Australian Government
Department of Health and Ageing
Office of the Gene Technology Regulator

The Biology of *Lolium multiflorum* Lam. (Italian ryegrass), *Lolium perenne* L. (perennial ryegrass) and *Lolium arundinaceum* (Schreb.) Darbysh (tall fescue)

Lolium arundinaceum Schreb. (tall fescue). (Figure from Burnett (2006) Grasses for dryland dairying. Tall fescue: Species and Cultivars. Department of Primary Industries, Victoria #AG1241).

Version 1: May 2008

This document provides an overview of baseline biological information relevant to risk assessment of genetically modified forms of the species that may be released into the Australian environment.

TABLE OF CONTENTS

PREAMBLE

This document describes the biology of *Lolium multiflorum* Lam. (Italian ryegrass), *Lolium perenne* L. (perennial ryegrass) and *Lolium arundinaceum* Schreb. (tall fescue), with particular reference to the Australian environment, cultivation and use. Information included relates to the taxonomy and origins of cultivated *L. multiflorum*, *L. perenne* and *L. arundinaceum*, general descriptions of their morphology, reproductive biology, biochemistry, and biotic and abiotic interactions. This document also addresses the potential for gene transfer to occur to closely related species. The purpose of this document is to provide baseline information about the parent organism in risk assessments of genetically modified *L. multiflorum*, *L. perenne* and *L. arundinaceum* that may be released into the Australian environment.

Italian ryegrass, perennial ryegrass and tall fescue are all tufted grasses used for both pasture and turf in Australia. Italian ryegrass is a vigorously growing annual or biennial which is native to Europe. Perennial ryegrass is a long-lived, densely tillered perennial, which is native to Europe and neighbouring countries with a temperate climate. Tall fescue is a coarse-leaved perennial native to Europe and North Africa. These three grasses have been grouped together as they have many characteristics in common, are found together in pastures and turf, and interbreed as part of the *Festuca-Lolium* complex. The biology of these grasses will be presented together, with the individual species described only where they differ significantly.

Lolium arundinaceum is the current name for *Festuca arundinacea* following a recent reclassification (as discussed in Section 1). However, much of the older literature concerning tall fescue in the genus *Festuca* and its taxonomy is still of relevance to tall fescue and so will be included in this document.

SECTION 1 TAXONOMY

The *Lolium* and *Festuca* genera are classified within the family Poaceae (Wheeler et al. 2002). Poaceae was previously known as Gramineae (eg Mallett & Orchard 2002). Within the subfamily Pooideae, also called Festucoideae, the *Lolium* and *Festuca* genera belong to the tribe Poeae (also called Festuceae) (Wheeler et al. 2002). Currently, there are 39 genera listed within the Poeae tribe (Wheeler et al. 2000).

The *Lolium* and *Festuca* genera are closely related. The overall taxonomy of *Lolium* and *Festuca* is ill-defined and there is no comprehensive or definitive world wide taxonomic treatment. These grasses are commonly referred to as the *Festuca-Lolium* complex (Jauhar 1993). *Lolium* is thought to be of more recent origin than *Festuca* (Charmet et al. 1997; Pašakinskiene et al. 1998), and may have derived from *Festuca* via an inflorescence transformation from panicle to spike (Essad 1962 cited in Bulínska-Radomska & Lester 1988).

The number of species in *Lolium* is thought to be around seven to ten, all of which are diploid (Charmet & Balfourier 1994). There are no native *Lolium* species in Australia (Wheeler et al. 2000; Wheeler et al. 2002; Wipff 2002; Jessop et al. 2006). However, about seven introduced species of *Lolium* (Table 1) have become naturalised in Australia (Wheeler et al. 2000; Wheeler et al. 2002; Wipff 2002; Jessop et al. 2006).

There are 400 or more species within the genus *Festuca* of varying ploidy levels (Charmet & Balfourier 1994; Jessop et al. 2006), although species estimates do vary (Wheeler et al. 2000;

Wheeler et al. 2002; Jessop et al. 2006). The grasses in the genus *Festuca* were originally classified into six sections: Bovinae, Ovinae, Montanae, Scariosa, Sub-bulbosae and Variae (Gaut et al. 2000), and includes broad-leaved (Bovinae-subgenus *Schedonorus*) and fine-leaved species (Ovinae – subgenus *Festuca*). About twelve *Festuca* species (six native and six introduced) are present in Australia (Table 2). Originally more *Festuca* species were classified as being present in Australia, but three Australian species have been transferred to the genus *Austrofestuca* (Wheeler et al. 2002), and others have been transferred into various genera including Australopyrum, *Diplachne*, *Dryopoa*, *Festucella*, *Glyceria*, *Panicularia*, *Poa*, *Triodia*, *Tripogon*, *Uniola* and *Vulpia* (APNI 2006).

Festuca and *Lolium* have been distinguished on the basis of inflorescence morphology (the former species have a spicate inflorescence with two sterile glumes and the latter species are paniculate with one sterile glume in all but the terminal spikelet (Stebbins 1956)), so this has been used to support their status as separate genera (Clayton & Renvoize 1986). However, there is much debate as to whether this separation is phylogenetically accurate. A spontaneous mutation in *L. multiflorum* occurred which converted the spicate inflorescence into a paniculate form, thus erasing the taxonomic distinction between the two genera, and illustrating how closely related the genera are (Jauhar 1993). Many studies have found that molecular, cytological, morphological and fertility data do not support separate genera, instead highlighting the especially close relationship between *Lolium* and broad-leaved *Festuca* (subgen. *Schenodorus*) (Bovinae) species (Peto 1933; Crowder 1953; Stebbins 1956; Terrell 1966; Lehväslaiho et al. 1987; Bulínska-Radomska & Lester 1988; Darbyshire & Warwick 1992; Aiken et al. 1992; Loos 1993; Charmet & Balfourier 1994; Xu & Sleper 1994; Stammers et al. 1995; Charmet et al. 1997; Gaut et al. 2000).

The closest relationships are among *L. pratense*, *L. arundinaceum*, *L. perenne* and *L. multiflorum*. *Lolium-Festuca* crosses (×*Festulolium* Aschers. & Graebner.) can be fertile and have an ability to backcross with either of the parents (Wipff 2002). In 1956, Stebbins proposed that *Lolium* was merely a section of the large and diverse *Festuca* genus (Stebbins 1956). Taking more recent evidence into account, Jauhar (Jauhar 1993) suggested that *Lolium* should become a subgroup of *Festuca*, with the outbreeding species (*L. perenne*, *L. arundinaceum* and *L. multiflorum*) including in the Sect. Bovinae, and the in-breeders remaining in the Sect. *Lolium*. Other taxonomists have recognised the close relationship between some species in the *Festuca* and *Lolium* genera by placing the species of *Festuca* subgenus *Schedonorus* in the genus *Schedonorus* P. Beauv (Soreng & Terrell 1997). However, only the inflorescence would distinguish the genus *Schedonorus* from *Lolium* (Bulínska-Radomska & Lester 1988; Darbyshire 1993). Hence, Darbyshire 1993 has proposed that the broadleaved species in *Festuca* subg. *Schedonorus* be reclassified to *Lolium* subg. *Schedonorus* (Darbyshire 1993). This subgenus includes tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.), meadow fescue (*Lolium pratense* (Huds.) Darbysh.) and giant fescue *Lolium giganteum* (L.) Darbysh. Although there is still debate regarding this nomenclature (Aiken et al. 1997), these are the scientific names that will be used in this Biology document.

The taxonomy is further complicated by the fact that some taxonomists give species status to some hybrids of *Lolium* and/or *Festuca* sp. Many of the *Lolium* species hybridise freely, eg. *L. perenne*, *L. multiflorum* and *L. rigidum* (Wheeler et al. 2002) resulting in fertile progeny (Wipff 2002), with the hybrid populations showing a continuum of variation (Wheeler et al. 2002). Hybrids also occur between the *Lolium* species *L. arundinaceum*, *L. pratense* and *L. giganteum* (Wipff 2002). In fact, *L. pratense* and *L. arundinaceum* were previously classified as a single species, *F. elatior* in older literature (Gibson & Newman 2001).

Table 1. *Lolium* species in Australia

Scientific name	Synonyms/Varieties/ Subspecies	Common name	Areas present in Australia	Flowering time	Natural hybrids (and their respective synonyms if available)
L1 [b,h,o]*Lolium arundinaceum* (Shreb.) Darbysh.,	[*a,b,t)d,e,f]*Festuca arundinacea* Shreb. [a,b,h]*Schedonorus phoenix* (Scop.) Holub., *Poa phoenix* Scop., [c]*Festuca elatior* var. *arundinacea*, [f,h]*Festuca elatior* L., [h]*Schedonorus arundinaceus* (Shreb.) Dumort., *Festuca arundinacea* Schreb., [n]*Festuca arundinacea* var. *glaucescens*	[a,b,c,h,t]Tall fescue, [b,t]Tall meadow fescue, Alta fescue, Reed fescue	[a,b,d,i,t]NSW, VIC., TAS., SA ([c,g]naturalised), WA, [b,e,i,t]QLD, [d,e]ACT	[t]October - April	[k,o]L1 × L7 = [k]*F. ×aschersoniana* Doerfler [k,o]L1 × L2 (S) = *F. ×fleischeri* Rohlena [r]L1 × F9 [k,o]L4 × L1 [k,o]L5 × L1
L2 [w]*Lolium giganteum* (L.) S.J.Darbysh	([*w)f]*Festuca gigantea* (L.) Vill.	[w]Giant fescue, Tall brome, Giant green fescue	[f]ACT		[k,o]L1 × L2 (S) = *F. ×fleischeri* Rohlena [o]L2 × L7
L3 ([*a,b,t)e,f]*Lolium loliaceum* (Bory & Chaub.) Hand.-Mazz	[g]*Lolium subulatum* Vis., *Rottboellia loliacea* Bory & Chaub., *Lolium rigidum* Gaudin var. *rottboellioides* Heldr. Ex. Boiss., *Lolium rigidum* Gaudin ssp. *lepturoides* (Bois.)Sennen & Mauricio, *Lolium lepturoides* Boiss.	[a,b,t]Stiff ryegrass, [b,t]Rigid ryegrass, Annual ryegrass, Wimmera ryegrass	[d,e,i,t] NSW, VIC., TAS., SA ([g]naturalised), WA, [d,e,i] QLD, [d,e]N.T., [e]ACT	[t]September - February	[s]L3 × L5 (S) [j,s]L3 × L8 (S) [s]L3 × L9 (S) + (F) [j,s]L3 × L10 [s](S)
L4 ([*a,b,t)d,e,f,h]*Lolium multiflorum* Lam.	[g]*Lolium italicum* A.Braun, *Lolium perenne* L. var. *multiflorum* (Lam.)Parn., [h]*Lolium perenne* var. *multiflorum* (Lam.) Husn., [o]*Lolium perenne* var. *aristatum* Willdenow.	[a,b,h,o,t]Italian ryegrass, [b,c,t]Westerwolds ryegrass, [o]Annual ryegrass	[d,i,t]TAS., SA[d,e,i,t]([g]naturalised), NSW, VIC., WA, QLD, [d,e,i]ACT, [d,e]N.T. ([c]naturalised in Australia and sown pasture species)	[t]September - December	[k,l,o,s]L4 × L5 [o,s](F) = [*b,e,f]*Lolium ×hybridium* Hausskn., [b]*Lolium multiflorum* Lam. × *L. perenne* L., [e]*Lolium multiflorum* × *L. perenne* , [k]*Festulolium holmbergii* (Doerfler)P.Fourn. [o]L4 × L9 (F) = [*b]*Lolium ×hubbardii* Jansen & Wachter ex B.K.Simon, [b]*Lolium ×hubbardii* Jansen & Wachter, *Lolium multiflorum* Lam. × *L. rigidum* L., [e,f]*Lolium hubbardii* B.K.Simon [s]L4 × L10 (F) [k,o]L4 × L1 [k,o]L4 × L7 [o](S) + (F)

Scientific name	Synonyms/Varieties/ Subspecies	Common name	Areas present in Australia	Flowering time	Natural hybrids (and their respective synonyms if available)
L5 [(*a,b,t)d,e,f]*Lolium perenne* L.	[e]*Lolium perenne* var. *italicum* (A.Braun) Rodway, *Lolium perenne* L. var. *perenne*, [e,t]*Lolium perenne* var. *cristatum* Pers.	[a,b,c,h]Perennial ryegrass, [b]English ryegrass	[d,e,i,t]NSW, VIC., TAS., SA ([g]naturalised), QLD, N.T., [d,e,i]ACT, W.A ([c]naturalised in Australia and sown pasture species)	[t]August - February	[s]L3 × L5 (S) [k,l,o,s]L4 × L5 [o,s](F) = [*b,e,f]*Lolium ×hybridium* Hausskn., [b]*Lolium multiflorum* Lam. × *L. perenne* L., [e]*Lolium multiflorum* × *L. perenne* , [k]*Festulolium holmbergii* (Doerfler)P.Fourn. [s]L4 × L8 (S) [o,s]L5 × L9 (F) [s]L5 × L10 (S) [k,o]L5 × L1 [k,o]L5 × L7 [o](S) + (F) = [u]*Festulolium loliaceum* [r]L5 × F9
L6 [(*w)f]*Lolium persicum* Boiss. & Hohen.		[w]Persian ryegrass, Persian darnel	[f]ACT		[m]L6 × L10 (F)
L7 *Lolium pratense* (Huds.) Darbysh.,	[e]*Festuca elatior* var. *pratensis* Hack, [a]*Festuca elatior* L., [a,b]*Schedonorus pratensis* (Hudson) Beauv., [b]*Festuca elatior* sensu J.M.Black, [(*a,g,t)b,e,f]*Festuca pratensis* Huds. , [b,g]*Festuca elatior* L. subsp. *pratensis* (Huds.) Hack, [g]*Festuca elatior* auct.non L: J.M.Black(1943)	[a,t]Meadow fescue	[a,b,d,e,i,t]NSW, [d]VIC., [b,d,t]SA ([g]naturalised), WA, [d,e,i]ACT ([b]naturalised in Australia)	[t]Summer-Spring	[k,o]L1 × L7 = [k]*F. ×aschersoniana* Doerfler [o]L2 × L7 [k,o]L4 × L7 [o](S) + (F) [k,o]L5 × L7 [o](S) + (F) = [u]*Festulolium loliaceum* ([f,v]*Festuca loliacea* Huds.)
L8 [(*w)f]*Lolium remotum* Schrank	[w]*Lolium linicola*	[w]Hardy ryegrass	[d]VIC., [e]ACT		[j,s]L3 × L8 (S) [s]L5 × L8 (S) [j,s]L8 × L10 [s](S)
L9 [(*a,b,t)d,e,f]*Lolium rigidum* Gaudin	[g]*Lolium subulatum* auct.non Vis: J.M.Black(1943), *Lolium perenne* L. ssp. *rigidium* (Gaudin)A.Love & D.Love, *Lolium multiflorum* Lam. var. *rigidum* (Gaudin)Trab., [t]*Lolium subulatum* Vis, *Lolium rigidum* Gaudin subsp. *lepturoides* (Boiss.) Sennen & Mauricio	[a,b, c,t]Wimmera ryegrass, [b,c,t]Annual ryegrass, [b,t]Rigid ryegrass, [o]Stiff ryegrass	[d,e,i,t] NSW, VIC., TAS., SA ([g]naturalised), QLD, N.T., [d,e,i]ACT, WA ([c]naturalised in Australia and sown pasture species)	[t]August - December	[s]L3 × L9 (S) + (F) [o]L4 × L9 (F) = [*b]*Lolium ×hubbardii* Jansen & Wachter ex B.K.Simon, [b]*Lolium ×hubbardii* Jansen & Wachter, *Lolium multiflorum* Lam. × *L. rigidum* L., [e,f]*Lolium hubbardii* B.K.Simon [o,s]L5 × L9 (F) [s]L9 × L10 (S) + (F)
L10 [(*a,b,t)e,f]*Lolium temulentum* L.	[g,t]*Lolium arvense* With., [e]*Lolium temulentum* var. *arvense* (With.) Lilj., *Lolium temulentum* L. var. *temulentum*,	[a,t]Darnel, [b]Bearded darnel, [b,t]Drake	[a,d,i]VIC., [a,d,i,t]NSW, SA ([g]naturalised), WA, QLD, [d,e,f]ACT, [a,b,i,t]TAS.	[t]June - January	[j,s]L3 × L10 [s](S) [s]L4 × L10 (F) [s]L5 × L10 (S)

Scientific name	Synonyms/Varieties/ Subspecies	Common name	Areas present in Australia	Flowering time	Natural hybrids (and their respective synonyms if available)
	[f]*Lolium temulentum* var. *linicola* Benth., *[b,g,t,]*Lolium temulentum* L. forma *temulentum*, *[b,g]*Lolium temulentum* L. forma *arvense* (With.) Junge, [g]*Lolium temulentum* L. var. *leptochaeton* A.Braun, *[t]*Lolium temulentum* var. *arvense* Lilj.				[m]L6 × L10 (F) [j,s]L8 × L10 [s](S) [s]L9 × L10 (S) + (F)
*[b]*Lolium ×hubbardii* Jansen & Wachter ex B.K.Simon	[b]*Lolium ×hubbardii* Jansen & Wachter, *Lolium multiflorum* Lam. × *Lolium rigidum* L., [e,f]*Lolium hubbardii* B.K.Simon	[b]Ryegrass	[d]VIC., TAS., SA ([g]naturalised), [e]QLD		
*[b,e,f]*Lolium ×hybridium* Hausskn.	[b]*Lolium multiflorum* Lam. × *Lolium perenne* L., [e]*Lolium multiflorum* × *L. perenne*	[b]Ryegrass	[d]VIC., TAS., SA ([g]naturalised), WA, N.T.		

(Note: ACT was only differentiated from NSW in [d]AVH (AVH 2006), [e]APC (APC 2006), [f]APNI (APNI 2006) and [i]Mallett and Orchard (2002)).

Lolium ×hubbardii and *Lolium ×hybridium* are recorded in the table twice as both species and hybrids. Although they are hybrids they are also given species status in some literature (APNI 2006; Jessop et al. 2006).

Key:* = introduced into Australia,• = native to Australia, (F) = Fertile (if known), (S) = Sterile (if known), (S) + (F) = some progeny may be fertile (if known). Literature sources: [a] = (Wheeler et al. 2002), [b] = (Jessop et al. 2006), [c] = (Lamp et al. 2001), [d] = (AVH 2006), [e] = (APC 2006), [f] = (APNI 2006), [g] = (Barker et al. 2005), [h] = (Wheeler et al. 2000), [i] = (Mallett & Orchard 2002), [j] = (Jenkin 1954), [k] = (Gibson & Newman 2001), [l] = (Giddings et al. 1997a), [m] = (Senda et al. 2005), [n] = (Kopecky et al. 2006), [o] = (Wipff 2002), [p] = (Thorogood 2003), [q] = (Meyer & Watkins 2003), [r] = (Ruemmele et al. 2003), [s] = (Jenkin & Thomas 1938) (*L. multiflorum* is referred to as *L. italicum*),[t] = (Sharp & Simon 2002), [u] = (Giddings et al. 1997a), [v] = (GRIN 2005), [w] = (Randall 2002), [x] = (Tasmanian Government 2005).

Table 2. *Festuca* species in Australia

Scientific name	Synonyms/Varieties/ Subspecies	Common name	Areas present in Australia	Flowering time	Natural hybrids (and their respective synonyms if available)
F1 [(•x)e,f]*Festuca archeri* E.B.Alexeev			[e,x]TAS.		
F2 •[a,e,f,t]*Festuca asperula* Vickery		[a,t]Graceful fescue	[a,d,e,i,t]NSW, VIC., [a,d,e]Tas, [i]ACT	[t]December - February	
F3 [(•b,g,t)e,f]*Festuca benthamiana* Vickery	[e,g]*Festuca duriuscula* var. *aristata* Benth.	[b]Fescue	[e]VIC, [b,d,i,t]SA	[t]October - November	
F4 •[a]*Festuca glauca* Vill.			[a]NSW		
F5 [(*w)e,f]*Festuca longifolia* Thuill.		[w]Hard fescue, Blue fescue	[e]QLD?		
F6 •[a,e,f,t]*Festuca muelleri* Vickery			[a,d,e,i,t]NSW, VIC., [d,e,i]ACT	[t]December - March	
F7 *[a,e,f,t]*Festuca nigrescens* Lamk.	[a]*Festuca rubra* L. subsp. *commutate* Gaud., [t]*Festuca rubra* L. var. commutate Lam.	[a]Chewings fescue	[a,d,e,i,t]NSW, VIC., TAS., [a]S.A, WA, [d,e,i]ACT	[t]November - January	
F8 (•[t])[e,f]*Festuca plebeia* R.Br.			[d,e,i,t]TAS.	[t]December - February	
F9 (*[t])[b,d,e,f]*Festuca rubra* L.	*[a]*Festuca rubra* L. subsp. rubra, [e]*Festuca rubra* subsp. commutata Gaudin, *Festuca rubra* L. var. rubra, [b]*Festuca duriuscula* sensu J.M.Black, *Festuca asperula* sensu H.Eichler. [g]*Festuca duriuscula* L., *Festuca asperula* auct.non Vickery: H.Eichler(1965)	[a,c,t]Red fescue, Creeping fescue	[a,b,c,d,e,i,t]NSW, VIC., TAS., [b,d,e,t]SA ([g]naturalised), [d,e,i]ACT, [i,t]WA ([b]naturalised in Australia)	[t]October - January	[r]L1 × F9 [r]F9 × F10 = H1 [r]F9 × H1 (backcross) [r]L5 × F9

(Note: ACT was only differentiated from NSW in [d]AVH (AVH 2006), [e]APC (APC 2006), [f]APNI (APNI 2006) and [i]Mallett and Orchard (2002)).

