INVESTIGATION OF THE USE OF OATS IN ANNUAL MEDIC PASTURES

by

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ABSTRACT

The removal of volunteer annual grasses from annual medic pastures can dramatically improve the following cereal crops by providing important cereal root disease breaks, improved biological nitrogen fixation and reduced grass weed competition in medic-cereal rotations. Early removal of these volunteer grasses has the disadvantage of creating a winter feed shortage due to low medic productivity. A comparison of adding cereal root disease resistant oats to medic based pastures with the effects of either early removal or retention of volunteer grasses was conducted. Adding oats increased total pasture production and improved early dry matter production, so that sheep were introduced 21 days earlier than the grass-free medic pasture and 11 days earlier than the grass+medic pasture type. Final sheep liveweight gain was similar between all pasture types (128 g/sheep/day) suggesting compensatory growth in spring was occurring, particularly on the grass-free medic pasture type. Wheat yield and quality were directly related to the previous pasture type, with significant reductions after grass+medic and oat+grass+medic pasture types (average both pasture types 53% less) due to take-all disease, grass weed competition and reduced available N. Improving the low productivity of medic when grown in grass mixtures was the focus of additional experimentation. Establishment in autumn (20/10°C day/night) simulated temperatures compared to winter (15/8°C day/night) improved the productivity and competitevness of medic in both monocultures and mixtures, particularly after defoliation and a period of regrowth (66% increase in medic dry matter in medic12:2 oats mixture). Total season dry matter production was always greater in medic/oat mixtures than monocultures with sowing ratios that strongly favour increased medic density (> medic 3:1 oat) maximising medic production in mixtures. Delaying defoliation and high medic populations were the most successful management methods to maximise medic production in medic/oat mixtures. Delayed sowing of low density oats into established medic stands reduced seedling competition but provided little gain to early pasture productivity. This relationship did not alter with stocking rate. Appraisal of the Australian Medicago Genetic Resource Centres collection of medics and a limited number of CSIRO plant industries *Rhizobium meliloti* strains failed to find accession × rhizobium combinations better than the current commercial cultivar Paraggio for medic/oat mixtures. The capacity to improve the competitvness of the medic component in medic/oat mixtures was found to be limited as was the usefulness of this mixture to medic-cereal rotations.

STATEMENT

I hereby declare that the research work presented in this thesis is original and has not been accepted for an award or any other degree or diploma in any other university or tertiary institution. To the best of my knowledge this thesis contains no material previously published or written by another person, except where due reference is made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan or photocopying.

Signed: Date: 15/02/2004

Grant Neville Roberts

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I dedicate this thesis to my parents (Jan and Neville) and grandmother (Marcia) who truly believe in my abilities.

Chapter 1

1. GENERAL INTRODUCTION

Historically, the reason for including improved ley pastures in southern Australian dryland farming systems has been for the dual purpose of providing forage for extensive livestock production and rehabilitation of the soil before cropping (White *et al.* 1978; Reeves 1987). A ley farming system involving annual medic (*Medicago* spp.) or subterranean clover (*Trifolium subterraneum*) based pastures was developed to cater for the perceived need for the flexibility to rotate between crop and livestock enterprises (Puckridge and French 1983). Improvements in soil fertility and wheat yields (Puckridge and French 1983) and the similarity in economic performance of cropping and livestock enterprises was the catalyst for this system to function. Ley pastures as defined in this thesis will be restricted to annual pastures that have been established and managed in rotation with crops within a Mediterranean type environment. These are typically characterised by the sowing of improved pasture legumes species, management of grazing, application of phosphorous fertiliser (McCown 1993) and rotation with cereals (Tow and Schultz 1991).

Over the last two decades the cereal-ley farming system has been placed under enormous economic pressure due to reduced profitability in the livestock industry (McCown *et al.* 1988). This has resulted in a diminished area of ley pastures managed with less inputs, often being replaced by pulse and oilseed crops and fertiliser nitrogen, which together are potentially more profitable than livestock enterprises (Loomis and Conner 1992; McCown 1993). These cash crops have allowed the practice of continuous cropping to be introduced which can in some situations reduce the need to have pastures in the system at all (Hamblin 1987; Higgs 1987). The shift away from cereal-ley farming has occurred concurrently with a general decline in the legume content of pastures and thus their value in rotations. Several authors including Gillespie (1983) and Dear and Loveland (1985) have commented on reasons for this decline. Carter *et al.* (1982) gives a comprehensive list of reasons for the decline of medic based pastures in South Australia. As the commodity prices have favoured a shift towards cereal and pulse production, the inclusion of the legume based pasture in the farm rotation now requires greater justification than before. This means that both livestock production in the pasture phase and the yield and quality of following cereal crop must be maximised.

The use of the self-regenerating annual legumes in pastures has allowed improvements in both the quantity and nutritional quality of forage available for animal production (Webber *et al.* 1976). In addition there were approximately 15-20 million hectares of winter crops which relied on annual pasture legumes to maintain or improve the soil nitrogen (N) status, and break the cycles of pests and diseases (Carter 1981; Puckridge and French 1983; Carter 1987; Leys 1990). Initially these pastures consisted of the above mentioned introduced annual legumes, and also volunteer grasses and herbs (Rossiter 1966; Cocks 1975). The annual grasses, rye-grass (*Lolium rigidum*), barley grass (*Hordeum leporinum* and H. *glaucum*), brome grass (*Bromus diandrus* and B. *rigidus*), silver grass (*Vulpia myuros*, V. *bromides* and V. *fasiculata*) and wild oats (*Avena fatua* and A. *ludoviciana*) were particularly successful in persisting. They resist germination after summer rains (Chapman *et al.* 1999) yet germinate rapidly after autumn rains. They compete well against other pasture plants in the establishment phase, exploit soil nitrogen, recover from grazing and set large numbers of seeds, ensuring their persistence in annual pastures (Rossiter 1966; Cocks 1969; Cocks and Donald 1973; Cocks 1975).

These annual grasses, while useful as grazing plants early in the season can also be serious weeds of pastures and crops. Competition from them reduces legume nitrogen input (Perry *et al.* 1980; Butler 1990; Thorn 1992; Angus *et al.* 1994; Evans 1994) and legume seed production and they are hosts to root diseases for the following cereal crops (Perry *et al.* 1980; MacNish and Nicholas 1987; Cotterill and Sivasithamparam 1988). Competition from the annual grasses in crops the year after pasture is also a serious problem (Barrett and Campbell 1973; Smith and Levick 1974; Perry *et al.* 1980; Amor and Kloot 1987; Poole and Gill 1987; Medd and Pandey 1990).

There is now greater recognition of the need to control grasses in both the cropping and pasture phase if maximum economic productivity is to be achieved throughout the rotation. Hence while it may appear that integrated pastures and crops in rotation are complementary, closer analysis identifies a degree of competitiveness or antagonism between the crop and the animal units grazing the pasture (Allden 1980) which are essentially competing for similar farm resources (land, capital, management etc). If annual legume pastures are to maintain their place in the farming system they must ensure high production in both livestock and the subsequent cereal crop, enhancing the profitability of the entire rotation.

Eliminating grasses from legume pastures has been shown to overcome many of the above problems and produce associated benefits (Venn 1984; MacNish and Nicholas 1987; Inwood and Roget 1993; MacLeod *et al.* 1993). However there has been concern that the livestock enterprise would suffer if total grass removal was practised leading to reduced pasture production early in the season and health problems associated with high legume content diets (Leys 1990). There is clear evidence that early pasture production is reduced when grasses are removed in early winter (Stephenson and Mitchell 1993; Little *et al.* 1993; Scammell 1996) even though total season pasture production is rarely reduced (Venn 1984; Thorn and Perry 1987).

The inclusion of cereals as companion crops in annual legume pastures has been practiced by some farmers and may improve early and total forage production; however the benefits must be weighed against reduced legume establishment due to competition (Wheeler and Freer 1986) and the potential effects on following crops. Oats are resistant to the main strains of take-all (*Gaeumannomyces graminis* var. *tritici*) and the recent availability of cultivars resistant to cereal cyst nematode *(Heterodera avenae*) (Barr 1989) suggests that a following crop would not be adversely affected by their inclusion in legume based pastures.

Experiments by Roberts (1990; 1991) have examined this hypothesis under both cutting and grazing regimes and have shown that improvements in early pasture availability and a reduction in grass availability is possible. However the medic component was shown to be at a disadvantage in these experiments. A review of the literature has highlighted the lack of detailed research into medic/grass relationships as well as the value of this mixture to southern Australian dryland cropping regions. Further investigation is therefore required to determine if the introduction of suitable oat cultivars into medic based pastures would improve the productivity and profitability of medic-cereal rotations. A major objective of the project reported in this thesis is to examine if the legume component can be productive enough, in oat-medic mixtures, to allow it to fulfil its role in providing forage and seed, improvement in soil nitrogen and an adequate break in cereal root diseases. An examination of practical management options to optimise production from the oat-medic mixture is also required.

The principal aims of this research were (1) to assess the importance of annual grasses in the cereal/medic farming system, including the effects on pasture legume, sheep and cereal production; (2) to compare the effects of adding oats to medic based pastures with the effects of the common practices of either early removal or retention of volunteer grasses in medic pastures in a pasture/cereal rotation; (3) To gain a greater understanding of the environmental conditions and management techniques required to maximise medic growth in oat/medic mixtures; (4) to seek vigorous medic accessions that would be more competitive in oat/medic mixtures. Figure 1.1 summarises the experimental approach taken in this thesis for achieving these goals. The initial grazing rotation experiment (experiment 1) showed how to generate additional winter pasture growth with oat/medic mixtures; however, medic growth was suppressed. Three questions were generated from this experiment leading to additional experiments (experiments 2-6) with the aim of evaluating the potential of oat/medic mixtures in a ley farming system.

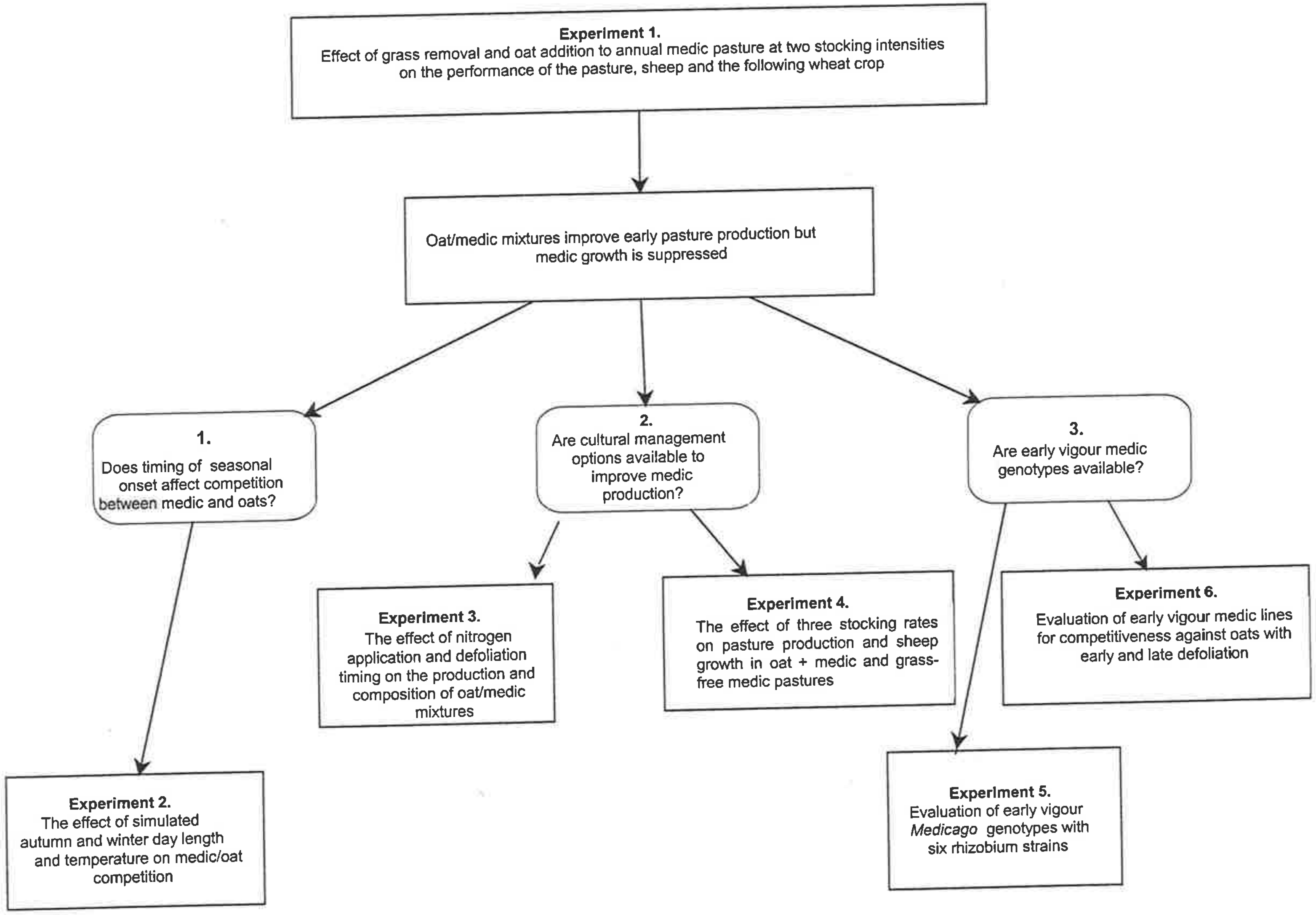

Figure 1.1 Hierarchal flow chart of questions and experiments reported in this thesis.

Chapter 2

2. LITERATURE REVIEW

2.1 INTRODUCTION

Throughout this literature review the emphasis will be placed on pastures grown in the southern Australian dryland farming zones, particularly those based on the annual *Medicago* spp. Such pastures experience the Mediterranean type climate prevalent across much of southern Australia. Aschmann (1973) described the Mediterranean climate as one with at least 65% of the annual rainfall in winter, average winter temperature below 15°C and no more than 3% of the hours in the year falling below freezing. Mean annual rainfall in areas with this climate varies from 275-900mm (Buddenhagen 1990) and the length of the growing season ranges from five to seven months with hot, dry summers (Prescott and Thomas 1949). Rainfall is unreliable and soil water availability is often well below the optimum for plant growth (Nix 1976). The soils are typically low in nitrogen and phosphorous and susceptible to both wind and water erosion. These regions are generally situated between the latitudes of 30° and 40° in both the southern and northern hemisphere (Leeuwrik 1974).

The review will examine the significance of the *Medicago* and volunteer grass species in crop-pasture rotations of the low rainfall areas of southern Australian. Specific experiments with oat-medic mixtures will be reviewed along with a brief examination of the role of competition in annual grass-annual legume mixtures and the methods used to determine competition between two species in a mixture. The replacement series approach used throughout the experiments in this thesis is described in detail along with the advantages and disadvantages of such a method. The following headings provide an overview of the topics discussed:

- 2.2 The Role and Performance of Annual Medics in Cereal-Pasture Rotations
  - 2.2.1 Medics in Grazing Pasture
  - 2.2.2 Medic Use in Crop Rotations
  - 2.2.3 Regeneration Ability of Medics
- 2.3 The Effects of Presence and Removal of Annual Grasses in the Pasture Phase of Crop-Pasture Systems

A point of clarification is made regarding use of the term pastures. The term "pasture", even when restricted to the broadacre cereal/livestock zone, is often used loosely and ambiguously to mean anything from a paddock containing mostly annual legumes, annual grasses or broadleaved herbaceous weeds or a mixture of all three and anything else. However the botanical composition of this pasture is extremely important as it determines its usefulness both for animal forage and for its effect on subsequent crop production. A specific distinction is therefore made in this thesis between pastures composed of several species in varying proportions and pastures composed predominately of annual legumes such as the *Medicago* and *Trifolium* species. The latter shall be referred to as ‘legume dominant pastures'. This distinction must be made as research has shown that it is the legume and its frequency in a pasture that has the largest effect on livestock and crop production (Carter 1987).

2.2 THE IMPORTANCE OF ANNUAL MEDICS IN CEREAL-PASTURE ROTATIONS

Throughout southern Australia the annual medics are widely distributed throughout the 250 to 450 mm rainfall areas and are especially suited to the drier, light textured, alkaline soils (Amor 1965; Robson 1969), although new, specialised introductions after 1969 have enabled annual medics to be grown in the neutral to acid soil, medium rainfall areas as well. Their ability to persist under low rainfall and continuous grazing conditions and to produce relatively high amounts of seed (Puckridge and Carter 1980) has meant they have developed and maintained their niche in these areas. The annual medics generally have a dual role of providing high quality grazing fodder for livestock and improving soil fertility by the biological fixation of atmospheric nitrogen and increase of organic matter reserves (Webber 1990). This ability to ameliorate soil nitrogen levels is utilised in pasture-crop rotations to improve cereal grain yields and quality. An additional benefit of the annual medic is its inherently high levels of hard seed, a highly desirable attribute, allowing self regeneration after a year or more without seed production, such as through a year or two of cereal cropping. The breakdown of hard seed over several years is seen as a low cost method of maintaining medic pastures in addition to a drought survival mechanism. It has also been shown that annual medics do not host the common cereal root diseases including the two most wheat-yield-limiting soil diseases across southern Australian, Cereal Cyst Nematode (*Heterodera avenae*) and take-all (*Gaeumannomyces graminis* var. *tritici*).

Thus with appropriate management, annual medics have the ability to provide protein rich grazing pasture, nitrogen and root disease breaks for following cereal crops and to regenerate themselves from a bank of hard seed in the soil.

2.2.1 Medics in Grazed Pasture

Pastures are the main source of feed for livestock enterprises within the ley farming system, with crop stubbles playing a subsidiary role in the dry period of the year (Cannon 1974). The annual medics have been shown to provide a highly nutritious diet for grazing sheep and excellent sheep growth rates and wool production have been recorded from grazed medic pastures (Brownlee 1973; Brownlee and Denney 1985; Brand *et al.* 1991; Roberts 1991; Chaichi 1995). The experiment with Brownlee (1973) showed that barrel medic cv. Jemalong supported clean wool production up to 16.47 kg/ha per annum at a stocking rate of 6.2 sheep/ha, although supplementary feeding was required during autumn. The subsequent experiment in which Brownlee and Denney (1985) evaluated a range of medic cultivars gave similar results with an average of 3.6 kg/ewe per annum of clean wool production over 4 years of experimentation. The weaned lambs grazing with these ewes also had a mean live-weight gain of 74 g/lamb/day.

The success of pasture production can be attributed in large part to the matching of growth and development phases to the climatic pattern. The opening rains (rainfall sufficient to germinate, establish and maintain the growth of seedlings) can fall any time from March to June and may cease any time from September to December. Thus the length of the effective growing season may vary from four to nine months depending on the district and season and is determined by the relationship between rainfall and evaporation (Puckridge and Carter 1980).

Critical time for availability of pasture herbage for grazing animals is the autumn to early winter period when pasture growth (and availability) is low (Puckridge and Carter 1980). The effect of grazing intensity also influences the level of medic biomass available to be returned to the soil. White *et al.* (1994) found in the comparison of grazed medic based pastures with 4, 7 and 10 sheep/ha that soil nitrogen accretion levels did not differ after six years; however, there was a trend for an increase in total soil N and organic matter levels at the low stocking rate. The authors suggested that shoot residues remaining in the low stocking rate treatment, due to under utilization of the pasture, was possibly the reason for the observed differences. Hence grazing intensity affects the production, composition and nitrogen accretion of the pasture.

2.2.2 Use in Crop Rotations

The use of medic based pastures as a break crop from cereal root diseases and to provide nitrogen for following cereal crops is well known (Amor 1965; Carter 1978; Cocks 1988b). The annual medic species have helped in overcoming nitrogen deficiencies in cereal crops in annual cropping zones (White *et al.* 1997) and substantially higher crop yields have been noted where medics have grown well (French *et al.* 1968). The benefits following legumes cannot always be completely explained in terms of residual fixed N. Peoples *et al.* (1992) suggest that cereal crops can also benefit from the legume rotation by:

1. Improvements in soil structure, water holding and buffering capacity, and increased nutrient availability following incorporation of legume residues.
2. Breaking cycles of cereal disease and pests and phytotoxic and allelopathic effects of different crop residues.
3. Diversification and enhancement of soil microbial activity and possibly heterotrophic N_2 fixation following addition of legume residues.
4. Increased nitrate remaining in the soil due to less being taken up by the legume or increased mineralisation under the legume.

Nitrogen Input and Soil Amelioration: Annual legumes have foliage N contents of 2-4% and seed protein contents of 17-40% and N content would be much lower without N fixation. The legume's ability to form a symbiotic partnership with *Rhizobium* spp. allows them to obtain their N requirements from the atmosphere via nitrogen fixation in root nodules (Peoples *et al.* 1992). The process of legume nitrogen transfer to cereals is usually via the decomposition of legume residues (Ladd 1992), although Ladd *et al.* (1983) showed that only a small proportion of nitrogen fixed from preceding medic pastures is actually utilised by the immediately following cereal crop. Danso and Papastylianou (1992) suggested that the increased assimilation of nitrogen in cereals following legumes is attributable to a greater availability of soil nitrogen arising from the lower soil nitrogen uptake by the preceding legume. The effect of legumes in rotations can therefore be one of a nitrogen saving effect as well as the addition of soil nitrogen.

Peoples and Baldock (2001) provided an extensive summary of the nitrogen fixing ability of a range of pasture legumes utilised in Mediterranean agriculture and an overview of the ability of annual medics to provide biologically fixed nitrogen. Estimates of the amount of N fixed by annual medics varies greatly, with values as high as 220 kg/ha per year being achieved in a rain fed environment (Peoples and Baldock

2001). Crawford *et al.* (1989) also recorded 200 kg/ha of N in one season under a medic pasture. Butler (1988) suggested a range from 52-102 kg N/ha while Dahame (1978) in a soil survey of medic established areas estimated a mean of 200 kg N/ha per year. Clarke and Russell (1977) recorded an annual average of 100 kg/ha of N being added to topsoil with medics and Hossain *et al.* (1995) obtained figures between 28-56 kg N/ha. However, nitrogen yield (not nitrogen actually fixed) has been recorded as low as 30-99 kg N/ha over an eight month period when grazing was introduced onto medics (Peoples *et al.* 1992). The term nitrogen yield was used because an estimate of N fixation was not available, only the net N found in dry matter samples. It is unclear when the N yield was measured in this data set but is likely to have been at the end of the grazing period, which was 8 months. Due to the complexities in measuring N_2 fixation *in situ*, the effects of grazing on nitrogen fixation in medics are largely unknown and warrant further investigation. Such information is essential to gain an understanding of the N dynamics under medic pastures and of management factors that influence the amount of N fixed. Hossain *et al.* (1995) suggested severe defoliation of medic in their experiment reduced medic re-growth which in turn reduced nitrogen fixation. Butler (1987) also found that repeated defoliation drastically reduced N_2 fixation in *Medicago littoralis* in pot trials; however, in field micro plots water rather than defoliation appeared to control N_2 fixation. Both methods produced a linear relationship between medic dry matter yield and amount of fixed N. Based on these results agronomists desire to maximise legume dry matter production in order to maximise biological nitrogen input to the soil which in turn becomes available for following cereal crops.

There is clear evidence that medics increase total nitrogen in the soil with Mullaly *et al.* (1967), Tuohey and Robson (1980) and Papastylianou *et al.* (1981) all reporting increases in total soil nitrogen after a range of years of medic pastures. In one of the few grazing experiments on medics where nitrogen was measured, White *et al.* (1994) showed after six years an increase in total soil N of 15-20%. However, there was little evidence of increased N availability to following cereal crops. This experiment was conducted in Syria and the authors suggested that the reduced time available for microbial degradation of biomass residues could account for the differences between their experiment and ones conducted in Australian climates. Yet Alston and Graham (1982) working in Australia found that soil total nitrogen and mineral nitrogen were not correlated after medic pastures. Therefore in order to maximise biological fixation over the whole system it is beneficial to reduce nitrate levels in the soil by utilising the N in a cereal crop forcing the following medic pasture to 'fix' its own nitrogen again. The authors suggested that the use of rotations such as a pasture ley followed by a cereal crop would accomplish this. Peoples *et al.* (1992) suggested that the strong inverse relationship between the level of plant-available soil N at establishment and the proportion of nitrogen fixed is possibly the most important limitation to N_2 fixation. Simpson (1987) also suggested that as soil N increases with time under pasture it reaches a maximum or equilibrium content of organic N, at which point the depletion of this accumulated N is desirable in order to re-establish efficient biological nitrogen fixation. This would suggest that to maximise nitrogen inputs from legumes over the whole rotation, soil nitrate levels need to be depleted at regular intervals e.g. preferably by growing a cereal crop; hence the ley farming concept.

