Improving the Production and Persistence of Temperate Pasture Species in Subtropical Dairy Regions of Australia

by

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Declaration

I certify that the contents of this thesis have not been submitted in any previous application for a degree or are currently being submitted for another degree elsewhere.

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List of publications

Refereed scientific papers

Donaghy, D.J. and Fulkerson, W.J. (1997). The importance of water soluble carbohydrate reserves on regrowth and root growth of *Lolium perenne* (L.). *Grass and Forage Science* **52**, 401-7.

Donaghy, D.J. and Fulkerson, W.J. (1998). Priority for allocation of water soluble carbohydrate reserves in *Lolium perenne* (L.) *Grass and Forage Science* **53** (In Press).

Donaghy, D.J., Scott, J.M. and Fulkerson, W.J. (1997). The effect of defoliation frequency and summer irrigation on survival of perennial (*Lolium perenne*) and biennial (*Lolium multiflorum*) ryegrass in the subtropics. *Australian Journal of Experimental Agriculture* **37**, 537-45.

Conference proceedings

Donaghy, D.J. and Fulkerson, W.J. (1996). Persistence of temperate pastures in a subtropical environment. *Proceedings of the 8th Australian Agronomy Conference, Toowoomba*, 211-4.

Summary

In subtropical dairy regions of Australia, temperate pasture species are sown to overcome a shortage of forage in the cooler months (late autumn to mid-spring), due to a decline in growth and quality of tropical grasses. Ryegrass (*Lolium*) species are the most widely sown temperate grasses, and with appropriate management, are capable of high yields of quality forage under the subtropical climate. Perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pastures are less costly, and provide a higher quality forage with more even dry matter (DM) production throughout the year, than annual (*L. temulentum* L. or *L. rigidum* Gaudin) or biennial (*L. multiflorum* L.) ryegrass pastures. However, under current management, perennial ryegrass pastures have not persisted beyond 2 years in the subtropics, and this lack of persistence is associated with severe stress conditions over summer. Previous studies have indicated that perennial ryegrass survival over summer could be substantially improved, and incursion of tropical grasses minimised, by appropriate defoliation management.

The studies reported in this thesis aimed to confirm the importance of defoliation interval under grazing, and to determine the mechanism by which defoliation affects the survival of perennial ryegrass and white clover. The initial strategy was to determine the critical time of defoliation on subsequent plant survival over summer. The observed association between ryegrass survival and tiller and root growth, and water soluble carbohydrate (WSC) reserves, was then studied further in the glasshouse, in order to determine the mechanism of action. Inducing plants to become dormant over summer, or to regenerate from seed the following autumn, was then evaluated as an alternative to managing plants to survive summer. Lastly, the effect of defoliation on the white clover component of mixed perennial ryegrass/white clover pasture was studied.

In the introduction (Chapter 1), the role of temperate pastures in subtropical dairying regions of Australia was highlighted, along with the problem of lack of persistence of perennial ryegrass/white clover pastures. A review of the literature follows in Chapter 2, which described the subtropical region as an environment for pasture growth. The

morphology of ryegrass and white clover plants was then examined, along with their physiological response to variation in climate and management, particularly defoliation management. Methods common to more than one study in this thesis are outlined under 'General methods' in Chapter 3. Methods specific to particular studies are described in the relevant Chapters.

Chapter 4 examined the effect of varying defoliation intervals (under cutting) pre-summer, and irrigation management during summer, on survival of perennial ryegrass over summer. Defoliation interval was timed to coincide with ryegrass plant development stages such as stem elongation, seed set and leaf/tiller stage of the regrowth cycle, to identify the period during which defoliation had the greatest effect on persistence. This study found that the critical time for defoliation was from winter to early spring, with the optimal defoliation interval for perennial ryegrass being related to the expansion of 3 new leaves/tiller. Defoliation during mid-spring, coinciding with stem elongation, had no effect on subsequent survival over summer. Frequent defoliation during late spring and early summer improved plant survival, but this was presumed to be by preventing development of a dense pasture canopy conducive to the spread of leaf rust (*Puccinia coronata*), and perhaps also by reducing shading by tropical grasses. Increased survival of perennial ryegrass plants under this optimal defoliation regime was associated with development of larger tillers, and a more extensive root system, than under more frequent defoliation. An infrequent irrigation interval during the summer (10 to 14 days) was shown to benefit only deeper-rooted tropical grasses and weeds.