Key:* = introduced into Australia,• = native to Australia, (F) = Fertile (if known), (S) = Sterile (if known), (S) + (F) = some progeny may be fertile (if known). Literature sources: [a] = (Wheeler et al. 2002), [b] = (Jessop et al. 2006), [c] = (Lamp et al. 2001), [d] = (AVH 2006), [e] = (APC 2006), [f] = (APNI 2006), [g] = (Barker et al. 2005), [h] = (Wheeler et al. 2000), [i] = (Mallett & Orchard 2002), [j] = (Jenkin 1954), [k] = (Gibson & Newman 2001), [l] = (Giddings et al. 1997b), [m] = (Senda et al. 2005), [n] = (Kopecky et al. 2006), [o] = (Wipff 2002), [p] = (Thorogood 2003), [q] = (Meyer & Watkins 2003), [r] = (Ruemmele et al. 2003), [s] = (Jenkin & Thomas 1938) (*L. multiflorum* is referred to as *L. italicum*),[t] = (Sharp & Simon 2002), [u] = (Giddings et al. 1997a), [v] = (GRIN 2005), [w] = (Randall 2002), [x] = (Tasmanian Government 2005).

(The following species were listed as being present in Australia but no specific distribution or further taxonomic information was found. [f]*Festuca billardierei* Steud. (synonyms [e]*Festuca scabra* Labill., *Triticum scabrum* R.Br, *Agropyron scabrum* (R.Br) P.Beauv.), [f]*Festuca duriuscula* L. (synonym [e]*Festuca ovina* var. *duriuscula* (L.) Hack.), F10 = [f]*Festuca ovina* L. (synonyms [e]*Festuca ovina* subvar. *durissima* Hack., *Festuca ovina* subsp. *eu-ovina* Hack., hybrids [r]F9 × F10 = H1, [r]F10 × H1(backcross)), and [f]*Festuca stuartiana* Steud.).

SECTION 2 ORIGIN AND CULTIVATION

2.1 Centre of diversity and domestication

Western Europe is the main centre of origin of Poeae (Festuceae) (Wipff 2002; Meyer & Watkins 2003). Italian ryegrass, perennial ryegrass and tall fescue are native to Europe, temperate Asia and Northern Africa (Lamp et al. 2001). They are defined as ‘cool season grasses’ because of their preferential adaptation to cool and moist environments (Romani et al. 2002). Tall fescue is a widely adapted Eurasian grass, with natural populations found in sites varying from arid to very wet. The limits of its natural range are determined by extreme cold and by rainfall below 450 mm per year (Easton et al. 1994).

Perennial forage grasses are not domesticated in the strict sense, as ‘wild’ collections are generally phenotypically indistinct from cultivated forms. The exception to this rule is Italian ryegrass which was selected from a continuum of *Lolium* sp. and now has species status as *L. multiflorum* (Casler & Duncan 2003). In contrast, cultivars of turfgrasses are considered as domesticated from their wild forms (Casler & Duncan 2003).

Tall fescue was first documented in Victoria in 1901, with the first commercial cultivar, “Demeter” released in the 1930’s (Grassland Society of Southern Australia Inc 2008c). The first commercial cultivar of perennial ryegrass, named “Victorian” was also released at a similar time (Grassland Society of Southern Australia Inc 2008b).

2.2 Commercial uses

Italian ryegrass (annual or short-lived perennial), perennial ryegrass and tall fescue (both perennial species) are used for forage and turf purposes throughout the temperate regions of the world including North and South America, South Africa, Australia and New Zealand (Lamp et al. 2001).

All three grass species are often present together. Due to its ability to establish quickly and grow rapidly in its first year, Italian ryegrass is often included in permanent pasture mixtures to provide feed while the slower growing perennials become established. It also provides good winter growth, whereas perennial ryegrass and tall fescue have little or no growth in winter (Lamp et al. 2001).

The Alberta Agriculture, Food and Rural Development (Alberta Agriculture 2005) estimated 2003 worldwide seed production for perennial ryegrass at 185,352 megatonnes (MT) and tall fescue seed production at 123, 869 MT, the majority in the USA. In 2003/2004, nearly 8,000 MT of perennial ryegrass seed and over 5,500 MT of tall fescue seed was exported from the USA.

2.3 Cultivation in Australia

Italian ryegrass, perennial ryegrass and tall fescue are used in both pasture and turf in Australia.

2.3.1 Pasture

All three species are used for dairying and sheep grazing predominantly in the temperate areas of Australia (New South Wales, Victoria and Tasmania) (Blair 1997; Lazenby 1997; Callow et al. 2003). Pastures are usually a mix of species that can include Kentucky bluegrass (*Poa pratensis*), white clover (*Trifolium repens*), fescues (*Festuca* and *Lolium spp.*), ryegrasses (*Lolium spp.*), chicory (*Chicorium intybus*), red clover (*Trifolium pratense*) and others. Approximately 550 tonnes of certified tall fescue seed is being used in Australia annually (Villalta & Clarke 1995).

Annually oversown Italian ryegrass is the main forage for dairy cows for the cool season in the subtropics of Australia (Lowe et al. 1999a). However, there are drawbacks in the use of annual pasture including annual establishment cost, grazing problems in excessively wet weather and short growing season. Studies assessing the merits of sowing perennial pasture types in the subtropics have shown that modern cultivars of both perennial ryegrass and tall fescue can also support good milk production as well as overcoming the drawbacks of using annually sown pasture (Lowe et al. 1999b).

Most introduced pasture species in Australia were northern European in origin. However, it has been recognised that the Mediterranean climate (hot, dry summers, rainfall predominantly in autumn, winter and spring and mild winters which allow some growth) resembles that of southern Australia more closely than that of northern Europe. Cultivars from the Mediterranean are now being used to develop cultivars for use in Australia (Lamp et al. 2001) (see Section 2.4.1).

Tall fescue

Tall fescue is widely adapted to a range of growing conditions and two types of tall fescue are currently grown in Australia – those that originate from temperate Europe or America (ie spring/summer active varieties) and those that originate from the Mediterranean (ie winter active/summer dormant).

Temperate (also known as Continental) varieties are suited to areas with 650 – 700 mm or more rainfall, or on water-logged soils in Victoria (VIC) with 900 mm rainfall. They are therefore recommended for Queensland (QLD), North coast of New South Wales (NSW), high rainfall areas of northern and central NSW tablelands and slopes, VIC, irrigated areas of South Australia (SA) and south coast of Western Australia (WA), and high rainfall areas of Tasmania (TAS; (Milne 2005). Slow growth will occur during winter if there is sufficient soil moisture (Easton et al. 1994; Harris & Lowien 2003). The temperate varieties can be further divided into soft - and tough- leaved types. The tough-leaved varieties flower earlier and are hardier with better tolerance to low summer rainfall, mismanagement and lower soil fertility (Grassland Society of Southern Australia Inc 2008c).

Mediterranean varieties are suited to areas with dry summers and 450 – 550 mm rainfall and are therefore better adapted to summer drought than the temperate varieties (Easton et al. 1994; Harris & Lowien 2003). The level of summer dormancy varies between cultivars, and can range between totally dormant to some summer production. These varieties are more suited to western areas of NSW tablelands and slopes, southern NSW, south-east SA, central and east coast of TAS and south-west WA (Milne 2005).

Use of tall fescue is limited by its slow establishment, particularly when compared with ryegrass (Easton et al. 1994). Mature tall fescue may be cut in early Spring for silage (Burnett 2006a).

Ryegrass

Perennial ryegrass is used for dryland pastures or irrigated for grazing, hay or silage. It has excellent seedling vigour which makes it easy to establish and it has a rapid recovery after grazing (Lowien et al. 2004). It is widely sown in the high-rainfall (600 – 800 mm) zones of south-eastern Australia despite the fact it shows poor persistence that makes it susceptible to invasion by less desirable species and causes loss of quality and production (Waller & Sale 2001). This poor persistence is due in part to the Mediterranean-like hot, dry summer climate to which the traditional perennial ryegrass cultivars are not suited. Breeding programmes using Mediterranean germplasm together with grazing management strategies have been proposed as a means of increasing persistence and productivity (Waller & Sale 2001).

The Pasture Species Database provides the following information about Italian ryegrass (Grassland Society of Southern Australia Inc 2008a):

> It is an annual/short rotation grass used for pasture and high quality hay and silage production in areas of high rainfall (> 650 mm), a temperature range of 0 – 30^{o} C and under conditions of high fertility. It is not tolerant of dry conditions. Its major use is as a special purpose winter/spring fodder crop for beef and dairy; use in sheep production requires careful management. It establishes quickly and can withstand heavy grazing.

Italian ryegrass is widely grown both under irrigated and dryland conditions in the temperate regions of Australia, and, for example, is the major grass species used in the high rainfall areas of south-western Australia (Bolland et al. 2001). It is also oversown into summer-growing subtropical and tropical perennial pastures in eastern Australia (Queensland and New South Wales) to sustain forage production during lower winter temperatures (Lowe et al. 1999b).

2.3.2 Turf

All three species are also used for turf primarily in temperate regions (Lamp et al. 2001; Canturf 2006; Gardenet 2006; Yates 2006). Growing mixes of species in turf is thought to be advantageous to monocultures for various reasons, including better use of soil moisture during times of low rainfall (Skinner et al. 2004). Most turfs are made up of a mixture of grasses, such as ryegrasses (*Lolium spp.*), fescues (*Festuca* and *Lolium spp.*), buffalo grasses (*Stenophrum* and *Buchloe spp.*), couch or Bermuda grasses (*Cynodon spp*.), bentgrasses (*Agrostis spp.*) and field and bluegrasses (*Poa spp.*) (Canturf 2006; Yates 2006).

2.3.3 Commercial propagation

Seed production

The Australian pasture seed industry has a research and development program that is administered by the Rural Industries Research and Development Corporation (RIRDC 2003). Seed for cultivars such as those listed in Appendix 1 can be produced under a seed certification scheme (Smith & Baxter 2002) that ensures a minimum standard for purity, seed germination and seed-borne disease. Seed certification, which is overseen by a national authority in Australia (Australian Seeds Authority Ltd. 2006b), is voluntary and documents seed for its genetic purity and physical quality.

Certified seed is classed according to its generation along the pedigree. Breeders seed is used to produce Pre-basic, which is then used to produce Basic, which in turn is used to produce First Generation or C1 certified seed. Most certified seed is C1 class grown from Basic seed.

The information in Figure 1, which is an extract from the South Australian Seed Certification Scheme (Smith & Baxter 2002), provides an example of the sorts of conditions applying to the production of certified seed of a grass species in Australia. Such production may require practices that are not commonly applied to pastures, such as wide row spacings, irrigation, residue burning, isolation from neighbouring species that may cross pollinate and herbicide application to control weeds.

Figure 1. Certified Seed Crop Standard for Tall Fescue (Smith & Baxter 2002)

Sowing Seed

Basic seed.

Paddock History

Land must not have grown or been sown to tall fescue in the previous two (2) years, unless it was the same cultivar and certification class where a minimum one (1) year break between crops is recommended to meet varietal purity standards.

New crops at the seedling inspection containing mature or volunteer tall fescue plants will be rejected from certification.

Inspections

Seedling inspection

Pre-harvest inspection

Registration inspection (Refer to 3.5.3)

Crop Standards

Cultivar and Species purity:
Maximum allowed in:
Contaminant Basic Certified

Other off-types or cultivars of *tall fescue* 1 per 30 m² 1 per 10 m²

Seed produced from regenerated seedlings in the second and subsequent years (max.) nil ≤ 15%

Plants of other species, the seeds of which are difficult to distinguish in a laboratory test or which will readily cross-pollinate with the crop being grown for seed 1 per 30 m² 1 per 10 m²

Isolation

For areas larger than 2 hectares:

Basic: 100 metres from other cultivars

Certified: 50 metres from other cultivars

For areas of 2 hectares or less, double the isolation distances.

Stand Life

Basic: two (2) years (maximum)

Certified: five (5) years (maximum)

Where Basic stands are down-graded certified seed may be produced for a further three (3) years. Crops that have thinned out significantly from the previous year will be rejected.

Classes

C1: from areas sown with Basic seed.

Seed Quality Standards

Minimum Pure Seed (% by mass) 96.0%
Minimum Germination (% by count) 70.0%
Maximum Other Seeds (% by mass) 3.0% *of which no more than 1.0% shall be seeds other than Lolium sp.*

Seed production, whether for certified or non-certified seed, is closely associated with seed processing, which primarily involves seed cleaning and packaging and, if required, dressing the seed with fungicides and/or insecticides (DPIW 2004).

Turf growing

While turfgrass grown in commercial turf farms can be established either through vegetative means (sprigs or plugs[1]) or by direct seeding, it is common for the cool-season grasses such as ryegrass and tall fescue to be established from seed (Perez et al. 1995). After sowing and germination, the turf is managed using a variety of approaches that may include frequent irrigation, regular mowing, vacuum removal of clippings, fertiliser application and weed control. The turf is maintained for up to 24 months before being harvested and supplied to end users such as landscapers, sports field managers and home gardeners (Perez et al. 1995). Specialised turf harvesters (or sod cutters) are designed to cut rectangular sods of turf that are then transported as rolls or pads before being laid directly on a prepared surface to provide an 'instant' lawn. Cost effective and less complete turf coverage for areas not requiring immediate use may involve the planting of sprigs or plugs by methods developed by individual turf suppliers.

2.3.2 Scale of cultivation

Appendix 1 lists examples of commercial cultivars of *L. perenne*, *L. multiflorum* and *L. arundinaceum* grown as pasture or turfgrasses in Australia.

A breakdown of the cultivation statistics for each of the three grasses is not possible to obtain because, apart from seed production, none of the species is harvested for individual sale and therefore production statistics for the three species are subsumed within the statistics for more general categories such as pasture or turf. However, estimates of the use of perennial ryegrass and tall fescue in Australian pasture have been made. Pasture containing perennial ryegrass was estimated to cover an area of 35, 420 km^2 and pasture containing tall fescue an area of 10,992 km^2 across the Australian states, compared to 78,151 km^2 and 35,420 km^2 for white clover and lucerne respectively (Hill & Donald 1998). The relative importance of the three species can be further gauged from the figures for seed production. Perennial ryegrass is the most important sown pasture grass species in temperate Australia and other temperate regions of the World (Cunliffe et al. 2004). Within Australia, 2003 sales of ryegrass seed for pasture were estimated at 6,200 tonnes, with approximately 60% of this being perennial ryegrass. Annual sales of tall fescue seed were estimated at between 400 - 500 tonnes (RIRDC 2003). A breakdown of certified seed production is given in Table 3.

In 2003, ryegrass (approximately 4,600 tonnes) and tall fescue (approximately 700 tonnes) were the only pasture seeds imported into Australia in significant amounts (RIRDC 2003).

Table 3. Production (tonnes) of certified seed of three grass species in Australia between 2002 and 2006*

Species	Cultivar	2002/03	2003/04	2004/05	2005/06
Lolium perenne	Kangaroo Valley	0	8	0	N/A
	Tasdale	8	6	0	N/A
	Victorian	520	1326	1459	1809
	Proprietary Varieties	478	754	665	1173

[1] sprigs are small pieces of stem with leaves and some root development; plugs are usually squares of sod measuring approximately 50 mm wide x 50 mm deep; sods are rolls or pads of mature grass (typically approximately 2 m long for coverage of small areas and up to 25 m long for coverage of large areas) with a layer of roots and growing medium at the base.

Lolium multiflorum	Tama	N/A	N/A	48	N/A
	Proprietary Varieties	780	1866	2846	3395
Lolium arundinaceum	Demeter	75	168	165	315
	Proprietary Varieties	255	451	395	951

* data obtained from Australian Seeds Authority (Australian Seeds Authority Ltd. 2006a). N/A, not available.

2.3.3 Cultivation practices

Autumn and early winter (March – June) are the best times to sow tall fescue. Sowing in September in high altitude areas can also be successful if there is high rainfall. Tall fescue has poor seedling vigour, with the roots and crown developing slowly. As a result, tall fescue is sensitive to competition from more vigorous pasture and weed species (Harris & Lowien 2003). However, some of the new cultivars have improved seedling vigour.

Like ryegrass, tall fescue has a high requirement for nitrogen and its persistence is likely to be poor if high soil fertility is not maintained (Grassland Society of Southern Australia Inc 2008c). Generally tall fescue is sown in combination with legumes and as long as these are fertilised regularly with phosphorous and sulphur they will provide sufficient nitrogen for tall fescue growth (Harris & Lowien 2003). Seeding rates for tall fescue in pastures in Australia vary from 6-10 kg/ha for dryland pastures, (Harris & Lowien 2003) up to 25 kg/ha recommended by some authors for irrigated fields or areas of high rainfall (Grassland Society of Southern Australia Inc 2008c).

Perennial ryegrass can withstand close continuous grazing and is ideally suited to intensive sheep and cattle grazing. Italian ryegrass with its more upright and open growth habit is suited to grazing systems with lengthy intervals between grazing, or for silage production (Jung et al. 1996). Seeding rates for perennial ryegrass are 8-15 kg/ha for diploids or 12-15 kg/ha for tetraploids (Grassland Society of Southern Australia Inc 2008b). Rates for Italian ryegrass are slightly higher at 10-20 kg/ha for the diploids or 15-25 kg/ha for tetraploids (Grassland Society of Southern Australia Inc 2008a).

2.4 Crop Improvement

Pasture

Factors which are considered when a new pasture plant introduction is made include; adaptation to the environment, for example climatic conditions and soil factors; higher yields than the resident species and increased winter/autumn production; higher nutritive value/herbage quality; seedling vigour; even spread of growth; persistence and tolerance to grazing; ability to combine with other grasses and legumes; adequate seed production; pest and disease resistance; no adverse effects on animals; ease of harvest; herbicide tolerance and lower endophyte toxicity; and increased seed yield (Cunningham et al. 1994; Blair 1997; Oram & Lodge 2003).

Turf

The major selection criteria for turf fall into three main groups: 1) turf growth characteristics and appearance (which includes visual quality, shoot/turf density, percentage ground cover/turf density, leaf texture, turf colour, spring ‘greenup’, seedling vigour and establishment, seed yield, and maturity), 2) disease resistance and 3) resistance or tolerance to environmental factors (including wear, acid, salt and drought stress) (Stewart 2002; Meyer & Watkins 2003; Thorogood 2003).

2.4.1 Breeding

Breeding in Italian ryegrass, perennial ryegrass and tall fescue for pasture and turfgrass has been extensively reviewed (Cunningham et al. 1994; Easton et al. 1994; Reed 1996; Meyer & Belanger 1997; Meyer & Watkins 2003; Oram & Lodge 2003; Thorogood 2003; Bonos et al. 2006). Breeding objectives depend on where and how the grass is to be grown (Thorogood 2003). Grasses are phenotypically variable and adapt readily to their environment (Casler & Duncan 2003). Breeding for turf selects plants that can be mown close to the ground and maintain dense, high quality turf. This requires selection for finer, shorter leaf blades, finer stems and shorter internodes (Casler & Duncan 2003).

Classical breeding approaches such as phenotypic and genotypic recurrent selection have been widely used in grasses that are cross-pollinated and are predominantly self-incompatible. Identification of superior genotypes and their subsequent interbreeding to produce new combinations of genotypes with improved expression of specific characters is the basis of this process. Selection of germplasm from new cultivars, old pasture, turf types, the wild, or combinations of these, can be used (Stewart 2002; Bonos et al. 2006). Quantitative trait loci (QTL) have been identified in perennial ryegrass for some complex traits such as water-soluble carbohydrates (Turner et al. 2006), crown rust (*Puccinia coronata* Corda) resistance (Thorogood et al. 2001) and delayed leaf senescence (Thorogood et al. 1999). Crown rust resistance was also identified in a perennial x Italian ryegrass population (Sim et al. 2007). Experiments have also been conducted to produce tetraploid perennial ryegrass cultivars using colchicine treatment, due to the improved performance of European tetraploids (Nair 2004). Molecular and genomics approaches have also been employed in grass breeding including production of restriction fragment length polymorphism (RFLP) markers, simple sequence repeats and expressed sequence tag-simple sequence repeats (EST-SSR) markers (Zhang et al. 2006).