Butler and Ladd (1985a), West and Wedin (1985), Evans *et al.* (1987) and Hossain *et al.* (1995) have shown with other legumes that there is a high correlation between dry matter produced and nitrogen fixed. Hence, provided an efficient medic × rhizobium strain association exists, the level of nitrogen fixed is closely related to medic growth. This is influenced by seasonal climatic variability, stand density, mineral nutrition, supply of mineral nitrogen in the soil and grazing management practices (Papastylianou *et al.* 1981; Evans 1992; Loomis and Connor 1992).

The inclusion of medics can also influence characteristics of the soil other than nitrogen addition. Changes in total soil nitrogen are often associated with parallel changes in water stable aggregates (Rowland *et al.* 1984). In addition Greenland (1971) has noted changes in soils after legume pastures with an increase in porosity, increase in aggregate and micro-aggregate stability, decrease in bulk cohesive strength, an increase in water retention at any given suction and increased amounts of available water. These changes in soil physical condition are attributed to increased biological activity with the microbial degradation of plant residues leading to formation and stabilisation of aggregates. The microbial decay increases the production of polysaccharides, which bind the clay particles together, this being suggested as the most important mechanism by which pastures affect aggregate stability (Robson 1990).

Use as a Disease Break: Both annual medics and sub clover are regarded as non-host plants to Cereal Cyst Nematode (CCN) (*Heterodera avenae*) and take-all (*Gaeumannomyces graminis* var. *tritici*), two damaging cereal root diseases of southern Australia. Medics have not been recorded as hosts of CCN and Meagher and Rooney (1966) and Meagher and Brown (1974) found no evidence of cysts forming on barrel medics in known CCN infested areas. Eastwood (1990) and Rovira (1990) supported these findings. Similar results have been found for take-all with Cotterill and Sivasithamparam (1988a; 1988b) and MacLeod and MacNish (1989) reporting annual legumes as non-hosts and useful break species. Annual medics are also resistant to the legume and oat-damaging stem nematode (*Ditylenchus dispaci*) (Fisher 1990). In addition annual medics do not host many of the foliar fungal and viral pathogens of cereals and as such do not provide a reservoir from which epidemics can develop (Burgess *et al*. 1990; Rovira 1990). However, medic has been recorded as a host of both root lesion nematode (*Pratylenchus spp*.) and Rhizoctonia (*Rhizoctonia solani*), both potentially damaging root pathogens with wide host ranges (Fisher 1990).

2.2.3 Regeneration Ability of Medics

The self regenerating attribute of the annual medics and their ability to persist after a period of cropping, due to a mechanism of hardseededness, is most favourable for low rainfall ley farming systems. Hardseededness in medics involves the medic seed having an impervious seed coat and some form of embryo dormancy (Quinlaivan and Nicol 1971), although embryo dormancy appears to be of lesser importance (Reed *et al*. 1989). Approximately 90% of newly ripened legume seeds are hard (impermeable to water) in Mediterranean environments (Taylor and Ewing 1988). A proportion of these hard seeds soften (become permeable to water) during the following summer and autumn (Taylor 1996) and germinate upon opening rains. Generally few seeds soften during the growing season, so the residual hard seeds persist until the next summer-autumn period (Taylor *et al*. 1984). Seed softening appears to be a two-stage process as described by Taylor (1996). Preconditioning, or the first stage of softening takes place with rising temperatures and is influenced by the genotype, environment and temperatures at ripening. Generally the rate of softening increases with increasing temperature (Taylor 1993). The second stage requires diurnal fluctuations which differ between species and genotypes. For example *Trifolium subterranean* and Cyprus barrel medic (*M.*

truncatula) requires soil temperature fluctuations in the vicinity of 60/15°C where as *Medicago polymorpha* requires a range of approximately 35/10°C in autumn (Taylor 1993; 1996).

The natural regeneration of pasture legumes has two distinct advantages; high seedling plant density and low cost. The key to high legume herbage yields, especially in winter, is high plant density (Abd El-Moneim and Cocks 1986; Cocks 1988b). This is most easily achieved through having a high density of legume seed reserves in the soil (Carter 1987). The high seed yielding ability of medics provides an economical means of achieving high medic seed reserves and the mechanism of seed softening allows a proportion of these seeds to germinate in following seasons. This system, with appropriate management that maintains the soil seed bank reserve, has the ability to supply the high plant density required for high pasture production at low cost. Annual medic survival is therefore dependant upon the ability of the plants to produce high seed yields and an adequate mechanism to avoid premature germination. The above statements have been objectives of annual pasture legume breeders and researchers, with a large emphasis placed on the legume being able to satisfactorily regenerate (Crawford *et al.* 1989). Hence appropriate hardseededness in the legumes and management of the seed bank are important in cereal-pasture legume rotations. Against this Quigley (1988) has reported that high concentrations of cereal straw can reduce softening of hard medic seed by increased thermal insulation. In addition the cereal straw provides a carbon source for pathogenic fungi to attack the medic seedlings and increase mortality. The results of Quigley (1988) show that the entire farming system must therefore be taken in into account when managing the regeneration of medic pastures.

In future, the regeneration of the annual legumes in the pasture phase may be of less importance if the approach of phase farming is adopted as suggested by Reeves and Ewing (1993). In this system the need to have hardseeded legumes and to actively manage the soil seed bank for pasture regeneration after a period of cropping is negated as the pastures are resown after a period of absence due to cropping. Phase farming can be differentiated from "traditional ley" farming by (a) pasture and cropping phases of rotations being longer than those which have characterised Australian ley farming and (b) a lesser proportion than 50% of the area under ley at any time (McCown 1993). Indeed it has been suggested by Reeves and Ewing (1993) that the high current level of continuous cropping in southern Australia is simply the first stage of a two phase rotation in which a period of pasture will follow in the future. However, it may be economics and farmer antagonism to livestock which is sustaining this high level of continuous cropping, more than any real understanding of a phase type system by the land owners. The authors argue that the timing of the introduction of the pasture phase is not important. They assume that the soil damaging and fertility depletion effects of cropping will be repaired completely in the pasture phase, which may or may not be completely true. Furthermore unless it can demonstrated that there is a longer term benefit that can be exploited to the land owner's advantage, the pasture phase may never occur. Annual pastures may therefore take second stance to continuous cropping until the land owner deems them necessary, perhaps to overcome problems encountered in continuous cropping such as herbicide resistance in weeds or rising nitrogen fertiliser costs.

2.3 THE EFFECTS OF PRESENCE AND REMOVAL OF ANNUAL GRASSES IN THE PASTURE PHASE OF CROP-PASTURE SYSTEMS.

2.3.1 Effects on Pasture Quantity and Quality

The annual grasses have long been acknowledged as substantial components of volunteer annual pastures and are regarded as particularly useful in providing early winter feed (Jones *et al.* 1984; Anon. 1988; Venn 1984). It is common for the grasses to germinate and establish themselves early in autumn (Cocks 1974) and to continue to provide forage throughout the winter period. In contrast Taylor *et al.* (1979) commented on the poor growth of medics in winter with most growth occurring in an approximate eight week period starting in mid August. Amor (1965) suggested that early rainfall in autumn would favour medic establishment over grasses, as the seedlings were able to start runner growth before winter. Conversely with late starts to the rainfall season, the annual grasses grow more rapidly than medic at the lower temperatures and shortened day-length and thus provide the major part of available forage. The experiment conducted in autumn by Smith *et al.* (1972) showed that Wimmera ryegrass (*Lolium rigidum*) was superior to other species, including subclover, in its ability to attain critical herbage weight before other species. "Critical herbage weight" was defined in this experiment as the weight of herbage at which sheep began to gain live weight. The superiority of ryegrass was attributed to a more erect growth habit compared to subclover, which made it more available to grazing sheep, rather than an increase in herbage per hectare on offer. *Vulpia* spp. are exceptions to the annual grasses as they grow slower and become more prostrate during grazing.

Reduced annual legume pasture growth rates have been observed by several researchers after grass removal. Both Dunlop and Thorn (1984) and Thorn and Perry (1987) confirmed a reduction in pasture on offer (up to 30%) when selective grass herbicides were utilised in grass/clover swards. In both cases this resulted in reduced sheep liveweight in winter. However, in the case of Thorn and Perry (1987) compensatory growth in Spring and summer, due to the higher quality legume feed on offer (1.6% vs. 1.0% nitrogen in January), resulted in significantly higher liveweight at the end of the season for the grass-free pastures. Stephenson and Mitchell (1993) showed that early removal of barley grass in a barley grass/subclover pasture reduced dry matter production by 41% and allowed the broadleaf weed Indian Hedge Mustard (*Sisymbrium orientale* L.) to increase in the pasture, although grazing did suppress the mustard. In contrast, Venn (1984) found that in an ungrazed medic-barley grass pasture which had grass removal with the selective grass herbicide, fluazifop-butyl, there was no significant effect on pasture production due to the compensatory increase in the medic component from 27 to 75%. The 'other' component in this pasture consisted of broadleaf weeds with the authors suggesting an increase in these weeds due to the lack of grazing. Some researchers e.g. Carter (1982; 1987) have suggested that the problem of early winter growth is one of low legume plant density and cites the evidence of poor soil seed reserves and low sowing rates as reasons. Certainly the relationship between increased legume plant density and early pasture production has been documented before by Adem (1977) and Abd El-Moeim and Cocks (1986), providing evidence for this argument.

As already shown by Stephenson and Mitchell's (1993) work, the removal of volunteer grasses from an annual pasture can have secondary implications such as the proliferation of broadleaf weeds (Panetta and Randall 1990; Dowling and Wong 1993). In order for the legume production to be maximised when grasses are removed, broadleaf weeds need to be minimised with selective herbicides or 'spray grazing'. Spray grazing is a technique which combines sub lethal herbicide rates (usually hormone sprays) and high grazing pressure to force livestock to eat the affected broadleaf weeds (Lee 1994).

The intake of nutrients is the most important factor determining the production of grazing animals and this is influenced by the amount of pasture on offer and the nutritive value (concentration of nutrients, digestibility and metabolisable energy) of the pasture. In general, green feed in late autumn /winter is of high quality but by spring the grazing animals are presented with a mix of high quality new growth, and lower quality ageing, or senescent or dead material (Doyle *et al.* 1993). If the main purpose of the annual pasture is to produce high quality grazing forage then the most important indicator of quality is the resultant performance of the livestock. Grasses may have an important role in early winter when pasture availability and growth rates are low. Davies and Greenwood (1972) and Smith *et al.* (1972) demonstrated that grass swards do not have to produce as much DM as subclover for sheep to maintain critical liveweight. However, the type of grass can alter this result, with Wimmera ryegrass being superior to silver grass (*Vulpia* spp.) in the experiment by Smith *et al.* (1972). This is likely to be the result of the feeding value and grazing accessibility of the grass being higher than the clover in winter (Purser 1980). Davies and Greenwood's experiment did however conclude that despite the lower availability of grass-dominant pasture required for maintenance, there was greater sheep liveweight gain and wool production in the end on clover-dominant pastures. This agreed with the findings of Gallagher *et al.* (1966) which showed that sheep grazing only perennial grasses, compared to grass+perennial white clover, had lower live-weight gain, final live weight and clean wool production. Their conclusion was that clover content was the main factor influencing level of liveweight and associated wool production, most likely due to the higher nutritive value of clover.

The digestibility of annual plant components declines with progression through flowering to seed set and senescence (Doyle *et al.* 1993). Along with this decline is a comparable decline in the levels of the essential nutrients (Doyle *et al.* 1990). The annual grasses also provide residual dry matter after senescence of the pasture, albeit low in quality due to poor digestibility (McIvor and Smith 1973; Stewart 1981; Pearce *et al.* 1987; Ballard *et al.* 1990). The use of paraquat (Dowling 1988) or glyphosate (Jones *et al.* 1984) in spray topping or hay freezing techniques can be useful in preserving the nutritive value of these grasses for longer (Arnold and Barrett 1974). The conclusions from studies undertaken with paraquat is that spraying the grasses at heading results in higher concentrations of nitrogen, phosphorous, potassium and sulphur along with an increase in “in vitro” digestibility. (Pullman and Allden 1971; Barret *et al.* 1973; Arnold and Barret 1974). The resulting nutrient preserved grass/legume mix allows livestock to maintain or improve liveweight and in the case of sheep, wool growth (Arnold and Barrett 1974). Similarly Davidson *et al.* (1988) found that application of glyphosate increased digestibility but reduced dry matter yield. Arnold *et al.* (1970) also found that changing the composition of pastures from 55:45 to 25:75 grass/clover with paraquat improved the nitrogen and phosphorous concentration of the mix by more than 50%. This allowed merino wethers to maintain their bodyweight into the first two months of summer while the control plots lost 4kg/head. The problem was that the feed supply on the sprayed plots was completely utilised and by the end of summer there was no difference between treatments. This highlights the fact there are very few ways of maintaining sheep growth rates over summer without the use of supplementary feeding. Continuing with the reduced grass theory, Little *et al.* (1992; 1993) confirmed the importance of stopping grass seed set before summer to reduce the negative impact of grass seeds on sheep production, particularly prime lambs (see section 2.3.2.1).

The conclusion from the above review is that the grass component of grazed pastures is of less importance in determining quantity and quality than the legume component. There is however evidence to suggest that grasses can enhance the capacity to provide early grazing in winter when legume growth is slow and thus allow the introduction of grazing onto the pasture earlier.

2.3.2 Effects on Animal Health

The various components of pasture can affect the health of ruminants through their nutritional quality, quantity, the presence of toxins or other anti-nutritive factors and the presence of injurious seeds or awns (Giesecke 1990). Providing a balanced diet of both gramineous and legume pasture species can reduce the risk of animal health problems associated with grazing high legume content pastures. The effect on animal health of the addition or exclusion of annual grasses from pastures is often minimal and mainly depends on the grass species in question. However, grasses are generally better adapted to grazing and develop fewer metabolites that are harmful to stock than legumes (Culvenor 1970). If grazing animals are subjected to only one type of pasture plant then they are forced to obtain their entire nutritional requirements from that species. The pasture plant must therefore have an appropriate level of protein, energy, fibre and essential major and minor elements in the correct proportions, to satisfy the requirements of the grazing animal. Pure legume stands can have difficulty providing all these requirements due to their composition and growth patterns as well as their inability to extract some trace elements from the soil. Examples are soils low in selenium and cobalt (a component of vitamin B12) where ill thrift can occur on rapidly growing clover pastures (Giesecke 1990).

2.3.2.1 Animal health problems resulting from grasses in the pastures

Annual ryegrass toxicity (ARGT): Annual ryegrass toxicity is a serious disease that affects grazing ruminants causing livestock deaths, poor conception rates and the inability to utilise pasture or hay made from infected stands. Stock become infected by the ingestion of glycolipid toxins, known as corynetoxins, which are produced from *Clavibacter* spp. bacteria that colonise the seed galls of a nematode *Anguina funesta* in the developing ovary of annual rye-grass and possibly *Avena* spp. (Chatel *et al* 1979; Riley 1987). The effects of the toxin is cumulative (Jago and Culvenor 1987) hence the main strategy of control is to limit the intake of the toxin. The only sure method in pastures known to have rye-grass plants infected is to stop the grass setting seed (Trotman 1979).

Injury/contamination from grass seeds: The awned caryopses of barley grass, brome grass and silver grass can seriously injure livestock, especially sheep, by lodging in their feet, ears, eyes and mouths, and can penetrate the skin (Thomas 1986; Leys 1990). In bad cases deaths can occur but loss of liveweight due to discomfort is more common. The awns of the same three species also contaminate wool and reduce its yield (Thomas 1986; Sinclair 1991). Little *et al.* (1992) showed that barley grass seeds reduced the growth rate of lambs by 6.2 kg/hd over a 63 day period and there was a downgrading of the value of the carcass.

2.3.2.2 Animal health problems resulting from grass removal from the pastures

The removal of annual grasses reduces the incidence of ARGT and the problems associated with grazing the awned grasses but these problems can be replaced by new diseases. The diseases are generally a result of a high protein/low fibre diet, the majority of them occur during periods of rapid pasture growth, and mainly affect young sheep (Singh and Tuckwell 1989).

Coumestrol: Medics can contain oestrogenic coumestans similar to the high levels of phyto-oestrogens found in cultivars of subclover (Lloyd Davies and Dudzinski 1965) which caused partial or permanent infertility problems with grazing ewes (Francis and Millington 1965). The problem has been reported with the perennial *Medicago sativa* (Coop and Clark 1960; Smith *et al.* 1979) but seems less prevalent with the annual medics. These coumestans are usually stimulated when the medic plant is under attack by insect pests, viruses, poor nutrition or fungal diseases. Increases in legume proportion in the pasture increase the levels of coumestrol while grasses and broad leaf weeds act to dilute the concentration in the pasture (Croker 1994).

Enterotoxaemia: This disease is caused by a bacterial toxin produced from *Clostridium perfringens* and is the result of lush feed containing little fibre (Hungerford 1975). It is easily controlled by a vaccination program.

Redgut: Redgut as diagnosed by Lenghaus (1987) is a sudden death syndrome of sheep grazing leguminous pastures. The disease has been recorded with the grazing of lucerne, Haifa White clover, Trikkala subclover, Paradana balansa clover and Paraggio barrel medic (Hindmarsh 1989). The sheep die from ammonia toxicity as a result of high protein intakes coupled with low fibre levels (Lenghaus 1987). To prevent the disease, fibre must be added to the diet either by straw (not always successful as it depends on the sheep eating enough) or increasing the grass content of the pasture (Singh and Tuckwell 1989).

Bloat: Bloat (ruminal tympany) is not a major problem but may occur when sheep are introduced to legume dominant pastures (Lloyd Davies 1987). Food intake and live weight gains may be severely reduced in sheep but cattle may die if precautions such as anti-bloat capsules are not used (Wheeler 1987). Bloat is the result of altering the rumen contents so as to cause a build up of foam, reducing gas emissions (Hungerford 1975). The problem can be avoided by feeding out hay before allowing sheep to enter legume dominant paddocks or putting sheep onto grassy paddocks (McLean 1973; Singh and Tuckwell 1989) and lengthening the interval between grazing (Haggar 1989).

Scouring and Illthrift: A sudden change onto lush green feed, such as legumes, results in a digestive upset which may result in scouring (McLean 1973; Hungerford 1975). The loss of the intestinal contents may reduce the normal absorption of feed constituents, resulting in illthrift (Singh and Tuckwell 1989). The solution to the problem is early provision of roughage in the form of grasses or hay. However, success depends on the livestock actually eating the roughage.

2.3.3 Nitrogen Input in Grass-Legume Mixtures

The ability of the annual legumes to fix atmospheric nitrogen is well known (Robson and Abbott 1987), however, to maximise the nitrogen contribution to the farming system the legume must be growing and fixing N_2 at an optimal level. Factors that affect the total N input into the system include the proportion of legume content in the pasture, legume dry matter production, percentage nitrogen content of the legume, efficiency of N fixation and the nitrogen losses due to grazing (Simpson 1987; Thorn 1992). Most of this nitrogen is stored in the soil as either mineral or organic N. Legumes however, compete poorly with grasses and forbs for nutrients and water and may suffer a growth disadvantage even though they are capable of supplying their own nitrogen (Simpson 1987; Thorn 1992). The amount of N fixed per unit area, is approximately proportional to the legume dry matter produced (Butler and Ladd 1985a) and thus a reduction in legume growth from grass competition reduces the amount of nitrogen fixed (Evans 1994). The superior competitive ability of grasses can also decrease the efficiency of N_2 fixation more than the equivalent reduction in legume dry matter (Butler 1990). Butler (1988) found in a mixture of *Medicago littoralis* and perennial ryegrass grown in field microplots that increasing the proportion of ryegrass decreased the amount of N fixed by the medic, due to competition from the ryegrass and slowing of the medic growth. Other experiments have shown that association with grass has the effect of either decreasing or increasing the proportion of N_2 fixed by *Medicago* spp. depending on whether competition or reduction in available soil N is the dominant effect (West and Wedin 1985; Butler and Ladd 1985a). The competition from grasses is therefore a complex association between available soil N levels and the relative proportions of the legume and grass. Butler and Ladd (1985b) suggest that grass competition will always increase the proportion of fixed N to soil-derived N in the legume as the grass will reduce the amount of soil N available for the legume. Butler (1987) showed that when medic was grown with ryegrass, the medic fixed more N (total N) than when grown alone but only when the plants were regularly defoliated, presumably reducing the competition for light. Hence the proportion of legume N from fixation can increase when grasses are grown in competition with the legume. However, total legume N is decreased due to competition from the grass which has a dominant effect on legume dry matter production (Philips and Bennett 1978; Butler and Ladd 1985b). Grazing of a grass-medic mixture is likely to have two effects: (1) reduced nitrogen fixation by limiting the supply of carbohydrate to nodules due to loss of photosynthetic capacity, (2) decreased competition for light between the grass and legume, which would normally favour the legume, thereby increasing N fixation (Butler 1990). However, grazing animals return a proportion of ingested N to the pasture as urea which stimulates grass growth (Simpson 1987), in patches where it is voided.

Not only is nitrogen fixation of the legume reduced by the competitive effects of the grass but the grass also removes soil N during its growth (Leys 1990). Legume nitrogen is therefore not available until it is returned to the soil either through the grazing animal or by decomposition of residues (Haystead 1982; Ladd 1992). If the grass and legume are grazed then some nitrogen is also lost from the system in the meat, wool and milk products of the grazing animal (Simpson 1987; Butler 1990).

2.3.4 Effect on Cereal Root Diseases

A driving force for the removal of the annual grasses from the farming system has been the realisation of their role in acting as alternative hosts for the major cereal root diseases. The three major diseases are Cereal Cyst Nematode (*Heterodera avenae*), take-all (*Gaeumannomyces graminis* var. *tritici*) and Rhizoctonia (*Rhizoctonia solani*).

Cereal cyst nematode: The major host plants of this pathogen are the roots of volunteer susceptible cereals and wild oats (Meagher and Brown 1974). The ecology of the nematode is such that 85% of eggs hatch each year (Brown 1973); hence the most important means of controlling the pathogen is to have two years of non host plants before sowing a susceptible cereal.

Take-all: All research has shown a positive correlation between the annual grass content in preceding pastures and the incidence of take-all in the subsequent cereal crop

(MacNish and Nicholas 1987; Cotterill and Sivasithamparam 1988b). The elimination of annual grasses in the year preceding the crop is an insurance against the disease which can otherwise cause average annual yield losses in wheat of 29% (Roget and Rovira 1991). The most important consideration is the early removal of these grasses before the end of July after which rising soil temperatures together with Spring rainfall (should it occur) accelerates the growth of the fungus (Roget and Rovira 1991). Wong *et al.* (1993) confirmed these results showing that preseason weed management was critical in the reduction of take-all in following wheat crops. Inwood *et al.* (1991) and Inwood and Roget (1993) have also ranked in descending order the annual grasses which accentuate the disease; barley grass > brome grass > annual rye-grass > silver grass. Importantly oats are resistant to all but one strain of take-all (McEwen *et al.* 1990) with Cotterill and Sivasithamparam (1988a) even reporting suppressed hyphal growth of the take-all pathogen under an oat crop.

Rhizoctonia: Even though rhizoctonia has a wide host range the early rain establishment of annual grasses provides an ideal root system to attack and colonise, allowing the disease to increase in severity over the season (Roget 1988). Cultivation is the most appropriate method of control of this disease. This appears to be because the propagules of *Rhizoctonia* spp. are associated with soil organic matter which if fragmented reduces the propagule size and severity of pathogenicity of the hyphae (Rovira 1986). Meagher and Chambers (1971) also showed that *Heterodera avenae* in combination with *Rhizoctonia solani* produced significantly more damage than as individuals alone, suggesting that the control of CCN may also be important in reducing rhizoctonia, particularly as rhizoctonia has such a large host range and there are no known break crops.

2.3.5 Effect on Soil

Soil structure: The annual grasses with the exception of *Vulpia* spp. have been reported to have a deeper and denser root system (Ozanne *et al.* 1965) than the annual legumes, which frequently have the majority of their roots in the top 20 cm (Hamblin and Hamblin 1985). The greater root mass of these grasses results in higher levels of soil organic matter, with the root system and surface residues protecting the soil from erosion. Tisdall (1990) also reports that structural stability of soils is increased under grasses more quickly than under legumes. The reasons cited are that grasses produce more roots than legumes and also increase the amount of water-soluble material and mucilage available to the soil. Presumably this improves structure by increasing the organic matter availability.

The reduced plant cover and reduction in fibrous root systems in winter when grasses are removed, if not replaced with adequate pasture legumes, can also make the soil more susceptible to compaction by stock. The effect is more pronounced in the heavy textured soils and in higher rainfall regions where the soil is wet and exposed (Lee 1994).