In Chapter 5, the effect of defoliation frequency on perennial ryegrass survival over summer was examined *under grazing*. Again, defoliation at the 3-leaf stage of regrowth during this time led to greater persistence of perennial ryegrass, and plants had larger tillers and a more developed root system, than when pasture was grazed more frequently at the 1- to 1½-leaf stage. In addition, WSC levels were found to remain higher in infrequently-grazed plants throughout the summer. However, even then, WSC levels declined over summer, possibly due to 'carbon (C) starvation', where frequent cloud cover during this time presumably retards photosynthesis and hence buildup of WSC, while high night temperature would be expected to reduce WSC levels through increased respiration. Under grazing, the shallower root system resulting from more frequent defoliation, led to a substantially greater loss of perennial ryegrass plants through sod pulling (physical removal of plants from soil by grazing stock) than under infrequent (3-leaf) defoliation.

In these and other studies, WSC have been implicated in survival of perennial ryegrass through summer. In Chapter 6 we set out to determine the importance of WSC plant reserves on top and root growth, and on tiller dynamics of perennial ryegrass in a glasshouse. Variable WSC levels were obtained by altering defoliation frequency, and then the relative importance of WSC reserves and current photosynthate on early regrowth was determined by monitoring regrowth in light and darkness. Regrowth following defoliation was strongly and positively correlated to the stubble WSC content at defoliation, with regrowth in the first 3 days completely reliant on WSC. Presumably as a consequence of commencement of photosynthesis by the emerging leaves, after one week of regrowth, only one-third of leaf DM was attributed to WSC, and two-thirds to current photosynthate. However, the *capacity* of the plant to subsequently photosynthesise was also related to WSC. Thus, after a full 3-leaf regrowth cycle, plants with initially high WSC levels at defoliation still maintained a higher level of regrowth than plants with low WSC levels.

Our field studies led us to hypothesise that survival of perennial ryegrass plants over summer is related to their level of WSC plant reserves. The levels of WSC can be modified by defoliation frequency but the weather conditions are an unmodifiable environmental factor which suppress WSC levels in the subtropics. WSC plant reserves, in turn, are believed to influence plant persistence through their effect on tiller dynamics and root growth. For this hypothesis to be tenable there must be a clear priority for WSC reserves, with root growth having a lower priority than top growth.

Quantitative evidence that a priority for allocation of WSC reserves exists during regrowth of perennial ryegrass, with roots and tillers deprived of WSC until leaf regrowth resumed, was found in Chapter 7. Plants were grown under controlled glasshouse conditions where a gradient of WSC levels was obtained by varying defoliation interval and ambient temperature before defoliation, and harvest height at defoliation. On a regrowth time scale, tiller initiation was most sensitive (lowest priority), root regrowth moderately sensitive, and leaf regrowth relatively insensitive, to a decrease in WSC prior to defoliation. The time of daughter tiller initiation also coincided with the start of replenishment of stubble WSC levels. In contrast to this *sequence* of events, the *absolute effect* of a reduction in WSC on growth was different, with root elongation and survival most affected by low WSC levels (lowest priority).

In Chapter 8, the hypothesis that nitrogenous (N) reserves assume an important role in persistence of perennial ryegrass during periods when WSC are limiting, was tested by varying soil N status in late spring and early summer. This was presumed to increase the levels of N reserves within the plant, and had previously been shown to enhance summer survival of perennial ryegrass *under cutting* in other studies. To ensure low WSC levels during summer, defoliation frequency was altered as in Chapter 4, and this study was conducted *under grazing*. It was found that addition of N fertiliser had no effect on survival of perennial ryegrass over summer, and it may be that other factors, particularly the effect of the grazing animal, may negate any positive effect of higher N reserve levels. Consistent with the results in previous chapters, frequent defoliation reduced persistence of perennial ryegrass, and again this was associated with lower WSC levels, smaller tillers, and shallower roots, than less frequent defoliation.