Many improved cultivars for use in pasture or turf are available in Australia (see Appendix 1). Information in Table 4 and Table 4 give some indication of the types of characteristics which have been selected for. Owing to the poor persistence of perennial ryegrass in pastures (see Section 2.3.1) particular attention has been paid to the improvement of this species and in the 1980s a National Perennial Ryegrass Improvement Program (NRIP) was initiated (Waller & Sale 2001).

Cross-breeding between *Festuca* and *Lolium* species is used to introduce traits (eg improved drought and frost tolerance and rust resistance) not present in the individual species (Humphreys & Thomas 1993; Oertel & Matzk 1999; Skibinska et al. 2002; Humphreys et al. 2005; Kosmala et al. 2006).

Festulolium (*Festuca* × *Lolium* crosses) have been released as short-term perennials, but further work to improve hardiness, palatability and digestibility is necessary (Oram & Lodge 2003). Natural and artificial hybrids are also known to occur between some *Festuca* and *Vulpia* species (Ainscough et al. 1986). Some genes that enable *Vulpia* to grow successfully on infertile, acid soils could therefore be transferred to tall fescue by standard backcrossing procedures (Oram & Lodge 2003).

Table 4. Examples of key features in Italian ryegrass, perennial ryegrass and tall fescue cultivars breed for either turf or pasture use in Australia*.

Species	Key features (turf cultivars)	Species	Key features (pasture cultivars)
Perennial ryegrass	• Rapid establishment • Dark green • Heat and stress tolerance • High endophyte	Perennial ryegrass	• High rust tolerance • Versatile grazing management
Perennial ryegrass	• Very dark green • Dense turf • High endophyte	Italian ryegrass	• Quick growth • Persistence • Rotational grazing
Perennial ryegrass	• Wear tolerance • Heat and disease tolerance • High endophyte • Shade tolerance	Italian ryegrass	• High rust tolerance • Australian cultivar • Rotational grazing
Tall fescue	• Very dark green, fine leaf texture • Strong, vigorous, dense turf • Dwarf type • Deep root growth (drought resistant)	Tall fescue	• Palatability • Good summer growth • Versatile grazing management
Tall fescue	• Vigorous establishment resists weed invasion • Very dark green, fine leaf texture • Vigorous rooting system • Endophyte to resist leaf and crown eating insects	Tall fescue	• Insect tolerance • Persistence • Versatile grazing management
Tall fescue	• Low mowing tolerant • Shade and sun tolerant • Deep root growth (drought resistant) • Dark green colour, fine leaf texture • Brown patch and leaf spot resistant	Tall fescue	• Persistence • Winter growth • Versatile grazing management

*(Pacific Seeds Ltd 2005); (Heritage Seeds Pty Ltd 2005)

2.4.2 Genetic modification

Genes have been introduced into Italian ryegrass, perennial ryegrass and tall fescue using various methods, including biolistics, protoplasts, whiskers and *Agrobacterium* are reviewed in (Lee 1996; Wang & Ge 2006), examples of which follow:

Italian ryegrass

Biolistics (Ye et al. 1997; Dalton et al. 1999); protoplasts (Wang et al. 1997); whiskers (Dalton et al. 1998); and *Agrobacterium* (Bettany et al. 2003).

Perennial ryegrass

Biolistics (Spangenberg et al. 1995b); protoplasts (Wang et al. 1997); whiskers (Dalton et al. 1998); and *Agrobacterium* (Wang et al. 1997; Wu et al. 2005).

Tall fescue

Biolistics (Spangenberg et al. 1995c; Cho et al. 2000; Wang et al. 2001), protoplasts (Wang et al. 1992); whiskers (Dalton et al. 1998); and *Agrobacterium* (Bettany et al. 2003).

All three grass species have been genetically modified (Wang & Ge 2006). Some of the known traits are listed in Table 5. None of these GM grasses have been approved for commercial release in Australia or internationally.

Table 5. Traits used for genetic modification of tall fescue, perennial ryegrass and Italian ryegrass

Trait	Plant species	Reference
Phosphinothricin tolerance	Tall fescue	(Bettany et al. 2003; Wang et al. 2003; Wang & Ge 2005)
colour marker	Tall fescue	(Bettany et al. 2003)
	Italian ryegrass	(Bettany et al. 2003; Takahashi et al. 2005; Takahashi et al. 2006)
hygromycin tolerance	Tall fescue	(Wang et al. 2003; Wang & Ge 2005);
	Perennial ryegrass	(van der Maas et al. 1994);
	Italian ryegrass	(Bettany et al. 2003; Takahashi et al. 2005; Takahashi et al. 2006)
cold tolerance	Tall fescue	(Hu et al. 2005)
altered nutrition	Tall fescue	(Wang et al. 2001)
decreased lignin levels	Tall fescue	(Chen et al. 2003; Chen et al. 2004);
brown patch resistant/gray leaf spot resistant	Tall fescue	unpublished
rhizoctonia resistant	Tall fescue	unpublished
drought tolerance/increased salt tolerance	Perennial ryegrass	(Wu et al. 2005)
reduced pollen allergen	Perennial ryegrass	(Bhalla et al. 2001; Petrovska et al. 2005)
	Italian ryegrass	(Bhalla et al. 2001; Petrovska et al. 2005)
increased fructan content	Perennial ryegrass	(Hisano et al. 2004)
	Perennial ryegrass	(Ye et al. 2001)
disease resistance	Perennial ryegrass	(Xu et al. 2001).
altered senescence	Perennial ryegrass	(Li et al. 2004)

Another breeding goal includes reducing toxicity of endophyte infected material through genetic manipulation of the host or endophyte or both (Oram & Lodge 2003).

A number of these GM plants have been trialled overseas including those with altered lignin content, reduced pollen allergens and herbicide tolerances.

SECTION 3 MORPHOLOGY

3.1 Plant morphology

Lamp et al (2001) describe the vegetative morphology of Italian ryegrass, perennial ryegrass and tall fescue as follows:

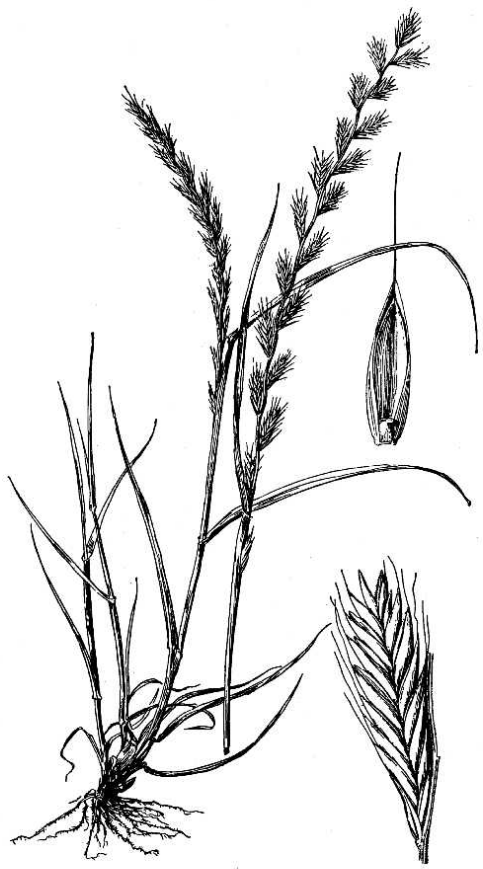
“Italian ryegrass is annual to biennial usually, but cultivars that may persist for more than two years have been developed. **Leaf blades** green to dark green, hairless, flat, upper surface evenly ribbed, lower surface smooth and shiny. Length up to 40 cm, width 5-12 mm. Young leaves are rolled in the bud. **Auricles** small and narrow. **Ligule** white, translucent, shorter than wide. **Leaf sheath** hairless with fine longitudinal ribs as in leaf blades, rounder at back.

Perennial ryegrass is a tussock-forming perennial with a fibrous root system, up to 60 cm high. **Leaf blades** dark green, hairless, flat, upper surface evenly ribbed, lower surface smooth and shiny. Length up to 30 cm, width up to 7 mm. Young leaves usually folded in the bud (V-shaped cross-section) but occasionally rolled (spiral cross-section), particularly in young plants. **Auricles** small and narrow. **Ligule** white, translucent, shorter than wide. **Leaf** purple.

Tall fescue is a perennial tussock-forming grass with a fibrous root system, grows up to 2 m high. **Leaf blade** 10-60 cm long, usually 3-10 mm but can be up 15 mm, green, hairless except for a few hairs on and near the auricle, pronounced longitudinal grooves on upper surface, lower surface smooth and glossy, margins rough to touch when fingers are moved down the margins. Young leaves rolled in the bud. **Auricles** with a few hairs on them. **Ligule** membranous and very short. **Leaf sheath** hairless, rounded at back, may be smooth or rough. Mainly green but can be red to brownish purple at base."

3.2 Reproductive morphology

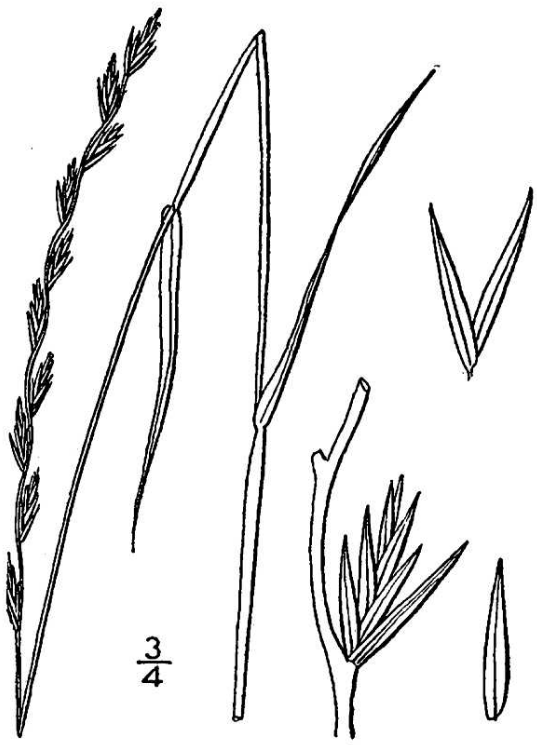
Lamp et al (2001) describe the reproductive morphology of Italian ryegrass, perennial ryegrass and tall fescue as follows:



- **Italian ryegrass (*Lolium multiflorum* Lam.)**

From: USDA-NRCS PLANTS Database / Hitchcock, A.S. (rev. A. Chase). 1950. *Manual of the grasses of the United States*. USDA Miscellaneous Publication No. 200. Washington, DC. (USDA 2006a).

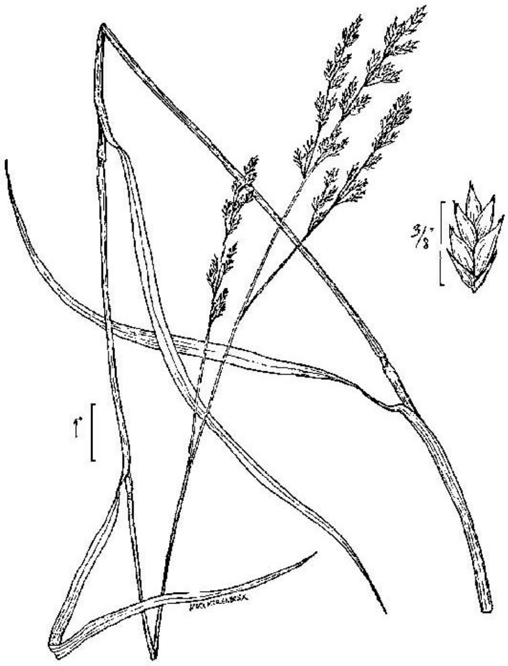
"Italian ryegrass: **Inflorescence** a spike up to 30 cm in length. The spikelets edge-on to the rachis (cf. Agropyron, in which the spikelets are side-on to the rachis. **Rachis** is recessed opposite each spikelet, which more or less fits into the recess. **Spikelets** consist of 10-20 florets laterally flattened, green, 15-25 mm long. **Glume** – 1 per spikelet, which is in the axil of the glume , lanceolate, about 10 mm long, outer surfacer ribbed like the upper surface of the blade, 5 nerved, covers less than the lower half of the spikelet. **Lemma** lanceolate, 5-8 mm long, 5 nerved. **Awn** nearly terminal, fine, straight, about 10 mm long. **Palea** similar to lemma in shape and size, 2 nerves with tiny hairs along them. **Anthers** 3, yellow or purple" (Lamp et al. 2001).



- **Perennial ryegrass (*Lolium perenne* L.)**

From :USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. An *illustrated flora of the northern United States, Canada and the British Possessions*. Vol. 1: 281. (USDA 2006a).

"Perennial ryegrass: **Inflorescence** a spike up to 20 cm in length; the spikelets are edge-on to the rachis. Rachis is recessed opposite each spikelet, which more or less fits into the recess. **Spikelet** usually 7-9 florets per spikelet, laterally flattened, green, 10-15 mm long. **Glume** 1 per spikelet, which is in the axil of the glume, terminal spikelet has 2, lanceolate, 7-10 mm long, outer surface ribbed like the upper surface of the leaf blade, 5 nerved, covers approximately the lower half of the spikelet. **Lemma** lanceolate, about 5 mm long, 5 nerved. **Palea** similar to lemma in shape and size, 2 nerves with tiny hairs along them. **Anthers** 3, yellow" (Lamp et al. 2001).



- **Tall fescue (*Lolium arundinaceum*)**

From :USDA-NRCS PLANTS Database / USDA NRCS. *Wetland flora: Field office illustrated guide to plant species*. USDA Natural Resources Conservation Service. (USDA 2006a).

"Tall fescue: **Inflorescence** an open panicle, 10-20 cm long, erect or nodding, green or purplish. **Spikelets** contain 4-8 florets. Shape elliptic to oblong, 8-18 mm long, flattened laterally. **Glumes** usually unequal, pointed, keeled. Lower glume wider, lanceolate to lanceolate oblong, 4.5-7 mm long. Lower glume 1 nerved, upper 37 nerved. Upper glume about one-third as long as spikelet. No awns. **Lemma** 6-9 mm long, rounded on back, lanceolate to lanceolate oblong, 5 nerves. May or may not have a short terminal awn. **Palea** about as long as lemma, rough keels, 3 nerves. **Anthers** 3" (Lamp et al. 2001).

SECTION 4 DEVELOPMENT

4.1 Reproduction

Grasses can reproduce both sexually and vegetatively. Italian ryegrass, perennial ryegrass and tall fescue are all wind pollinated out-crossers. The main mode of reproduction is by seed, but tall fescue and perennial ryegrass can be maintained vegetatively in the sward for many years as some cultivars have short rhizomes (USDA 2006a). This occurs rarely in turf and is more typical on spaced plants in sandy soils (Stewart 2002; Meyer & Watkins 2003). Grasses can also spread by tillering (Najda 2004; PLANTS 2006; USDA 2006a) – see Section 4.1.1 below for further discussion. In intensely managed turf or pasture, where the grass is mowed short or grazed regularly, flower heads are removed preventing sexual reproduction, so reproduction may sometimes be entirely vegetative (Grime 1979). Italian ryegrass regenerates entirely by seed (Alaska Natural Heritage Program 2005).

4.1.1 Asexual reproduction

Grasses classified as 'annuals' complete their growth cycle in a single growing season and reproduce only by seed whereas those classified as 'perennials' reproduce vegetatively as well as by seed. Most of the commonly grown forage grasses, even if they complete their growth cycle in a single season (e.g. some cultivars of *L. multiflorum* – see Appendix 1), function as perennials because they can reproduce vegetatively (Oregon State University 2000).

There are three types of growth habit that allow perennials to spread vegetatively and persist: bunch (also tufted or tussock-forming), stoloniferous, and rhizomatous (Langer & Hill 1991). A stolon is a prostrate, above-ground stem that arises from a parent plant and bears nodes from which self-sustaining plants with roots can develop even if the physical connection with the parent is broken (Crampton 1974). A rhizome is very similar except that it is defined as an underground stem. All three types of growth are dependent on the development of tillers, the basic unit of grass structure. A tiller is a shoot that arises from an axillary bud within a leaf sheath and can develop its own root system to effectively become a separate plant (Oregon State University 2000). In bunchgrasses, the tillers grow vertically (intravaginal branching) either from the crown or from above-ground nodes (aerial tillers) whereas in the formation of stolons or rhizomes, the tillers grow out horizontally (extravaginal branching) (Oregon State University 2000). Note, however that the vertical stems produced at the nodes of stolons and rhizomes can, themselves produce vertical tillers. While many of the species with stolons or rhizomes are classed as sod-forming, the extension growth of structures produced by extravaginal branching in some species can be very limited so that the species is classed as being a bunchgrass (see discussion of *L. perenne,* below).

Bunchgrasses have minimal lateral spreading compared with the sod-forming grasses and ultimately it is seed that allows significant spread of the species. However, they may form dense clumps if they tiller extensively and the true perennials may live as long as 100 years with the centre dying out leaving an outer ring of active growth (Crampton 1974). Crown derived tillers that become partially separated from the rest of the clump (for example, as a result of hoof damage) are able to strike more roots and survive independently (Langer & Hill 1991).

Sod-forming grasses could potentially live indefinitely by continual vegetative reproduction and, in many cases have a reduced seed-forming ability (Crampton 1974). They can usually recover quickly from excessive grazing, trampling or mowing and form a uniform cover of foliage and stems. For example, trampling can promote the spread of perennial ryegrass by pushing tillers apart and burying them so that they spread underground and then produce new tillers where they surface (Matthew et al. 1989).

Perennial ryegrass is classed as a bunchgrass (Oregon State University 2000; Thorogood 2003). The survival from one season to the next (perennation) and lateral spread, albeit limited, in pastures depends mainly on the production of upright tillers. However, the species can produce stolons and this may account for the tendency of perennial ryegrass to dominate in heavily grazed pastures (Waller & Sale 2001). The propensity for stoloniferous development is linked to cultivar genotype as well as to environmental factors such as soil type, degree of shading and grazing pressure (Donaghy 2001). The species has also been described as producing short rhizomes from which plants can resprout quickly following fire (Sullivan 1992).

Italian ryegrass is a bunchgrass that is only spread by seed (Carey 1995). However, it tillers profusely and can therefore be a persistent pasture species in those climates which support a biennial growth cycle.

Tall fescue is classed by some as a sod-forming grass with short rhizomes (Oregon State University 2000) and by others as a tufted bunchgrass that may or may not have rhizomes (Meyer & Watkins 2003). In pasture cultivars, most rhizome growth occurs after the second Autumn post-sowing (Milne 2005). While the rhizomes of pasture tall fescue do not spread as far as those of other species, their activity can be high in flood irrigated environments and is one reason why tall fescue persists better in this environment relative to perennial ryegrass (Milne 2005). Recently there has been the development of the cultivar RTF ™ (Rhizomatous Tall Fescue) with an extensive rhizomatous habit that makes the cultivar more appealing to the turfgrass industry than conventional fescues because of its ability to fill in bare areas and to self-repair. With regard to tiller formation and persistence, the rate of new tiller formation in tall fescue is about one-third the rate of perennial ryegrass, but tall fescue tillers survive three times longer and are much larger (Milne 2005; Burnett 2006a).

4.1.2 Sexual reproduction

All three grass species reproduce sexually by producing seed, although this may not be the main form of reproduction in mown turf or heavily grazed pastures (Section 4.1.1). They produce an inflorescence in the form of a spike or panicle (see Section 3.2). In the Kangaroo Valley cv of perennial ryegrass, it takes approximately 132 days from seedling emergence to spike emergence, and then a further 16 days for anthesis to occur when planted in NSW (Shah et al. 1990). In Melbourne, grass pollen was detected from August to May, with the peak from November to January when most grass plants were flowering (Smart & Knox 1979). The pollen is spread by wind.

In perennial ryegrass when the florets are mature the lodicules at the base of the floret swell with cell sap and force open the palea and lemma. The anthers of the stamens are extended on long filaments. The anthers split lengthwise from the tip to release clouds of pollen. At the same time the feathery stigmas project on either side of the floret ready to receive pollen. The basal older florets of the midspike flower first and then progresses toward the outermost floret and basal and apical spikelets (Thorogood 2003).