Soil Acidification: Leaching of nitrate mineralised from nitrogen fixed by pasture legumes is a major contributor to soil acidification (Helyar and Porter 1989; Helyar 1992). Nitrate leaching is often greatest in the early part of the growing season, when the pastures have small and shallow root systems (Helyar 1992). Grasses have a natural advantage over legumes at the beginning of the growing season in their ability to establish quickly and provide a root system capable of absorbing some of the nitrate before it is leached down the soil profile (Butler 1990). The decomposition of dead grass roots immobilises more nitrogen than legume roots and less nitrate is liberated from the dead residues of grass roots than legume roots and nodules (Oram 1990). In winter the depth of rooting of the annual pastures, and the density of the roots in the deeper soil layers is the most important determinant of nitrate and cation capture (Oram 1990). The shallow rooting nature and reduced root density of annual legumes reduces their ability to perform this task (Ozanne *et al.* 1965; Hamblin and Hamblin 1985). In grass-free pastures these abilities to reduce nitrate leaching are lost and higher levels of nitrate will be added to the soil both in the year of the pasture and later through decomposition of the nitrogen enriched legume residues.

Due to the high buffering capacity of the soil the incidence of acidification is unlikely to be a problem in the low rainfall highly alkaline regions where medics are grown. The problem is of considerable importance in the higher rainfall regions where a neutral to low pH is already inherent in the soils. In these areas the use of lime to ameliorate soil acidity will be of vital importance (Helyar 1992).

2.3.6 Invasion by Broadleaf Weeds

The effect of grass removal is to eliminate an aggressive competitor within the pasture species complex. This creates a niche for broad-leaved weeds to exploit if legume density is not sufficiently high to compensate (Leys 1990). Dowling and Wong (1993) noted this in their rotation experiment, the broadleaf component varying inversely with annual grass percentage. Panetta and Randall (1990) also measured an increase in the invasion by three corner jack (*Emex australis*), under grazing, when barley grass was removed. In a grazing experiment examining the effects of removing barley grass from subterranean clover Stephenson and Mitchell (1993) measured an increase in Indian hedge mustard after grass removal and noted this as a potential problem in early grass removal pasture systems. It is also common for the proliferation of nitrophilis broad-leaf weeds such as slender thistle (*Carduus pycnocephalus* L.), *C. tenuiflorus* Curtis, Scotch thistle (*Onopordum acanthium* L.), Capeweed (*Arctotheca calendula* L.) and long storksbill (*Erodium botrys* Cav. Bertol) at low stocking rates in nitrogen rich soils if grasses are removed (Puckridge and Carter 1980; Rossiter and Ozanne 1970). The effects of a broadleaf invasion are not always evident in the first year, Barret *et al.* (1973) noting an increase in the second year in the proportion of Capeweed after grass removal occurred in subclover pastures. The removal of the grass occurred with low rates of the non-selective herbicide paraquat, which may have also damaged the subclover temporarily favouring Capeweed productivity.

2.3.7 Annual Grasses as Competitors in Annual Pasture and Cereal Crops.

The annual grasses are serious competitors in both the pasture phase and cropping phase of a rotation because of their ability to set large amounts of seed with low innate dormancy (Gill 1996; Medd 1996). This ensures a large grass presence in both phases of the rotation. The use of grass selective herbicides within the annual pastures has been shown to increase the proportion of the legume. Venn (1984) showed an increase in medic proportion from 27 to 75% with the use of the grass selective herbicide fluazifop-butyl on barley grass in an ungrazed situation. Stephenson and Mitchell (1993) showed that a grass selective herbicide applied early could increase the proportion of subclover. The earlier this treatment was applied the greater the increase suggesting the effect of competition is most pronounced at the seedling stage of the legume which is in agreement with the work of Cocks and Donald (1973) on annual pastures. In competing against grass weeds the most important factor is legume density as shown initially by Willoughby (1954) in his experiments on ryegrass/subclover mixes. Leys *et al.* (1993) also concluded this in their work on reducing silvergrass (*Vulpia bromoides)* in subclover pastures. The review of the cultural methods of controlling *Vulpia* spp. by Michalk and Dowling (1996) ranked competitive pasture and crop species in the top two methods of *Vulpia* management. However, as pastures are in a dynamic system their experiments also showed that after three years the silvergrass returned no matter what the legume density, unless a companion grass such as ryegrass was also in the mixture. The effects can often be complicated by grazing when high stocking rates combined with selective grass removal interact to increase subclover proportions as in the experiment of Thorn and Perry (1987). In addition to the effects of grasses on legume density and dry matter production they also reduce nitrogen input by the legume as previously reviewed in section 2.3.3. Experiments such as the above confirm the poor ability of the annual legumes to compete against particular grasses on their own.

The effect of competition is also relevant to the following cereal crops. This effect has been studied most intensively with annual ryegrass but some information also exists for the other annual grasses. Small increases in densities of ryegrass can reduce crop yield significantly (Perry *et al.* 1980). Reeves (1976) reported a consistent relationship between ryegrass density and yield loss in wheat. High densities of ryegrass have been shown to compete with wheat for nitrogen as early as the two-and-a-half leaf stage (Smith and Levick 1974; Forcella 1984). Perhaps the best example of the effect of ryegrass on southern Australian farming systems was described by Trenbath (2001) in which a modelling exercise highlighted the positive and negative factors that ryegrass can have on crop-pasture situations. The results of this modelling showed that the competitive effects in crop phases was such that it would eventually cause the rotation to become non-viable even if the pasture phase had improved productivity and increased sheep production. Great brome grass (*Bromus diandrus*) has been shown to have similar competitive ability for nitrogen and phosphorous when grown with wheat, resulting in reduced tiller number, biomass and grain yield (Gill and Blacklow 1984). Wild oats ranks perhaps even higher as a weed in winter cereals due to its ability to persist from year to year and its highly competitive nature (Medd and Pandey 1990; Carlson and Hill

1985). Importantly stopping grass seed set the year before sowing a cereal has shown to be highly effective in minimising the impact on subsequent cereal yield (Reeves and Smith 1975).

2.4 METHODS OF GRASS CONTROL IN ANNUAL LEGUME PASTURES

2.4.1 Agronomic Management to Control Annual Grasses

Maximising Legume Content: Selection of appropriate legume species and cultivars is essential for the replacement of annual grasses. Carter *et al.* (1982) suggest mixtures of species and cultivars of varying maturity to exploit both differences in soil types and seasonal variation. The aim is to maintain persistence of the legume at a high density from year to year so that it is able to compete against both grasses and broad leaf weeds. In order to achieve this, sufficient seed reserves are required (Carter 1981, Carter and Cochrane 1985; Dear and Loveland 1985).

Rotations and Soil Fertility: Both the length of rotation and level of soil fertility can influence the level of grass in pastures. The grass component will tend to increase with time as soil nitrogen levels increase (Medd *et al.* 1987). The composition of these grasses may also change with time; as the pasture ages ryegrass may give way to an increase in barley grass and *Vulpia* spp. (McGowan 1967; FitzGerald 1976). Rossiter (1966) also reported species such as brome grass and barley grass favouring high phosphorous levels while *Vulpia* spp. dominated at low P levels. Increased P levels also improve legume growth providing both competition and nitrogen for grasses (Thorn 1985). Adjusting the rotational sequence will influence the fertility of the soil and hence influence both grass density and composition.

2.4.2 Grazing Management to Control Annual Grasses

Grazing pressure can have a significant effect on grass content in pastures both in the year of grazing and the years following. Rossiter (1966) and Carter (1987) have both commented in their reviews that low grazing pressure can induce grass dominance while high grazing pressure will maintain legume dominance. Latta (1994) showed that increasing stocking rate of sheep to double the district average reduced the grass component in annual medic based pastures with a subsequent improvement in the legume component and increased wool production over two years. Sharkey *et al.* (1964) found that at low stocking rates Wimmera ryegrass dominated subclover-ryegrass pastures and that the effect became more pronounced over time. The predominant influence however was the consumption of subclover seed, either at maturity or over summer which is more attributable to inappropriate time of grazing as compared to an effect of stocking rate. Greenwood *et al.* (1967) and Lloyd Davies and Greenwood (1972) in their study of brome grass and subclover reported that at higher stocking rates (high 12 sheep/ha and low 8 sheep/ha), *Bromus mollis* density was reduced over time and required nitrogen fertiliser to persist with subclover. Similar results were reported by FitzGerald (1976) in a grazing experiment on subclover-based pastures with two stocking rates (high 12.3 sheep/ha and low 8.1 sheep/ha). At the high stocking rate subclover tended to dominate and quickly eliminate ryegrass. There were also differences in the botanical composition of the grasses with barley grass invading the pastures and dominating at the low stocking rate and silver grass at the high. It is known that sheep grazing after grass heading will selectively remove legumes and ryegrass in preference to the less palatable barley grass and *Vulpia* spp. (Carter 1990; Leys 1990). Curtis *et al.* (1989) using three stocking rates on subclover-grass (*Bromus*, *Hordeum*, *Lolium* and *Vulpia* spp.) pastures also concluded that as stocking rate increased, the grass component tended to disappear more rapidly than other components of the pasture, suggesting that grazing sheep select the grass component first. Carter (1968) and Carter and Lake (1985) supported this result, with increases in stocking rates from 7.4 sheep/ha to 22.2 sheep/ha reducing barley grass seasonal production from 2466 to 312 kg/ha respectively. Corresponding reductions in grass seed production were also measured. Dunlop *et al.* (1984) using a comprehensive range of stocking rates from 5.9 to 16.3 sheep/ha showed that the percentage of subclover was increased slightly with increasing stocking rate but the main effect was the reduction in grass percentage, from 26% to 11% from the lowest to highest stocking rate.

These effects reported in annual pastures are also common in perennial grazing systems with Cameron and Cannon (1970) demonstrating the sensitivity of the botanical composition of perennial grass and subclover to grazing intensity over seven stocking rates. Carter and Day (1970) working with the same mixtures also reported a reduction in perennial ryegrass with increasing stocking rates (16.6 sheep/ha compared to 13.2 and 10 sheep/ha), both within years and between years. As the ryegrass decreased the proportion of subclover increased; however, other invasive weeds such as *Vulpia myuros*, *Bromus* spp., *Hordeum* spp. and *Arctothea caledula* also increased, often making up over half of the pasture yield.

There are conflicting views as to whether sheep select legumes in preference to grasses or vice versa. In both perennial and annual pastures lax grazing favours the taller-growing species (usually grasses) and heavy grazing the more prostrate species such as sown legumes (Carter 1990). This would suggest that under low stocking rates sheep actively seek the grass species. However, it is unclear whether this is because foraging of the grass is easier due to its erect growth habit (Jamieson and Hodgson 1979) or if palatability is the reason. In addition the removal of taller growing species such as grasses may also favour the prostrate species such as legumes due to the removal of shading. Animal preference for green grass and a negative selection for green legumes when grass is present have also been recorded in tropical situations (Humphreys 1991). Norton *et al.* (1990) found that sheep grazing a mixture of tropical legumes (*Desmodium intortum*, *Macroptilium atropurpureum* and *Macrotyloma axillaris*) and grasses (*Brachiaria decumbens* and *Paspalum plicatulum*) selected against the legume and had a high preference for grass. Conversely Curll *et al.* (1985) reported a strong preference for clover in the diet of sheep continuously grazing perennial ryegrass-white clover swards. Therefore grazing preference depends on both the species of grass and species of legume.

In general terms diet selection of sheep is influenced by (i) ease of eating which can be correlated with the particle length of the feed; (ii) sensory factors such as taste, texture and odour; (iii) water content of the herbage; (iv) sward architecture (Colebrook *et al.* 1990). In summary as sheep are selective grazing animals, low stocking rates will allow them to choose the species they prefer at the time based on the four points above. As stocking rate increases the ability of grazing animals to remain selective decreases due to the reduction of herbage per animal on offer. It is under these scenarios that the management of annual grasses may occur as the total height of the pasture is reduced relatively evenly allowing prostrate legumes to exploit the remaining space (for light etc).

2.4.3 Mechanical and Cultural Control Methods

Because of the increased incidence of herbicide resistance, non chemical methods of grass control have been regaining favour. These methods usually involve some sort of mechanical control of the grass but can be as simple as burning the surface seeds in summer before the pasture year (Matthews *et al.* 1996). The use of shallow cultivation in the autumn, to promote germination and emergence of grasses to be killed by cultivation or non selective herbicides has been a successful method of reducing grass populations before a pasture phase (Sykes *et al.* 1990; Davidson 1990). Mechanical topping using a slasher or cutting the pasture for hay or silage are also useful methods of stopping grass seed set (Smith *et al.* 1972; Reeves and Smith 1975). The effect of a reduced grass seed reserve is not apparent until the second year of pasture or later in the rotation as the control strategy is implemented after the plants have already competed with the crop or pasture.

2.4.4 Herbicides

The most consistent and effective form of grass removal and botanical composition manipulation occurs when herbicides are utilised on grass-legume pastures. Herbicide application in pastures has gained widespread use amongst some sectors of the farming community, mainly in cereal-pasture rotations where cereal production is to be optimised. Two methods are employed: early winter removal of grasses with grass selective herbicides and control of grass seed set with non selective herbicides in late spring - "spraytopping" or "hay freezing". The most widely adopted technique has been the "spraytopping" technique, as it is highly visible (desiccation of plants is obvious) and low cost with a lower adoption rate of grass selective herbicide use due mainly to cost and reduction (perceived or real) in winter dry matter.

Selective Herbicides: The ability to selectively remove annual grasses from pastures with minimal or no effect on annual legume growth was only made available with the introduction of the aryloxphenoxypropionate (AOPP) and cyclohexanedione (CHD) group of herbicides. Venn (1984), Wallace and Maling (1992) and Stephenson and Mitchell (1993) have all shown the highly selective nature of these herbicides with associated improvements in legume growth after early application due to reduced competition. There is a large selection of these herbicides, each with variations in their ability to control the various grass species, but none are currently registered to control *Vulpia* spp., winter grass (*Poa annua*) or Yorkshire fog (*Holcus lanatus*) (Leys 1990). The use of simazine and simazine/paraquat mixtures has been highly successful in controlling *Vulpia* spp. in subclover pastures and although these are not strictly selective herbicides, at the low rates used, activity is restricted to the annual grasses with minimal damage on subclover (Leys and Plater 1993; Mackereth *et al.* 1993; Stephenson *et al.* 1993; Wallace 1993). Although Dear *et al.* (1992) reported potential reductions in dry matter yield in subclover when increasing rates of simazine were used to try and control annual grasses, particularly *Vulpia* spp. Unfortunately the activity of this mixture has variable results when used on medic based pastures, with the possibility of unacceptable medic damage by rates required to obtain adequate grass control (Stephenson *et al.* 1993). Propyzamide and carbetimide are also alternatives to the AOPP and CHD herbicides and can control most grass species including *Vulpia* spp. and winter grass (Leys 1990). Dunlop and Thorn (1984) and Thorn and Perry (1987) successfully used propyzamide to control annual grasses in their experiments to compare grass-free and grassy pastures.

Selective grass herbicides are mainly used when a reduction in take-all and CCN is required, as their high cost compared to other grass control measures reduces their attractiveness for other purposes. The AOPP and CHD group of herbicides are in the high risk category of developing herbicide resistance (Powles and Mathews 1992) and thus their use is often reserved for in-crop situations where maximum economic benefit is gained. By limiting the exposure to in-crop situations the development of resistance to this chemistry is also delayed (Sykes *et al.* 1990). Methods of combating grass resistant escapes are centred on stopping the survivors setting seed and involve heavy follow-up grazing and spray topping with non-selective herbicides (see below). The use of grass selective herbicides in early winter requires a sufficiently high legume plant density to compensate for the loss of the grass in the pastures and to smother grass plants that survive or emerge after spraying (MacLeod and MacNish 1989).

Non-Selective Herbicides: The use of non-selective broad spectrum herbicides to control grass seed set at flowering is a highly effective method of reducing grass density in the following years of a rotation. The application of sub-lethal rates of paraquat, paraquat/diquat or glyphosate to the annual grasses at early seed set, stops seed development (Pratley 1988; MacLeod and MacNish 1989). To maximise the efficiency of this technique heavy grazing pressure and then spelling prior to spraying is important. This ensures that the seed heads of individual species are evenly developed i.e. concurrently, as the effects of the low rates of herbicides used are very growth stage sensitive. Differences in flowering synchrony between ecotypes and between seasons add to the variation in the level of control obtained (Leys 1990). The advantages of this technique are: low cost, reduced damage to the eyes of sheep, reduced vegetable matter in wool, increased palatability of forage (Thorn 1985) and reduced herbicide resistance potential (Matthews 1994). The management of *Vulpia* spp. still remains a major challenge with spray topping (Leys *et al.* 1991; Bowran and Wallace 1996) not providing adequate management over the long term (Dowling *et al.* 2000) although the benefits of using an integrated approach (Michalk and Dowling 1996) to provide adequate *Vulpia* control have clearly been shown (Vere *et al.* 2002).

While this can be an important tool for grass seed control the timing of the herbicide application is extremely important; should it coincide with flowering of the legume, the potential for reduced seed set is increased. The use of paraquat also appears to be less damaging to medic seed yields than glyphosate (Thorn 1985; Leys 1990). Latta (1994) demonstrated that glyphosate caused 100% loss of medic seed production when applied at grass anthesis. The effect carried over into the second year as reduced medic plant density and winter herbage production resulting from low seed production in the first year. The use of early flowering legume cultivars can reduce this loss of seed as a proportion of the seed has been set before the application of the herbicide. In addition the type of herbicides used can also have unintentional impacts on nitrogen fixation in annual legumes. Fajri *et al.* (1996) have shown that herbicides such as simazine/paraquat mixtures at the recommended rate and growth stage can have a greater impact than grass competition on subclover nodulation and fixation, reducing N inputs to the system.

In conclusion, there are a range of grass-control measures that can manipulate the percentage of grass in annual pastures. The most popular and successful of these has been the use of herbicides, with an extremely high adoption of the non-selective herbicide strategies.

2.4.5 Herbicide Resistance

The control of grass weeds both in crops and pasture has been revolutionised with the advent of herbicides. Herbicide technology to control grasses has rapidly advanced from the broad spectrum non-selective knockdown type herbicides (e.g. glyphosate, paraquat) to the more selective in-crop type herbicides (e.g. diclofop-methyl) (Matthews 1994).

These grass selective herbicides are popular for early removal of grasses from pastures as they are highly effective against the majority of volunteer annual grasses, *Vulpia* spp. excepted. These herbicides have been so successful that other forms of control have often been neglected and almost complete reliance has been placed on herbicide control of grass weeds in all phase of the rotation. The result has been massive selection pressure for annual grasses that are resistant to many of the herbicides applied. Confirmed herbicide resistance to at least one herbicide group has been reported in each of annual ryegrass (Heap and Knight 1986), wild oats (Morrison *et al.* 1992), barley grass spp. (Powles 1986; Tucker and Powles 1991) and *Vulpia bromoides* (Purba *et al.* 1993). The major concern is that these grasses have developed resistance and cross resistance in the herbicide groups aryloxphenoxypropionate, cyclohexanedione, sulfonylurea, triazine and dinitroaniline, which are among the most useful for selective grass control in both crops and pastures (Powles and Holtum 1990).

With the increase in grass selective herbicide resistance, the ability to maintain legume dominant pastures with these herbicides will become increasingly difficult. Importantly if resistant grass escapes (following spraying) are not stopped from setting seed then the use of grass selective herbicides in the pasture phase will increase herbicide resistance. The most common method to combat this problem is heavy grazing or spraytopping (see section 2.4.4) in pastures that have had the non-resistant grasses removed selectively (Davidson 1990; Sykes *et al.* 1990; Powles and Matthews 1992). Integrated weed management using as many non chemical control options as possible throughout the rotation will help to delay the advent of herbicide resistance. Matthews (1996) outlined many of these methods including cultivation, burning, time of sowing, crop density, competitive crops, green manuring and seed catching.

In conclusion the desired end use of the pasture is the most important consideration in determining pasture quality. If the purpose of the pasture is to act as a source of biologically fixed nitrogen, to improve soil organic matter, provide a higher degree of ground cover and act as a disease break, then a legume dominant grass-free pasture would be considered a high quality pasture. This pasture should also optimise cereal production. However a livestock producer who wishes to optimise livestock growth and quality may prefer a pasture that had a combination of both grasses and legumes. Herein lies the dilemma for mixed livestock-crop producers, which enterprise to optimise if both cannot be satisfied from the one pasture? Later in this literature review it will be shown how increasingly difficult it becomes to satisfy both livestock and cereal enterprises with the same volunteer annual grass-legume pasture.

2.5 GRASS-ANNUAL LEGUME MIXTURES

2.5.1 Competition between Annual Grasses and Legumes

Grass-legume associations have been used extensively throughout the world to increase total herbage yield compared to monoculture swards, particularly when no additional nitrogen fertiliser has been applied (Haynes 1980). This section of the review therefore examines the competitive relationships between grasses and legumes and considers pasture management techniques that alter the balance of legumes and grasses with an emphasis on competitive advantage for the legume. It is generally accepted that grasses supplied with adequate N normally have a competitive advantage over legumes and therefore tend to dominate pastures, but in order to maintain high pasture productivity, a balance between grasses and legumes is desirable (Haynes 1980). It is important to define the term competition as it applies to plants. Haynes (1980) suggests that plants are not competing so long as they do not have to compete for water, oxygen, nutrients, or CO_2 and there is adequate light and heat for both plants. The more similar the needs of the two plants the more intense the competition hence intraspecific competition is generally thought to be more intense than interspecific competition (Haynes 1980). Competition itself is only one facet of interference between plants although Harper (1977) suggests it may be an extremely dominating one. Non-competitive interferences may be the direct stimulation of one species by another such as nitrogen fixed by a legume which then becomes available for use by a non legume (Haynes 1980). Studies by De Wit *et al* (1966) found that in treatments where nitrogen fixation was precluded (no *rhizobium*) from the legume in a grass-legume association, there was no yield benefit from the association and the legume was a poor competitor. However in treatments where the legume was allowed to fix nitrogen (+*rhizobium*) the yield benefit became apparent and the legume was more competitive. Legumes in association with grasses would appear to require higher light intensities than grasses for maximum growth rates. The review by Donald (1963) clearly showed the density/yield relationship for monoculture subclover and other plants. When resources are non limiting, and clover plant density is increased, intraspecific competition is mainly for light. However, the addition of a grass to clover can greatly alter this relationship. The studies by Stern and Donald (1962a; 1962b) showed that conferring a competitive advantage to a grass via the addition of nitrogen allowed the grass to shade the subclover. This competitive disadvantage is caused because pasture grasses are often taller and have a faster growth rate, allowing them to shade out the legumes by reducing light availability. Further supporting this is Trenbath's (1974) review of past studies in which he concluded that the plant with its leaf area higher in the canopy is at an advantage. Hence the need for defoliation of the canopy in grass/legume mixtures to maintain the legume component (Haynes 1980).

Plant rooting structure may also play a significant role in competition between grasses and legumes. Often legumes have a prominent taproot (e.g. lucerne) which allows them to utilise water and nutrients at a greater depth than grasses, supposedly conferring an advantage (Sheaffer 1989). Legumes are also less competitive than grasses for potassium. Such competitiveness has been associated with the greater fibrous root mass and volume as well as larger root exchange capacity of the grasses (Haynes 1980). It is, however, unclear whether these same results also apply to annual legumes that have a more fibrous rooting structure (such as annual medics) rather than a distinctive taproot. It may simply be that the annuals are short lived and do not require a well developed taproot.

In addition grasses and cereals have their growing points close to the ground which allows them some degree of protection from adverse climatic conditions and intense grazing (Haynes 1980). In contrast the annual legume's main form of defence is its prostrate growth pattern, significantly below the competing grass, making it less susceptible to grazing unless selectively targeted.

The advantage that justifies the growing of a mixture has commonly been thought to be a higher yield from the mixture than from an equal area divided between monocultures of the components in the same proportion as that in which they occur in the mixture (Trenbath 1974).

Haynes (1980) in his review alluded to the topic of allelopathy which is seldom addressed by most researchers in their work on grass-legume competition. Some plants liberate chemical retardants from their roots and shoots into the surrounding environment which may have a deleterious effect on other plant's growth. This effect has also been recorded in various grass-legume mixtures (Peters and Zam 1981; Cope 1982; Leigh *et al.* 1995). Halsall *et al.* (1995) found that extracts from a range of legumes, grasses, cereals, broad-leaved weeds and oilseeds exerted allelopathic effects on *Trifolium* spp. including subclover and *Medicago* spp. including *M. truncatula, M. polymorpha* and *M. littoralis*. The effects included reductions in germination, shoot and root growth and nodulation. The lack of research involving both competition studies and allelopathy may be due to the complex nature of the work being undertaken. Rarely would an individual researcher or research team possess the skills required in both the fields of allelopathy and competition; hence the possible interactions are ignored.

Pasture plants obtain their nitrogen from either mineral N derived from soil mineralisation of organic N, or from the air by symbiotic rhizobia of nodulated legumes (Haynes 1980). The nitrogen fixing ability of the legume can be extremely important in determining pasture botanical composition as influenced by competition for nitrogen. The legume has the ability to increase the supply of available nitrogen in the root zone by symbiotic fixation as well as to compete for nitrogen that is already available (Simpson 1965). Since this balance in grass-legume swards can be easily altered by the application of nitrogen, it seems pertinent to discuss such an important topic.