As discussed previously, as C starvation may still limit survival of perennial ryegrass under optimal pasture management in a subtropical environment, an alternative may be to induce plants to avoid the summer, and 2 approaches were evaluated.

Firstly, in Chapter 9, varieties of perennial ryegrass which exhibited physiological summer dormancy were evaluated, by growing plants in the field until dormancy was observed, then transferring plants to a controlled-environment glasshouse, where temperature and moisture were varied to separate the effect of both on maintaining dormancy. As addition of water to dormant tillers caused over 85% of these tillers to regenerate, even at high temperature (38/20°C day/night), summer dormancy is unlikely to be a beneficial trait in the subtropics where an erratic summer rainfall pattern would cause dormancy to break, and these regenerating plants would have little chance of surviving under subsequent hot and dry conditions.

Secondly, in Chapter 10, an attempt was made to perennate biennial ryegrass and/or rely on seedling recruitment to re-establish a new pasture after summer. Although the biennial ryegrass genotype used was capable of regenerating a pasture in the second year with similar production to the establishment year, 32% of edible (ryegrass and white clover) DM was lost by the need to defer defoliation in late spring. As there was little high temperature dormancy of seed, it is expected that in a wet summer, few seeds would remain to germinate when cooler autumn conditions prevail. Furthermore, the management required to ensure survival of biennial ryegrass into late spring, to allow plants to set seed, is more critical than for perennial ryegrass, as the biennial genotype was observed to be more sensitive to frequent defoliation.

Since white clover is the usual companion species for perennial ryegrass, any consideration of the persistence of perennial ryegrass must also consider the persistence of white clover, and this was undertake in the study reported in Chapter 11. The white clover variety 'Osceola' was used, as this has been previously shown to be more persistent, presumably due to its higher summer activity, slowing the invasion of tropical grasses into sown temperate pasture. The study was conducted under cutting, with defoliation height and irrigation varied over summer to influence the competitive ability of Osceola in relation to tropical grasses. Despite high summer growth activity, Osceola was not vigorous enough to out-compete tropical grasses (primarily kikuyu (*Pennisetum clandestinum*)). The low seedling recruitment of white clover and poor survival of seedlings, indicate that perenniality of white clover under irrigation relies almost exclusively on stolon survival. In turn, stolon survival relies on the physiological process of stolon 'breakup', which results in the loss of the primary taproot, and fragmentation of the plant at stolon internodes, to produce many small stolon fragments, reliant on development of nodal roots for survival. The present studies identified that in the subtropics, stolon breakup is in the summer, in contrast to spring in temperate regions. The breakup period coincided with above-optimal temperatures for white clover, at a time when there was a high likelihood of waterlogging through summer rainfall, and a buildup of plant nematodes in roots to levels likely to be detrimental to white clover growth and performance. The factors are believed to combine to cause a high death rate (greater than 70%) of stolon fragments within the first month of breakup.

Chapter 12 monitored the dynamics of white clover stolons under grazing conditions, with the aim of identifying the factors affecting survival of fragmented stolons. Stolon breakup under grazing reflected observations from Chapter 11, and furthermore was repeated in 2 and 3 year old plants. Apart from a buildup of plant nematodes in roots as observed in studies in Chapter 11, various species of fungi were isolated in stolon fragments at this time. A defoliation interval equivalent to the 3-leaf stage of the companion perennial ryegrass led to greater DM production and a higher level of persistence than if plants were defoliated more frequently. More frequent grazing in spring decreased survival of growing points over summer, and this may have been due to a decrease in white clover reserve levels and restricted rooting, as was the case with perennial ryegrass.