Genetics of reproduction

All three grass species are self-incompatible. There has been debate about the number of loci controlling the self-incompatibility in perennial ryegrass (Spoor 1976; McCraw & Spoor 1983). However, the presence of a two-locus (SZ) multiallelic gametophytic incompatibility system, which prevents self seed setting and inbreeding depression is now generally accepted (Cornish et al. 1979; Fearon et al. 1983). Despite the presence of this self-incompatibility system, perennial ryegrass will set seed when selfed (Spoor 1976; Thorogood 2003). In general, the number of seeds set on selfing plants is considerably lower than in crosses, self seed setting has been reported to vary from 2.2% to 32.3% and 100% in an inbred line (Jenkin 1931; Jenkin & Thomas 1938; Beddows et al. 1962; Foster & Wright 1970; Thorogood & Hayward 1991; Meyer & Watkins 2003). Italian ryegrass possesses a similar 2 locus (SZ) incompatibility system which may be overcome to produce self-pollinated progeny (Fearon et al. 1983). As in perennial ryegrass, self-fertilisation is prevented when both the S and Z alleles present in the pollen are matched in the style.

Photoperiod and/or vernalisation requirements

Flowering in most temperate perennial grasses requires dual induction. The primary induction is brought about by low temperature or short days (acting independently or in combination), while the change to long days and higher temperatures are usually needed for secondary induction (Cooper & Calder 1963; Heide 1994; Meyer & Watkins 2003; Thorogood 2003). The primary induction enables initiation of inflorescence primordial and the secondary induction causes culm elongation, inflorescence development and anthesis (Heide 1994). In some species such as perennial ryegrass it is only after the switch to secondary induction that floral initiation begins.

Perennial ryegrass has the most extreme vernalisation requirement of the three species. Little seeding in perennial ryegrass (cv Yatsyn) in the subtropics is seen because of the lack of vernalisation (F. Wilson pers comm. in Lowe et al. 1999b), whereas Italian ryegrass and tall fescue seeded profusely in late spring and early summer.

Perennial ryegrass has an obligate vernalisation requirement of at least two weeks at less than 4˚C before the inflorescence development will initiate (Cool & Hannaway 2004), although under certain conditions short day treatment may eliminate the requirement for a period at low temperatures (Evans 1960). The requirement for primary induction of perennial ryegrass increases with the latitude of origin of the germplasm (Aamlid et al. 2000). In some perennial ryegrass varieties high temperatures can substitute for long days for secondary induction. (Aamlid et al. 2000). Vernalisation is possible in the embryo, seedling or mature plant (Cooper & Calder 1963).

In *Lolium,* the differences in inductive requirements are clearly related to past climatic and agronomic selections (Cooper 1960). Separate plants of the same genotype adjust to their surroundings and as such may flower at different times. The flowering period of the species also varies with location, although the anthesis period (the time of day during which pollen shedding begins and ends) is indicative of the species. Westerwolds ryegrass (*Lolium multiflorum*) which has been selected as a summer-annual catchcrop shows no inductive requirements, while in the perennial Italian variety an obligatory winter requirement prevents tillers formed during mid-late Summer from flowering and ensures an overlapping succession of vegetative tillers from year to year (Cooper 1960).

Extreme primary induction requirements are found in the genus *Festuca*, including in tall fescue (Heide 1994). In the UK, few tillers flower in the calendar year that they are produced (Gibson & Newman 2001). Tall fescue is predominately self-sterile. The flowers are hermaphrodite, homogamous and wind-pollinated (Gibson & Newman 2001). Tall fescue needs cold vernalisation to flower, then daylengths greater than 12 hours (Hannaway et al. 2004).

Grass species allocate different resources to flowering. Reproductive allocation (RA), defined as weight of reproductive structures as a proportion of total above-ground biomass was measured as 7.6% for tall fescue and 18.7% for perennial ryegrass. It was shown for 40 grass species to be negatively correlated with potential maximum height (Wilson & Thompson 1989).

4.2 Pollination and pollen dispersal

Pollen

Plants (within and among species) can vary substantially in floral fertility, number of panicles, amount of pollen and quantity of seed produced. Tall fescue plants shed pollen in the early to mid-afternoon hours (Meyer & Watkins 2003) and perennial ryegrass anthesis occurs once daily around midday and is more profuse on warm, bright days (Thorogood 2003). In the UK, perennial ryegrass pollen was released at 0500-0600 and 1100-1300 except on dull days when anthesis was suppressed. In Melbourne, a bimodal release was also seen with a major peak between 1400-1800h and a minor peak between 0600-1000h (Smart & Knox 1979).

The pollen production of perennial ryegrass in Victorian pasture has been estimated as 5.4×10^3 pollen grains per anther, 23.0×10^5 pollen grains per spike and 2.11×10^{13} pollen grains per hectare (Smart et al. 1979). This gives an estimate that 1 hectare of perennial ryegrass pasture could produce 464 kg of pollen per season. The estimate for the amount of pollen from perennial ryegrass on roadside verges is 10 fold lower at 48 kg per hectare per season due to competition from other plants (Smart et al. 1979).

Pacini et al. (1997) stated that tall fescue pollen could survive in open air for 48 hours but was completely non-viable 72 hours after opening of anthers. However, Wang et al. (Wang et al. 2004b) found that pollen could only survive up to 22 hours under controlled conditions in a growth chamber, whereas under sunny atmospheric conditions, viability was reduced to 5% in 30 minutes with complete loss of viability in 1½ hours. Under cloudy conditions pollen remained viable for up to 4 hours, with about 5% viability after 2½ hours. When pollen viability was lower than 5% no seed set could be obtained. Relatively high temperatures (36^oC and 40^oC) and high doses of radiation reduced pollen viability, while humidity did not. Temperature (in the range 14-26^oC) also affects the growth of pollen tubes in perennial ryegrass with higher temperatures giving better pollination (Elgersma et al. 1989).

Pollination

As grasses are mainly wind pollinated, some of the following factors are expected to influence pollination levels, including

1) plant factors such as timing of flowering of pollen donors and receptor plants, level of pollen production (higher in cultivars with high levels of sexual reproduction), plant height, form, size, number of panicles, position of flowers and pollen weight
2) climatic conditions such as wind speed, direction and humidity
3) ecological factors such as distance between the donor and acceptor plants (isolated plants are more likely to hybridise with pollen from a distant source than individual plants growing in groups), density of the donor plants, and geographical and/or vegetative barriers
4) genetic factors such as ploidy level and genetic compatibility (Rognli et al. 2000; Johnson et al. 2006).

As Italian ryegrass, perennial ryegrass and tall fescue are highly outcrossing, wind-pollinated species, extensive gene flow can occur. Both pollen shedding profiles and pollen viability data is necessary to estimate the possible gene flow.

In trials with perennial ryegrass, although pollen deposition declined with distance up to 80 m, there was considerable variation in dispersal of pollen over time (early to late anthesis) as well as in traps of various orientations (forward, backward and upward) (Giddings et al. 1997a; Giddings et al. 1997b). Further trials with perennial ryegrass showed that the amount of pollen deposited does not always decrease smoothly with increasing distance from the source. It is suggested that pollen clouds are taken high up into the atmosphere, move with weather and are deposited in times of calm weather, so it is therefore conceivable that pollen could move significant distances from the source. Both wind speed and turbulence are expected to be factors (among others) in this process (Giddings et al. 1997b). However, it is unknown whether the pollen collected in pollen traps is viable (Wang et al. 2004a).

Studies on pollen flow have shown that little outcrossing occurred beyond 6m from the field border in perennial ryegrass (Copeland & Hardin 1970). In GM tall fescue gene flow experiments transgenes were detected at 50 m and 100 m with frequencies of 0.29-0.88%. The highest frequencies (0.88% at 50 m and 0.58% at 100 m) were in the direction of the prevailing wind (Wang et al. 2004a). In a further study tall fescue transgenes were detected in recipient plants at up to 150 m from the central plot. The highest frequencies (5% at 50 m, 4.12% at 100 m and 0.96% at 150 m) were recorded in the prevailing wind direction. No transgenes were found at 200 m in any direction (Wang et al. 2004b). A later study (Cunliffe et al. 2004) showed that gene flow in perennial ryegrass had a leptokurtic distribution with high gene flow close to the source which declines to a horizontal asymptote at 36 m. Beyond this levels decreased from <5% at 36 m to <2% at 144 m, depending on wind direction.

In the USA for foundation seed of cross-pollinated grasses, the isolation standard required by USDA is 274 m (Wang & Ge 2006) and allowed level of contamination of other varieties is 0.1% with the allowed levels of seed from other inseparable species is significantly less (Montana Seed Growers Association 2008). In South Australia the isolation distance for basic seed is 200 m from other grasses if the area is less than 2 ha, or 100 m if greater than 2 ha (see Figure 1) (Smith & Baxter 2002).

4.3 Fruit/seed development and seed dispersal

Development of seed

The seed of grasses is more correctly called the caryopsis and it is technically a fruit (Langer & Hill 1991). It consists of the endosperm which is surrounded by the aleurone layer then the fused testa (seed coat) and pericarp (fruit wall). The scutellum separates the embryo, which comprises the radical, enclosed in the coleorhiza and the plumule surrounded by the coleoptile. The dry grass seed normally contains 14% water. Tall fescue seed are mature 29-30 days after anthesis at which time the endosperm is hard and flinty (Gibson & Newman 2001). Seeds of the three species range from 2.6-4 mm long and 0.7-1.7 mm wide (Weiller et al. 1995).

Due to factors such as plant breeding, seed production between different cultivars of Italian ryegrass, perennial ryegrass and tall fescue can vary greatly (Table 6). Generally, seed yield of perennial ryegrass is low and unpredictable (Elgersma et al. 1989). However, estimated seed production in a NSW study was 14040 seed/m^2 for perennial ryegrass and 9740 seed/m^2

for tall fescue (Lodge 2004). In USA Italian ryegrass cultivars gave numbers of pure live seed (PLS) of between 675-1289 m^2 (Venuto et al. 2002).

Table 6. Seed production in three grass species

	Tall fescue	Perennial ryegrass	Italian ryegrass
Seed production (g/m²)	100 (Cole & Johnston 2006) 100.2 ± 5.51 (cv Safari) (Fairey & Lefkovitch 2001) 117.1 ± 6.39 (cv Tomahawk) (Fairey & Lefkovitch 2001)	150-180 (Cole & Johnston 2006)	
Mean seed/panicle (mg)	172.7 ± 11.26 (cv Safari) (Fairey & Lefkovitch 2001) 135.3 ± 8.86 (cv Tomahawk) (Fairey & Lefkovitch 2001) 160 (cv Albena) (Stoeva 2005) 182 (cv Elena) (Stoeva 2005)	80 (cv Bulgarian) (Stoeva 2005)	
1000 seed weight (g)	2.07 ± 0.077 (cv Safari) 1.87 ± 0.070 (cv Tomahawk) 1.8 - 2.5 (FAO 2008) 1.2 (cv Albena) (Stoeva 2005) 2.3 (cv Elena) (Stoeva 2005)	1.739 (cv Taya) (Larsen & Andreasen 2004) diploids: 1.3 - 2.7 tetraploids: 2.0 - 4.0 (FAO 2008) 1.8 (cv Bulgarian) (Stoeva 2005) 1.780 ± 0.272 (Thompson et al. 1993) 2.5-4.3 (Hill et al. 1985)	*Multiflorum* diploid varieties: 2.0 - 2.5 tetraploid varieties: 3.0 - 4.6 (FAO 2008) Westerwold diploid varieties: 2.5 - 3.0 tetraploid varieties: 3.7 - 5.1 (FAO 2008)

Seed dispersal

Grass seeds are capable of germination after passing through the digestive systems of grazing animals such as cattle and sheep (Yamada & Kawaguchi 1972; Yamada et al. 1972; Johns & Greenup 1976; Janzen 1984; Chambers & MacMahon 1994; Hulme 1994; Fischer et al. 1996) or horses (Campbell & Gibson 2001). The potential of cattle to disperse the seeds of perennial ryegrass, Italian ryegrass and tall fescue has been assessed in two feeding studies (Yamada & Kawaguchi 1972; Yamada et al. 1972). Seeds of the three species could be recovered from faeces 12-24 hours after feeding. Viable seeds were recovered for all species and seedlings started to emerge after one week (Yamada & Kawaguchi 1972; Yamada et al. 1972). In a study of seed dispersal by sheep, seeds of Italian and perennial ryegrass were transported in the wool of grazing sheep, and in the case of perennial ryegrass the seeds remained in the wool for 1-2 months (Fischer et al. 1996).

In the UK, a study in grassland showed no significant predation of grass seed by molluscs or arthropods, but did show removal by rodents (Hulme 1994), although this was reduced by seed burial. Viable Italian ryegrass seeds have been found in the faeces of the European hare with the authors concluding that hares could be a means of seed dispersal (Vignolio & Fernández 2006). While some bird species have been shown to graze on *Lolium spp*. (Patton & Frame 1981) no literature is available on the potential of seed dispersal by birds. Seed dispersal in irrigation water has been observed for *Lolium spp.* in Chile, with germinable seeds recovered from the irrigation water (Tosso et al. 1986). Human activity is also a likely source of seed dispersal with perennial ryegrass seed transported on cars (Hodkinson & Thompson 1997).

4.4 Seed dormancy and germination

Both seed size and shape can have an effect on the presence of seeds in the seed bank. This is probably related to the ease of burial of the seed. The common mechanisms of burial (such as penetrating cracks in soil, being washed into soil by rain, ingestion by earthworms) will operate more effectively with small, compact seeds. Earthworms can also eat seeds in the seed bank and bring them to the surface where they can germinate (Thompson et al. 1987). A study in northern NSW (Armidale and Tamworth) indicated that ant predation of tall fescue was significant (Johns & Greenup 1976). Germination requirements, dormancy mechanisms and resistance to pathogens also contribute to persistence in soil (Thompson et al. 1993).

Perennial and Italian ryegrass both form transient type I seed banks, a transient type I seed bank enables a species to take advantage of seasonal gaps in vegetation cover (Thompson & Grime 1979). This is due to their large seed, lack of pronounced dormancy mechanisms, ability to germinate in a range of temperatures or in light and dark (Thompson & Grime 1979).

It is likely that the length of dormancy could vary widely among and within cultivars and even among and between individual plants of the same cultivar due to genetic and environmental factors. The environment in which seeds develop on the parent plant often plays a role in determining dormancy status. Temperature, water supply, shading, daylength and nutrient supply are the main factors attributed to modifying the proportion of seeds exhibiting dormancy in a number of plant species. For example, Italian ryegrass seeds become larger and more dormant as temperature is reduced from 27°C to 15°C, and perennial ryegrass seeds respond similarly (Steadman et al. 2004).

A study in NSW of tall fescue and perennial ryegrass indicated that 14 months after seed production the seed bank contained 14% of the perennial ryegrass and 10% of the tall fescue seed released. After 26 months no seed bank remained of either species (Lodge 2004). Perennial ryegrass seed were not found in a seed bank study in the UK (Akinola et al. 1998), although in another study perennial ryegrass comprised 7.5% vegetative cover and 0.6% of the transient seedbank (Williams 1984). Perennial ryegrass has been seen to persist in the soil for less than 5 years (Thompson et al. 1993).

Italian ryegrass, perennial ryegrass and tall fescue germinate rapidly without pre-treatment as they all lack a physiological dormancy (Hill & Pearson 1985; Lodge 2004). One month after harvest mean germination of perennial ryegrass (cv. Kangaroo Valley) and tall fescue (cv. Demeter) seeds was 70.5% and 62.5%, respectively (Lodge 2004). In two Italian ryegrass cultivars (Tribune and Lemtal) 50% of the seed germinated within three weeks of harvest (Hides et al. 1993). In comparison to other grasses, perennial ryegrass (cv. Derby) is relatively quick to germinate. Lush and Birkenhead (1987) showed in a study in Australia that it takes 2.8 days (in spring) to 6 days (in winter) for 50% of seeds to germinate in the field.

Perennial ryegrass was superior in its ability to germinate under conditions of moisture stress compared to six other grass and legume species (McWilliam et al. 1970). In constant temperature experiments, temperatures within the range 5-30°C did not limit the germination of seeds of perennial ryegrass (cv. Victorian) (McWilliam et al. 1970). In addition, it has been reported that maximum germination occurred at 30/10°C (12 h/12 h) and high germination levels may also occur above 30°C for cv. Kangaroo Valley (Lodge 2004).

At constant temperatures, germination of Italian ryegrass (cv. Grasslands Tama, Ucivex) and tall fescue seeds (cv. Demeter, AF5, AF6, Kenhy) was lowest at 15°C and 10°C compared to other temperatures tested (Hill et al. 1985). Germination of tall fescue and Italian ryegrass was also reduced at 35°C (or 30/25°C for cv. Grasslands Tama) (Hill et al. 1985). Maximum germination occurred at 30/20, 30/15 and 30/25°C (12 h/12 h) for tall fescue (Lodge 2004).

In the USA, a study showed no germination of naturally dispersed tall fescue seed in undisturbed soil (Smith 1989). In NSW, seedling emergence of tall fescue and perennial ryegrass occurred in May/June, with only 31% tall fescue and 73.8% perennial ryegrass surviving until November and none in the following March (Lodge 2004). However, under controlled conditions, seeds of tall fescue and Italian ryegrass maintained germinability for at least 12 months (10°C and 95% relative humidity) (Kulik & Justice 1967) although after 5 years the percent germination of Italian ryegrass seed dropped off rapidly (Rutledge & McLendon 1996).

4.5 Vegetative growth and dispersal

After imbibition the caryopsis swells slightly, the root emerges through the coleorhiza from the proximal end of the grain after 3-5 days, just before the coleoptile. The coleoptile is purplish in colour and grows up between the palea and lemma, splitting at the top when it has grown 5-10 mm to allow emergence of the first leaf (Gibson & Newman 2001).

Early growth rates are dependent on the seed reserves, with growth rates during the first 20 days being related to the seed or caryopsis weight. This was also influenced by the perenniality, which gave slower than expected growth and polyploidy, which increased growth rates (Hill et al. 1985). The number of live leaves/tiller is normally regarded as approximately constant and is three for perennial ryegrass and slightly higher (mean = 3.7) for tall fescue (Yang et al. 1998). Both ryegrass and tall fescue produce their first root below their last live leaf and have approximately twice the number of active roots on tiller axis than leaves as roots turnover more slowly than leaves (Yang et al. 1998).

Perennial ryegrass plants are very long lasting (30+ years), depending on management and environmental factors. However, the effective life of a pasture is 5-10 years (Grassland Society of Southern Australia Inc 2008b). The persistence of perennial ryegrass varies between cultivars. For example, for cv. Yatsyn, only about 40% of the plants survived under grazing from one year to the next (Lowe et al. 1999b), similar to results seen from a sheep grazed perennial ryegrass pasture in SW Victoria (Waller et al. 1999). Tall fescue has been described as a long-lived perennial (10+ years) (Hannaway et al. 2004). Italian ryegrass cultivars are either annuals (Westerwolds types) or biennials that persist for two years (Grassland Society of Southern Australia Inc 2008a). In the subtropics of QLD, tall fescue was the most persistent grass in irrigated pasture under grazing and Italian ryegrass the least persistent (Lowe et al. 1999b).

Perennial ryegrass tillers produced after reproductive growth in the spring form the basis of the plant population for the following year. Few tillers (<10%) survive for more than twelve months so the plant is dependent on tiller replacement for survival (Grassland Society of Southern Australia Inc 2008b). Perennial ryegrass is known to form compact tussocks with large numbers of long leaf blades (Fustec et al. 200).

Vegetative dispersal

Perennial ryegrass and tall fescue are able to form clones, with adventitious roots, from cut stem pieces kept in water. It was therefore assumed that weed control by cutting the stems of these plants could contribute to their dispersal (Uchida & Arasea 2005). No literature is available on the likelihood of vegetative dispersal occurring in this manner under field conditions. Tiller growth as a means of perennial ryegrass vegetative dispersal is also possible over short distances in pasture. The average distances of aerial tiller dispersal over the two year study were 4.5-4.8 cm and 3.6-4.2 cm. The maximum length of aerial tiller dispersal found in this study was 15 cm in the first year and 15.5 cm in the second year. While aerial tillering may not lead to long distance dispersal of perennial ryegrass it is important for maintain the population (Sawada 1991).

SECTION 5 BIOCHEMISTRY

Italian ryegrass, perennial ryegrass and tall fescue are not pathogens and not capable of causing disease in humans, animals or plants. However, they do contain endophytes which produce alkaloids that act as deterrents to insect herbivory but also affect utilisation as animal feed. Grass pollens are one of the most important airborne allergen sources worldwide and cause hayfever in many susceptible individuals.