2.5.2 Nitrogen Transfer from Legume to Grass

The previous sections 2.3.1 and 2.5.1 demonstrated that pasture productivity can be improved when legumes and grasses are grown together in mixtures as opposed to monocultures. A key factor is the nitrogen input into the system derived from biological nitrogen fixation (Barea *et al.* 1988). The issue of biologically fixed nitrogen transfer from legume to grass is important when discussing competition within grass-legume mixtures. As the legume is normally part of a N-supplying symbiosis, N availability in the grass-legume mixture is affected by, and in turn affects, the competition between the legume and grass components (Simpson 1987). The nitrogen allows the legume to sustain its growth but part of this nitrogen can be transferred from the legume to the grass (Haynes 1980; Weaver 1988). Legume nitrogen can be transferred to associated grasses in two ways; (1) direct transfer from legume plants within the mixture or (2) indirectly after a period of decomposition of legume residues. However, in practice both methods may be occurring concurrently (Simpson 1987). Vallis (1978) gave an excellent review of nitrogen relationships in grass/legume mixtures. A large number of the examples used were associated with subclover, M. *sativa*, or tropical grass/legume associations. Through these examples he summarised some important findings that are not commonly discussed in other literature. These include the concept of legumes actually competing for N themselves until their own N *rhizobium*/symbiotic relationship provides enough N. Of particular importance was the discussion of mineral N supply on symbiotic fixation and both the positive and negative effects associated with having the correct *rhizobium* strains. Often overlooked in later literature is the positive effect that small quantities of 'starter' N can have on nitrogen fixation, particularly between the exhaustion of seed N reserves and the establishment of an effective N-fixing system.

With regard to the direct transfer of N from legume to grass, the literature appears to be unclear as to the method and quantity of nitrogen transferred. It would appear that legume species and cultivars differ in their ability to transfer nitrogen directly (Laidlaw *et al.* 1996) and that they are also affected by the growing environment and management of the legume-grass mixture. Most research has been conducted using perennial clovers or lucerne and it is unclear how applicable these results are to annual legumes. There is also the question of the methodology used to detect nitrogen transfer. The most common method employed is the application of labelled ^{15}N isotopes or the total nitrogen difference method. The advantages and disadvantages of these methods have been reviewed and discussed by Witty (1983), Hardenson *et al.* (1984), Chalk (1985) and Danso (1986). Their conclusion was that the labelling of ^{15}N enriched material was the only direct method suitable to distinguish between the relative contributions of nitrogen sources: soil, fertilizer and atmospheric nitrogen to the grass. Chalk (1985) did however suggest that inaccuracies with the method could occur if the isotope was not distributed to the plant roots through the soil in an even manner by effective mixing of the isotope throughout the soil profile. Mycorrhiza may also play a significant role in facilitating nitrogen transfer from legumes to grasses.

Direct N Transfer: Wacquant *et al.* (1989) conducted a unique hydroponics experiment which showed that nitrogen could be excreted from legumes and captured and utilised by an associated grass species in the same solution. While the concept was not new the degree of accuracy in measuring direct transfer perhaps was. The conditions used in this experiment were however far removed from a pasture grown in real field conditions. As such it is not surprising that the associated grass species utilised the N excreted from the legume when no other sources were available. Measurement in soil is much more complex and less accurate. Dubach and Russelle (1994) concluded that legumes could transfer significant amounts of symbiotically fixed N to neighbouring plants through the decomposition of fine roots and nodules. However, apart from artificial research similar to Wacqant *et al.* (1989), it is unclear from many researchers' articles and reviews whether the transfer of N from legume to grass is occurring directly in the growing period or whether a lag time is required. Weaver (1988) gave a brief review of several research results with various clovers and grasses confirming that N transfer can be quite variable and is related to the amount of nitrogen fixed by the legume.

Simpson's (1965) early work in pots examining nitrogen transfer from subclover, white clover or lucerne to cocksfoot was inconclusive suggesting that only lucerne had the ability to directly transfer nitrogen through direct excretion of N to the grass. The results were inconclusive as the experiment could not determine if the N transfer from lucerne was due to shedding or decay of nodules induced by defoliation or due to direct excretion of N from the intact root system. However in a later field experiment, utilising the same three legumes Simpson (1976) demonstrated that subclover was transferring 20% of its fixed N_2 to the grass. While Simpson used two perennials and the annual subterranean clover, there has been little work to confirm these results with an annual *Medicago* plant. A possible problem with Simpson's pot experiment is that it was conducted with low inherent soil nitrogen suitable for the experiment but probably not applicable to field conditions. It is possible that under higher initial soil nitrogen levels the legumes may actually excrete some fixed nitrogen throughout the growing season or are unable to utilise the soil N (Doughton and MacKenzie 1984). It could be that the negative feed-back mechanism of reducing symbiotic fixation under higher soil nitrogen levels is not as efficient or effective as it could be. Hence the legumes over compensate by producing more nitrogen than they require and the excess is excreted from the root nodules. It is possible that at very low soil nitrogen levels all the nitrogen fixed symbiotically is utilised by the legume plants with no measurable levels of nitrogen left over to be transferred to the grasses. At higher soil nitrogen levels this may not be the case, with some nitrogen excreted in excess. Since it is rare for symbiotic N_2 fixation to supply all the demand for N by the legume plant (see chapter 6), at low soil nitrogen levels the legume utilises all nitrogen that is fixed leaving none to be excreted.

Dahmane and Graham (1981) went further in a pot experiment using ryegrass and medic to examine the growth and N fixation of the monocultures and mixed swards under a range of phosphorous levels. Their results showed that ryegrass benefited from growing in a mixture with the medic, producing similar dry matter per pot to the monocultures, although having only half as many ryegrass plants per plot. Their conclusion was that either reduced interspecific competition was offered by the medic or there was a transfer of N from the medic to ryegrass. While higher N percentage was measured in the ryegrass plants grown in mixture the total N on a per pot basis was similar to the monoculture once again providing an inconclusive result. However the research of Burity *et al.* (1989) supports the concept of direct transfer as they estimated that 20 kg N/ha was transferred from lucerne to grass when grown in mixtures over two regrowth harvests in their experiment.

Indirect Transfer: The methods of indirect transfer of N are usually through animal ingestion and excretion back onto a different area of pasture or simply from ungrazed pasture residues decomposing to provide plant available nitrogen (Simpson 1987). Due to the random nature of animal excretion this form of N transfer is uneven with nitrogen deposition often concentrated around animal campsites (Hilder 1964). Large losses in original plant N to the atmosphere are also common (Denmead *et al.* 1974) and animal excretion appears to be an inefficient N cycling system (Ball and Ryden 1984).

The Role of Mycorrhiza: It is unclear as to the role vesicular-arbuscular mycorrhiza (VAM) have in transferring N, in terms of legumes to grasses. Although it would appear that N transfer is facilitated or enhanced by the presence of fungi (Haystead *et al* 1988), it is unlikely to be a direct effect of the VAM (Hamel *et al* 1991; Hamel *et al.* 1992). Using experimental techniques designed to examine the direct effect of VAM on nitrogen transfer, Frey and Schuepp (1992; 1993) concluded that nitrogen transfer was possible and enhanced with VAM. However the amounts were very low, 4.7% from berseem clover to apple and less than 0.1% from berseem to maize. One of the reasons that grasses have a competitive advantage over legumes is their superior ability to take up phosphate (Barea *et al.* 1988). However, the presence of VAM in grass-clover swards has been found to confer a competitive advantage to the legume by improving the legume's phosphorous nutrition (Haynes 1980). This occurs because legumes are more mycotrophic (need to be colonized by VAM) than grasses and the imbalance in phosphorous uptake can be compensated for with VAM enhancing legume nodulation and N_2-fixation (Barea *et al.* 1988). Mycorrhizal hyphae can also absorb and translocate $^{15}NH_4$ from the soil to root cells (Barea *et al.* 1988) and facilitate transfer between plants (Van Kessel *et al.* 1985; Francis *et al.* 1986).

Ledgard and Steele (1990) summarised biological nitrogen fixation in mixed legume/grass pastures as a highly dynamic system where differences in legume growth potential, inorganic soil N level and grass competitiveness regulate the amount of N fixed and transferred. Many stresses that are superimposed on this such as defoliation, environmental stress, pests and diseases will also alter the dynamics of this system.

2.5.3 Oat-Medic Mixtures

The literature available on cereal/legume mixtures is quite extensive, particularly regarding mixtures of grain crops (intercropping). However, there are few studies specifically on oat/medic mixtures. The use of sown oats as early grazing fodder has been practiced for many decades and the productivity of this forage has been measured by several researchers across the world including Crowder *et al.* (1955), Wheeler (1963), Kemp (1974), McDonald and Wilson (1980) and Hughes and Haslemore (1984). In the study conducted by Kemp (1974) in northern NSW, sown oats out-yielded sown Wimmera ryegrass at a range of nitrogen levels and was able to be grazed two weeks earlier, confirming the usefulness of oats as an early fodder species. Of the studies conducted with oats and annual legumes the majority of measurements have examined productivity and methods of improving this productivity such as Poole and Gartrell (1970), Brownlee and Scott (1974) and Bolland (1987).

Sowing ratios: In grass-legume mixtures, adjustments to the sowing ratio can affect botanical composition, total yield, forage quality and nitrogen fixation of the legume. The desired sowing ratio is therefore strongly determined by the end use of the mixture. Oats have a competitive advantage over medic in winter (Scott and Brownlee 1974; Roberts 1991) and the major method of enhancing the legume component is by adjusting the seedling density of the two species. Several researchers have shown that manipulation of the sowing ratio in medic/oat mixtures will greatly alter the proportion each species contributes to the total forage dry matter production.

A replacement type experiment (refer to section 2.6) was conducted by Litav and Zeligman (1977) in which two *Medicago polymorpha* cultivars and oats were established under freedom from competition in the seedling stage. There were three ratio treatments (1:2, 1:1 and 2:1) as well as monocultures and the plants were cut twice for DM yield. The authors utilised the replacement method of de Wit (1960) to analyse competition between the species. The results clearly showed the competition balance in favour of oats, the predominant factor for the ratio oats:medic being the density of oats in the mixture. Oat DM yield was virtually unaffected by the presence or absence of medic at both harvests whereas medic yields were greatly reduced in mixtures relative to monoculture. There was no difference between the *Medicago* cultivars. The values of the Relative Crowding Coefficients (see section 2.6) show how much stronger a competitor oats was than medic. Yet the fact that the product of the relative crowding coefficients for both DM and N was greater than 1 (1.89 and 2.34 respectively) indicates that they were not competing entirely for the same space i.e. they were competing partly for different resources, probably because the Medic was fixing some N.

Naidu (1979) also conducted a cutting experiment with monocultures and mixtures of barrel medic and oats, using relative plant frequencies of 1.0, 0.75, 0.5, 0.25 and 0.0 for each species. The monoculture seeding rate was 20 kg/ha for medic and 60 kg/ha for oats. On half the plots, four DM harvests were taken. On the other half, the third harvest was omitted to allow a deferred hay cut to be made. The treatments with oats provided most of the dry matter early in the season, its dry matter increasing linearly with increasing seeding rate of oats. However, by spring medic growth accounted for a higher proportion of the harvested herbage. Total dry matter over the Winter-Spring period was greatest in the mixtures followed by the medic monoculture, the author suggesting that the severe defoliation imposed on the oats by cutting frequently (4 harvests) reduced tiller numbers and hence DM production. Naidu cited further evidence of this with oat tiller numbers and total DM in the deferred hay cut treatment yielding more than the conventional defoliation treatments. It is also possible than N may have become limiting for the oats as well. The medic, being a more prostrate species had fewer of its growing points removed and was eventually able to take advantage of the reduced competition. If soil was limiting of N for the oats the ability of the medic to fix its own N may have helped in improving its productivity within the mixture.

Roberts (1990) utilised a cutting experiment with an additive design to determine an appropriate sowing rate and oat cultivar for use with barrel medic. The experiment consisted of monoculture barrel medic (cv Parragio) at 18kg/ha, compared to barrel medic at 18 kg/ha plus oats sown at 15, 30 and 45 kg/ha. Two different dual purpose (forage/grain) oat cultivars (cv Marloo and Wallaroo) were utilised in the experiment. There was no effect of oat cultivar; however, increasing the oat seeding rate from 15 to 45 kg/ha provided an additional 30-50% available dry matter above the medic monoculture yield, 66 days after establishment. Severe defoliation of these treatments by cutting them to 2cm above ground level allowed the medic component to become more competitive and by the beginning of Spring, was producing the equivalent of the oats yield in the mixtures. A feature of this experiment was the suppressing effect of the oats/medic mixture on the broad leaf weeds. An inverse linear relationship was obtained between increasing oat density and broadleaf weed dry matter, suggesting this mixture could be useful in suppressing weeds in pastures.

Realising that oat cultivar had little effect, Khan (1991) compared *Medicago scutellata* (snail medic), a large seeded erect cultivar, with oats in a replacement series with five ratios (0:100, 25:75, 50:50, 75:25, 100:0). A high seeding rate of 100 kg/ha was used for both cultivars which is significantly higher than other experiments and provided an interesting result. Dry matter production was not significantly different between treatments until 118 days after establishment when the treatments with oats produced significantly more dry matter than medic monoculture. The important outcome in this experiment was that very high seeding rates of medic, comparable to a densely regenerating medic stand, could provide good early dry matter.

A useful comparison of oats, ryegrass and both barrel medic cv. Jemalong and snail medic cv. Sava in mixtures was conducted by Bowdler and Lowe (1980). While this experiment was conducted in southern Queensland, an atypical climatic zone for medics compared to Mediterranean-climate southern Australia, and utilised supplementary irrigation, the results are still relevant in demonstrating the potential annual grass/legume mixtures can provide in forage dry matter. In their experiment barrel medic grown with oats or ryegrass was more productive than snail medic/oat or snail medic/ryegrass combinations. However, snail medic provided earlier winter production, reaching its maximum growth rate approximately 1 month earlier than barrel medic. Importantly the barrel medic/oat combination was capable of producing similar dry matter production to oats fertilized with 366 kg/ha of nitrogen. They concluded that barrel medic was compatible with oats in providing high quality (digestibility, protein content) forage throughout the growing season without the need to utilise artificial nitrogen fertilisers.

In reviewing these sowing rate experiments the important conclusion is that medic is at a competitive disadvantage when in an oat/medic mixture well supplied with nitrogen. They also reconfirm the ability of the oats to provide most of the herbage early in the season because of poor medic growth in the winter period. Medic seeding rates need to be very high and sowing ratios need to be strongly biased towards the medic component if it is to contribute significantly to the mixture. The overall production of the oat/medic mixture can, however, be very high, even when compared to oats that are fertilised with high amounts of nitrogen.

Undersowing: Experiments aimed at establishing annual legumes and cereals using the undersowing technique have also been conducted in Australia. Undersowing is the practice of planting a winter cereal and a light seeding rate of annual legume at the same time. The concept is to allow the annual legume to set enough seed in the establishment year to re-establish in the following pasture year. The practice has been widely used to establish pasture legumes at minimum cost but has had limited success in low rainfall environments due to competition from the establishing cereal and poor weed control options in legume/cereal mixtures. In field experiments Poole and Gartrell (1970) compared three species of medic at two seeding rates sown with wheat. Over four trials they showed significant reductions (23-84%) in medic seed production irrespective of medic seeding rates or species selection. Continuing on from this, Brownlee and Scott (1974) also examined barrel medic undersown with wheat. The results of the regression analysis emphasised the large depressing effect of wheat on the associated medic dry matter production when sown at the same time. In further experimentation Scott and Brownlee (1974) established barrel medic under a range of cereals (wheat, barley and oats) and described an inverse relationship between cereal dry matter production and medic dry matter production and seed set. Both of their experiments suggested that unless very low seeding rates (6-11 kg/ha) of cereal were used at establishment, the medic was severely disadvantaged.

The same results are apparent with subclover, as the experiments by Bolland (1987) showed. He examined the effect of increasing subclover undersowing rates from 2 to 8kg/ha in association with both oats and wheat. Seedling establishment was significantly higher as sowing rate increased; however, there was no increase in seed soil reserves of the subclover, suggesting that it could not produce seed under these conditions. The low legume seeding rates used in the above experiments may have contributed to the poor results. However, the failure of annual legumes to establish with the undersowing technique is common and highlights how competitive cereals are for available resources in a given environment. In all these experiments the authors comment on the small competitive effect the annual legume has on the cereal. Usually they hypothesise the advantage of faster early growth and erectness of the cereal in competing for light as the primary reasons for the increased competitive ability of the cereal. In the majority of these experiments the sowing rate of annual legume was low, which is in line with common farmer practice; however, this would have undoubtedly contributed to the poor competitive ability of the medic.

2.6 METHODS OF EXAMINING COMPETITION AND YIELD RESPONSES

This section of the review briefly describes the advantages and disadvantages of various methods that can be employed to determine whether one species is influencing the growth of another in a mixture, and the effect on total production.

Two contrasting experimental designs, "additive" and "replacement series", have been used to study the interactive behaviour of components in mixed stands (Jolliffe *et al.* 1984). Recently a third model set termed "response surface designs" has been utilised by researchers (Cousens 1996) in an attempt to overcome some of the problems encountered with additive and replacement series design.

Additive Designs: This design consists of two species grown together, the density of one maintained constant and that of the other varied (Harper 1977). This design has also been referred to as the "additive series" (Snaydon 1991) "partial additive design"

(Rejmanek *et al.* 1989) and more recently termed the "conventional additive design" by Cousens (1996) so as to avoid confusion. The first species is regarded as an indicator and the relative aggressiveness of a group of species can be compared to the indicator. Analysis of this design is complicated and difficult because the proportional composition and density of the mixture are both changed, confounding the effects (Harper 1977; Rejmanek *et al.* 1989). Experiments of this nature are often used to determine the effects of one species invading the area occupied by another e.g. a weed invading a crop (Harper 1977; Cousens 1996).

Replacement Series Design: This design is also known as the substitutive design (Harper 1977) and was introduced by de Wit (1960). The design uses a non-linear, hyperbolic model to define the relationship between yield and plant density (Kropff and Lotz 1992). The characteristic of the replacement series model is that it consists of pure stands of each species and a range of mixtures, formed by replacing given proportions of one species with an equivalent proportion of the other (Harper 1977; Connolly 1986). While the overall density in all treatments usually remains constant (Hall 1974), this is not always essential such as the experiments of de Wit *et al.* (1966). In their experiments they equated two legumes plants with one grass plant. Thus legume monocultures had twice as many plants as grass monocultures, and mixtures were composed by replacement in those proportions. The simplest form of replacement series consists of two monocultures and a single mixture treatment, usually containing 50% of each species. The design has been popular because the graphical presentation of the yield data allows the identification of the stronger competitor and the extent of the niche overlap between species (Firbank and Watkinson 1985).

Results of experiments based on replacement series can, in theory, take any of the following four basic forms (Harper 1977, derived from de Wit 1960).

(1) *Neutral Interference*: where the yield of the two species in mixtures results in each contributing to the total yield in direct proportion to their ratio of sown seed. This may occur at densities so low that individuals do not interfere with each other or at very high densities where the mutual interference is equal. In figure 2.1a the effect of species I on J is the same as J on J and the effect of J on I is the same as I on I.

(2) *Compensation*: where one species of the mixture yields less than expected according to its density and the other more (Khan 1991). The competitive ability of the two species is different. In figure 2.1b the effect of I on J is greater than J on J and the influence of J on I is less than I on I. The opposite occurs if J is the stronger competitor (Figure 2. 1c). De Wit (1960) and van der Bergh (1968) found this situation occurred with mixtures of cereals and of grasses, competing for the same resources. They described such species as being mutually exclusive.

(3) *Mutual Antagonism*: A rare situation where each species of the mixture contributes less than expected form its density. The effect of I on J is greater than J on J and the effect of J on I is greater than I on I (Figure 2.1d).

(4) *Mutual cooperation*: where the yield of the mixture is greater then expected from yields in monoculture. The effect of I on J is less than J on J and the effect of J on I is less than I on I (Figure 2.1e). Harper (1977) describes this as the ability of the species to escape competition in the mixture. This type of response leads to an increase in forage yield and maximises the productivity of the resources available. This situation may occur when the two species are not competing for exactly the same resources, as with mixtures of grass and a legume, when the legume has an independent source of N. (de Wit *et al.* 1966).

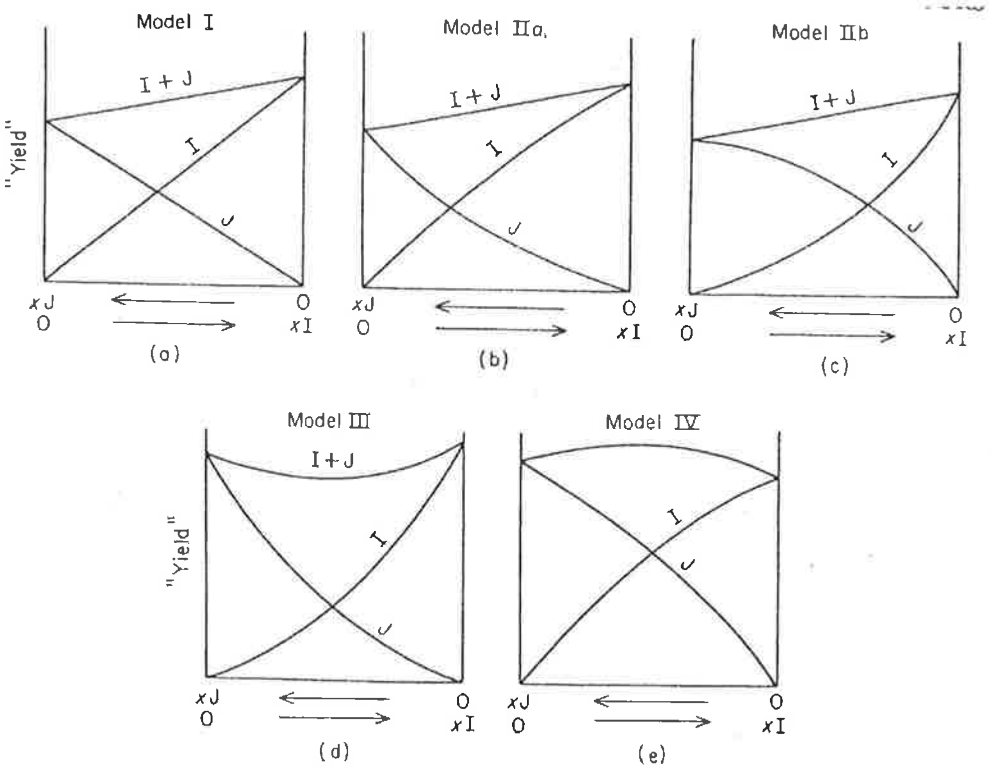

Figure 2.1 Replacement series diagrams representing the responses of species to competition and the yields of their mixtures; (a) neutral interference, (b) and (c) compensation, (d) mutual antagonism and (e) mutual cooperation (from Harper 1977).

An extension of the replacement series model is the concept of "relative yield" and "relative yield total". Relative yield is defined as

$$\text{Relative yield} = \frac{\text{Yield of I in mixture}}{\text{Yield of I in monoculture}}$$

The sum of the relative yield for both species in a mixture provides the relative yield total (RYT). The values of RYT are used to describe the mutual relationships of pairs of species and whether they are making the demands on the same resources. Values of RYT of 1.0 indicate that the two species are making similar demands on the resources of the environment. RYT > 1.0 suggests that the species are not competing for exactly the same resources and may be showing some form of complementary relationship. RYT < 1.0 implies mutual antagonism (Figure 2.1d) (Harper 1977).

The effects of competition, and hence the results of replacement series experiments, may vary with total density which is the main criticism of the replacement series design. It is therefore necessary to grow both monoculture and mixtures over a range of densities if one wishes to separate the effects of intraspecific and interspecific competition (Firbank and Watkinson 1985). Alternately the same effect can be achieved with a number of harvests over time, as the plants enlarge to fill the space available (this is possible where multiple harvests arc conducted such as pasture DM harvests but not in crops where a single harvest of grain may occur). Cousens (1996) argued that this form of in-depth analysis is not always required and hence the replacement series design is acceptable provided the limitations of its interpretation are understood.

