapid changes in pathotype and dynamics of composition of *G. graminis* may occur. For example, cultivation of oats appeared to select Gga types and suppress those of Ggt and the frequency of Gga would be expected to increase relative to that of Ggt.

Host mediated selection of plant pathogens requires variation within the pathogen population for virulence on their respective hosts. *G. graminis* exhibits considerable variation in virulence in naturally-occurring populations isolated from field crops and grass pastures (Asher 1981). Intensive cereal production and the use of hosts which differ in their susceptibility to infection (eg. *Lolium rigidum*, oats, wheat) may be expected to apply varying intensities of selection pressure upon *G. graminis.* This may result in the selection and subsequent accumulation of pathogen genotypes which are better adapted to parasitising different hosts (Harvey 1993).

These results indicate that *Lolium rigidum* genotypes which vary in their susceptibility to Ggt may also alter the pathotype composition and/or inoculum density of take-all in subsequent pastures or crops. Essentially a *Lolium rigidum* genotype which is more tolerant to a range of Ggt pathotypes should carry over a lower diversity and density of Ggt inoculum.

In addition to possible mechanisms of resistance possessed by genotypes of *Lolium rigidum,* work by Kidd (1995), suggests that differences in the abilities of grass genera to sustain the Ggt fungus over summer, may reflect a more rapid break-down of infected debris in *Lolium rigidum* than in other grasses. This is supported by the experiments with pure grass swards that demonstrated more rapid decline over time in levels of Ggt inoculum maintained with *Vulpia* spp. and *Lolium rigidum* compared to *Hordeum* spp.

Given the possibility of Ggt pathotypes being a factor and/or other mechanisms of resistance, these are areas requiring further research, perhaps with the aim of developing a screening technique to assess the infecting ability of *Lolium rigidum* genotypes and the subsequent identification of genotypes resistant to Ggt. *Lolium rigidum* is an integral part of pastures in a wide range of agricultural environments across southern Australia. Further research which seeks to enhance any resistance to Ggt would allow the development of a Ggt-resistant *Lolium rigidum* which would be a valuable pasture plant in rotation with wheat or barley, particularly in low-rainfall environments.

CHAPTER 5

GENERAL CONCLUSIONS

During the course of this thesis, I have attempted to improve the understanding of four key issues related to the control of *Gaeumannomyces graminis* var *tritici* (Ggt) which causes take-all in cereals. These issues are:

(1) The impact of grass removal on carry-over of Ggt, using selective and non-selective herbicides

(2) The levels of Ggt on four different annual pasture grasses representing four genera

(3) The relative abilities of these four grass genera to host and carry over Ggt

(4) The variation within *Lolium rigidum* genotypes in their ability to host and carry over Ggt

In Chapter 2, data from three years of field experimentation on timing of grass removal, shows that early applications of herbicides are required if carry-over of Ggt is to be significantly reduced. However, an important additional result is that to achieve a significant reduction in carry-over of Ggt, the timing of herbicide application depends on the distinctions of "high and low rainfall environments", which relates to the time available for the degradation of Ggt-infected material before soil moisture becomes limiting.

In a "higher rainfall environment" of the cereal belt (>450 mm annual rainfall) at Kapunda, South Australia, herbicide applications before early August (26/7/89, 3/8/90 and 9/8/91), significantly reduced carry-over of Ggt. But in a "lower rainfall environment" (<350 mm annual rainfall) at Palmer, South Australia, herbicide application was needed by the end of June (27/6/91) to give significant reductions in Ggt. While this observation is from only one trial in a "lower rainfall environment", comparison between the two trials in the same year

using identical herbicide treatments, with the major variation between the two trials being annual rainfall (450 mm and 335 mm annual rainfall) supports the need for earlier spraying in drier areas.