5.1 Toxins

Throughout the world Italian ryegrass, perennial ryegrass and tall fescue are widely grown for turf and forage. In contrast to many plants which possess chemical defences, grasses are not well defended. Most grasses have co-evolved with grazing animals and survive defoliation by their growth habit rather than intrinsic toxicity (Cheeke 1994). An examination of a number of toxic plant databases listed tall fescue (Cornell University 2001; University of Purdue 2006); and perennial ryegrass (Food and Drug Administration 2006; University of Purdue 2006) as toxic to animals. However, the Canadian Poisonous Plants Information System (Canadian Biodiversity Information Facility 2006) and Veterinary Library, University of Illinois, USA (University of Illinois 2005) did not list any of the three species as toxic. This is probably because the grasses alone are not toxic (even though they produce their own alkaloids), but become so when they have certain fungi associated with them, or when there are mineral deficiencies. However, in a review of plant toxicants which may be present in milk the genus *Festuca* (which would have included tall fescue) was listed as containing pyrrolizidine alkaloids which are known to be hepatotoxic and/or pneumotoxic in horses, cattle, sheep goats or pigs (Panter & James 1990).

Endophyte related diseases

Italian ryegrass, perennial ryegrass and tall fescue can all contain toxin-producing endophytes (see details below and Section 5.4 for more details). The endophytes produce alkaloids which can be harmful to livestock. In tall fescue and perennial ryegrass this is caused by the toxin ergovaline which is a vasoconstrictor so can cause heat stress by constricting blood vessels as well as other symptoms. For sheep and cattle an ergovaline concentration of between 0.75-1.25 mg/kg dry plant tissue can pose a risk if these grasses are the sole food (Harris & Lowien 2003). For perennial ryegrass a lolitrem B concentration of between 1.5-2.5 mg/kg dry plant material can pose a risk. However, as a general rule if the hay or silage makes up <50% of total ration there is unlikely to be a problem (Kemp et al. 2007).

Ryegrass staggers (fescue toxicosis, summer slump)

Ryegrass staggers occurs in animals grazing pastures containing perennial ryegrass and tall fescue infected with endophytes (see Section 6.4). The main cause is Lolitrem B from perennial ryegrass. It is most concentrated in older tissues, the base of the plant and seed. The concentration increases under drought or with high soil nitrogen when the plant is water stressed (Reed 1999b; Kemp et al. 2007). The highest incidence is in summer and autumn. Symptoms in affected animals can vary from tremors in mildly affected stock, to lack of coordination and collapse in more severe cases (Reed 1999b). It can also cause slower weight gains, decreased milk production, poor appetite, retention of winter coat, reproductive problems, and elevated temperature (University of Purdue 2006). Ryegrass staggers is not usually fatal, and animals usually recover unaided (Reed 1999a), although mortality can occur due to misadventure such as affected animals falling over cliffs or into water (Cheeke 1995).

Fescue foot and fat necrosis (dry gangrene)

Fescue foot and fat necrosis affect animals grazing pasture infected with endophytes. It is caused by ergovaline (Kemp et al. 2007) and is a problem generally associated with tall fescue, although it is theoretically possible that perennial ryegrass could produce this disorder (Kemp et al. 2007).'Fescue foot' is a painful swelling of the fetlocks, which causes lameness. It tends to develop in the late autumn and winter, and the extremities (typically tail, ears, and rear feet) undergo necrosis (University of Purdue 2006). Animals need to be removed from the fescue pasture otherwise gangrene can set in which may cause death of the animal (Lamp et al. 2001). Fat necrosis develops when lesions develop in fat inside the abdomen causing the animal to die (Lamp et al. 2001; University of Purdue 2006). Both these conditions contribute to poor animal performance (resulting in low meat and milk production) (Lamp et al. 2001).

Ergot

Ergot is another fungal disease associated with pasture grasses, including perennial ryegrass and tall fescue. The disease is caused by a number of species of *Claviceps* depending on grass type (eg *Claviceps purpurea* is associated with perennial ryegrass and tall fescue), and is toxic to grazing animals and humans on consumption (Clarke 1999b). Summer ill-thrift or winter lameness in livestock is associated with ingestion of ergot alkaloids (Harris & Lowien 2003). Clinical signs include behavioural changes, swelling, lameness, abortions, convulsions, gangrene, and death. In sublethal cases, once the source of ergot is removed, recovery from neurologic signs is likely, but recovery from the vascular effects and gangrene is unlikely (University of Purdue 2006).

Grass tetany

Cattle grazing on pastures which are low in magnesium, calcium and sodium, and high in potassium and nitrogen, are at risk of developing grass tetany. Most veterinary texts define 'grass tetany' as a deficiency of magnesium (Mg) and many different circumstances can cause this condition to arise. Low levels of blood magnesium in cattle (hypomagnesaemia) are usually associated with low levels of blood calcium, particularly in pregnant cows (late in gestation) and those with calves. At these low levels muscle movement is restricted and breathing fails, often resulting in animal death. The disorder is prevalent on the northern, central and southern tablelands and slopes, but has also occurred elsewhere in Australia (Elliot 1999).

5.2 Allergens

Grass pollens are one of the most important airborne allergen sources worldwide. Allergic sensitisation may affect as many as 20% of the general population and as much as 40% of atopic individuals. Symptoms of grass pollen allergy are most often distinctly seasonal and predominantly consist of rhinitis and conjunctivitis (Andersson & Lidholm 2003). As many as 21 genera of grasses have been implicated in grass allergy, but the main contributor is perennial ryegrass due to its large pollen output. Italian ryegrass and tall fescue also produce prolific amounts of pollen and in certain environments and seasons can cause hayfever (Mallett & Orchard 2002). Estimates suggest that in Melbourne a person may be exposed to 0.5-1.0 mg grass pollen during the 4 months of the pollen season (Smart et al. 1979). A human respiratory intake of 1μg of grass pollen maybe sufficient to cause symptoms of hayfever in susceptible individuals (Smart et al. 1979).

The allergens identified have been classified into a number of groups, with Group 1 grass pollen antigens being the most prominent. About 90% of allergic individuals display IgE antibody reactivity to Group 1 allergens, and in several species, this has been shown to account for a considerable part of the specific IgE binding to the pollen extract (Andersson & Lidholm 2003).

Grass allergens are typically glycoproteins of approximately 30 kDa, which are released quickly from pollen upon hydration (Cosgrove et al. 1997). One pollen allergen, Lol pIb, is located mainly on starch granules in the pollen grain so when the ryegrass pollen encounters water, the grains burst releasing approximately 1000 starch granules from each pollen grain (Singh et al. 1991). The identification and characterisation of allergens is difficult due to the high degree of cross reactivity between different grass species (van Ree et al. 1998; Wissenbach et al. 1998), and the existence of isoallergens within a single group of allergens from one species (Wissenbach et al. 1998).

Many pollen allergens have been cloned and characterised, including several *Lolium* pollen allergens. The Structural Database of Allergenic Proteins (SDAP) lists a number of allergenic proteins from *L. perenne* including Lol p 1 (Perez et al. 1990; Griffith et al. 1991) (and isoallergens Lol p 1.0101, 1.102 and 1.0103), Lol p 2 (Ansari et al. 1989a; Sidoli et al. 1993), Lol p 3 (Ansari et al. 1989b), Lol p 5 (Singh et al. 1991; Klysner et al. 1992) (and isoallergens Lol p 5 1.0101 and 1.0102), and Lol p 11 (van Ree et al. 1995). Additional allergenic proteins, Lol p 4, Lol p 10 and another isoallergen for Lol p 5 (Lol p 5c), are listed in a review by Andersson and Lidholm (Andersson & Lidholm 2003). Lol p 1 proteins are classed as Group 1 allergens. No allergenic proteins are listed for Italian ryegrass or tall fescue in the review by Andersson and Lidholm (Andersson & Lidholm 2003) or on SDAP (University of Texas 2006).

Besides the protein component of pollen, carbohydrate structures such as N-glycans are also thought to be an important part of allergenicity, particularly in relation to cross reactivity between different plant allergens. The most abundant N-glycans in perennial ryegrass pollen are those carrying both xylose and core α1,3-linked fucose residues (such as MOXF3 and MMXF3) (Wilson & Altmann 1998). (1→3)-β-D-glucan has also been measured from perennial ryegrass pollen at approximately 600 ng/106 pollen grains, which was estimated to be a level sufficient to cause allergic reactions (Rylander et al. 1999).

5.3 Other undesirable phytochemicals

Some grass species have been thought to exhibit allelopathy. Allelopathy is the direct or indirect effect of one plant on another through the production of chemical compounds that escape into the environment (Rice 1979). This is most pronounced in tall fescue.

The allelopathic potential of tall fescue has been documented and is thought to be the reason that it is difficult to establish legumes in tall fescue pastures (Smith & Martin 1994). Aqueous and ethanol extracts of tall fescue leaf and stem tissue have been shown to exhibit allelopathic effects upon alfalfa, Italian ryegrass, rape (*Brassica rapa*), red clover (*Trifolium pratense L.*) ball clover (*T. nigrescens*), crimson clover (*T. incarnatum*) and birdsfoot trefoil (*Lotus corniculatus*) (Peters 1968; Stephenson & Posler 1988; Luu et al. 1989; Smith & Martin 1994; Chung & Miller 1995; Springer 1996; Applebee et al. 1999).

A wide range of organic acids in the tall fescue extracts were involved in the inhibition of birdsfoot trefoil (Luu et al. 1989), with seedling growth rates being more affected than germination. The inhibition has been shown to be dose-dependent and occurred in soil as well in the glasshouse (Stephenson & Posler 1988). It varies both between tall fescue genotypes (Peters & Mohammed Zam 1981), and between seasons with the greatest inhibition of birdsfoot trefoil growth occurred for extracts prepared in the Autumn, when the tall fescue plants were growing strongly (Stephenson & Posler 1988). Increased carbon dioxide levels were seen to enhance the phytotoxicity of tall fescue to alfalfa (Applebee et al. 1999).

The allelopathy observed for tall fescue is not due to the presence of an endophyte. In clover, the presence of tall fescue inhibits seed germination and reduces seedling shoot and root lengths, whether the tall fescue contains an endophyte or not. However, the presence of the endophyte in tall fescue did reduce the length and density of clover root hairs which might impact on its ability to take up nutrients and water (Springer 1996).

Italian ryegrass has also shown allelopathy (McKell et al 1969), particularly against clovers and medics (Chung & Miller 1995). Aqueous extracts of Italian ryegrass foliage inhibited the germination and seeding growth of alfalfa (Smith & Martin 1994), although this effect is less severe than with tall fescue extracts. No allelopathic response of wheat to Italian ryegrass was seen, but below-ground competition reduced wheat height, leaf number, tillering, area and dry weight (Stone et al. 1998).

There have been no reports of allelopathy from perennial ryegrass. Similarly, allelochemicals released by endophytes of perennial ryegrass had no direct effect on growth of white clover (Prestidge et al 1992). However, allelopathy has also been observed between two populations of perennial ryegrass, where the growth of one population reduced the growth of the other in mixed cultures when the growth medium was not replaced (Kraus et al. 2002). In other species such as US prairie plants, no allelopathic effects of tall fescue extracts were observed (Renne et al. 2004).

5.4 Beneficial phytochemicals

Pasture Nutrition

Tall fescue has a high nutritive value compared to perennial ryegrass, although trials in SE Queensland showed similar average daily milk production and milk quality from perennial ryegrass and tall fescue pastures (Harris & Lowien 2003).

The herbage yield and composition of pasture grasses are influenced by many environmental (eg climatic and weather conditions, soil type and nutrients in the soil, and fertilisation and cutting management) and genetic factors (eg forage type, species and cultivar) (Tas 2006).

Generally, pasture is most palatable, most easily digested and most nutritive earlier in the season when leaves are young (USDA 2006b). Although the nutritive value of pasture declines with age, total yields increase, which results in a conflict between quality and yield. Taking this into consideration, early cutting of pasture for hay and silage (at heading emergence) is probably the most cost-effective way of producing feed for both production and maintenance of stock, despite the sacrifices in total yield that result (Andrews 1997).

There is a tendency for leaves to become coarse, tough and unpalatable with age, making digestion more difficult for grazing animals. For example, in a perennial ryegrass study, *in vitro* digestibility was between 80-88% during the vegetative, early bloom and heading stages of growth but dropped to 71% when the grass was mature. Protein levels are also higher early in the season, or at immature stages of development. For example, in a tall fescue study conducted in the US, protein was 16.2% in May compared to 9.1% in July, and in perennial ryegrass crude protein levels dropped from 13.2% to 9.1% between the heading and mature stages of growth. In the same study, protein levels increased with increased applications of nitrogen fertiliser, by 8% and 5.8% in the vegetative and early stages of growth, respectively (USDA 2006b).

SECTION 6 ABIOTIC INTERACTIONS

Populations of Italian ryegrass, perennial ryegrass and tall fescue are variable. Grasses in general are highly plastic and are capable of responding to fluctuating environments and stresses by morphological and physiological changes as to phenotype (Bradshaw 1965). Therefore, it has been possible to breed many cultivars with improved adaptation to a wide range of environments and conditions (Lodge 2004).

6.1 Nutrient requirements

The major nutrient deficiency that limits grass growth in soils in temperate regions of Australia is nitrogen. However, sowing pastures which contain a legume component reduces the need for applications of nitrogen fertilisers (Andrews 1997). Depending on the use of the pasture, nutrient requirements vary. For example, the greatest losses via nutrient removal in animal products, from high productivity dairy pastures, is nitrogen and potassium, wool and dairy enterprises are similar in terms of sulphur losses, and beef and dairy enterprises are similar in their loss of phosphorus (Sale & Blair 1997).

Nitrogen is important in turfgrass for healthy growth and colour, although excessive nitrogen can lead to shallow-rooted grass that is more susceptible to stresses such as drought and heat (Fagerness et al. 1998). Phosphorus is also important, although the fibrous root system of grasses is efficient at extracting phosphorus from the soil. The addition of potassium to turfgrass is important for improving stress tolerance. The micronutrient that is most often deficient in turf, especially in alkaline soils, is iron (Fagerness et al. 1998). Iron deficiency results in chlorosis or yellowing of foliage due to a lack of chlorophyll synthesis.

Italian ryegrass requires a highly fertile soil to perform well and responds well to applications of nitrogenous fertilisers (Lamp et al. 2001). It has a wide range of soil adaptability, being tolerant of acidic to alkaline soils (pH 5.0 to 7.8). Below pH 5.0, aluminum toxicity may be a problem and higher pH can cause chlorosis due to iron and manganese deficiencies. The best growth occurs when soil pH is maintained between 5.5 and 7.5 (Hannaway et al. 1999).

Perennial ryegrass grows best on fertile, well-drained soils but has a wide range of soil adaptability, and tolerates both acidic and alkaline soils (pH range of 5.2 to 8.0; Cool & Hannaway 2004). It responds well to applications of nitrogen (both as absolute N and N fixed by legumes) and phosphorus, and is moderately tolerant of acid soils although there is a sensitivity to Al concentration when soil pH is low (pH_{Ca} < 4.4) (see discussion in review by Waller & Sale 2001). Nitrogen application has been proposed as a measure to improve persistence of perennial ryegrass in intensively grazed dairy pastures (Harris et al. 1996).

Tall fescue is adapted to a wide range of soils, including those that are acid or alkaline, saline, of low fertility, medium to heavy textured, or subject to waterlogging (Lamp et al. 2001; Meyer & Watkins 2003; Lodge 2004) (Lodge 2004), but is more productive on highly fertile soils (eg basalt to fine granite; Harris & Lowien 2003). It responds well to applications of phosphorous, nitrogen and sulphur. For example, tall fescue will grow on less fertile soils that are regularly fertilised to maintain phosphate and sulphur (Easton et al. 1994; Harris & Lowien 2003). It grows better on alkaline, saline, wet and compacted soils than other cool season grasses. Optimum growth occurs at a pH of 5.5 to 6.5, but tall fescue can tolerate a pH range of 4.7 to 8.5 (Meyer & Watkins 2003). Experiments have shown increased tillering (emergence , number of proportion of buds developing into tillers) following application of nitrogen fertiliser (Wilman & Pearse 1984) and increased seed yield (Simpson & Bull 1970).

6.2 Temperature requirements and tolerances

Italian ryegrass is characterised by rapid establishment (even in very wet conditions). Its growing season is autumn, winter and spring, and also summer if sufficient moisture is available. It is particularly valued for its winter growth which is higher than perennial ryegrass (Lamp et al. 2001). It was found to have the fastest primary (uncut) growth during establishment, and a broader tolerance of temperature than perennial ryegrass and prairie grass (*Bromus catharticus*) (Hill et al. 1985). In subtropical southern Queensland where the hot, humid summers accelerate the decline in perennial ryegrass density, farmers plant Italian ryegrass (Callow et al. 2003). It can grow in a temperature range of 0-30°C with optimum growth occurring between 15-18°C. It is tolerant of cold winters (Grassland Society of Southern Australia Inc 2008a).

Perennial ryegrass is less tolerant of heat than tall fescue, although there is variation between cultivars (Razmjoo et al. 1993). It is best adapted to cool, moist climates where winterkill is not a problem. During hot summers, perennial ryegrass becomes dormant and it will not tolerate climatic extremes of cold, heat, or drought. Optimum growth occurs between 20 and 25˚C. Forage production suffers when daytime temperatures exceed 31˚C (daytime) and 25˚C (night-time) regardless of moisture availability (Thorogood 2003). It is tolerant to cold winters and can maintain growth down to 4°C (Grassland Society of Southern Australia Inc 2008b). Experiments have shown that perennial ryegrass accessions can have freezing tolerances (LT_{50}) as low as -10.3˚C to -13.95˚C for most cultivars grown in the US (Hulke et al. 2007) or -3˚C to -12.6˚C for northern European cultivars (Humphreys & Eagles 1988). This difference may be due to experimental protocols. Generally cultivars with poor winter hardiness were very early heading, whereas those with better winter hardiness were later heading (Humphreys 1989). A positive correlation exists between LT_{50} estimates and lowest temperature of coldest month in the place of origin of the accession (Humphreys & Eagles 1988), illustrating the plasticity of this species.

Tall fescue is a shade tolerant species and is more cold tolerant than perennial ryegrass, but in a turf environment needs a higher soil temperature for germination than other grasses such as Kentucky bluegrass or bentgrass (Meyer & Watkins 2003) as germination is limited by temperatures less than 12^{o}C (Grassland Society of Southern Australia Inc 2008c). Cultivars with a Mediterranean origin have a growing season from autumn to late spring, and are dormant over winter. Other tall fescue cultivars have a growing season from spring to autumn, with little or no growth over winter (Lamp et al. 2001). It is tolerant of hot conditions as it can grow from 0-35^{o}C (Grassland Society of Southern Australia Inc 2008c).

6.3 Water stress

There is variation between the three species of grass in their ability to tolerate dry conditions. A study in the UK indicated that tall fescue could survive four years without rain, whereas perennial ryegrass died after two years and Italian ryegrass only survived for 12-15 months (Wilman et al. 1998).

Tall fescue

Tall fescue is the deepest rooting cool season grass species (Meyer & Watkins 2003) and is the most drought tolerant when compared to others in the *Lolium-Festuca* complex (Wilman et al. 1998). Water stress in tall fescue leads to leaf rolling, stomatal closure and a reduction in transpiration rate (Renard & Francois 1985). The dense fibrous root stock of tall fescue forms an extensive root system that has the ability to draw water from >1 m in the soil profile (Garwood & Sinclair 1979). In a comparison with seven other grasses in the *Lolium-Festuca* complex, tall fescue had the greatest number and weight of roots at 50-100 cm deep, although frequent cutting of shoots reduces the root system and hence the plants drought tolerance (Gibson & Newman 2001). This has also been seen with a combination of severe moisture stress and grazing pressure (Lazenby 1997). Generally tall fescue recovers rapidly from drought, especially in endophyte infected plants, where enhanced accumulation of cell solutes and a decreased osmotic potential following drought has been observed (Lodge 2004). However, there is variability in the degree of drought tolerance between cultivars and regions depending on environmental factors (Aronson et al. 1987; Sheffer et al. 1987; Ervin & Koski 1998; Lodge 2004) (Lodge 2004). Mediterranean cultivars are able to 'avoid' the drought due to morphological adaptations such as small plant size and higher root: shoot ratio. The temperate cultivars are more able to make physiological adjustments such as osmotic adjustment in leaf blade tissue or decrease in the rate of leaf senescence and can grow through dry conditions (Assuero et al. 2002).

Tall fescue is also tolerant of flooding and has been recorded as occurring in pastures that are inundated with water for up to 4 weeks (Gibson & Newman 2001) or up to 8 months of flooding during winter (Razmjoo et al. 1993).