Response Surface Designs: These refer to designs in which the densities of both species are varied, without the constraint of holding total density constant (Wright 1981; Spitters 1983; Cousens 1985; Firbank and Watkinson 1985; Connolly 1987). These designs are either factorial combinations of densities of two species, or a series of replacement series at different total densities. Analysis is achieved by fitting a non-linear equation to the data (Cousens 1996). It is claimed by Spitters (1983), Connolly (1988), Rejmanek *et al.* (1989) and Snaydon (1991) that these designs can overcome some of the confounding effects that make the interpretation of both additive and replacement series designs difficult. Connolly *et al.* (1990) used two plants *Stellaria media* and *Poa annua* over a wide range of mixed densities and at three different nutrient levels to show that the response function approach can be qualitatively different from a substitutive approach such as used in replacement series experiments. However much depends upon the questions asked in the experiment. If absolute competitive ability of the two species is important then this approach would be required, however, if only knowledge about the mixture and the end result in practical terms is required then less complicated designs and analysis may be still be valid.

In conclusion from the review of experimental designs to determine competitiveness in two species mixtures, the replacement series design is a useful method to identify which species is more competitive and the overall effect on the mixture. The majority of authors would agree that the replacement series method described by de Wit (1960; 1961) is a useful tool to determine the nature of competition between two species. However, it is incapable of detecting frequency-dependant competitive effects (DeBenedictis 1977). Interpretation is therefore limited to the environment and density the experiment is conducted in and not all questions regarding the level of competition can be answered as the level of intraspecies competition can not be distinguished from interspecies competition (i.e. you get the net effect of replacing one species by another).

2.7 CONCLUSION

The review of the literature highlights the significant role of annual legumes and grasses in the cereal-livestock zone of southern Australia, their most important role being to provide winter forage for the livestock industries based in these areas. The annual medics are particularly important for the low rainfall, alkaline soil areas, where the alternative pulse options are few and are associated with high risk of crop failure. The literature suggests that a grass/medic combination can provide excellent grazing pasture. The addition of an annual grass in these pastures can provide valuable early grazing by improving the early dry matter availability. However, their importance in improving the nutritional quality of the pasture is questionable with little evidence to suggest that grasses/legume mixtures are superior to pure legumes. There are numerous studies to show that high density subclover stands can provide high protein, high digestible diets for grazing animals. Similar results have been shown from a limited number of grazing experiments involving medics. In addition maximum symbiotic nitrogen production and the breaking of cereal root disease cycles is achieved when grasses are removed and a high density legume pasture remains. Maximising the legume dry matter production is essential for high nitrogen accumulation. This nitrogen is also available for following cereal crops. Grasses do, however, provide rapid growth early in the season and would ideally be included in grazing stock's diet from an animal health point of view, to provide a source of roughage and fibre.

Eliminating the annual grasses in medic pastures ensures maximum dry matter production of the medic and in turn nitrogen fixation and accumulation. In addition this grass removal also facilitates the removal of the root disease hosts for Cereal Cyst Nematode and take-all and reduces the number of grass seedlings available to compete against the following cereal crops. There are many management techniques available to reduce grass biomass and density in the pasture phase and the use of the grass selective herbicides has been highly successful. However, the annual grasses have developed high levels of resistance to most of these herbicides and the associated reduction in early winter growth is often cited as reason to avoid this practice. The selection of an appropriate companion grass if any is therefore an important consideration and must be made in the context of the whole rotation.

The use of sown cereals for grazing, particularly selected CCN resistant varieties of oats, would seem likely to be the most favourable alternatives to the volunteer annual grasses where a gramineous species was desired in the pasture phase. Oat varieties resistant to CCN and take-all have been released and combining these with annual medics that are naturally resistant to these two root diseases should eliminate these disease effects on following cereal crops. There is little information on whether such mixtures are of a net benefit to the annual cereal-livestock farming systems of southern Australia. The gaps in the literature include production figures for grazed grass/medic pastures in terms of pasture growth, botanical composition, nitrogen input, sheep production and the ability of the medic to regenerate. There are no scientific studies on comparisons of grass/medic, grass-free medic or oat-medic mixtures in a farming systems context where stocking rate has also been varied. In addition the effect of medic/oat mixture on a following cereal crop where a whole rotation has been compared for its robustness has not been conducted.

The aim of the following experiments is to examine the usefulness of oat/medic mixtures in the ley farming system by comparing them directly to grass/medic and grass-free medic pastures. In addition experiments where management and genotype is manipulated to influence the density and yield of individual components and hence final result, will be conducted to gain an understanding of the competitive behaviour of medic/oat mixtures. In this way some of the above gaps in knowledge will be addressed.

The hypotheses that can be developed after examining the literature are:

1) A need to quantify the autumn early winter feed gap for medic based pastures and if cereal cyst nematode resistant oats can help overcome this shortage.
2) The effect that the addition of oats has on the medic in terms of growth, N fixation and seed productivity.
3) The effect that the addition of oats to a medic based pasture has on the following cereal crop.
4) Can agronomic management techniques be utilised to improve medic growth in medic-oat mixtures?
5) Can more competitive medicago species and rhizobium strains be identified to replace existing cultivars and strains?

Chapter 3

3. EXPERIMENT 1 - EFFECT OF GRASS REMOVAL AND OAT ADDITION TO ANNUAL MEDIC PASTURE AT TWO STOCKING INTENSITIES ON THE PERFORMANCE OF THE PASTURE, SHEEP AND THE FOLLOWING WHEAT CROP.

3.1 INTRODUCTION

The annual grasses have been well recognised as important weeds of winter crops contributing to crop losses in southern Australia (Amor and Kloot 1987; Barrett and Campbell 1973; Medd and Pandy 1990; Smith and Levick 1974). Research by King (1984), Cocks (1975), Cotterill and Sivasithamparam (1988a;1988b), MacLeod *et al.* (1993), MacNish and Nicholas (1987), Rovira and Simon (1982) has shown that the cereal root diseases Cereal Cyst Nematode (*Heterodera avenae*), take-all (*Gaeumannomyces graminis* var. *tritici*) and Rhizoctonia (*Rhizoctonia solani*) can increase in severity if their respective grass hosts are not eliminated early from the pasture phase of the rotation. These disease hosting species include the volunteer annual grasses barley grass, ryegrass, brome grass, silver grass and wild oats each with the variable ability to host one or more of the above root diseases.

Research has also verified that grass removal and creation of legume dominance in the pasture phase has many benefits, usually improving yield and quality of the following cereal crop (Venn 1984; Murray 1994; Stephenson 1993; Leys 1990). The removal of these grasses from legume based pastures preceding cereal crops with grass selective herbicides has been widely promoted. However this recommendation has met with resistance. The most important reason cited is the loss of early winter feed for livestock grazing. Other reasons include an increased potential for grass herbicide resistance, multiplication of broadleaf weeds and health problems in livestock associated with grazing high legume content pastures (Little *et al.* 1993; Mackereth *et al.* 1993; Latta and Carter 1993).

Substitution of the volunteer grasses with a gramineous species that does not host cereal root diseases, rather than the complete exclusion of grass species, may provide a solution to the problems generated with both grassy and grass-free annual legume pastures.

Previous research by Roberts (1990; 1991) and Roberts *et al* (1993) has shown that the addition of oats at medic establishment can also reduce volunteer grasses and broadleaf weeds in grass/medic pastures by competition as well as providing additional grazing forage early in the season.

The previous experiment failed to establish a stocking rate effect on pasture growth due to exceptional pasture production in 1991 and consequently the effect of intensive grazing pressure on the three pasture types could not be determined. To examine this effect further the stocking rate was increased in this experiment. This experiment was aimed at evaluating the effect of addition of Cereal Cyst Nematode (CCN) and take-all resistant oats to volunteer grass/annual medic based pastures, comparing it to a grass-free medic and grassy medic pastures in terms of (1) pasture growth, (2) botanical composition, (3) water use, (4) sheep body weight gain and (5) the effect on a following wheat crop.

3.2 MATERIALS AND METHODS

3.2.1 Site of Experiment

The field experiment was conducted throughout 1991-1993 at the University of Adelaide Roseworthy Campus, South Australia. The campus is situated 50 km North of Adelaide on the Adelaide plains (latitude 34°32′S, longitude 138°41′E, 64m above sea level).

Previous paddock history was: 1986 volunteer grass-medic pasture, 1987 wheat, 1988 oat-medic pasture, 1989 wheat and regenerated medic pasture in 1990 (cv. Paraggio). The experiment was established in 1991 and the establishment details, results and discussion for that year are cited in the thesis of Roberts (1991). In order to investigate further these pasture treatments and particularly the effect on the following wheat crop the experiment was extended for three years the second (1992) and third (1993) year phases of the rotation are presented in this thesis.

Soils: Soils in the area are typical of those occurring in the semi-arid Mediterranean climate regions where medics are grown and consist of a mixture of solonized brown soils, red brown earths, grey calcareous soils and the lighter textured transitional brown soils. Using the Northcote (1984) classification key, the above soils are classified under the general profile forms of Um, Gc, Gn, Dr and Db respectively.

The experimental site is situated on a clay loam with increasing clay content and calcite fragments down the profile. Surface pH 7.5 (water) increasing to 8.0 at 80 cm depth. The soil is hard setting with low organic matter levels (approximately 1.0-1.5% organic carbon).

Climate: The rainfall and temperatures are representative of a Mediterranean-type climate with hot dry summers and cool wet winters. The mean annual rainfall at Roseworthy is 440 mm with 75% (327 mm) of this falling during the growing season of April-October. Long term rainfall and temperature data along with 1992 and 1993 monthly rainfall and temperature data are presented in Appendix Table A.1.

3.2.2 Design of Experiment

The experiment in 1992 comprised three pastures types,

volunteer grass + medic (grass+medic),

grass-free medic (GF medic),

sown oat + volunteer grass + medic (oat+grass+medic)

each at two stocking rates, 13.2 sheep/ha and 19.8 sheep/ha in a randomised complete block design. There were three replicates. Eleven sheep were allocated to each paddock of these pasture types and stocking rates were adjusted by paddock size. Paddock sizes were 116.7m × 71.4m for 13.2 sheep/ha and 116.7m × 47.6m for 19.8 sheep/ha. The stocking rates used in this experiment were based on previous experiments by Tow and Alkailah (1981), Tow (1989) and Roberts (1990, 1991) and were chosen to try and capture grazing intensity as a variable.

In 1993 after removal of fencing, wheat was sown across these six main treatments to assess the effect of the different pastures on wheat yield and quality.

Cultivar Selection: *Medicago truncatula* (barrel medic) cv. Paraggio is a cultivar released in 1982 with broad adaptation. It is adapted to a range of soil types from neutral to alkaline sands and sandy loams in 350 mm mean annual rainfall areas to heavy textured, red brown earth and clay loam soils of 500 mm rainfall. As a direct replacement for the cv. Jemalong barrel medic it produces more herbage and seed. It has a specific advantage over other cultivars in that it is tolerant to spotted alfalfa aphid (*Therioaphis trifolii* (Monell) f. *maculata*), blue-green aphid (*Acyrthosiphon kondoi* Shinji) and cowpea aphid (*Aphis craccivora* Koch), all damaging pests of medics. It has also exhibited better seedling vigour than Jemalong and improved hardseededness break down making it ideal in cropping rotations (Oram 1982; Crawford 1987). Importantly barrel medic has not been recorded as a host of CCN (Meagher and Rooney 1966) and pure medic stands do not host take-all (Cotterill and Sivasithamparam 1988b, MacLeod and MacNish 1989). As such barrel medic should act as a sufficient break crop for both these diseases.

Avena sativa (oat) cv. Marloo is a dual purpose variety suited both for grazing and grain production. Its growth habit is classified as intermediate between erect and prostrate. Importantly, Marloo is resistant to both CCN and the strain of take-all that affects cereals (Brown 1975) making it a suitable replacement for volunteer grasses (Barr *et al.* 1988). Marloo also has some tolerance to stem nematode (*Ditylenchus dipsaci*) a potential problem when oats and pulses are consistently grown in a rotation. The nematode has a wide host range, being recorded on peas, beans, vetch, wild oats as well as different species of clover and grasses (Bosch and Cooper 1986; Whitehead and Tite 1987; Kamel *et al.* 1989). Moderate resistance to barley yellow dwarf virus and bipolaris (*Bipolaris sorokiniana*) has also been noted on this variety (Barr *et al.* 1988). A previous cutting experiment by Roberts (1990) compared Marloo against the closely related, earlier flowering cultivar Wallaroo in mixture with Paraggio medic. The results suggested that the intermediate growth habit provided by Marloo gave a slight advantage over the more erect Wallaroo cultivar in terms of early production and regrowth dry matter.

3.2.3 Establishment - Pasture 1992

As the experiment was a continuation from 1991, plant emergence counts of medic, grass and broad-leaved weeds were conducted across the treatments on March 15 1992 after the break of the season to assess the variability that would be inherited in the 1992 season (Appendix Table B.1). As there was high variability between treatments it was decided to spray the existing plant populations with 1.5 L/ha of glyphosate (450g/L) on April 2 and sow the desired medic and oat components. The previous medic cultivar Paraggio generally only has only one main germination period per season and could be killed easily. The predominant grasses in the experimental site, barley grass and annual ryegrass, have a similar germination pattern. Because of the high content of grass seed in the soil and through stimulation of germination by cultivation it was thought sufficient grass plants would establish for the grass+medic and oat+grass+medic treatments after spraying with glyphosate.

Oats cv. Marloo was sown in the oat+grass+medic treatment at 55 kg/ha and 3 cm deep on May 12. Medic cv. Paraggio was sown at a rate of 18 kg/ha together with 100 kg/ha of Hi-Fert Goldphos® (18% P, 10% S) and 1 cm deep on May 13. A 14-row Connor Shea seed drill with 15 cm row spacing, narrow points and pasture chains to cover the seed was used for seeding.

Plants emerged on June 4 and were sprayed with 50 ml/ha LeMat (omethoate) on June 16 to control red-legged earthmite (*Halotydeus destructor*) and lucerne flea (*Sminthurus viridis*). The grass herbicide Fusilade (fluazifop-P 212 g/L) was applied at 500 ml/ha plus 2% wetter and 1% crop oil on June 29 to control the volunteer grasses in the grass-free medic treatment.

Sheep selection, allocation and management: An initial flock of 250, 1.5 year old Merino wethers were drafted randomly into three groups (representing replicates) and their body-weights recorded according to the method of Moule (1965). The sheep were ranked in descending order of body-weight for each of the three groups. Eleven sheep were allocated to each of the six pasture treatments based on body-weight, such that each pasture treatment received a mean body-weight similar to the group (replicate) mean according to the method of Roberts (1975). This method explained by Roberts (1975) helps minimise bias. Eleven sheep were kept as spares. All sheep were drenched with Ivomec® (ivermectin) to control internal parasites.

Sheep were introduced onto the three different pasture types once the pasture had achieved approximately 1 t/ha of available dry matter. This occurred on July 18 for the oat+grass+medic pasture type, July 29 for the grass+medic pasture type and August 8 for the grass-free medic pasture type. The sheep were weighed and removed from the pastures on November 8. Sheep that were not introduced immediately onto pastures were kept on a grass+medic pasture diet and weighed again to obtain starting weights before their introduction to their pasture type.

3.2.4 Pasture 1992 - Measurements

Plant Establishment Counts and Levy Point Quadrat Counts: Plant establishment (plants/m^2) was estimated on June 24 by counting all sown and volunteer species in twenty 0.1 m^2 quadrats distributed randomly across each plot. Botanical composition and percentage bare ground were estimated on September 4 using the Levy point quadrat method as described by Levy and Madden (1933). Sixteen frames (10 pin) per treatment were taken with vegetative point hits separated into oats, medic, grass, other (broadleaf weeds) and bare ground. Point data were converted into percentage overlapping cover and bare ground by dividing the species hits by the total of all vegetation hits.

Take-All, Cereal Cyst Nematode and Root Lesion Nematode Bio-assays: A soil bio-assay was conducted on June 2 to assess the levels of *Gaeumannomyces graminis* var. *tritici* (take-all, *Ggt*) inoculum, *Heterodera avenae* (cereal cyst nematode, CCN) and *Pratylenchus* (root lesion nematode) in each pasture treatment. Each plot was divided into four strata and four 10 cm diameter soil cores to a depth of 20cm were taken randomly along each stratum. The four soil cores were bulked for each stratum and thoroughly mixed before being placed into 22 cm diameter pots in a controlled temperature glasshouse. Seven wheat (cv. Condor) plants per pot were grown for six weeks to early tillering, then destructively sampled by carefully washing all soil away from the roots. Roots were examined for CCN and take-all damage. The presence of CCN damage was assessed by examining the roots for knotting and galls as well as reduction in root length, similar to the method employed by Rovira and Simon (1982).

A technique developed by Pittaway (1989) was used to assess wheat seminal roots for take-all damage. The number of seminal roots was counted on each plant and the percentage of seminal roots with stelar lesions suspected of being take-all was recorded by the method of Roget and Rovira (1991). These suspected lesions were then removed and placed in 3% sodium hypochlorite for 30 seconds to surface sterilise the root segments. Root segments were then triple rinsed in sterile water and patted dry before being placed on antibiotic agar plates using standard sterile techniques. Agar plates consisted of reduced strength antibiotics (Neomycin sulphate, Chloromycetin succinate and Streptomycin sulphate) in a 2/3 potato dextrose, 1/3 water agar mixture. The antibiotics were selected to exclude bacterial growth. Root segments that did not appear to have any lesions were also subjected to the above treatments and incubated to act as controls. The agar plates were incubated at 20°C and examined firstly after three days and then at two-day intervals for any fungal hyphal growth emanating from the root segments. The fungal hyphae of root segments exhibiting this growth were subcultured onto carnation leaf agar (2/3 potato dextrose, 1/3 water agar plates with gamma irradiated carnation leaf) and re-incubated before being placed under a light bank to promote spore development. These subcultures were then examined and identified to determine if the fungal growth was *Gaeumannomyces graminis* var. *tritici* (*Ggt*) or another pathogen. Results were expressed as the percentage of seminal roots infected with *Ggt*. Other species of fungi and bacteria were also identified including *Rhizopus* spp., *Trichoderma* spp., *Fusarium* spp., and *Michrodochium bolleyi*. However their presence was not in sufficient numbers to warrant further investigation.

Visible damage to the root cortex of the wheat plants was observed and was suspected of being caused by root lesion nematodes (RLN). After the wheat roots had been examined and scored for CCN and take-all they were assessed for the number of RLN's per wheat plant by the method developed by the South Australian Research and Development Institutes nematology group which is a combination of Southey (1986) and Gastel (1990) methods. The wheat roots were chopped into 2 cm pieces and placed on tissue paper supported on a coarse sieve. The sieve was placed inside a filter, the stem of which led to the bottom of a large boiling tube. Water was misted over the root tissue in the filter, from above, at approximately 2 L/hr intermittently for 1.5 min. in every 10 min. for three days. The collection procedure used the principle of the nematodes being heavier than water and sinking to the bottom of the boiling tube. After collection samples were transferred to a counting dish and examined under a microscope. The root lesion nematode was identified as being *Pratylenchus neglectus* which is known to be common in these soil types. Numbers were expressed per gram of dry root weight and per wheat plant.

Herbage harvests: Harvests were taken to determine the available dry matter (DM), total growth and botanical composition of the three pasture types under the two stocking rates (Table 3.1). To determine pasture growth rates between harvests, one 0.7m × 0.7m square and 1m tall secured cage exclosure(s) was placed randomly in each of four strata in each pasture plot. They were initially placed on the plots before the introduction of the sheep on to the oat+grass+medic pasture type.

Table 3.1 Summary of herbage harvests and sheep introduction dates in 1992.

Dates	Time period between harvests	Harvests made	Introduction of sheep to pasture treatments
July 18	0	H1 open	Sheep introduced onto oat+grass+medic pasture type
July 29	11 days	H2 open H2 closed	Sheep introduced onto grass+medic pasture type
August 8	10 days	H3 open H3 closed	Sheep introduced onto grass-free medic pasture type
August 31	23 days	H4 open H4 closed	
September 26	26 days	H5 open H5 closed	
October 23	27 days	H6 open H6 closed	
November 8			Sheep removed

The 'open' and 'closed' quadrat method of McIntyre (1946) was used to determine pasture availability and cumulative growth. Quadrat size was 0.6m × 0.6m and plants were cut to ground level. At harvest 1 cage exclosures were secured in the paddock and a quadrat cut that visually represented growth and composition inside the exclosure was taken outside and adjacent to each exclosure. This was termed an "open" cut. At the second harvest the pasture was cut inside the exclosure (termed "closed" cut) before it was shifted to a new area and secured. The visually matched "open" cut for the second harvest was then taken outside the cage. The four quadrats were combined for each plot for statistical analysis.

Pasture growth and growth rates were then calculated as follows:

$$\text{Pasture growth} = (\text{H}n\text{+1 closed}) - \text{H}n\text{ open}$$

where n = harvest number

$$\text{Pasture growth rate} = \frac{((\text{H}n + 1\,\text{closed}) - \text{H}n\text{ open})}{\text{No.of days between harvest}}$$

Total pasture growth for the season was estimated by adding together the pasture growth between each harvest. Harvests were conducted in all treatments at the introduction of the sheep onto each of the three pasture types and at three subsequent times until pasture senescence began. Botanical composition was determined on "open" quadrat samples by hand separation into oats, medic, grass and other species components in the laboratory. Herbage samples were dried in a forced-draught dehydrator for 24 hrs at 85°C.

Medic pod and seed harvests: Medic pods were harvested in March 1993. Ten galvanised metal infiltrometer rings measuring 29.5 cm in diameter were placed randomly along 10 strata in each plot and pushed into the ground to define the sample area. A portable electric vacuum cleaner was used to extract the medic pods off the surface of the soil. Samples were sieved to remove excess dirt and medic vine residue before being washed with Perclean® (perchlorethlene) by the method of Carter *et al.* (1977). An attempt was made to remove pods from the previous year which appeared darker in colour; however the majority of pods from 1991 were buried when the pastures were resown and were not collected in the sampling procedure.

Medic pod samples were weighed and counted. A random sub sample of ten pods per sample was taken and the pods dissected and seeds removed counted and weighed. To determine the proportions of viable soft seeds and hard seeds the seeds were then placed in plastic petri dishes on three pieces of filter paper (Whatman ® quality No.1). Ten ml distilled water containing 1.6g/litre of the fungicide thiram was applied to each plate. Samples were placed in an incubator for 14 days at 20°C to determine the proportion of viable soft seeds as per the method of Taylor (1996). The number of seeds that swelled and germinated were expressed as a percentage of the total number of seeds.

Yield components measured from the seed harvest included: Number of pods per m^2, number of seeds per pod, mean seed weight, total seed yield, percentage soft seed (permeable, readily germinable) and yield of germinable seed (total seed × percentage soft seed).

Regeneration of the medic and volunteer weeds was measured before the wheat was sown on May 20 1993; after killing this population with cultivation (see section 3.2.5), further plant counts were taken once the wheat was established on July 6 1993 and the year after wheat on June 21 1994. Plant regeneration counts in 1994 were only taken in sub plots of the first time of wheat sowing (see section 3.2.5). Medic data were examined for relationships between 1992 seed yields and subsequent regeneration in 1994.

Soil water Content Measurements: Sub surface soil moisture was determined using a neutron probe (Greacen 1981; Hodnett 1986). Two access tubes were placed in each plot at opposite ends of the fenced paddocks on April 29, 1992, thirty seven days before the pasture plants emerged. Soil core samples 50 mm in diameter were extracted to a depth of 100 cm using push tubes attached to a hydraulic soil sampler. Mild steel access tubes, with a length of 120 cm, external diameter of 50 mm, and a wall thickness of 1.8 mm, were sunk in the holes to a depth of 100 cm, leaving 20cm above ground level. The access tubes were sealed at the bottom using a glued rubber bung and covered with an aluminium can when not in use.

Seeding of the pasture treatments around the access tubes was carefully conducted by guiding the Connor Shea seeder tynes with narrow points on a slight angle past the access tubes to ensure plants were evenly distributed around the access tubes.

The neutron moisture meter used was a Campbell Pacific Nuclear 503 single purpose hydroprobe with a 50 mCi Americium-Beryllium neutron source and was used to take 16 second counts at 20, 40, 60 and 80 cm depths below the soil surface. Three readings were taken at each depth and averaged. Before field measurements, standard counts were made in a sealed access tube in a 205-L drum of water. Count ratios were calculated as count reading divided by the standard count.

Calibration of neutron moisture meter: The neutron probe was calibrated against gravimetrically determined moisture at one site in each of the three experiment replications using a method similar to that suggested by O'Leary and Incerti (1993). One wet and three dry calibration access tubes were installed in each of the three replicates. The wet access tube sites were soaked for 3 days by constant release of water from a drum into an infiltration ring (4 days prior to excavation day) and the dry access tube sites were in field condition at the time of calibration in March. Three 16 second counts were taken at each depth and averaged. Three 50 mm diameter × 1m depth push tube core samples were taken adjacent to each access tube. Core sections were taken at depths of 20, 40, 60 and 80 cm and oven-dried at 105°C to determine gravimetric water content. Separate soil pits were excavated to determine bulk density. Bulk density was determined as the mean of six soil cores measuring 73 mm in diameter and 50 mm long extracted at each of the four depths. Volumetric water content for each depth was calculated from the gravimetric and bulk density soil samples. The regression of neutron count ratio against measured volumetric water content was determined to provide calibration equations for each depth.