Although grass removal from pastures for the control of Ggt is not new, few studies have been published which critically examine the issue of timing. The only other reports on this subject are the works by Macleod and MacNish (1989), which suggests that herbicides should be applied by about the six leaf stage of sub-clover growth and Kidd (1995) who reported significant reductions in Ggt carry-over where grasses were removed between 5 June and 14 June, at a site with 400 mm annual rainfall. These findings generally agree with data presented here.

Comments by Thorn and Perry (1983) and Macleod and MacNish (1989) are consistent with the requirement for removal of grasses early enough for biological breakdown of Ggt-infected debris. Data presented here agree with these comments, particularly in light of the late June requirement for grass removal in "lower rainfall environments", where it appears reasonable to assume that this is due to the need to provide sufficient time when soil moisture conditions are conducive for biological breakdown of Ggt-infected debris.

Essential to the length of time for biological breakdown of Ggt-infected material, is consideration of the efficacy, in particular rate of herbicide action in causing grass death. Some herbicides, particularly selective herbicides (araloxyphenoxyproprionates), take up to four weeks longer to kill the grass, reducing the time for breakdown of the infected debris, and perhaps necessitating even earlier applications (season permitting), or the use of a non-selective herbicide.

To better understand carry-over of Ggt from the pasture phase to the cereal phase, it is critical to have an understanding of the percentage of grass in a pasture required for significant carry-over of Ggt. In particular, there needs to be an understanding of the critical levels of *Hordeum* spp. as this has consistently proved to be a "high host" genus.

Chapter 2 assessed the effect of percent grass populations, irrespective of genus, on the soil bioassay for Ggt and wheat root infection levels in wheat sown in the year subsequent to the pasture. In all but three cases (where the percent composition of grass was less than 10%), and when grass herbicides were applied before the 3 August (in the higher rainfall environment), Ggt on wheat roots sown the following year was significantly reduced compared to the non-treated control.

There were three exceptions where higher grass levels did not cause significant increases in Ggt. In two cases, grass removal had occurred by 8 August, ostensibly allowing time for break down of infected material. However, the following season did not provide conditions conducive for biological break-down of Ggt-infected debris, viz where adequate soil moisture prevailed for the time required by microbial activity to break down material, consequently giving low levels of Ggt infection on wheat roots. In the third case, grass percentage in the pasture was 42 % but this only resulted in 6% Ggt infection on wheat seminal roots. I have no explanation for this low level of disease in wheat following this grassy pasture.

As *Hordeum* spp. appeared to have the greatest ability to carry-over Ggt, it was appropriate to examine the critical density of this genus which can be tolerated in annual pastures before significant increases in levels of Ggt carry-over occur. An experiment (Chapter 3) conducted in a "low rainfall" environment (335 mm annual rainfall), using natural Ggt inoculum with

Hordeum spp., mixed with other grass genera and a pasture legume, indicated that a density of 10% (approximately 165 plants /m^2) was sufficient to significantly increase carry-over of Ggt.

Cotterill and Sivasithamparam (1988b) reported that compared to a fallow, higher levels of Ggt inoculum occurred following a pasture which had pasture composition of 11.7% *Hordeum* spp. and was *Lolium rigidum* dominant (70.2%). My results suggest that even though the presence of *Hordeum* spp. in this experiment was comparatively low, this genus probably contributed most to the levels of Ggt measured.

Although it is not strictly possible to compare my results with data from other authors, work by Cotterill and Sivasithamparam (1988a) reported significant increases in carry-over of Ggt once the proportion of grass exceeded 20% of the total pasture population (compared to a grass-free sub-clover stand) and Macleod and MacNish (1989) estimated that carry-over of Ggt increases 5% for every additional 100 kg dry matter per hectare of grass. These figures support the notion that only a small proportion of grass (<10%) is tolerable in a pasture, particularly if the dominant pasture grasses are *Hordeum* spp..