Perennial ryegrass

Perennial ryegrass is sensitive to drought (Garwood & Sinclair 1979), which leads to a reduction in herbage production under mild moisture deficit and dormancy or death under severe drought. The inability of perennial ryegrass to survive dry summers in areas where annual rainfall is below 650-700 mm limits its use in Australia (Waller & Sale 2001). Minimum annual rainfall requirement is 457 to 635 mm (Thorogood 2003). However, there is some natural variation for drought tolerance in accessions which have been collected from consistently dry habitats, compared with commercial cultivars (Reed et al. 1987). Some perennial ryegrass cultivars can survive drought for 2 years with cutting, but is not as productive as tall fescue. Its roots are able to draw water from approximately 80 cm deep in the soil (Garwood & Sinclair 1979).

Numerous drought tolerance or avoidance mechanisms have evolved including variation in size or number of stomata, depth of epidermal ridging, leaf water conductance and leaf osmotic potential (reviewed in Casler et al. 1996). Studies in both temperate (Waller et al. 1999) and subtropical (Lowe et al. 1999b) Australia indicated that perennial ryegrass survived the hot dry conditions by dying back and then, when conditions improved, the plants would produce new tillers in the centre of the crown.

Perennial ryegrass is moderately tolerant to waterlogging or flooding, less than tall fescue (Razmjoo et al. 1993). It will tolerate extended periods of flooding (up to 25 days) when temperatures are below 27˚C.

Italian ryegrass

Italian ryegrass is not tolerant of dry conditions and did not survive 2 years of drought without irrigation (Garwood & Sinclair 1979). However, Italian ryegrass is moderately tolerant to waterlogging (Grassland Society of Southern Australia Inc 2008a).

Variation between cultivars is seen. For example, the Italian ryegrass cultivar Aristocrat is useful in areas prone to severe rainstorms as it has been bred for greater resistance to seed shedding and lodging during adverse weather (Oram & Lodge 2003).

6.4 Herbicides

All three grasses are used in turf and pasture, and control of turf weeds such as *Poa annua* and pasture weeds such as *L. rigidum* and *Avena spp.* is desirable. For this reason, many cultivars are tested for their susceptibility to various herbicides.

P. annua in turf can be controlled by applying split applications of ethofumesate eg. 2.2 + 1.1 or 2.2 + 2.2 kg/ha (Dernoeden & Turner 1988). At these concentrations, perennial ryegrass cultivars could be safely treated with the herbicide. *P. annua* has shown some susceptibility to sulfosulfuron, an acetolactate synthase-inhibiting herbicide. Perennial ryegrass cv. Paragon was found to be tolerant to the herbicide if applied at rates up to 6 - 22 g/ha whereas tall fescue cv. Coronado was not tolerant to application rates necessary for adequate *P. annua* control (Lycan & Hart 2004).

In a study which tested the tolerance of perennial pasture grass seedlings to pre- and post-emergent herbicides, simazine, atrazine, flamprop-*m*-methyl, imazethapyr, fenoxaprop-ethyl, and triallate caused less severe toxicity to perennial ryegrass cv. Kangaroo Valley and tall fescue cv. Demeter, than other herbicides tested such as fluazifop and tralkoxydim. The less toxic herbicides caused yield reductions between 0-45%, 30 days after spraying. Simazine caused yield losses of 20-50% in both perennial ryegrass and tall fescue, which may be deemed acceptable in swards with high weed burdens (Dear et al. 2006). Atrazine and fenoxaprop-p-ethyl also showed some selectivity for weeds versus perennial grass species.

Herbicide resistance

Herbicide resistance in plants is a common phenomenon that occurs as a consequence of the widespread use of herbicides for weed control. It was first recognised in Australia in 1981 when annual ryegrass (*Lolium rigidum*) developed resistance to diclofop-methyl (VDPI 2005). The Herbicide Resistance Action Committee (HRAC), whose aim is to create a uniform classification of herbicide modes of action in as many countries as possible, has proposed a number of herbicide groups (HRAC 2008a). An increasing problem is cross resistance across the groups and Integrated Weed Management techniques are becoming more important for achieving weed control (VDPI 2005).

Italian ryegrass biotypes show resistance (or multiple resistance) to a range of herbicides. Of particular impact is resistance to glyphosate and diclofop-methyl. Glyphosate is a Group G herbicide (inhibition of EPSP synthase) and resistance has been reported in two Italian ryegrass populations from Chile and Oregon (Perez-Jones et al. 2007) and, with the worldwide usage of the herbicide, may be expected to occur more widely. The mechanism for this resistance is thought to involve lower spray retention, lower foliage uptake from the abaxial leaf surface and altered translocation patterns (Michitte et al. 2005; Michitte et al. 2007). Diclofop-methyl is a Group A herbicide (inhibition of acetyl CoA carboxylase). The presence of Italian ryegrass in wheat crops is a significant problem (see Section 8) and, while post-emergent spraying with diclofop-methyl has been successful, diclofop-methyl resistant *L. multiflorum* has developed (Hoskins et al. 2005). In countries other than Australia, Italian ryegrass biotypes have also been found showing resistance to herbicides from Group B (inhibition of acetolactate synthase), Group C (inhibition of photosynthesis at photosystem II), and Group K (inhibition of microtubule assembly) (HRAC 2008b).

Perennial ryegrass does not show such extensive herbicide resistance and only biotypes resistant to the Group A herbicides and to Group B herbicides have been noted (HRAC 2008b). The HRAC International Survey of Herbicide Resistant Weeds does not record any entries for tall fescue (HRAC 2008b).

6.5 Other tolerances

The plasticity of grasses has meant that in natural populations there is adaptation to a variety of abiotic stresses. These include tolerance to heavy metals, sulphur dioxide (SO_2) and salinity (Wilson & Bell 1985; Casler & Duncan 2003).

Salt

Salt tolerance has evolved naturally in many grasses, especially those in coastal marshes and rocky alpine habitats (Casler & Duncan 2003). The three grass species differ in their tolerance to saline conditions, with perennial ryegrass being the most salt tolerant and Italian ryegrass the least. Experiments selecting for salt tolerance in perennial ryegrass indicated that it could grow in solutions containing 200 mM NaCl (Ashraf et al. 1986; Ashraf et al. 1989), but it is not generally seen in saline habitats (Venables & Wilkins 1978). However, this may be due to its inability to withstand waterlogging as many saline habitats such as salt marshes have waterlogged soils (Ashraf et al. 1986). It has been classified as moderately salt tolerant (Rogers 2007). Tall fescue shows higher salt tolerance than either species of ryegrass (Grassland Society of Southern Australia Inc 2008c) with a small reduction in turf quality at $4.7 dSm^{-1}$ salinity level (deciSiemens per metre) (Alshammary et al. 2004). However, nitrogen status affects the response of tall fescue to salinity. Turf grown with non-limiting nitrogen is less salt tolerant than moderately nitrogen deficient turf (Bowman et al. 2006). Italian ryegrass is not tolerant of salinity (Grassland Society of Southern Australia Inc 2008a).

Sulphur dioxide

Tolerance to sulphur dioxide pollution is present in populations of perennial ryegrass which had been grown in polluted areas of the UK. This tolerance has evolved within 3.5 years for tolerance to acute levels (3000-6000µg m^{-3} SO_2 for 6h) and a year longer for tolerance to chronic pollution (317µg m^{-3} SO_2 for 123 days) (Wilson & Bell 1985).

Aluminium

Tall fescue has been shown to display some tolerance to elevated levels of aluminium (Grassland Society of Southern Australia Inc 2008c), whereas perennial ryegrass is described as not particularly tolerant (Grassland Society of Southern Australia Inc 2008b) and Italian ryegrass is not tolerant (Grassland Society of Southern Australia Inc 2008a).

Grazing

One of the other major abiotic stresses faced by a pasture or turfgrass is that of defoliation, either by a grazing animal or through mowing. In experiments, perennial ryegrass was less tolerant to defoliation than tall fescue (Cullen et al. 2006). Defoliation restricted new tiller development and caused tiller and plant death in perennial ryegrass. However, in nature perennial ryegrass is thought to employ a defoliation avoidance strategy by changing tiller size and density to prevent defoliation by grazing animals (Chapman and Clark 1984).

Fire

Most well–established perennial grasses can survive a cool-moderate burn[2] (Ward 1995). Green tall fescue pasture has some resistance to fire; perennial ryegrass is damaged more by fire than other temperate improved species because the surface crowns are easily burnt (McGowen 1997). Survival of perennial ryegrass is proportional to the fire intensity (Table 7).

Table 7. Survival of perennial ryegrass plants following fires at Hamilton (Victoria)*

Fire intensity[2]	Survival of plants
Unburnt	100%
Cool burn	98%
Moderate burn	79%
Hot burn	42%
Very hot burn	0%

* data taken from (McGowen 1997)

SECTION 7 BIOTIC INTERACTIONS

7.1 Weeds

Some of the main weeds found in the turfs and pastures in Australia are listed in Table 8 and Table 9, respectively. The main pasture weeds in a study in the subtropics were paspalum (*Paspalum dilatatum*), barnyard grass (*Echinochloa spp.*) and both red and white clover

[2] Cool-moderate burn (50 – 150˚C soil surface temperature) – most dead plant material burnt, some seed and perennial grasses survive unhurt. Usually a small residue of unburnt pasture remains; Hot burn (150 – 250˚C soil surface temperature) – all dead plant material, many seeds, young and weaker perennial grasses destroyed. Topsoil charred and bare; Very hot burn – soil virtually sterilised; all plant material and seed is destroyed in the top organic matter layer (Ward 1995; McGowen 1997).

(*Trifolium repens* check (Lowe et al. 1999b). In Victoria, both Bathurst burr and Amsinckia are considered to be significant pasture weeds (Department of Primary Industries 2007a; Department of Primary Industries 2007b).

Table 8. Common lawn and turf weeds in Australia (Cooper 2006; Gardenet 2006).

Common name	Scientific Name	Common name	Scientific Name
Azolla	*Azolla pinnata*	Nutgrass	*Cyperus rotundus*
Bachelors Button	*Cotula australis*	Onion Grass	*Romulea rosea*
Bindii	*Solvia pterosperma*	Parramatta grass	*Sporobolus africanus*
Burr Medic	*Medicago denticulata*	Paspalum	*Paspalum dilatatum*
Cats ear	*Hypochoeris radicata*	Pennyweed	*Hydrocotyle tripartite*
Chickweed	*Stellaria media*	Pennywort	*Hydrocotyle bonariensis*
Chilean whitlow	*Paronychia brasiliana*	Petty Spurge	*Euphorbia peplus*
Creeping Mallow	*Modiola caroliniana*	Pig weed	*Portulaca oleracea*
Creeping Oxalis	*Oxalis corniculata*	Prairie Grass	*Bromus catharticus*
Crowsfoot	*Eleusine indica*	Salvinia	*Salvinia molesta*
Cudweed	*Gnaphalium spicatum*	Sheep's sorrel	*Rumux acetosella*
Dandelion	*Taraxacum officinale*	Summer Grass	*Digitaria sanguinalis*
Fleabane, Canadian fleabane, Horseweed	*Conza canadensis*	Water couch	*Paspalum paspaloides*
Goose grass	*Eleusine indica*	White Clover	*Trifolium repens*
Kidney Weed	*Dichondra repens*	White Root Lobelia	*Pratia purpurascens*
Lambs Tongue, Ribwort	*Plantago lanceolata*	Winter Grass	*Poa annua*
Mullumbimby Couch	*Cyperus brevifolius*	Wireweed	*Polygonum aviculare*

Table 9. Common pasture weeds in Australia (Gardenet 2006).

Common name	Scientific Name	Common name	Scientific Name
African lovegrass	*Eragrostis curvula*	Mimosa	*Mimosa pigra*
Annual grasses	*Bromus*, *Hordeum*, *Vulpia*, *Lolium spp.*	Noogoora burr	*Xanthium spinosum*
Bathurst burr	*Xanthium spinosum*	Parramatta grass	*Sporobolus indicus*
Blackberry	*Rubus fruticosus*	Parthenium weed	*Parthenium hysterophorus*
Bracken fern	*Pteridium esculentum*	Paterson's curse	*Echium plantagineum*
Burr grasses	*Cenchrus spp.*	Poa tussock	*Poa labillardieri*
Calomba daisy	*Pentzia suffruticosa*	Rubber tree	*Calotropis procera*
Caltrop	*Tribulous spp.*	Rubber vine	*Cryptostegia grandiflora*
Cape tulip	*Homeria spp*.	Sedges	*Carex spp.*
Capeweed	*Arctotheca calendula*	Serrated tussock	*Nassella trichotoma*
Common pear	*Opuntia stricta*	Sifton bush	*Cassinia arcuata*
Crofton weed, soursob	*Eupatorium adenophorum*	Sorrel	*Rumex acetosella*
Fireweed	*Senecio madagascariensis*	Speargrass	*Heteropogon contortus*
Galvanised burr	*Sclerolaena birchii*	St John's wort	*Hypericum perforatum*
Gorse	*Ulex europaeus*	Sweet briar	*Rosa rubiginosa*
Groundsel bush	*Baccharis halimifolia*	Thistles	*Carduus*, *Carthamus*, *Cirsium*, *Onopordum*, *Silybum spp.*
Harrisia cactus	*Eriocereus martinii*	Tiger pear	*Opuntia aurantiaca*
Horehound	*Marrubium vulgare*	Wiregrass	*Aristida ramosa*
Lantana	*Lantana camara*	Woody weeds	*Dodonaea*, *Eremophila spp.*

7.2 Pests and pathogens

Some of the main nematode pests in Australian turfs and pastures are listed in Table 10, insect pests in Table 11 and Table 12, and diseases in Table 13 and Table 14, respectively.

The main insect pests of perennial ryegrass in Australia are black field cricket, black headed pasture cockchafer, red headed pasture cockchafer, common army worm, common cutworm, pasture tunnel moth and cereal rust mite (Cunningham et al. 1994). Pasture scarabs and Corbie grubs attack roots just below the ground. This attack is tolerated better by tall fescue than perennial ryegrass (Harris & Lowien 2003). However tall fescue is affected by redlegged earth mites, blue oat mites, field crickets, slugs and snails (Lowien & Harris 2004).

The main fungal pathogens of perennial ryegrass in Australia are crown rust, stem rust, net blotch and blind seed disease (Cunningham et al. 1994). Crown rust can seriously damage perennial ryegrass turf in the Autumn, especially under conditions of low fertility (Meyer & Belanger 1997). Stem rust and blind seed disease can be serious problems for seed production in southern Australia. Blind seed disease reduced seed quality and yield and has cost the Victorian seed industry up to $2.5 million in some years, especially when it is humid during seed harvest (Cunningham et al. 1994). Barley yellow dwarf virus (BYDV) and ryegrass mosaic potyvirus (RMV) have been reported in perennial ryegrass in Australia (Eagling et al. 1989; Eagling et al. 1992).

One of the major problems of tall fescue as turf is susceptibility to brown patch, caused by *Rhizoctonia solani* (Sleper & West 1996). However, the two most important fungal diseases selected against in breeding programs for tall fescue are crown rust and stem rust (Sleper & West 1996).

Damping off can cause severe seedling loss, especially if seed is sown into a cold, damp seedbed (Harris & Lowien 2003). Ergot can also infect tall fescue, causing black-purplish elongated ergots in the seed head, containing alkaloids that are toxic to livestock (Harris & Lowien 2003) (see Section 5.1).

Table 10. Common nematode pests of turf and pasture crops in Australia (Vargas 2005).

Common name	Genus name	Common name	Genus name
Awl	*Dolichodorus*	Seed-gall	*Anguina*
Cyst (larvae)	*Heterodera*	Sheath	*Hemicycliophora*
Dagger	*Xiphinema*	Spiral	*Helicotylenchus*
Lance	*Hoplolaimus*		*Rotylenchus*
Needle	*Longidorus*		*Tylenchus*
Pin	*Paratylenchus*	Stubby root	*Paratrichodorus*
Ring	*Criconemella*	Stunt	*Tylenchorhynchus*
Root knot	*Meloidogyne*	Sting	*Ipibora*
Root lesion	*Pratylenchus*		

Table 11. Common insect pests of turfgrasses in Australia (Gardenet 2006).

Order/Family	Scientific name	Common name	Symptoms
Coleoptera Curculionidae	*Listronotus bonariensis*	Argentine stem weevil	Yellow mottling of grass, dispersed dead yellow patches of turf. The maggot may be seen in the crown of the plant. Usually starts on the edges of turf.
	Sphenophorus brunipennis	Billbug	Damage occurs primarily from November through to January. Infected turf will turn yellow initially and then brown as the larvae chew through stolons and rhizomes. The turf can easily be removed from the soil similar to scarab beetle damage. A second generation can occur in February if environmental conditions are favourable.
Scarabaeidae	*Aphoditus tasmaniae* and *Adoryphorus couloni*	Black headed cockchafer and Red headed cockchafer	Destruction of the turf sward may occur in autumn through the feeding activity of large larvae when these are present at densities of 200–500 per m^2. Heavy infestations can result in the roots of turf plants being severed to such an extent that the turf can be rolled back in sheets.
	Cyclocephala signaticollis	Argentinian scarab	Grubs are very damaging root feeders. This causes the plant to weaken and may die in times of slight heat or water stress. This can be identified easily as affected plants lose their stability and wilt.
	Heteronychus arator	African black beetle	Irregular dead areas of turf eaten below ground.
	Sericesthis geminate and *S. pruinose*	Lawn or Pruinose scarab	Caterpillars feed on roots, loosening the sod, this way reducing the turf's ability to respond to stress.
Lepidoptera Hepialidae	*Oncopora spp.*	Sod webworm, Underground grass grubs	The removal of leaves in irregular areas. The presence of a fine silk web. Excretion on leaves.
Noctuidae	*Agrotis infusa* *A. ipsilon* *A. munda*	Common cutworm or Bogong moth Greasy cutworm Brown or Pink cutworm	The cutworm caterpillar strips the grass of its foliage, limiting the grasses' ability to grow. A more devastating action of the cutworm caterpillar, and the reason for its name, is its tendency to cut off plants above, at or below the soil surface, thus the caterpillar actually destroys far more than it consumes.
Pyralidae	*Pseudaletia convvecta* *Persectania ewingii* *Spodoptera mauritia*	Common armyworm Southern armyworm Lawn armyworm	Stripped area of leaves to soil level.
	Herpetogramma licarsisalis	Webworm	The larvae are foliage feeders and often leave behind the 'frass' (faecal pellets). The damage shows up as small dead patches of grass among unaffected grass.
Orthoptera Gryllotalpidae	*Scapteriscus didactylus*	Changa mole Cricket	Tunnelling near surface loosening the sod and damaging roots.

Table 12. Common insect pests of pasture grasses in Australia.