Water Use Estimation: Probe readings were taken at plant emergence on June 4 1992, at flowering on October 13 and between flowering and maturity on November 6 and November 18 and at maturity on December 2.

Estimates were made of water use from the beginning of the growing season until mid flowering and mid flowering until maturity, and of total water use for the growing season of the pasture. A simple water balance equation as used by Blumenthal and Ison (1993a and b) was adopted.

The equations were: WU(Emergence-Flowering) = SW1 - SW2 + R (mm)

WU(Flowering-Maturity) = SW2 - SW3 + R (mm)

WU(total) = SW1 - SW3 + R (mm)

where WU is total evapotranspiration, SW1(mm) is soil water at the start of the growing season, SW2(mm) is soil water at mid flowering, SW3(mm) is soil water at the end of the growing season and R is rainfall. The equation does not take into account any run off or deep drainage of water. It is possible that in 1992, an extremely wet year, that some surface runoff or deep drainage did occur but no attempt was made to measure this.

Total soil Nitrogen, Available soil nitrogen and Organic carbon %: Total and available soil nitrogen and organic carbon % were determined on March 6 1993 to detect effects of the previous two years' pasture treatments. Each pasture plot was divided into four strata and three 10 cm diameter soil cores to a depth of 20 cm were taken randomly in each stratum and bulked. Samples were stored in a freezer before being processed and analysed. Soil was passed through a 2 mm sieve for analysis. Total soil nitrogen was determined by the Kjeldahl, automated colour method; soil nitrate was determined using the KCL extraction and automated colour method; total organic carbon was determined by the Heanes wet oxidation method as described by Rayment and Higginson (1992).

Available sub soil nitrogen: Soil samples were taken to test for nitrate accumulated through leaching at depths in the profile to 100 cm. The ability to conduct these tests was limited by time and cost, hence only the grass-free medic and oat+grass+medic pasture type at the high stocking rate were compared. Four soil cores were taken in each of four strata to a depth of 100 cm in each of the three replicates on March 5 1993. The timing of sampling was selected to assess the levels of sub soil nitrate before further possible leaching by major rainfall events at the break of the season. The soil cores were separated on depth at 0-10, 10-20, 20-40 and 40-100 cm and the four strata samples bulked for each replicate. Available nitrate nitrogen was determined by the method of Rayment and Higginson (1992).

3.2.5 Wheat 1993 - Establishment

In 1993 all fencing was removed. Volunteer medic, oats and weed plants were allowed to emerge and were sprayed with 1.2 L/ha of glyphosate (450g/L) on June 3. The experimental site was then cultivated using an offset disc and harrowed on June 7 to prepare a seed bed. Wheat cv. Janz was sown at 70 kg/ha on June 13 with an International 511 seed drill across the six pasture treatments. Because large numbers of barley grass and ryegrass plants emerged in the grass+medic and oat+grass+medic plots with the wheat plants it was decided to resow two 8.5m wide strips of wheat across each treatment 6 days later on June 19. The affect of this second sowing was to kill emerging weed seedlings with cultivation, due to the seeding action, (especially barley grass) thus generating a reduced weed population (mostly grasses) and a second time of sowing. (Time of sowing 1, June 13 and time of sowing 2, June 19).

The experimental site was sprayed with Hoegrass® (diclofop-methyl 375 g/L) at 1L/ha on July 7 to control annual ryegrass and with Ally® (metsulfuron-methyl 600 g/kg) at 7 g/ha on August 8 to control broadleaf weeds including medic, three-corned jack, soursob and Indian hedge mustard. There is no selective post emergent chemical available to control barley grass in wheat.

3.2.6 Wheat 1993 - Measurements

Plant establishment counts: Plant establishment counts of wheat and volunteer species were made on all treatments on July 6. Ten 1/2m^2 quadrats were taken in each of four strata across each plot.

Wheat Ear density, Plant Biomass and Nitrogen %: Ear density and DM yield were measured on August 8 and October 15. Four 1/2m^2 quadrats were placed at random over six rows of wheat plants in each plot and sowing time. Wheat plants and the soil surrounding the roots were carefully dug to a depth of 20 cm and the plants and soil returned to the laboratory. The soil was washed off the roots so that the seminal roots could be examined for root pathogens. The number of plants and the number of fertile ears were recorded before root examination. Then the roots were cut off and the tops dried in a forced-draught dehydrator for 36 hrs at 65°C. The tops were ground for nitrogen analysis (Kjeldahl method). Results were expressed as percent plant nitrogen (oven dry basis) and total nitrogen per hectare.

Take-All, Cereal Cyst Nematode and Pratylenchus: Whole wheat plant samples (tops and roots to 15 cm) taken for both dry matter harvests were examined for the presence of take-all, CCN and root lesion nematode. The plants were counted and the roots scored for CCN knotting and take-all lesions before the roots were cut off for root lesion nematode analysis by the method described in section 3.2.4. Results were expressed as the percentage of seminal roots infected with Ggt (take-all) and the number of root lesion nematodes per plant and per gram of dry root weight.

Soil Water Content Measurements: The access tubes installed in the 1992 pasture phase were retained in place and used to take neutron probe moisture readings in the wheat crop in 1993. The same procedure as outlined in section 3.2.4 was used to collect soil moisture data. Data were collected only for the first time of sowing as there were no access tubes installed in the second time of sowing. The mean of three 16 second counts were taken at the same depths of 20, 40, 60 and 80 cm. Neutron probe readings were taken on May 5, June 18, July 23, August 8, September 6, October 11, October 21, November 1 and November 15.

An estimate of water use was made from the beginning of the growing season until anthesis, anthesis until maturity and for the whole growing season of the wheat crop as previously described in section 3.2.4 for the pasture treatments.

Grains/Ear, Grain weight, Grain Yield, Grain volume weight, Screenings % and Grain Protein %: Each time of sowing plot was divided into four strata for grain harvesting. Before grain harvest, twenty mature heads per stratum were picked randomly and the number of grains per ear recorded. A small plot Wintersteiger® harvester was used to harvest strips measuring 20m × 6 rows in each stratum. To determine grain weight 1000 grains were counted and the weight recorded. Grain volume weight was determined using a Franklin® MK III chrondomoter. The percent screenings was determined using a standard 12.7 mm × 2.0 mm slot screen. Grain samples were randomly sub sampled and ground using a Retsch® mill (0.5 mm screen) for Kjeldahl nitrogen analysis to determine grain protein concentration.

3.2.7 Statistical Analysis

Analysis of variance was conducted on data using the statistical programme Genstat V. Pasture dry matter production was analysed as a randomised complete block design with split plots in time across the six harvests to assess possible pasture type × stocking rate × harvest interactions. All other measurements were analysed as a 3 × 2, (pasture type × stocking rate) × three reps, factorial design. When required the data were transformed to conform with the rules governing the use of analysis of variance. Comparison of means was made using the Tukey's honestly significant difference range test (HSD) (Steel and Torrie 1960). Linear regression analysis was used to determine relationships between specific variables. Regression models for the same relationship were tested to determine if they were two distinct lines, two parallel lines or one common line by comparing the observed variance ratios against F tables.

3.3 RESULTS

3.3.1 Pasture 1992

3.3.1.1 Plant Establishment

June 24 1992: Good medic (*Medicago truncutula*) and oat (*Avena sativa*) plant stands were established along with a range of annual grass and broad-leaf weeds including Barley grass (*Hordeum leporinum*), Rye grass (*Lolium rigidum*), Soursob (*Oxalis pes-caprae*), Three-cornered jack (*Emex australis*) and Indian hedge mustard (*Sisymbrium orientale*). The results would have been partially influenced by the previous pasture treatments in 1991 even though the initial 1992 plant populations were killed and medic and oats resown. There was a significant pasture type ($P<0.05$) effect on plant density for all pasture components except three corner jacks (Table 3.2). There was also a significant ($P<0.05$) stocking rate effect on barley grass, the high stocking rate reducing mean plant density from 240 plants/m^2 to 178 plants/m^2.

Table 3.2 Mean plant emergence density (plants/m^2) of Oats, Medic, Soursob, Three Corner Jack, Indian Hedge Mustard, Ryegrass and Barley Grass on June 24 1992 in three pasture types (Mean of two stocking rates).

Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD ($P<0.05$)
Oats			96.5	
Medic	458	374	413	32
Barley Grass	0.8	362	265	44
Rye Grass	0.48	41	33	5.2
Soursob	16	12	12.6	2
Three Corner Jack	12.3	12.8	12.3	n.s.
Indian Hedge Mustard	5.6	3.3	4	1.4

3.3.1.2 Take-All, Cereal Cyst Nematode and Root Lesion Nematode Bio-assays

Take-All - June 2: The number of wheat test plant seminal roots infected with *Ggt* was significantly ($P<0.01$) highest in the grass+medic pasture type (Table 3.3).

Root Lesion Nematode: The root lesion nematode was identified as *Pratylenchus neglectus* known to be common in the district especially on lighter textured soil types. *Pratylenchus neglectus* numbers per wheat plant (but not per unit wheat root dry weight) were highest on the oat+grass+medic pasture type (Table 3.3). There was no correlation between root lesion nematode numbers and the incidence of take-all.

Cereal Cyst Nematode: Careful examination of the wheat roots provided no evidence of CCN damage. This result was expected as the previous bio-assay in 1991 (Roberts 1991) of CCN egg sacs and larvae revealed a very low level of CCN. Volunteer cereals and wild oats are the main host for CCN and these were only present in trace amounts.

Table 3.3 The effect of pasture type on Condor wheat roots infected with take-all (*Ggt*) and the number of *Pratylenchus neglectus*/wheat plant. Values are the mean of two stocking rates in 1992 (analysis of *Ggt* based on square root transformed data; figures in parenthesis are the means of original data).

	Grass-free Medic	Grass+Medic	Oat+Grass+Medic	Tukeys HSD ($P<0.05$)
% Wheat seminal roots with *Ggt* lesions	0.126(2.7)	0.456(22.4)	0.236(5.9)	0.164
Pratylenchus neglectus No./wheat plant	26.9	29.2	51.2	20.8

3.3.1.3 Available Pasture Yield and Botanical Composition

There were significant ($P<0.001$) pasture × stocking rate × harvest interactions for each of the individual medic, grass and broadleaf components (Appendix Tables B.2, B.3, B.4).

Medic DM: Available medic yield did not differ significantly between treatments until harvest 2 when the grass-free medic treatments were significantly higher (Figure 3.3a) than all others. This trend continued overtime with available DM in the grass-free medic pasture type increasing through to the final harvest, particularly at the low stocking rate. Medic DM availability was not affected in the grass-free treatment by stocking rate until harvest 5 when it was significantly reduced at the high stocking rate. Similarly, even though medic DM was significantly less in the oat+grass+medic pasture type from harvest 2 onwards compared to grass-free medic, by harvest 6 the medic DM levels were similar at the high stocking rate. Medic in grass+medic made little if any improvement over time. Stocking rate had little impact on available medic DM in the grass+medic treatments, with medic production severely reduced compared to the other pasture types at harvests 3-6.

Grass DM: Grasses were completely eliminated in the grass-free medic treatment. Grass yield increased significantly over time in grass+medic and oat+grass+medic treatments, but at a significantly ($P<0.05$) lower rate in the oat+grass+medic treatment than in grass+medic treatment, at each stocking rate (Figure 3.1 and Figure 3.2). Available grass DM was similar in all grassy treatments until harvest 4. From then onwards the grass+medic pasture type had significantly more grass (Figure 3.3b). Grass yield was also reduced by higher stocking pressure (Figure 3.3b).

Broadleaf Weed DM: Weed yield was significantly highest in the grass-free medic pasture type from harvest 2 onwards (Figure 3.3a). This component consisted initially of soursob, replaced later by three-corner jack and Indian hedge mustard.

Oat DM: Yield of oats increased with time at first, up to harvest 5 at the low stocking rate and harvest 4 with the high stocking rate, and thereafter declined. Yields of oats were significantly lower at the high stocking rate from harvest 4 onwards and by harvest 6 were reduced to 179 and 895 kg/ha for the respective high and low stocking rates (Figure 3.3b).

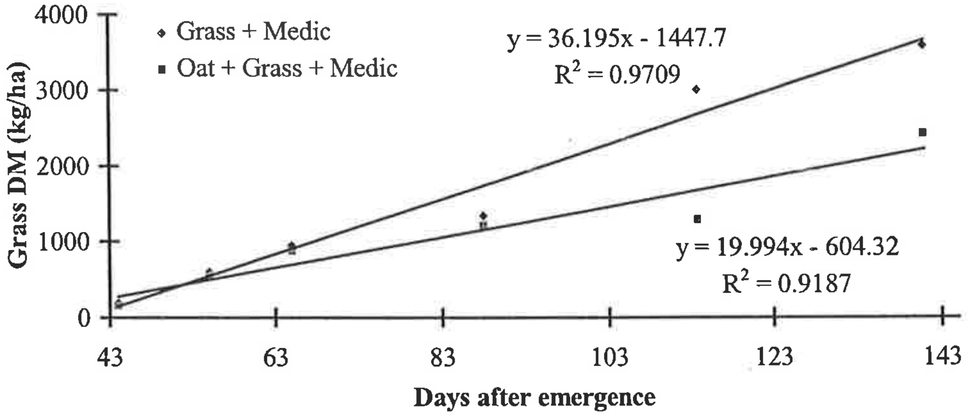

Figure 3.1 The effect of inclusion of oats on time trends in available grass dry matter for grass+medic and oat+grass+medic pasture types at 13.2 sheep/ha in 1992.

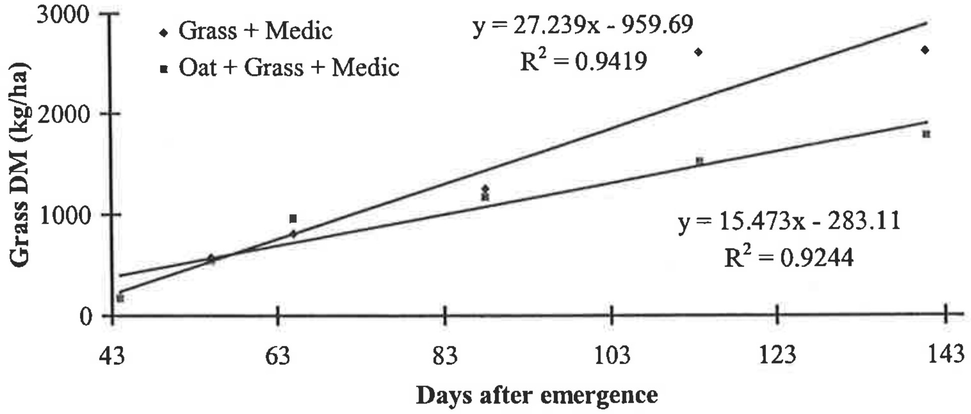

Figure 3.2 The effect of inclusion of oats on time trends in available grass dry matter for grass+medic and oat+grass+medic pasture types at 19.8 sheep/ha in 1992.

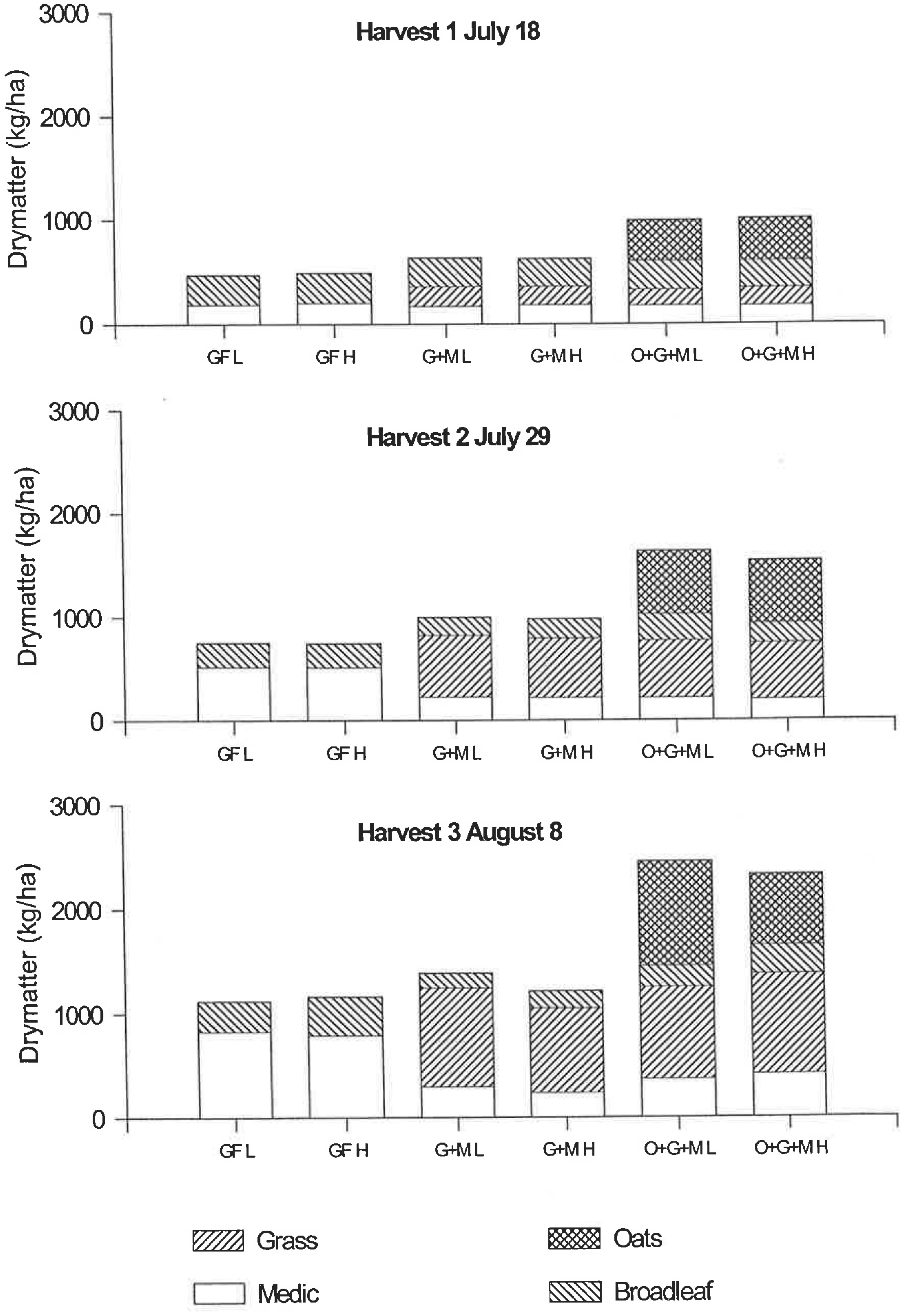

Figure 3.3a Available dry matter of medic, grass, broadleaf weeds and oats at harvest 1, harvest 2 and harvest 3 in 1992. H = (19.8 sheep/ha), L = (13.2 sheep/ha). Tukeys HSD ($P<0.05$) medic = 62, grass = 102, broadleaf weeds = 46.8 and total production = 132.

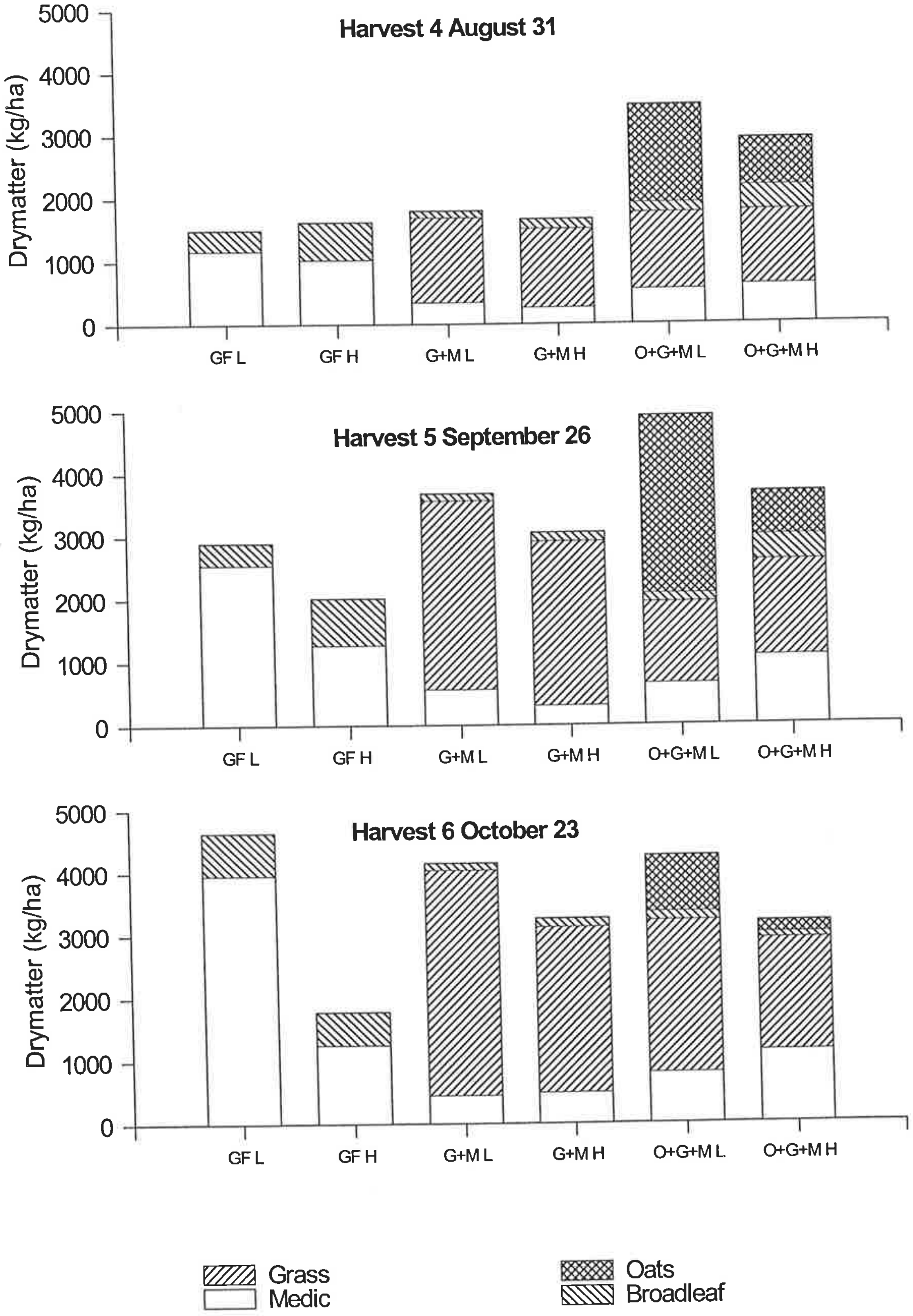

Figure 3.3b Available dry matter of medic, grass, broadleaf weeds and oats at harvest 4, harvest 5 and harvest 6 in 1992. H = (19.8 sheep/ha), L = (13.2 sheep/ha). Tukeys HSD ($P<0.05$) medic = 62, grass = 102, broadleaf weeds = 46.8 and total production = 132.

Levey Point Quadrat Counts: data for the levey point quadrat are presented in Table 3.4

Table 3.4 Botanical composition: percentage overlapping cover of oat, medic, grass, broadleaf weeds and bare ground (Levy point quadrat data) taken on September 4 1992 for three pasture types (Means of two stocking rates except bare ground). (Analysis based on arcsine transformed data, figures in parenthesis are the means of original data).

Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Oat			0.29(29)	
Medic	0.24(23.6)	0.05(6.0)	0.09(8.9)	0.13
Grass	0.003(0.3)	0.46(44.7)	0.19(18.8)	0.11
Broadleaf weeds	0.90(76.0)	0.52(49.2)	0.44(43.2)	0.21
				Pasture × SR
Bare ground 13.2 sheep/ha	0.18(18)	0.04(4.8)	0.07(7.7)	0.05
Bare ground 19.8 sheep/ha	0.22(22.1)	0.07(7.1)	0.18(17.9)	

Regression of the hand sorted pasture components taken at harvest 4 against Levy point quadrant data (Table 3.4) gave a poor correlation and could not be used to accurately predict botanical composition late in the season in this experiment. There was a significant Pasture type × Stocking rate interaction for bare ground with the higher stocking rate generally having more bare ground in all treatments.

3.3.1.4 Combined Species Available Yield

There was significant (P<0.001) pasture × stocking rate × harvest interaction for combined available DM production (Appendix Table B.5).