In an applied context, the results of these studies have shown that ryegrass needs to be defoliated at about the 3-leaf stage of regrowth to optimise growth and persistence (for perennial genotypes). An interval equivalent to this was also most appropriate for the companion white clover, especially large-leafed varieties. The winter and early spring has been defined as the critical time during which defoliation interval affected subsequent survival of perennial ryegrass plants over summer. In contrast, in late spring, plant survival over summer may be improved by reducing grazing interval to 1½ to 2 leaves/tiller, but only if leaf rust is severe. However, this will reduce growth and persistence of the plants in comparison to pastures devoid of rust and defoliated at a more appropriate interval. Grazing at the 3-leaf stage results in greater survival of ryegrass plants, and this presumably provides less opportunity for invasion of tropical grasses, than under more frequent defoliation. This greater persistence associated with infrequently-defoliated ryegrass plants was attributed to greater survival of tillers over the summer, with these tillers being larger and having a more extensive root system, compared to plants subject to more frequent defoliation. The effect of frequent defoliation on depressing root growth can be dramatically seen in the field via an increase in sod pulling by grazing stock.

Table of contents

List of common abbreviations

Adj - adjusted

C - carbon

$CaCl_2$ - calcium chloride

CO_2 - carbon dioxide

cv. - cultivar

cvv. - cultivars

DM - dry matter

g - gram

ha - hectare

kg - kilogram

L - litre

l.s.d. - least significant difference

Li - leaf appearance interval

m - metre

meq - milliequivalent

mg - milligram

mm - millimetre

N - nitrogen, nitrogenous

N/A - not available

^{o}C - degrees centigrade

^{o}S - degrees south

RLA - residual leaf area

s.e. - standard error

spp. - species

SWSC - stubble WSC

t - tonne

TNC - total nonstructural carbohydrates

vs. - versus

WSC - water soluble carbohydrates

List of scientific names of plants

African lovegrass (*Eragrostis curvula* (Schrad.) Nees)

Annual ryegrass (Darnel) (*Lolium temulentum* L.)

(Wimmera) (*Lolium rigidum* Gaudin)

Barley (*Hordeum vulgare* L.)

Barnyard grass (*Echinochloa crus-galli* (L.) Beauv.)

Berseem clover (*Trifolium alexandrinum* L.)

Biennial ryegrass (Italian or Westerwolds) (*Lolium multiflorum* L.)

Bromegrass (*Bromus inermis* Leysser)

Cocksfoot (*Dactylis glomerata* L.)

Couch (*Cynodon dactylon* (L.) Pers.)

Kentucky bluegrass (*Poa pratensis* L.)

Kikuyu (*Pennisetum clandestinum* Hochst. ex. Chiov.)

Lotus (*Lotus pedunculatus* Cav.)

Lucerne (*Medicago sativa* L.)

Maize (*Zea mays* L.)

Narrow-leaf carpet grass (*Axonopus affinis* Chase)

Oats (*Avena sativa* L.)

Paspalum (*Paspalum dilatatum* Poiret)

Perennial ryegrass (*Lolium perenne* L.)

Persian clover (*Trifolium resupinatum* L.)

Phalaris (*Phalaris tuberosa* L.)

Prairie grass (*Bromus unioloides* Kunth.)

Red clover (*Trifolium pratense* L.)

Red grass (*Themeda triandra* (R. Br.) Stapf)

Rhodes grass (*Chloris gayana* Kunth.)

Saltbush spp. (*Atriplex* spp.)

Setaria (*Setaria sphacelata* (Schunach.) Stapf & C.E. Hubbard)

Subterranean clover (*Trifolium subterraneum* L.)

Summer grass (*Digitaria sanguinalis* (L.) Scop.)

Tall fescue (*Festuca arundinacea* Schreb.)

Timothy (*Phleum pratense* L.)

Wallaby grass (*Danthonia caespitosa* Gaudin)

Wheatgrasses (*Agropyron* spp.)

White Clover (*Trifolium repens* L.)