Order/Family	Scientific name	Common name	Symptoms
Acarina Penthaleidae	*Halotydeus destructor* *Penthaleus major*	Redlegged earth mite Blue oat mite	"Silvering" or "whitening" of the attacked foliage. Mites lacerate the leaf tissue of the plants and suck up the discharged sap. Most damaging impact on newly establishing pastures, greatly reducing seedling survival and retarding development (Gregg 1997). Emerging seedlings may be totally wiped out by high mite numbers. Feeding on established plants reduces productivity and plant function and in turn pasture palatability to livestock (Moritz 1995).
Collembola Sminthuridae	*Sminthurus viridis*	Lucerne flea	Grasses are not preferred hosts but can sustain damage. Succulent green cells of leaves are eaten by a process of rasping up the leaf tissue. Damage appears as small holes in the leaves (McDonald 1995).
Hemiptera		Aphids	Honeydew.
Coleoptera Elateridae		Wire worms	Larvae attack germinating seeds and the stems of seedlings. Established pastures can support substantial populations with little effect, but newly seeded pastures can be severely damaged (Gregg 1997).
Lepidoptera Hepialidae	*Oncopera rufobrunnea* and *O. intricata*	Underground grass grub or corbie	Young larvae are gregarious and live under silken webbing spun among plant debris. Older larvae construct vertical silk-lined tunnels from which they emerge to feed at night on leaves and stems. May cause severe yield loss and increased weed invasion. Prefer grasses, especially ryegrass (Gregg 1997).
Noctuidae	*Agrotis infusa* *A. ipsilon* *A. munda*	Common cutworm or Bogong moth Black cutworm Brown cutworm	Caterpillars feed at night cutting through stems at ground level (Gregg 1997).
	Mythimna convvecta *Persectania ewingii* *Spodoptera mauritia*	Common armyworm Southern armyworm Lawn armyworm	Feed on grass component of pastures (Gregg 1997).
Scarabaeida	*Aphoditus tasmaniae*	Black headed cockchafer	Larvae emerge at night to forage on stems and foliage close to ground level. Damage is restricted to pastures at least 3-4 years old because the early larval stages feed on dung and other organic matter on the soil surface, which is often lacking in new pastures (Gregg 1997).
	Adoryphorus couloni	Red headed cockchafer	Larvae feed on the roots of grasses and may cut the roots just below ground level (Gregg 1997).
	Antitrogus morbillosus	Tableland pasture scarab	The extent of damage by the grubs is dependent on the level of infestation, seasonal conditions and grazing management. Usually worsened in shallow soil and where plant growth is restricted by dryness and overgrazing, which reduces the plants capacity to replace severed roots (Goodyer & Nicholas 2005).
	Anoplognathus spp.	Christmas beetles	

Order/Family	Scientific name	Common name	Symptoms
		(Goodyer & Nicholas 2005)	
	Heteronychus arator	African black beetle (Goodyer & Nicholas 2005)	Larvae feed on roots and may sever them (Gregg 1997).
	Othnonius batesi	Black soil scarab (Goodyer & Nicholas 2005)	
	Rhopaea spp.	Pasture white grub (Goodyer & Nicholas 2005)	
	Sericesthis geminata *Sericesthis nigrolineata*	Pruinose scarab Dusky pasture scarab	Larvae damage the roots. In severe infestations the roots can be entirely removed so that the pasture is torn up by grazing animals or birds searching for larvae. Less severe damage can cause water stress as a result of root loss and an inability to recover from defoliation (Gregg 1997).
Tenebrionidae		Pie dish beetles	Larvae attack germinating seeds and the stems of seedlings. Established pastures can support substantial populations with little effect, but newly seeded pastures can be severely damaged (Gregg 1997).
Orthoptera Acrididae	*Austroicetes cruciata*	Small plague grasshopper	Defoliates (Gregg 1997).
	Brachyexarna lobipennis	Striped winged meadow grasshopper	Defoliates (Gregg 1997).
	Chortoicetes terminifera	Australian plague locust	Defoliates (Gregg 1997).
	Locusta migratoria	Migratory locust	Defoliates (Gregg 1997).
	Nomadacris guttulosa	Spur throated locust	Defoliates (Gregg 1997).
	Phaulacridium vittatutum	Wingless grasshopper	Defoliates (Gregg 1997).
Gryllidae	*Teleogryllus commodus*	Black field cricket	Feeds selectively on young foliage of valuable introduced species. Leads to change in pasture composition and weed invasion. Perennial pastures are less susceptible than annual. Crickets are also a major cause of seed removal (Gregg 1997).
		Ants	Problem is most severe for surface sowings. Ants have been reported to remove up to half the sown seed prior to emergence (Scott 1997).
		Slugs	May be a problem in protected drill rows in the slots from direct drilling (Scott 1997; Burnett 2006b).
		Weevils	

Table 13. Common pathogens of turfgrass in Australia (Vargas 2005; Gardenet 2006).

Common Name	Scientific Name	Environmental Factors	Symptoms
Algae	Many algal species	High surface moisture, inadequate drainage and insufficient light and air movement.	Very primitive plant that is bluish-black in colour and seen on the ground surface. It may be peeled off when dry.
Brown patch	*Rhizoctani solani*	A lush lawn with high humidity, excessive soil moisture, inadequate drainage, excessive nitrogen and thatch levels. High levels of nitrogen can increase severity.	An irregular roughly circular shaped "smoke ring" in appearance. Up to 50 cm in diameter, leaves darken turning brown. This disease attacks the leaf.
Curvularia	*Curvularia spp.*	Warm /hot weather and high humidity.	Yellowing areas, fading to brown. Up to 6 cm in diameter.
Dollar spot	*Rustroemia floccosum*, syn: *Sclerotina homeocarpa*	Temperature range between 20-27ºC with high humidity. Excessive thatch levels with nitrogen deficient soils.	Fine mycelium can be seen on the leaves early in the morning dew. Small circular straw coloured areas up to 5 cm in diameter. These areas may merge together. This is a leaf disease.
Fairy ring	*Marasmius oread, Basidiomycetes*	Unknown, though a change in nitrogen source or levels may stimulate growth.	Ring of darker coloured, fast growing grass stimulated by the fungi breaking down organic material in mat or thatch.
Fusarium	*Fusarium nivale*	Temperature ranges of 5-15ºC. With excessive growth and a cool change in temperature. Poor soil drainage and turf possibly deficient in potassium (K) and/or phosphate (P).	There are small pale yellow to pink areas. These areas may enlarge and may merge together. This is a leaf disease.
Helminthosporium	*Helminthosporium spp*.	Warm moist conditions, wet soils and excessive nitrogen levels.	Small brown brown-red spots or lesions appear on leaves. They enlarge on the leaves and stem turning them blackish-purple in colour. The disease spreads in areas up to 5 cm in diameter. This is a leaf and stem disease.
Leaf spot	*Bipolaris sorokiniana* (syn. *Helminthosporium sativum*)	Hot, humid conditions.	Small dark purple to black coloured spots on the leaf blade. As spots enlarge, the centres often turn light tan. At temperatures exceeding 30°C, distinct spots are often absent and the entire leaf blade appears dry and straw coloured. A warm weather disease affecting leaf sheaths, crowns and roots. Severe thinning of turfgrass stand can occur in a short time.
Pythium blight, Grease spot, Cottony blight	*Pythium spp.*	Warm weather disease, most destructive between 30-35ºC. Survives well in water and poorly drained soils.	Circular reddish brown spots, 2-15 cm in diameter. Infected leaves appear wet, dark and active mycelium can be seen in the morning. Leaves then shrivel and turn reddish brown.

Common Name	Scientific Name	Environmental Factors	Symptoms
Red thread	*Corticium fuciforme*	Temperatures greater than 20ºC with dry nutrient deficient soils i.e. nitrogen. Occurs on water soaked turf.	Dark leaves in small areas and is more obvious in longer grass. Red-pink mycelium is seen on leaves. A leaf disease.
Rolf's Disease	*Sclerotium rolfsii*	Warm humid weather, dry soils with excessive thatch. Generally the turf is unhealthy.	Yellowish "donut" shaped area that is 6-8 cm in diameter. There is visible regrowth in the centre. The spores (sclerotia) may be present, they are 2 mm in diameter and orange-black or brown in colour.
Slime moulds	*Physarium spp. Mycilago spp.*	Moderate temperature with excessively wet soils with poor drainage.	Bluish-grey or yellowish-white. They are unsightly as they mass on the leaf surface. They spread up to 25 cm across. This is a saprophytic disease.
Smut, Leaf smut, Stripped or Flag smut.	*Ustilago* spp.	Moist, humid warm weather.	Blackish areas on leaves may be rubbed off with fingers.
Spring dead spot	*Leptosphaeria narmari* and *L. korrae*		Circular dead spots first appear in spring. The spots appear in many of the same places and expand for 3 to 4 years. After the second or third year, the disease often appears as rings of dead grass, and may disappear after 3 or 4 more years.
Take all patch	*Gaeumannomyces graminis*	Common to newly established turfs, diminishing with the build up of antagonistic microorganisms in soil. Favours high pH.	Patch of bronzed or bleached turf 10-15 cm diameter grows to 1 m over a period of years. Black runner hyphae can be seen under base of leaf sheath, on crowns and roots.

Table 14. Common pathogens of pasture in Australia.

Common Name	Scientific Name	Hosts	Environmental Factors	Symptoms/Damage
Barley yellow dwarf virus (BYDV)		Perennial ryegrass		Reductions in establishment, competitiveness, persistence, productivity and pasture quality (Clarke & Eagling 1994).
Blind seed disease	*Gloeotinia granigena*	Perennial ryegrass	Extended periods of leaf wetness in late November/early December and air temperatures of 15-25°C favour the highest incidence.	Seed heads. Infection usually results in seed death. Seed from heavily infected stands has reduced commercial value because of poor germination rates (Vargas 2005).
Brown blight	*Drechslera siccans* (syn. *Helminthosporium siccans*)	Perennial ryegrass, Italian ryegrass	The leaf-spot, crown and root rot stages occur during the cool weather of spring and fall, few signs of the disease are evident during warm summer months (Vargas 2005)	Small brown spots which enlarge and may develop white centres and/or dark brown streaks appear on the leaf blade. Heavy infections can result in severe thinning (Vargas 2005).
	Drechslera spp.	Perennial ryegrass		Foliage (Clarke & Eagling 1994).
	Helminthosporium spp.	Perennial ryegrass, Tall fescue		Foliage (Clarke & Eagling 1994).
Crown rust	*Puccinia coronata*	Perennial ryegrass, Tall fescue	Long, cool, wet winters or times when grass is growing most slowly (Vargas 2005).	Initially yellow spots develop on the leaves. Later orange-brown pustules 0.5 to 1 mm long occur on both leaf surfaces. The black spore (teliospore) stage can be found as early as September, and through the summer and autumn. Infected leaves die prematurely and severely rusted plants become stunted (Clarke 1999a).
Damping off	*Fusarium, Pythium and Phytophora*		Cool, moist conditions.	Damage is often done prior to emergence resulting in failure of seeds to emerge. If emergence occurs, seedlings collapse.
Ergot	*Claviceps spp.*	Perennial ryegrass, Italian ryegrass, Tall fescue		Dark purple sclerotia (resting body) develop in place of a healthy seed and protrude from the glume. There appearance is preceded by ay honey dew stage which appears 2-3 weeks after flowering (Clarke 1999b).
Fairy ring	*Marasmius oread, Basidiomycetess*	Perennial ryegrass, Italian ryegrass and Tall fescue	Unknown, though a change in nitrogen source or levels may stimulate growth.	Ring of darker coloured, fast growing grass stimulated by the fungi breaking down organic material in mat or thatch.

Common Name	Scientific Name	Hosts	Environmental Factors	Symptoms/Damage
Leaf spot	*Bipolaris sorokiniana* (syn. *Helminthosporium sativum*)	Perennial ryegrass, Tall fescue	Hot, humid conditions.	Small dark purple to black coloured spots on the leaf blade. As spots enlarge, the centres often turn light tan. At temperatures exceeding 30°C, distinct spots are often absent and the entire leaf blade appears dry and straw coloured. A warm weather disease affecting leaf sheaths, crowns and roots. Severe thinning of turfgrass stand can occur in a short time (Vargas 2005). Reduces yield and quality of tall fescue and its ability to recover after grazing. Longer the infection, greater the losses (Clarke & Eagling 1994).
Net-blotch	*Drechslera dictyoides* Paul and Parbery (syn. *Helminthosporium dictyoides* Drechslera)	Tall fescue	In spring spores are produced and can be transferred to healthy plant tissue, but the leaf-spot phase is inconspicuous at this time. Crown and root infection is thought to take place in spring, but symptoms are not expressed until the warm, dry weather of summer.	Initially occurs as irregular dark purple to black transverse strands, resembling dark threads drawn across the leaf creating a net-like appearance (Clarke & Eagling 1994).
Ryegrass mosaic virus (RMV)		Perennial ryegrass		Reductions in dry weight yields (Clarke & Eagling 1994).
Stem rust	*Puccinia graminis*	Perennial ryegrass, Italian ryegrass, Tall fescue		Reddish-brown elongated, 1-10 × 0.5-2 mm pustules with ragged edges occur on the leaves, stems and seed head. Later in the season the pustules may turn black when the fungus produces a resting stage spore (teliospore). These spores, in Australia, have no further part in the life cycle of the fungus (Clarke 1999a). Seed heads - problem for graziers and seed producers (Clarke & Eagling 1994).
Slime moulds	*Physarium spp. Mycilago spp.*	Perennial ryegrass, Italian ryegrass and Tall fescue	Moderate temperature with excessively wet soils with poor drainage.	Bluish-grey or yellowish-white. They are unsightly as they mass on the leaf surface. They spread up to 250 mm across. This is a saprophytic disease.

7.3 Endophytes

Tall fescue, Italian ryegrass and perennial ryegrass can all contain endophytes. Endophytes are fungi that live between the plant cells of many forage grasses (Kemp et al. 2007). The fungi and grasses have a mutalistic symbiotic relationship where the fungus derives its nourishment and means of reproduction from the grass and the grass host benefits from enhanced tolerance to biotic and abiotic environmental stresses (Joost 1995). These endophytes complete their lifecycle within host tissues, are maternally transmitted in seed, are completely non-pathogenic and are asexual (Tsai et al. 1994). Growth of the fungi is systemic through the aerial parts of the plant (Rasmussen et al. 2007). Sparsely branched hyphae grow parallel to the long axis of plant cells in intercellular spaces. During host flowering the fungus grows into ovules and seeds, with the rate of vertical transmission approaching 100% (Clay & Schardl 2002). In perennial ryegrass leaf blades, the ratio of fungal compartments (one genome copy = one compartment) to plant cells may be as high as 1:2 to 1:1 (Rasmussen et al. 2007).

The most studied symbioses are tall fescue with *Neotyphodium coenophialum* (previously known as *Acremonium coenophialum*) and perennial ryegrass with *N. lolii* (previously known as *Acremonium lolii*) (Schardl et al. 1997). They are evolutionarily derived from the sexual (telomorphic) fungi of genus *Epichloë* (*Ascomycotina, Clavicipitaceae*) which causes grass choke disease. Phylogenetic evidence comparing β-tubulin genes suggests that *N. coenophialum* is an interspecific hybrid with three *Epichloë* ancestors (Tsai et al. 1994). In most old pastures in Australia about 90% of perennial ryegrass plants are infected with *N. lolii* (Reed 1999b). The endophyte in Italian ryegrass is found only in the nodal region rather than in the upper portion of the leaf sheath (Latch et al. 1987) and is thought to be *N. occultans* C.D. Moon, B. Scott & M.J. Chr. (Dombrowski et al. 2006; Sugawara et al. 2006). The infection rate varies as, although half of the wild Italian ryegrass populations collected contained endophyte, eight cultivars from a Welsh plant breeding station were not infected with endophyte (Latch et al. 1987).

There is a rapid decline in endophyte (*N. lolii*) when perennial ryegrass seed is stored at room temperature for > 24 months (Reed et al. 1987), although viable endophyte has been found in some plants grown from 14 year old seed (Latch et al. 1987).

These fungi do not cause any disease in the grasses, and under most circumstances they are beneficial to the growth and survival of infected plants (Clay 1990; Joost 1995; Schardl & Phillips 1997; Schardl et al. 1997; Clay & Schardl 2002; Grewal & Richmond 2003; Schardl et al. 2004). For example, in tall fescue, *N. coenophialum* increases tillering and root growth, improves drought tolerance, and protects against certain nematodes, fungal pathogens, insect and mammalian herbivores.

Perennial ryegrass and tall fescue containing endophytes have been more persistent and productive in areas of NSW where African Back Beetle (*Heteronychus arator*), Prunose and Dusky Pasture Scarabs (*Sericesthis spp.*) are found on the tablelands and coastal areas (Kemp et al. 2007). However, growth comparisons indicate that endophyte infection in perennial ryegrass may only be advantageous under particular environmental conditions (Marks et al. 1991). While, endophyte-containing Italian ryegrass plants produce more vegetative tillers, root biomass and seed than uninfected plants (Elmi & West 1995).

Endophytes in tall fescue are able to affect plant osmotic relations to improve recovery after drought (Elmi & West 1995). Endophyte infected tall fescue maintained significantly higher photosynthetic rates at temperatures >25˚C than uninfected plants in the glasshouse (Clay 1990). Tall fescue infected with an endophyte accumulates more phosphorus than non-infected plants when grown in phosphorus-deficient soils. In response to phosphorus deficiency, endophyte-infected plants produce a reducing activity on the root surface and have increased phenolic concentration in roots and shoots (Malinowski et al. 1998).

Seeds from infected tall fescue and perennial ryegrass germinated at a higher frequency than uninfected and had more tillers and a greater biomass (Clay 1987). Infected tall fescue produced twice the number of filled seed than uninfected, although for perennial ryegrass there was no difference between infected and uninfected (Clay 1987).

Endophytes in Italian ryegrass might delay the appearance of herbicide resistance (Vila Aiub & Ghersa 2001). Uninfected plants showed faster germination at suboptimal temperatures (Gundel et al. 2006b) and under water stress (Gundel et al. 2006a), although this may be due to altered seed dormancy levels (Gundel et al. 2006a).

The endophyte and associated alkaloid concentration varies between plant cultivars (Rasmussen et al. 2007). The plants nutritional status may also affect the concentration of both endophyte and alkaloid in the plant (Rasmussen et al. 2007). Alkaloid concentration in tall fescue and perennial ryegrass is also altered by management practices, such as mowing. A decreased mowing frequency resulted in higher alkaloid production in the two species while the levels of some alkaloids were also increased when the mowing height was increased (Salminen & Grewal 2002; Salminen et al. 2003). The alkaloids produced by endophytes in tall fescue may decrease predation on the plants by birds (Madej & Clay 1991).

Despite being potentially toxic to grazing livestock (see Section 5.1), the good forage and agronomic characteristics of tall fescue infected with *N. coenophialum* and perennial ryegrass infected with *N. lolii*, in conjunction with their exceptional fitness and low management requirements places them amongst the most important forage grasses (Schardl & Phillips 1997). Strains of endophytes which do not produce toxic alkaloids, but which still produce compounds that are beneficial to plant persistence have been developed (Harris & Lowien 2003) and are included with the majority of the ryegrass sold in New Zealand (Easton 2007). In the USA, studies with tall fescue infected with non-ergot alkaloid producing endophyte strains provided cattle growth performance that did not differ from that of endophyte-free tall fescue (Parish et al. 2003). In Australia, many tall fescue varieties are commercially available containing a low toxicity endophyte which still helps protect the plant from insect attack and environmental stresses (Burnett 2006c). It is also possible to remove the endophyte from perennial ryegrass and tall fescue seed using a fungicide such as prochloraz (Leyronas et al. 2005). Renovated pastures in which endophyte infected tall fescue was reduced to <10% was sown with endophyte free seed and after 3 years rotational cattle grazing endophyte infected plants did not invade and increase (Tracy & Renne 2005).

SECTION 8 WEEDINESS

Weeds are plants that spread and persist outside their natural geographic range or intended growing areas such as farms or gardens. Weediness in Australia is often correlated with weediness of the plant, or a close relative, elsewhere in the world (Panetta 1993; Pheloung et al. 1999; Groves et al. 2005). The likelihood of weediness is increased by repeated intentional introductions of plants outside their natural geographic range that increase the opportunity for plants to establish and spread into new environments (e.g. escapes of commonly used garden plants) (Groves et al. 2005).

As noted earlier in this document, *Lolium* species have many weedy characteristics. They are wind pollinated, are primarily an outcrossing species with vegetative abilities, are capable of adapting rapidly to their environment, produce large amounts of seed, and are easily dispersed (see discussion in Section 4.3).

8.1 Weediness status on a global scale

The most comprehensive compilation of the world's weed flora is produced by Randall (Randall 2002). Most of the information contained in this book has been sourced from Australia and North American countries but also includes numerous naturalised floras from many other countries. Randall (2002) lists 10 species of *Lolium* which have been identified as having a documented weedy history, including all the *Lolium* species introduced into Australia (except the hybrids *Lolium* ×*hubbardii* and *Lolium* ×*hybridum* which are listed as naturalised) and the hybrid *Lolium arundinaceum* × *Lolium perenne* (refer to Table 1). Twenty-three species of *Festuca* have also been identified with a history of weediness, including all *Festuca* species introduced to Australia (refer to Table 2).

8.2 Weediness status in Australia

Groves et al. (2003) lists Italian ryegrass, perennial ryegrass and tall fescue as weeds in native and agricultural ecosystems in Australia, all three species are given a rating of 4 and 3 in these respective areas (refer to Table 15 for details). Italian and perennial ryegrass are primarily agricultural weeds, commonly found in fields, waste places and roadsides whilst tall fescue is most often found in open and damp sites along roadsides, creeks, swampy verges and in open paddocks (Sharp & Simon 2002). Perennial ryegrass and tall fescue are considered as weeds Australia wide, and Italian ryegrass is considered a weed in all areas of Australia except the Northern Territory (Lazarides et al. 1997). In South Australia, tall fescue is described as "becoming a weed in wetter areas" (Wheeler et al. 2000; Wheeler et al. 2002; Wipff 2002; Jessop et al. 2006). Perennial ryegrass is naturalised throughout the higher rainfall temperate areas, extending into Southern QLD with casual occurrences near Cairns and Alice Springs (Kloot 1983).