At harvest 1 the oat+grass+medic pasture type had achieved approximately 1 t/ha DM, the level at which it was decided to allow grazing to begin. At this stage the oat component was an addition to the pasture rather than a substitution and did not significantly affect the yields of other pasture components (Figure 3.3a). It was 11 days later before the grass+medic pasture type achieved approximately 1 t/ha DM and at this stage the oat+grass+medic pasture type had achieved over 1.5 t/ha DM with grazing. It took 21 days after harvest 1 for the grass-free medic pasture (medic+broadleaf weeds) to achieve over 1 t/ha of DM. Comparing the oat+grass+medic treatments (both stocking rates), the oat component was an addition to the other species for harvests 1-4. After this the grass+medic pasture type at the low stocking rate had achieved a similar total yield. Total DM at harvest 6 was reduced below 1.8 t/ha in the grass-free medic pasture type at the high stocking rate. At this same time the grass-free medic pasture type at the low stocking rate had the highest total available DM followed by the grass+medic and oat+grass+medic pasture types at the low stocking rate (Figure 3.3b). All pasture types with both SR increased DM over time until harvest 6 when the oat+grass+medic treatment at both SR and the grass-free medic at high SR had slight decreases.

3.3.1.5 Total Pasture Production from Sowing to Harvest 6

There was a significant (P<0.001) pasture × stocking rate interaction. The oat+grass+medic pasture types produced the highest DM over the whole growing season (Table 3.5). The grass-free medic pasture type at the low stocking rate produced markedly more (39%) than grass-free medic at the high stocking rate but was not significantly different to grass+medic pasture types at either stocking rate. Increasing stocking rate reduced production of grass-free medic by 29% but had no significant effect on the other two pasture types.

Table 3.5 Mean total pasture production (kg/ha), from July 18 to October 23 for three pasture types at two stocking rates in 1992.

	13.2 sheep/ha			19.8 sheep/ha		
	Grass-Free Medic	Grass+ Medic	Oat Grass+ Medic	Grass-Free Medic	Grass+ Medic	Oat Grass +Medic
Total Production	9004	8758	10334	6472	8575	10147

Tukeys HSD (P<0.05) Pasture × SR = 420

3.3.1.6 Pasture Growth Rate

There were significant ($P<0.001$) pasture type × between harvest and ($P<0.01$) stocking rate × between harvest interactions for pasture growth rate (Table 3.6, Table 3.7). Pasture growth rates were significantly higher for the oat+grass+medic pasture type at the beginning of the growing season. This was due to the oat component providing additional early DM. The grass+medic treatment growth rate peaked at harvest 5 after which it decreased at harvest 6, coinciding with the barley grass reaching maturity (Table 3.6). The grass-free medic treatment did not achieve its maximum growth rate until the end of the season. Prior to that it was distinctly slower than the treatments with grass and oat components. There was a significant pasture growth rate × stocking rate effect (Table 3.7). In general pasture growth rates were always higher with low stocking rate and achieved maximum growth rates in spring.

Table 3.6 Mean pasture growth rate (kg/ha/day) between six harvests for three pasture types in 1992 (means of two stocking rates).

	Grass-Free Medic	Grass+ Medic	Oat+Grass+Medic
July 18-July 29	0	0	77.4
July 29-Aug. 8	0	57.5	99.9
Aug. 8- Aug. 31	28.5	35.4	56.7
Aug. 31-Sep. 26	58.7	78.4	65.8
Sep. 26-Oct. 23	69.4	33.7	27.2
Tukeys HSD ($P<0.05$)	Between harvests × Pasture = 9.2		

Table 3.7 Mean pasture growth rate (kg/ha/day) between six harvests for two stocking rates in 1992 (means of three pasture types).

	13.2 sheep/ha	19.8 sheep/ha
July 18-July 29	26.3	25.3
July 29-Aug. 8	50.6	54.3
Aug. 8- Aug. 31	43.3	37.1
Aug. 31-Sep. 26	71.5	63.8
Sep. 26-Oct. 23	49.2	37.6
Tukeys HSD ($P<0.05$)	Between harvests × SR = 7.5	

3.3.1.7 Medic Seed Harvest

Pod Density and Seed Yield: There was a significant ($P<0.05$) pasture type × stocking rate interaction effect for both pod density and seed yield as measured in March 1993. The grass-free medic at the low stocking rate had the highest pod number/m^2 followed by grass-free medic at the high stocking rate (Table 3.8). Number of seeds/pod and mean seed weight were not significantly different among treatments; hence there was a strong positive correlation ($P<0.05$) between medic pod number and total seed yield (Figure 3.4) and pod number and germinable seed yield (Figure 3.5). Seed yield of the grass-free medic pasture type at high and low stocking rates was 4.2 and 5.6 times higher than the combined mean of grass+medic and oat+grass+medic pasture type treatments (Table 3.8).

% Soft Seeds and Germinable seeds: There was a significant ($P<0.05$) stocking rate effect on the percentage of soft seeds and significant ($P<0.05$) pasture type effect on germinable seed yields (Table 3.8). The percentage of soft seeds increased from 9% with 13.2 sheep/ha to 13% with 19.8 sheep/ha. The grass-free medic pasture type yielded 3.7 (high SR) and 4.6 (low SR) times more germinable seeds than the combined mean of the other pasture types.

Seed yield was positively correlated ($P<0.05$) with regenerated medic plant density in May 1993, before sowing of wheat, (Figure 3.6) and 1994 (Figure 3.7), the year after wheat.

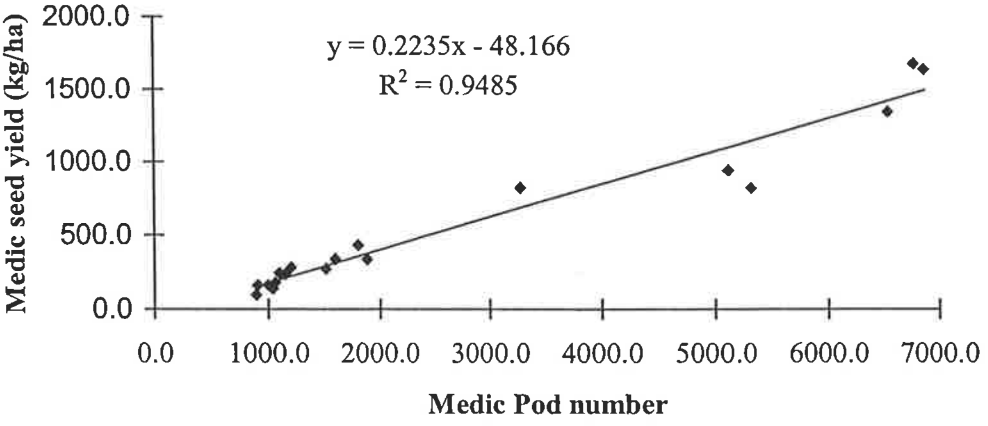

Figure 3.4 Relationship between medic pod number and medic seed yield in March 1993.

Table 3.8 Mean medic pod density, seeds/pod. seed weight, total seed yield, % soft seeds and germinable seed yield in 1993 (analysis for % soft seeds based on square root transformed data, figures in parenthesis are the means of original data)

	13.2 sheep/ha			19.8 sheep/ha			Tukeys HSD (P<0.05)		
	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Pasture	SR	Pasture × SR
Pod number/m^2	6735	1392	1307	4576	1295	1063			949
Number seeds/pod	4.33	3.82	4.38	3.79	3.91	3.74	n.s.	n.s	n.s.
Mean seed weight (mg)	5.3	4.86	4.92	5.13	4.24	4.47	n.s.	n.s.	n.s.
Seed yield (kg/ha)	1551	262	291	861	225	179			225
% Soft seeds	0.27(7.6)	0.34(11.8)	0.29(8.6)	0.34(12.2)	0.37(14)	0.36(13.5)	n.s	0.04	n.s
Germinable seed (kg/ha)	120	31	20.7	97	32	20	21.7	n.s	n.s

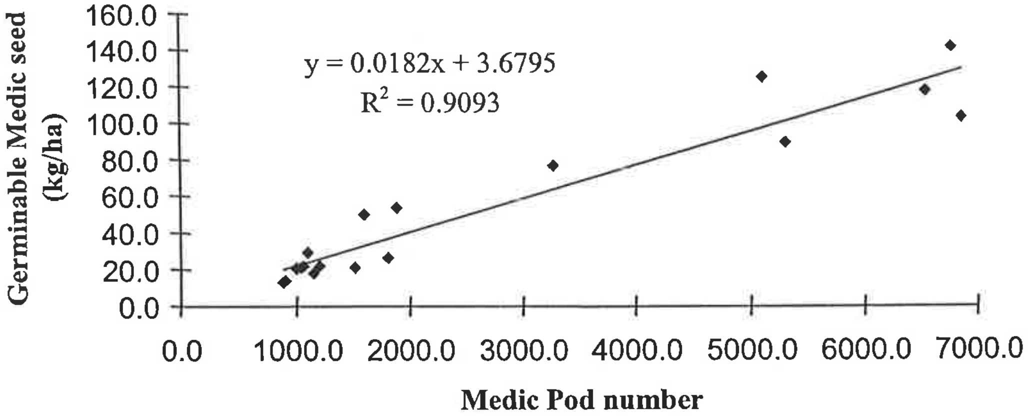

Figure 3.5 Relationship between the number of medic pods and germinable seed in March 1993.

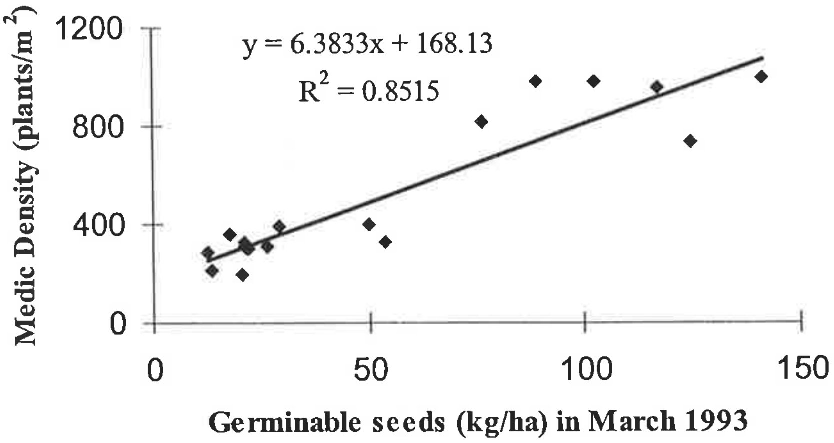

Figure 3.6 Relationship between germinable seed in March 1993 and medic plant density in May 1993.

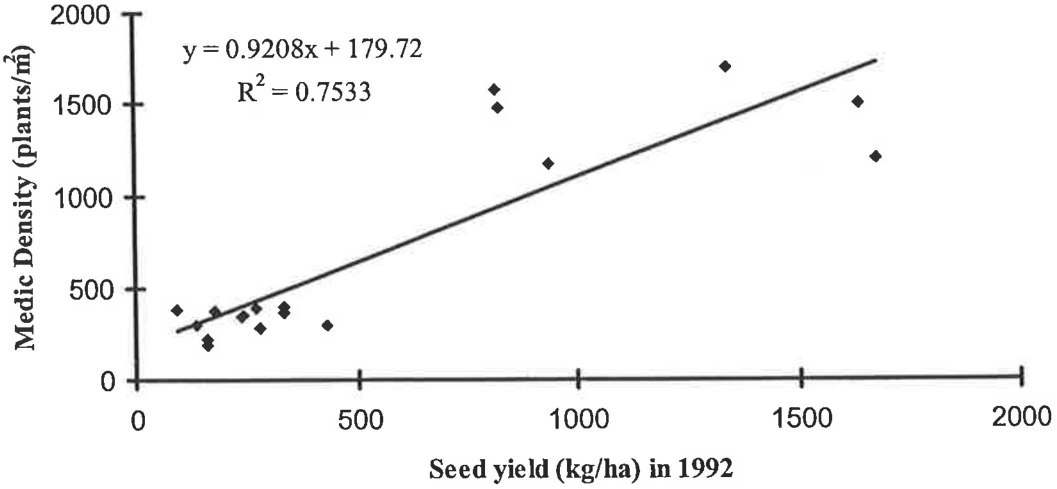

Figure 3.7 Relationship between seed yield in 1992 and medic plant density in June 1994.

3.3.1.8 Sheep Body-weight

Body-weight gain per sheep was not significantly different between stocking rates or pasture types, with a mean body-weight gain of 11.6 kg/sheep for the experiment. However, when gains are expressed on a daily basis (allowing for number of days spent on each pasture type) highest rates of gain were on the grass-free medic (Table 3.9). Total body-weight gain/hectare was 51% higher ($P<0.05$) at the higher stocking rate of 19.8 sheep/ha than at 13.2 sheep/ha. There was a significant ($P<0.05$) pasture type × stocking rate interaction for body-weight gain/hectare/day; highest gains were achieved at 19.8 sheep/ha on the grass-free medic pasture type.

Table 3.9 Mean body-weight (kg/sheep) and growth rate (kg/sheep/day) comparison of sheep from July 18 - November 8 1992 on three pasture types and two stocking rates.

	13.2 sheep/ha			19.8 sheep/ha			Tukeys HSD (P<0.05)		
	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Pasture	SR	Pasture × SR
Average treatment initial sheep body-weight (kg/sheep)	59.7	60.2	61.1	61.3	62	60.4			
Sheep body-weight gain during experimental period (kg/sheep)	11.5	10.8	12.3	12.2	11.3	11.5	n.s.	n.s.	n.s.
No. Grazing days	92	103	114	92	103	114			
Daily body-weight gain (kg/sheep/day)	0.125	0.104	0.107	0.132	0.109	0.101	0.016	n.s.	n.s.
Total body-weight gain (kg/ha)	151.8	142.5	162.3	241.5	223.7	227.7	n.s.	36	n.s.
Daily body-weight gain (kg/ha/day)	1.65	1.38	1.42	2.62	2.17	1.99			0.22

3.3.1.9 Pasture 1992 - Estimated Water Use

Neutron probe calibration revealed a high correlation between available water content and neutron count ratio. Mean bulk density and regression equations for the neutron probe used to estimate soil water content for each depth in paddock North 4A at Roseworthy are presented in Appendix Table B.6. Rainfall and evaporation data for 1992 are presented in Appendix Table A.1.

Significant treatment effects for water use and water use efficiency under pasture treatments in 1992 are shown in Table 3.10. Water use to flowering was significantly lower in the grass-free medic pasture type at the high stocking rate. Water use between flowering and maturity was highest in the grass-free medic pasture type. Total water use was higher in grass-free medic pasture types and lower with the high stocking rate. Water use efficiency to flowering was highest for the oat+grass+medic pasture type and higher at the low stocking rate. Water use efficiency in terms of seed production, was highest in the grass-free medic pasture type and significantly more at the low stocking rate than the high.

3.3.1.10 Pasture 1992 - Available Water at 0-800mm Depths.

Rainfall data are presented in Appendix Table A.1. At medic flowering there were significant effects of pasture type($P<0.05$) and of stocking rate on available water at 200-400 mm depth ($P<0.05$) and a significant ($P<0.05$) pasture type × stocking rate interaction at the 600-800 mm depth, (Figure 3.8a and Figure 3.8b). At this stage the grass-free medic pasture type at the high stocking rate had the highest available moisture through the soil profile. By medic seed maturity there was a significant ($P<0.05$) effect of pasture type at all depths and a significant ($P<0.05$) effect of stocking rate at 0-200 mm and 600-800 mm depths. The grass-free medic pasture had the least soil water at all depths.

Table 3.10 Mean soil water (mm) at plant emergence, water use (mm) between medic emergence and flowering and between medic flowering and maturity, total water use (mm) and water use efficiency (kg/ha/mm) for three pasture types at two stocking rates in 1992

	13.2 sheep/ha			19.8 sheep/ha			Tukeys HSD (P<0.05)		
	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Pasture	SR	Pasture × SR
Soil water (to 1m depth) at plant emergence (mm) (June 4th)	181	187	184	183	195	189	n.s.	n.s.	n.s.
Water use to flowering (mm) (October 13th)	260	267	271	221	274	270			26
Water use between flowering and maturity (mm) (November 6th)	177	100	111	192	71	92	33.7	n.s.	n.s.
Total water use (mm)	438	367	383	413	345	363	26	21.2	n.s.
Biomass to flowering (kg/ha)	9004	8758	10334	6472	8575	10147			420
WUE Biomass to flowering (kg/ha/mm)	34.6	32.8	38.1	29.3	31.4	37.8	2.6	1.4	n.s.
Medic seed yield (kg/ha)	1551	262	291	861	225	179			225
WUE Medic Seed (kg/ha/mm)	3.5	0.71	0.76	2	0.66	0.49			0.7

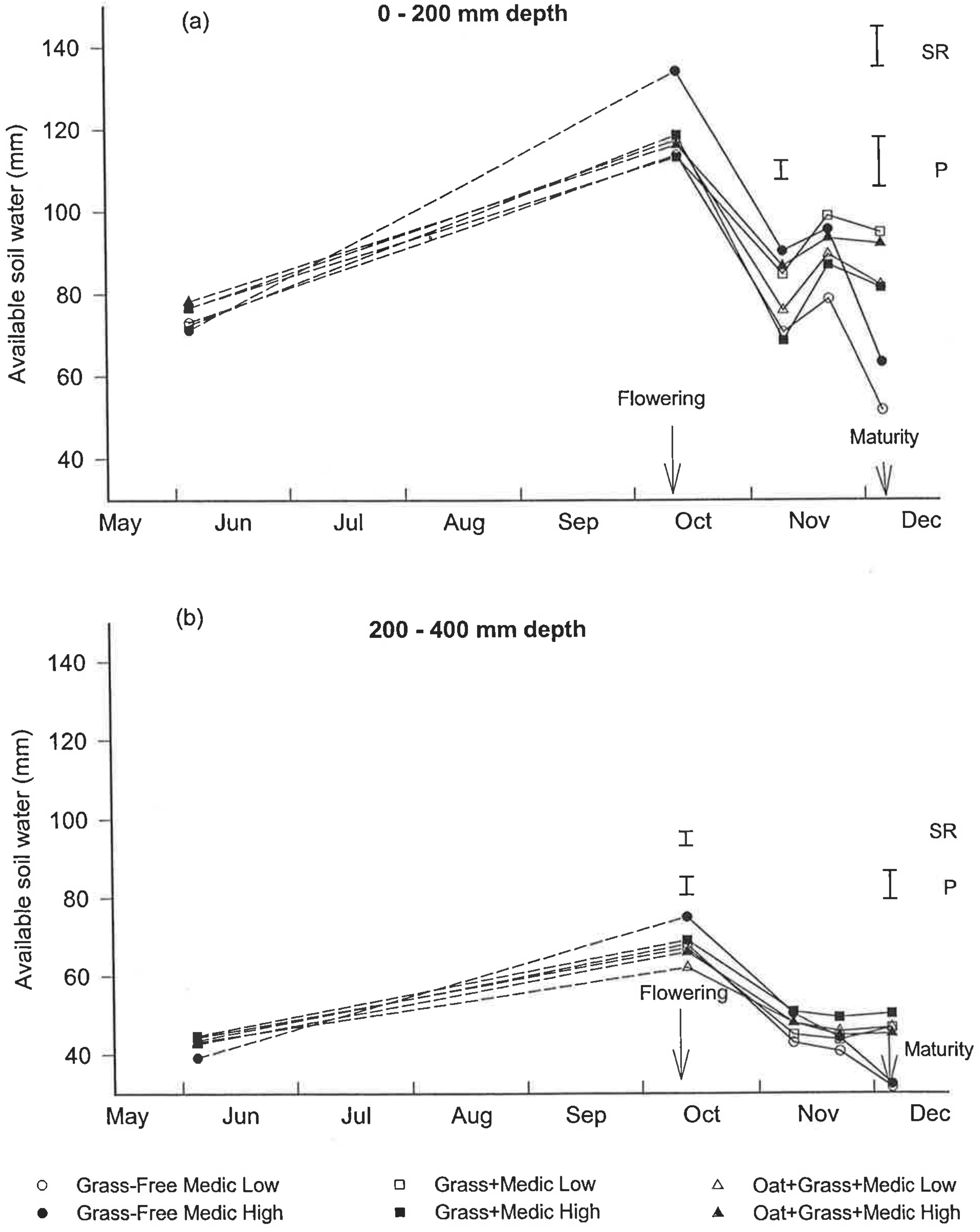

Figure 3.8a Soil water at (a) 0-200 mm and (b) 200-400 mm depth for three pasture types (P) and two stocking rates (SR) in 1992. Measurements taken at medic emergence, flowering and seed maturity. Vertical bars indicate Tukeys HSD (P<0.05).

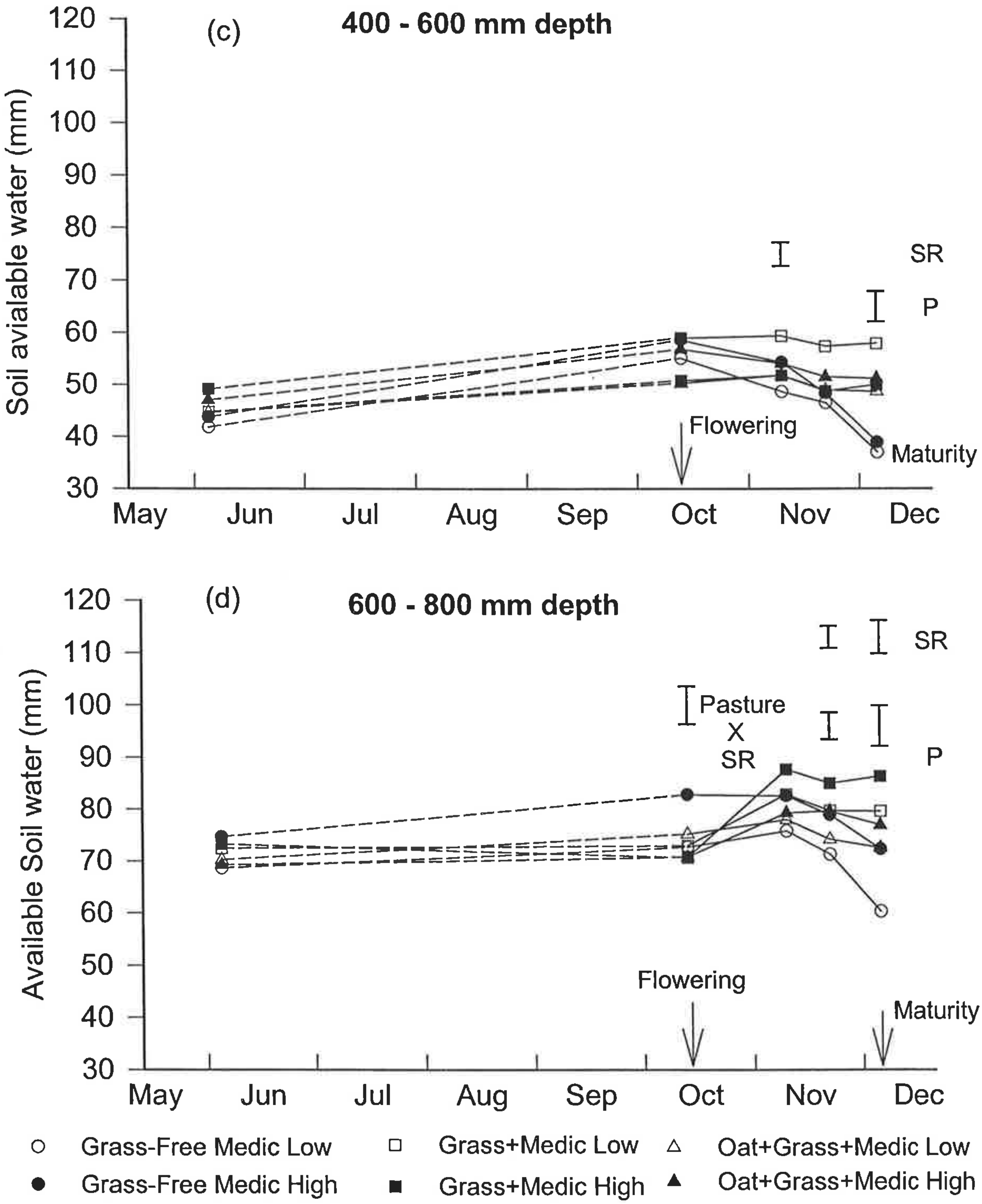

Figure 3.8b Soil water at (c) 400-600 mm and (d) 600-800 mm depth for three pasture types (P) and two stocking rates (SR) in 1992. Measurements taken at medic emergence, flowering and seed maturity. Vertical bars indicate Tukeys HSD (P<0.05).

3.3.1.11 Soil Nitrogen and Organic carbon

Total Nitrogen and Organic Carbon %: There was no significant effect of treatments on total nitrogen or organic carbon %. However there was a significant ($P<0.05$) correlation between total soil nitrogen and organic carbon (Figure 3.9). The carbon : nitrogen ratio was approximately 13.9.