The relationship between grass genera and crown weight and subsequent carry-over of Ggt was significant only for *Hordeum* spp. (Table 3.4) but there did appear to be a general relationship across all genera in increasing Ggt carry-over as crown size increased. These results agree with the results of Hornby (1975) and Wilkinson and Cook (1985).

Chapter 3 describes the most geographically diverse and sample-intensive studies in Australia of Ggt carry-over on crowns of four common grass genera. The findings show that *Hordeum* was consistently the genus which carried over highest levels of Ggt, and therefore is referred

to as a "high host" genus. *Bromus* and *Vulpia* genera can be considered as "medium host" grasses and *Lolium rigidum* can typically be considered a "low host" genus.

Although these results support the comments and observations of other authors, they do not agree with the findings of Macleod and MacNish (1989) who concluded that *Lolium rigidum* closely followed *Hordeum* spp. in susceptibility to Ggt. Clearly, if *Lolium rigidum* were highly susceptible, carry-over of Ggt would be significantly closer to that of *Hordeum* spp. It is conceivable that genetic variation in either the genotype of *Lolium rigidum* used in the experiments and/or some impact of different pathotypes of Ggt (Harvey 1995) may have affected this result.

Chapter 4 reports that significant differences do exist between *Lolium rigidum* genotypes in carry-over of Ggt. The range in Ggt infection on wheat roots sown subsequent to the growth of genotypes varied from 12.5% to 70.6% in Experiment 1. In Experiment 2, seminal root infection on wheat following different *Lolium rigidum* genotypes ranged from 1.5% to 38.1%. This variation has not been reported before and may go some way to explain anomalies reported in the literature regarding levels of Ggt infection on wheat roots following *Lolium rigidum*.

Although there remains insufficient data on the predominance of "high hosting" selections of *Lolium rigidum* in pastures, data in Chapter 3 point to a number of genotypes of *Lolium rigidum* which have very low ability to host Ggt, especially when compared with other grass genera tested in this study.

An important area for future research would be to study in more detail the "low" Ggt hosting genotypes of *Lolium rigidum* and determine whether these could be used to provide clover/medic plus grass pastures which did not promote take-all. Such a grass would need to be free of annual ryegrass toxicity (ARGT) and contain herbicide susceptible genes. Research on these characteristics is well developed (McKay and Ophel 1993).

Although there is ample evidence that the use of herbicides to selectively remove grasses and perhaps the development of a Ggt-resistant *Lolium rigidum* genotype will contol take-all, farmers are still resisting these concepts. Farmer criticism of the grass removal technique, include the inability to predict when grass control is not required, the lack of early feed as a result of the removal of grasses which often provide the bulk of early feed (Thorn 1983) and the possible development of herbicide resistance (Powles 1990). However, if there is a high density (>50%) of annual legumes in the pasture, the early removal of grasses has an insignificant impact on total pasture production. Furthermore, the quality of the pasture as livestock feed is greatly improved and subsequent financial returns in livestock production improved (Carter 1990b; Little *et al.* 1993).

In summary, my work has shown that the levels of Ggt in soil can be reduced by spraying out grasses early in the growing season and that there are differences between genotypes of *Lolium rigidum* in the ability to host and carry-over Ggt. This work offers the opportunity to develop effective and alternative strategies to control this important cereal root disease.

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APPENDIX (A)

Abstracts and conference papers arising from research presented in this thesis

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Journal papers: (Not published, currently with CSIRO internal refereeing - 14/7/97).

Inwood, R.J. and Roget, D.K. (1997). "Variation in the ability of common annual pasture grasses to carry-over *Gaeumannomyces graminis* var. *tritici.*"

Inwood, R.J. and Roget, D.K. (1997). "Ability of *Lolium rigidum* to carry-over *Gaeumannomyces graminis* var. *tritici.*"

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Rovira, A.D., Roget, D.K. and Inwood, R.J. (1991). "Effects of rotation and pasture management on diseases and yield." Australian Grain publication - Southern Focus, 1991.

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