Other *Festuca* and *Lolium* species present in Australia are also considered to be weedy. *L. rigidum* and *F. elatior* are weeds Australia wide, while *L. loliaceum*, *L. temulentum* and *F. rubra* are considered as weeds in all areas of Australia except the Northern Territory (NT). *F. nigrescens* and *L. pratense* are weeds in NSW and TAS, and WA, SA, NSW and TAS, respectively (Lazarides et al. 1997). *L. loliaceum* is commonly found on roadsides, in waste places, sandy areas, and often in maritime habitats. *L. rigidum* is primarily an agricultural weed found in crops, fields, roadsides, waste places, rocky hillsides, and sandy areas. It is regarded as one of the most significant weeds of cropping enterprises, especially as it now shows resistance to a number of Group A, B, G and K herbicides[3] (VDPI 2005) *F. nigrescens* is common in drier open habitats on roadsides and in pasture; and *F. rubra* occurs in damp open habitats (Sharp & Simon 2002).

No *Festuca* or *Lolium* species are registered as weeds of national significance to Australia (Department of the Environment and Heritage 2004).

[3] Note that the Classification system used by VDPI is slightly different from the HRAC system described in Section 6.1.4. The Groups listed relate to the HRAC system.

Table 15. Assessment of weediness of *Lolium* and *Festuca* species in natural and agricultural ecosystems in Australia (Groves et al. 2003)

Species	Australian rating natural ecosystems	Australian rating agricultural ecosystems	QLD	NSW	VIC	TAS	SA	WA	NT
Lolium arundinaceum	*4*	*3*	*1*	+	*1*	+	*2*	*3*	+
Lolium loliaceum	4	2		1	+	+	2	+	1
Lolium multiflorum	4	3	1	3	3	+	2	3	
Lolium perenne var. *cristatum*	2	+			+				
Lolium perenne var. perenne	4	3	1	3	3	+	3	3c	1
Lolium perenne × *Lolium rigidium*	2	+	+						
Lolium pratense	3	+		+			+	+	
Lolium remotum	3	+						+	
Lolium rigidum	5	5	2	5	5	5 (crops)	4	5	1
Lolium temulentum var. *arvense*	3	1	1	+	+	+	1		
Lolium temulentum var. *temulentum*	3	1	+	+	+		0	1	
Lolium ×hubbardii	3	1	+	+			1		
Lolium ×hybridum	3	1	+	+			1		
Festuca nigrescens	4	+		+		+			
Festuca rubra ssp. *rubra*	4	1		+	+	+	1	+	

Key:

0 – Reported as naturalised but only known naturalised population now removed or thought to be removed
1 – Naturalised and may be a minor problem but not considered important enough to warrant control at any location
2 – Naturalised and known to be a minor problem warranting control at 3 or fewer locations within a State or Territory
3 – Naturalised and known to be a minor problem warranting control at 4 or more locations within a State or Territory
4 – Naturalised and known to be a major problem at 3 or fewer locations within a State or Territory
5 – Naturalised and known to be a major problem at 4 or more locations within a State or Territory
+ – Present in a State or Territory but not given a rating as an agricultural weed, either because it was not considered a problem or because it was not known to occur in agricultural areas at present
c – Under active control in part of a State

8.3 Weediness in agricultural ecosystems

In terms of ability to spread in the environment, *L. perenne* and *L. multiflorum*, both being classed as bunchgrasses (see Section 4.1.1) rely mainly on spread by seed. In turf environments and in pasture that is being grazed or mown, the likelihood of seed developing is low. However, in ungrazed pasture and unmanaged habitats seed has an opportunity to form. Seeds of both species germinate rapidly and with high rates but for this reason are present in the seedbank for only a relatively short time (Sullivan 1992; Carey 1995) (see also discussion in Section 4.4).

The ryegrasses in general are significant weeds of wheat worldwide and their control has been investigated extensively (Kuk & Burgos 2007). Italian ryegrass can be a difficult-to-control contaminant in turfgrass farms and causes decreased marketability of cool-season sod (Beam et al. 2005).

While tall fescue can develop short rhizomes, it is not regarded as a spreading grass and there is little evidence in the literature that tall fescue *per se* is a significant weed of either pasture or cropping systems. It is slow to establish and is sensitive to competition from more vigorous pasture and weed species (Harris & Lowien 2003). However, the association of tall fescue with a fungal endophyte (see Section 7.3.1) often means that grazing stock may lose productivity in an infected pasture and that removal of the infected sod is desirable (Smith 1989; Defelice & Henning 1990).

Tall fescue is a wide-bladed grass, texturally different from a turf such as Kentucky bluegrass and its appearance in fine-leaf turf may therefore be undesirable and warrant removal. Volunteer tall fescue growing near certified seed production enterprises also requires control measures to prevent contamination of the seed (Mueller-Warrant & Rosato 2005).

8.4 Weediness in natural ecosystems

The ryegrasses and tall fescue occur as typical weed species in riparian zones in rural and urban areas of Australia. For example:

- Perennial ryegrass is listed as one of the perennial grasses that is a weed along waterways and wetlands of cool, high rainfall areas of Western Australia (Pen 2000) and is both invasive and has a high impact in a floodplain riparian woodland in the Northern Inland Slopes Bioregion of Victoria (Department of Sustainability and Environment 2004a).
- Italian ryegrass is listed as one of the introduced species that have replaced native samphire and rush communities along the Swan/Canning and Leschenault estuaries (Western Australia) flushed by stormwater (Pen 2000) and is invasive in a floodplain riparian woodland in the Northern Inland Slopes Bioregion of Victoria (Department of Sustainability and Environment 2004a).
- Tall fescue is invasive and has a high impact in a eucalypt swampy woodland in the Warrnambool Plain bioregion of Victoria (Department of Sustainability and Environment 2004b).

8.5 Control measures

Herbicide spraying with a range of herbicides (see Section 6.4 for a discussion of the herbicide Groups and of herbicide resistance) is the main control for the cool-season perennial grasses but some other management strategies have also been successfully employed, as described below.

Of the non-selective herbicides, glyphosate (Group G – inhibitors of EPSP synthase) is a commonly used systemic herbicide for grass control and glufosinate ammonium (Group H – inhibitors of glutamine synthase) is effective against most perennial grasses that do not produce rhizomes (Dernoeden 1999).

Use of selective herbicides for grass control is more limited. Diclofop-methyl (Group A – inhibitors of acetyl CoA carboxylase) has traditionally been used for controlling ryegrass weeds in wheat but resistance has developed. The advent of diclofop-methyl resistant ryegrasses (see Section 6.4) has meant that the use of herbicides from other groups may be necessary to achieve control. In general, the Group B herbicides (inhibitors of acetolactate synthase), especially the sulfonylureas, have proved to be successful for control of the cool-season grasses. For example:

- mesosulfuron-methyl, a relatively new herbicide may be suitable for controlling Italian ryegrass in wheat even though mesosulfuron-methyl resistant Italian ryegrass can develop because of the existence of cross resistance to chlorsulfuron in some diclofop-methyl resistant accessions (Kuk & Burgos 2007).
- nicosulfuron has been suggested as an appropriate herbicide to use for Italian ryegrass control in tall fescue or tall fescue/Kentucky bluegrass turf (Beam et al. 2005).
- chlorsulfuron can be used for spot spraying of tall fescue and perennial ryegrass clumps in more tolerant turf species such as Kentucky bluegrass (*Poa pratensis*) (Maloy & Christians 1986; Dernoeden 1999). Similarly, tall fescue is less tolerant to sulfosulfuron than Kentucky bluegrass or perennial ryegrass (Lycan & Hart 2004).
- triasulfuron used as a pre-emergent herbicide is effective against tall fescue and perennial ryegrass (Dear et al. 2006).

Examples of other herbicides used for control of the ryegrasses and tall fescue are given in Table 16; the references given describe the optimal conditions (e.g. herbicide rate, time of application, stage of growth)

Table 16. Examples of herbicides used in control of the ryegrasses and tall fescue

Herbicide	Group	Mode of Action	Grass controlled	Reference
Cyanizine (pre-emergent)	C1	Inhibition of photosynthesis at photosystem II	Perennial ryegrass, tall fescue	(Dear et al. 2006)
Metribuzin (pre-emergent)	C1	Inhibition of photosynthesis at photosystem II	Perennial ryegrass, tall fescue	(Dear et al. 2006)
Paraquat	D	Photosystem I electron diversion	Tall fescue	(Smith 1989)
Oxyfluorfen	E	Inhibition of protoporphyrinogen oxidase	Tall fescue	(Mueller-Warrant & Rosato 2005)
Glyphosate	G	Inhibitor of EPSP synthase	Tall fescue	(Smith 1989)
Pronamide	K1	Inhibitor of microtubule assembly	Perennial ryegrass	(Horgan & Yelverton 2001)
Pendimethalin	K1	Inhibitor of microtubule assembly	Tall fescue	(Mueller-Warrant & Rosato 2005)
Metolachlor	K1	Inhibitor of microtubule assembly	Tall fescue	(Mueller-Warrant & Rosato 2005)

Management of grass weeds other than through herbicide application is a possibility. For example:

- Both Italian ryegrass and perennial ryegrass are good soil stabilizers and therefore are sometimes deliberately seeded with other, more aesthetically pleasing grasses to aid establishment. However, because both show vigorous seedling growth and thus are very competitive, the ryegrass component in the final stand often needs to be reduced. Close, early mowing following establishment can often inhibit the ryegrasses (Brede & Duich 1984; Brede & Brede 1988). The fact that Italian ryegrass can outcompete regenerating native vegetation is one reason why there has been a move away from reseeding burned chaparral sites in the USA with the species (Carey 1995)

- If it becomes necessary in a sports field or other grassed amenity area to remove or replace a dominant species, the general principles are that the management strategy is shifted to favour the 'desired' grass and that persistent overseeding of the 'desired' grass eventually crowds out the 'unwanted' grass. As an example, in the conversion of perennial ryegrass golf fairways to Kentucky bluegrass fairways, high seeding of the bluegrass into the mature ryegrass fairway turf followed by low mowing (0.6 cm twice weekly for 4 weeks) allows for successful establishment of the bluegrass (Kraft et al. 2004).
- A biological control involving the planting of diclofop-susceptible Italian ryegrass has been proposed as a method of reducing the evolution of diclofop-methyl resistance in Italian ryegrass (Ghersa et al. 1994).
- On a small scale, ryegrasses and tall fescue can be successfully removed by physically digging up the clumps (Dernoeden 1999).
- In pastures, tall fescue is susceptible to overgrazing which may therefore be used to reduce the persistence of the grass; perennial ryegrass is less susceptible (Kemp et al. 2001).
- Tall fescue is not a strong competitor and can be controlled by planting of more vigorous species, especially legumes (USDA Forest Service 2005).

SECTION 9 POTENTIAL FOR VERTICAL GENE TRANSFER

Many factors may limit the formation of intra- and interspecific hybrids. These include ecological factors, such as distribution, and biological factors such as anthesis date, hours of pollen shed, genome and chromosome number (eg. *Festuca* 2n = 14, 28, 35, 42, 56 and 70, and 2, 4, 5, 6, 8, and 10 ploid, *Lolium* 2n = 14 and 28, and 2 and 4 ploid (Sharp & Simon 2002). The success of the hybrid is sometimes influenced by which of the two species in the cross acts as the male or female parent. The outcome of hybridisation can be variable, in some cases no seed is produced and in others seed is produced but it is not viable so will not germinate. In other instances the seed will germinate but result in weak seedlings which do not establish. Successful hybridisation results in established F1 hybrids, which could either sustain a hybrid population and/or backcross with parent plants, or if completely sterile maintain a vegetative population. Table 1, Table 2 and section 9.3 outline hybrids which may be relevant to Australia. However, due to confusion in the taxonomy, the list of hybrids presented may not be comprehensive.

9.1 Barriers to intraspecific crossing

Intraspecific gene transfer is the transfer of genetic material from parent to offspring by reproduction within the same species. This type of gene transfer can occur by sexual or asexual reproduction. Self-incompatibility and wind pollination are common in grass species, therefore outcrossing is the normal mode of reproduction. Self-incompatibility in both Italian and perennial ryegrass is controlled by a two locus incompatibility system. However, if self-pollination does occur both species will set seed; although the number of seeds may be low (see Section 4.1.2).

9.2 Natural interspecific and intergeneric crossing

This section deals with gene transfer between plants of the same genera by sexual reproduction. Examples of this are presented in Table 1 and Table 2.

Successful gene transfer requires that three criteria are satisfied. The plant populations must:

1) overlap spatially
2) overlap temporally (including flowering duration within a year and flowering time within a day); and
3) be sufficiently close biologically that the resulting hybrids are fertile, facilitating introgression into a new population (den Nijs et al. 2004).

As discussed in Section 1, hybridisation between *Lolium* sp and *Festuca* sp is common, with offspring showing varying degrees of fertility.

Lolium and *Festuca* species can form hybrids (refer to Table 1 and Table 2). *Lolium* species can also form hybrids with species belonging to other genera for example, *Vulpia* (×*Festulpia* Melderis ex Stace & R. Cotton) and *Bromus* (×*Bromofestuca* Prodan.) (Watson & Dallwitz 1992). As some of these species are present in Australia and some crosses form viable or vegetatively strong hybrids, gene transfer between *Lolium* and other genera can occur. Examples of some these hybrids are given in Table 17.

Table 17. Natural hybrids of tall fescue, Italian ryegrass and perennial ryegrass

Hybrid	Name	Fertile?
L. multiflorum × *L. perenne*	*L.* × *hybridium, Festulolium holmbergii* (Doerfler)P.Fourn.	yes
L. multiflorum × *L. rigidum*	L. × *hubbardii* Jansen&Wachter ex B.K.Simon	yes
L. multiflorum × *L. temulentum*		yes
L. multiflorum × *L. arundinaceum*		
L. multiflorum × *L. pratense*		some
L. multiflorum × *Dactylis glomerata*	(Thorogood 2003)	
L. perenne × *L. loliaceum*		no
L. perenne × *L. multiflorum*	*L.* × *hybridium, Festulolium holmbergii* (Doerfler)P.Fourn.	
L. perenne × *L. remotum*		no
L. perenne × *L. rigidum*		yes
L. perenne × *L. arundinaceum*		
L. perenne × *L. pratense*	*Festulolium loliaceae*	some
L. perenne × *Festuca rubra*		
L. perenne × *Glyceria fluitans*	(Thorogood 2003)	
L. arundinaceum × *L. pratense*	*F.* × *aschersoniana* Doerfler	
L. arundinaceum × *L. giganteum*	*F.* × *fleischeri* Rohlena	no
L. arundinaceum × *F. rubra*		

9.3 Crossing under experimental conditions

Sexual hybrids between *L. multiflorum* and *L. arundinaceum* have been readily obtained only unidirectionally, while the reciprocal cross is very difficult (Eizenga & Buckner 1986). In addition, chromosomal instability and poor female fertility can be a problem. This has been overcome by symmetric and asymmetric fusions performed between protoplasts of tall fescue and Italian ryegrass to make *Festulolium* hybrids (Takamizo et al. 1991; Spangenberg et al. 1995a) or from anther culture (Zwierzykowski et al. 1999). Anther culture has also been used to produce diploid hybrid progeny from tetraploid parents of *L. perenne*, *L. multiflorum* and *L. pratense* (Kopecky et al. 2005).

A viable *L. multiflorum* x *Dactylis glomerata* hybrid has been produced using auxin treatment and embryo rescue and this has been successfully backcrossed to *L. multiflorum*. (Oertel et al. 1996). No hybrids were produced without auxin, or between *L. perenne* and *D. glomerata* (Oertel et al. 1996). D. glomerata has also been successfully crossed with *L. arundinaceum* to produce a *L. arundinaceum* x *D. glomerata* hybrid using embryo culture, however this hybrid was sterile (Matzk 1981).

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APPENDICES

Appendix 1 – Examples of cultivars of *L. perenne*, *L. multiflorum* and *L. arundinaceum* grown commercially in Australia*

Species	Use	Plant type	Cultivar	Register of Australian Herbage Cultivars[4]	PBR in Australia[5]
L. perenne	Pasture	Very early maturing diploid	Boomer	No	Yes
			Drylander	No	No
			Everlast	No	No
			Fitzroy	No	Yes
			Kangaroo Valley	Yes	Yes
			Matilda	No	No
			Meridian	No	Yes
			Meridian Plus AR1	No	Yes
			Skippy	No	No
		Early maturing diploid	Ausvic	No	Yes
			Camel	No	Yes
			Kingston	No	Yes
			Roper	No	Yes
			Tomson	No	Yes
			Victorian	Yes	No
		Mid season diploid	Aries HD	No	Yes
			Avalon	Yes	Yes
			Bolton	No	Yes
			Bronsyn	No	Yes
			Bronsyn Plus AR1	No	Yes
			Cannon	No	Yes
			Cannon AR1	No	Yes
			Cowmax CM 105HP	No	No
			Extreme	No	No
			Grasslands Commando	No	Yes
			Grasslands Nui	Yes	No
			Lincoln	No	Yes
			Prolong	No	Yes
			Samson	No	Yes
			Samson AR1	No	Yes
		Late season tetraploid	Bealey	No	Yes
			Canasta	No	No
			Grasslands Sterling	No	No
			Grazmore	No	Yes
			Optima	No	No
			Quartet	No	Yes
	Turf		Premier II	N/A	No
			Barlennium	N/A	No

[4] The Register of Australian Herbage Plant Cultivars is a voluntary registration system for recording the origins, distinctiveness and agronomic merit of cultivars. The system of registration was set up in the 1960s under the Standing Committee of Agriculture and Resource Management (Kelman 2001). Like any non-statutory cultivar registration system it does not confer any legal protection over the name of the plant.

[5] Proprietary varieties in Australia are protected by Plant Breeder's Rights (PBR), which are exclusive commercial rights to a registered variety. The rights are a form of intellectual property and are administered under the Plant Breeder's Rights Act 1994 (for more information see the IP Australia website at http://www.ipaustralia.gov.au/pbr/index.shtml). All of the turfgrass cultivars listed have been developed overseas and none, as yet, has PBR status in Australia.

Species	Use	Plant type	Cultivar	Register of Australian Herbage Cultivars[4]	PBR in Australia[5]
			Brightstar	N/A	No
			Stallion Supreme	N/A	No
L. multiflorum	Pasture	'Biennial' early season flowering diploid	Dargo	No	Yes
		'Biennial' mid season flowering diploid	Caversham	No	No
			Eclipse	No	Yes
		'Biennial' late seaon flowering diploid	Concord	No	No
			Conquest	No	No
			Crusader	No	Yes
			Dargle	No	Yes
			Diplex	No	No
			Flanker	No	Yes
			Grasslands Status[Plus]	No	Yes
			Grasslands Warrior	No	Yes
			Hulk	No	Yes
			Mariner	No	Yes
			Marbella[Sud]	No	No
			Sonik	No	Yes
			Tabu	No	Yes
		'Biennial' late season flowering tetraploid	Feast II	No	No
			Denver	No	Yes
		Annual early flowering diploid	Aristocrat	Yes	No
			Noble	No	Yes
		Annual early flowering tetraploid	Betta Tetila	No	No
			Drummer	No	No
			Growmore Plus	No	No
			New Tetila	No	No
			Tetila (USA)	No	No
			Tetila Gold	No	No
		Annual mid season flowering diploid	Ceres Missile	No	No
			Ceres Pronto	No	No
			Progrow	No	Yes
			Surrey	No	No
		Annual mid season flowering tetraploid	Andy	No	No
			Grasslands Tama	Yes	No
			Robust	No	Yes
			Rocket	No	No
			Tetrone	No	No
			T Rex	No	No
			Winter Star	No	No
			Winter Star II	No	No
	Turf		Panterra	No	No
L. arundinaceum	Pasture	Temperate very early flowering	AU Triumph	No	No
			Dovey	No	No
			Quantum	No	No
			Quantum Max P	No	No
	Pasture	Temperate mid-late flowering	Advance	No	Yes
			Advance Max P	No	Yes
			Demeter	Yes	No
			Jesup	No	No
			Jesup Max P	No	Yes
			Lunibelle	No	No
			Torpedo	No	No
			Typhoon	No	No

Species	Use	Plant type	Cultivar	Register of Australian Herbage Cultivars[4]	PBR in Australia[5]
	Pasture	Temperate late flowering	Carmine	No	No
			Vulcan II	No	No
	Pasture	Mediterranean mid season flowering	Flecha	No	Yes
			Flecha Max P	No	Yes
			Fraydo	Yes	Yes
			Origin	No	No
			Prosper	No	Yes
			Resolute	No	Yes
			Resolute Max P	No	Yes
	Turf		Barlexas	N/A	No
			Barrera	N/A	No
			Bingo	N/A	No
			RTF™	N/A	No

*Data derived from Register of Australian Herbage Plant Cultivars, last updated 29/01/2007 (http://www.pi.csiro.au/ahpc/grasses/grasses.htm); Zurbo (Zurbo 2006); Lowien et al. (Lowien et al. 2004); Launders & Kemp, 2004 13616/id/d}; Lowien & Harris (Lowien & Harris 2004); Heritage Seeds (2008).