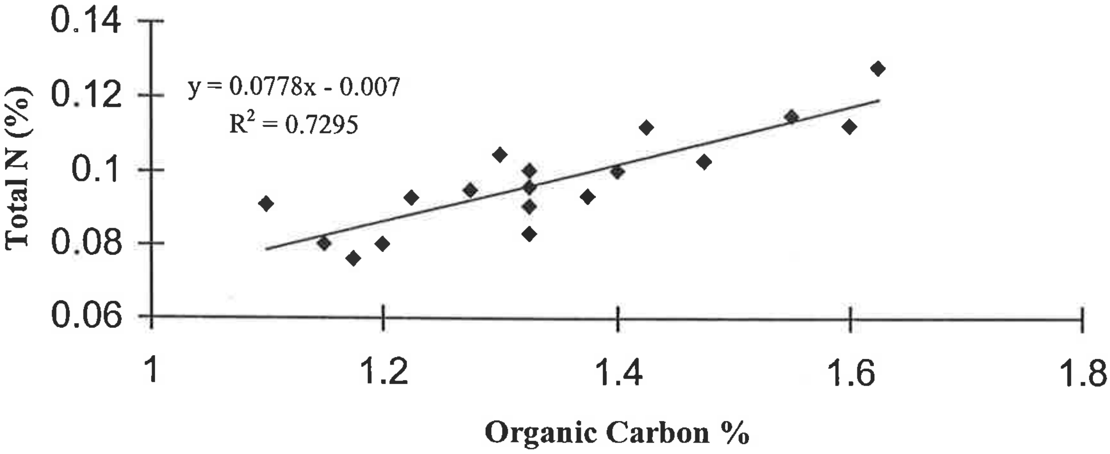

Figure 3.9 Correlation between soil organic carbon % and total soil nitrogen at 0-20cm depth after two years of pasture in 1993 (mean of all plots and three replicates).

Soil Nitrate(March 6th 1993): There was a significant ($P<0.05$) pasture type × stocking rate effect with the grass-free medic pasture type at 13.2 sheep/ha having the highest level of nitrate in the top 20cm of soil (Table 3.11).

Table 3.11 Mean soil nitrate concentration (mg/kg) at March 6 1993 at 0-20cm depth for three pasture types (P) at two stocking rates (SR) in 1992.

	Grass-free Medic	Grass+Medic	Oat+Grass+Medic	Tukeys HSD (P<0.05)
				P × SR
13.2 sheep/ha	31.8	22.6	14.1	6.6
19.8 sheep/ha	20	19.4	21.2	

Soil Nitrate Nitrogen to 1m in 1993: There was no significant pasture type × depth interaction or pasture type effect. However there was a significant ($P<0.05$) decrease in nitrate below the 0-10 cm layer (Table 3.12).

Table 3.12 Mean soil nitrate concentration (mg/kg) to 1m on March 5 1993 (mean of grass-free medic and oat+grass+medic pasture types at 19.8 sheep/ha).

Depth (cm)	Soil nitrate (mg/kg OD soil)
0-10	20.1
10-20	5
2-40	3.3
40-100	2.5
Tukeys HSD ($P<0.05$)	6

3.3.2 Wheat Crop 1993

3.3.2.1 Medic and Weed Regeneration Density

Regeneration May 20 1993: Medic plant density was significantly ($P<0.05$) higher following the grass-free medic pasture type than the other pasture types. In contrast both barley grass and ryegrass plant densities were significantly lower after grass-free medic and the highest barley grass densities occurred following the grass+medic pasture type (Table 3.13).

July 6 1993: After the initial weed and medic populations had been killed in May the subsequent cultivation to prepare a seed bed for sowing stimulated a second germination of medic and weeds. Medic plant density was significantly ($P<0.05$) higher following the grass-free medic pasture type in both early and late times of sowing, a result of the different number of cultivations. Both barley grass and ryegrass plant density were significantly ($P<0.05$) higher in the grass+medic pasture type for both early and late times of sowing (Table 3.14; Table 3.15). The effect of additional cultivation for the second time of sowing was to reduce all weed numbers by killing the emerging plant population (Table 3.15) but weed densities were still high.

Table 3.13 Mean regeneration plant densities (plants/m^2) of medic, soursob, three corner jack, Indian hedge mustard, annual ryegrass and barley grass on May 20 1993 following three pasture types and before sowing wheat (means of two stocking rates).

Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Medic	910	337	282	72
Barley Grass	13.7	194	157	19
Rye Grass	8.2	47	43	14.9
Soursob	28	25.5	27.2	n.s.
Three Corner Jack	21.3	18	18	n.s.
Indian Hedge Mustard	13.8	15.6	10.6	n.s.

Table 3.14 Mean plant densities (plants/m^2) of medic, soursob, three corner jack, Indian hedge mustard, annual ryegrass and barley grass for the first time of wheat sowing measured on July 6 1993 following three pasture types (means of two stocking rates).

Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Medic	700	257	216	38
Barley Grass	30	312	192	29
Rye Grass	14.2	161	129	14.8
Soursob	30	27.3	27.2	n.s.
Three Corner Jack	18.7	16.8	14	n.s.
Indian Hedge Mustard	12.5	13.3	14.8	n.s

Table 3.15 Mean plant densities (plants/m^2) of medic, soursob, three corner jack, Indian hedge mustard, annual ryegrass and barley grass for the second time of wheat sowing measured on July 6, 1993 following three pasture types (means of two stocking rates).

Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Medic	430	218	164	51
Barley Grass	14	142	96	17.8
Rye Grass	13	106	89	25.9
Soursob	25	20	23	n.s.
Three Corner Jack	16.8	13	13	n.s.
Indian Hedge Mustard	9.8	11.5	12.5	n.s

3.3.2.2 Wheat Plant Establishment Densities

Wheat plant densities were significantly ($P<0.001$) highest following the grass-free medic pasture type (Table 3.16) Mean density in the second sowing (160 plants/m^2) was significantly ($P<0.001$) higher than that in the first sowing (135 plants/m^2). These plant populations are considered too low for achieving potential yield in this environment and it is suspected that a mouse plague reduced the number of seeds before they germinated and emerged; however treatment differences were still consistent.

Table 3.16 Mean wheat plant density (plants/m^2) in 1993 (mean of two stocking rates).

Time of Sowing	Grass-Free Medic	Grass+Medic	Oat+Grass Medic	Mean
1st Sowing	185	111	111	135.7
2nd Sowing	217	132	131	160
Mean	201	121.5	121	
Tukey's HSD ($P<0.05$)		Pasture = 17.6		
			Time of Sowing = 7.3	

3.3.2.3 Wheat Plant Biomass, % Plant Nitrogen, Total Plant Nitrogen/ha

Dry matter yield on August 8 was significantly higher ($P<0.01$) in the grass-free medic pasture plots but not at anthesis, which occurred on October 15 in the early sown wheat and October 18 in the late sown wheat (Table 3.17). Wheat plant nitrogen percentage (August 8) was also significantly different ($P<0.05$) with a pasture × stocking rate × time of sowing interaction (Figure 3.10). Total plant nitrogen/ha in harvested DM was estimated to be approximately 30 kg/ha higher ($P<0.001$) following grass-free medic pasture type than in the other treatments (Table 3.17). Table 3.17 is the combined data set for both times of sowing and stocking rates as their main effects were pasture type. Figures 3.10, 3.11 and 3.12 show the interactions for the wheat yield components more clearly.

Table 3.17 Mean wheat plant densities (plants/m^2), dry matter yield, total nitrogen/ha, ears/m^2, grains/ear, grain weight (mg), grain yield (kg/ha) and % screenings for 1993 (means of two stocking rates and two times of sowing; analysis for % screenings based on square root transformed data, figures in parenthesis are the means of original data).

	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Plants/m^2	201	122	121	17.5
DM yield (kg/ha) Aug. 8.	4204	3097	3167	585
DM yield (kg/ha) Oct. 15.	6929	5761	5981	n.s.
Total Plant Nitrogen (kg/ha)	85.8	54.6	55.6	13
No. wheat ears/m^2	431	199	219	53
No. grains/ear	18.6	20.5	18.8	1.6
Grain weight (mg)	38.8	36.9	36.3	1.3
Grain yield (kg/ha)	3173	1509	1502	237
% Screenings	2.52(6.7)	2.85(8.4)	2.94(9.8)	0.74

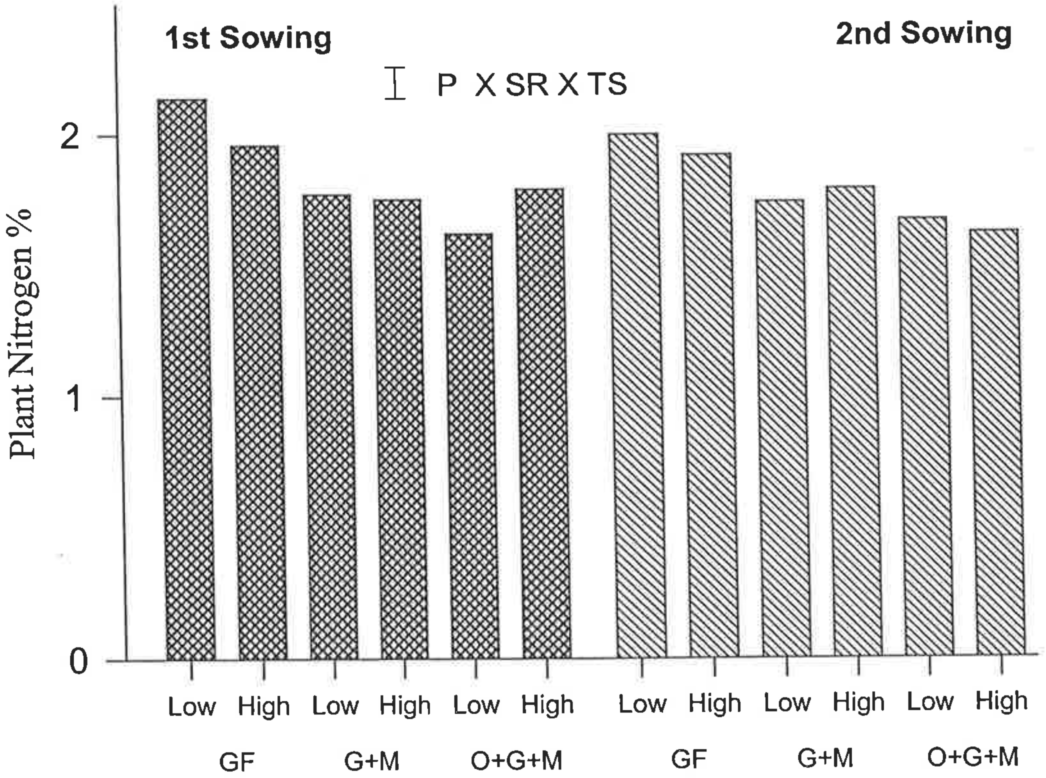

Figure 3.10 Wheat plant nitrogen (% dry matter basis) on August 8 1993 following three pasture (P) types at two stocking rates (SR) in 1992 and two times of sowing (TS). Vertical bar indicates Tukeys HSD (P<0.05).

3.3.2.4 Wheat Ear Density, Grains/Ear, Grain Yield, Grain Weight, Grain Volume Weight, Screenings % and Grain Protein %:

Wheat Ear Density and Grains/Ear: The number of wheat ears/m^2 were significantly ($P<0.001$) higher in the grass-free medic pasture type, about double the density in the other pasture types. The number of grains/ear was significantly though not markedly higher in the grass+medic pasture type (Table 3.17).

Grain yield: There was a significant ($P<0.05$) pasture type × time of seeding interaction as well as stocking rate ($P<0.001$) effect on grain yield (Figure 3.11). On average, grain yields after the grass-free medic pasture type were 2.1 times higher than following the other pasture types (Table 3.17). Grain yield was also higher in the low stocking rate treatments and higher in the second sowing than the first time of sowing (Figure 3.11).

Grain weight: There were significant pasture type ($P<0.05$), stocking rate ($P<0.05$) and time of sowing ($P<0.001$) effects. Grain weight was higher following the grass-free medic pasture type than the other two (Table 3.17). The high stocking rate reduced grain weight from a mean of 38 mg to 36.6 mg. The first time of sowing had a higher mean grain weight of 39.7 mg compared to the second time of sowing, 34.9 mg.

Grain volume weight: The grain volume weight of the first time of sowing (81.1 kg/hL) was significantly ($P<0.001$) higher than that of the second (79.7 kg/hL).

Screenings %: There were significant pasture type ($P<0.05$) effects with the percent screenings lower after the grass-free pasture type (Table 3.17). Stocking rate increased screenings from a mean of 7 % at the low stocking rate to 8.4 % ($P<0.05$) at the high stocking rate. First time of sowing had a mean of 5.5 % with the second time of sowing 11.3 % ($P<0.05$).

Grain Protein %: There was a significant ($P<0.001$) pasture type × stocking rate × time of sowing interaction (Figure 3.12). Grain protein % was significantly higher (in most treatments) following grass-free medic at both times of sowing. Delayed sowing increased grain protein percentage slightly.

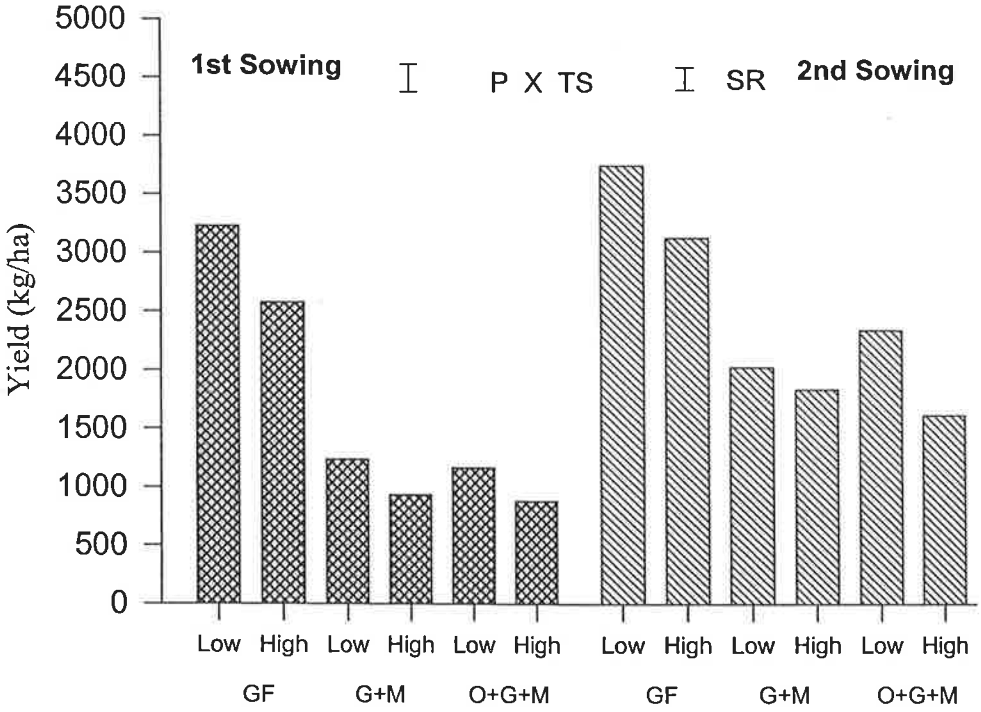

Figure 3.11 Grain yield (kg/ha) of wheat following three pasture (P) types at two stocking rates (SR) and two times of sowing in 1993. Vertical bars indicate Tukey's HSD (P<0.05).

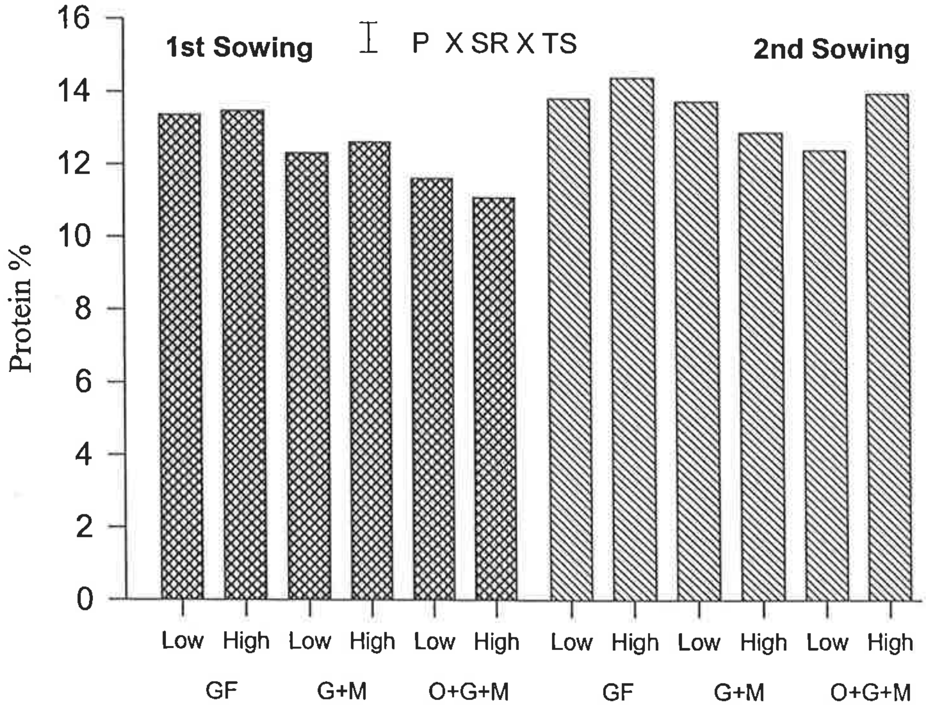

Figure 3.12 Wheat grain protein concentration following three pasture types (P) at two stocking rates (SR) and two times of sowing (TS) in 1993. Vertical bar indicates Tukey's HSD (P<0.05).

3.3.2.5 Incidence of Take-all, Cereal Cyst Nematode and Pratylenchus

Take-All: There was a significant (P<0.001) effect of pasture type at both sampling times (August 8 and October 15). The percentage of seminal roots infected with *Ggt* was very high (40%) after the grass+medic pasture type, intermediate for oats+grass+medic (27%) and low (5%) in the grass-free medic pasture type (Table 3.18). There was a positive linear relationship (P<0.05) between the density of barley grass plants in the pasture in 1992 and the level of *Ggt* infection in wheat plants in 1993 (Figure 3.13).

Root Lesion Nematode: Pratylenchus neglectus numbers/wheat plant increased significantly (P<0.05) from a mean of 4 in low stocking rate plots to a mean of 5 in high stocking rate plots. Numbers were reduced significantly (P<0.05) from a mean 31 to 23.8 nematodes/gram dry root weight with the second time of sowing.

Cereal Cyst Nematode: Careful examination of the wheat roots provided no evidence of CCN damage.

Table 3.18 The proportion of wheat seminal roots infected with take-all in 1993 following three pasture types (mean of two stocking rates; analysis of take-all based on square root transformed data, figures in parenthesis are the means of original data).

	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Proportion of wheat seminal roots with *Ggt* lesions Aug. 8.	0.16(0.02)	0.62(0.39)	0.5(0.25)	0.03
Proportion of wheat seminal roots with *Ggt* lesions Oct. 15.	0.23(0.05)	0.63(0.4)	0.49(0.27)	0.12

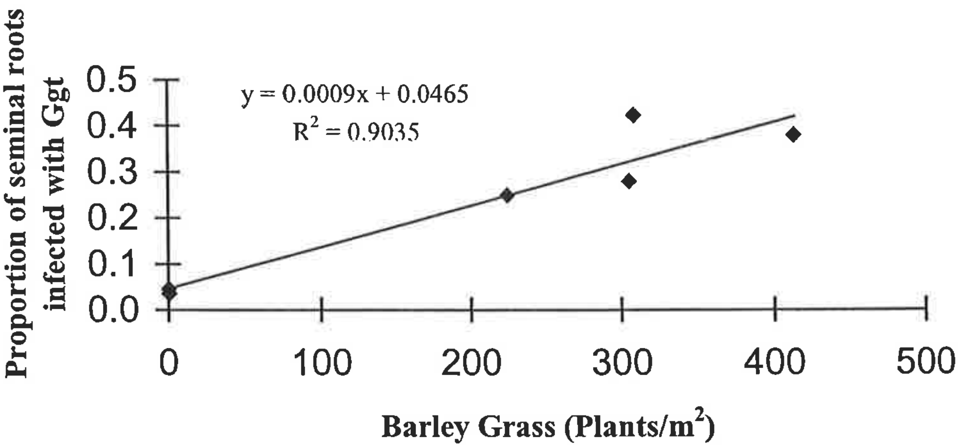

Figure 3.13 Relationship between barley grass plant density in 1992 and take-all infection in wheat in 1993 (mean of two sowing times and two stocking rates).

3.3.2.6 Wheat 1993 – Soil Water content 0-800mm depth and estimated Water Use

Soil moisture content was only collected for the first time of sowing. Soil moisture (0-200mm depth) on June 18 was significantly higher ($P<0.05$) from a mean of 54.1 mm following the low stocking rate to 61.2 mm following the high stocking rate and on July 23 from 81.7 mm for the low stocking rate to 89.3 mm for the high stocking rate. For all other probe reading times and depths there were no significant differences in soil moisture.

Water use to anthesis was significantly ($P<0.05$) lower following the grass-free medic pasture type. Differences between 1992 treatments in water use from anthesis to maturity and in total water use were not significant (Table 3.19). Water use efficiency for biomass on August 8 and October 15 was significantly ($P<0.01$) higher following the grass-free medic pasture type. The pasture × stocking rate interaction on water use efficiency for grain yield was significant ($P<0.05$); highest efficiency occurred following the grass-free medic pasture type at both high and low stocking rates (Table 3.19).

Table 3.19 Mean soil moisture (mm) at wheat plant emergence, water use (mm) between emergence and anthesis, and between anthesis and maturity, total water use (mm) and water use efficiency (kg/ha/mm) for wheat in 1993 following three pasture types at two stocking rates (1st time of sowing).

	13.2 sheep/ha			19.8 sheep/ha			Tukeys HSD (P<0.05)		
	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Pasture	SR	Pasture × SR
Soil water (1m depth) before seeding (mm)	166	163	172	162	166	154	n.s.	n.s.	n.s.
Water use to Aug. 8 (mm)	86	116	117	91	115	110	n.s.	n.s	n.s.
Water use to anthesis Oct. 15 (mm)	211	240	244	220	357	239	16.3	n.s.	n.s.
Water use between anthesis and maturity (mm)	88	87	89	96	65	72	n.s.	n.s.	n.s.
Total water use (mm)	299	327	333	316	302	311	n.s.	n.s.	n.s.
Biomass Aug. 8 (kg/ha)	4799	3181	3281	3878	2869	2816	585	n.s.	n.s
WUE Biomass Aug. 8 (kg/ha/mm)	55.7	27.3	28	42.8	24.9	25.6	14.6	n.s.	n.s.
Biomass Oct. 15 (kg/ha)	7199	5239	6884	6855	5878	5995	n.s.	n.s.	n.s.
WUE Biomass Oct. 15 (kg/ha/mm)	34	21.8	28.3	31	24.8	25			2.7
Grain yield (kg/ha)	3228	1236	1166	2576	935	880	237	194	n.s.
WUE Grain Yield (kg/ha/mm)	10.8	3.8	3.5	8.2	3.1	2.8			0.8

3.3.3 Medic and Weed Regeneration 1994

June 21 1994: At the June 21 count, medic plant numbers/m^2 were very high in the grass-free plots confirming excellent regeneration of the medic. In addition annual grass numbers were low; however, three-corner jack and Indian hedge mustard plant densities were significantly higher ($P<0.05$) in the grass-free medic treatments. Barley grass numbers/m^2 were highest ($P<0.05$) in the grass+medic pasture type (Table 3.20).

Table 3.20 Mean regeneration plant density (plants/m^2) of medic, soursob, three corner jack, Indian hedge mustard, ryegrass and barley grass of three pasture type treatments on June 21 1994, the year following wheat (mean of two stocking rates).

Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Tukeys HSD (P<0.05)
Medic	1438	378	274	140
Barley Grass	65	1543	518	224
Rye Grass	15	156	309	n.s.
Soursob	55.7	46.5	46.7	n.s.
Three Corner Jack	51	14.8	27.3	9.9
Indian Hedge Mustard	11.1	5.8	5.8	2.2

Plant population dynamics 1992-1994: There was no significant difference between stocking rates. Medic plant density of the grass-free medic pasture type increased from a mean of 450 plants/m^2 in June 1992 to 1438 plants/m^2 in June 1994 compared to a slight reduction in plant numbers for the grass+medic and oat+grass+medic pasture types over the same period (Figure 3.14). Barley grass plant density increased considerably in the grass+medic treatment plots and to a lesser extent in the oat+grass+medic. With ryegrass however, the increase was highest in the oat+grass+medic treatment plots (Figure 3.14). Three corner jack increased over time in the grass-free medic pasture type. Soursob increased in all treatments. Indian hedge mustard also maintained a significant ($P<0.05$) increase over time in the grass-free medic pasture type but reducing back to similar numbers as per the pasture phase in June 1992 (Figure 3.14).

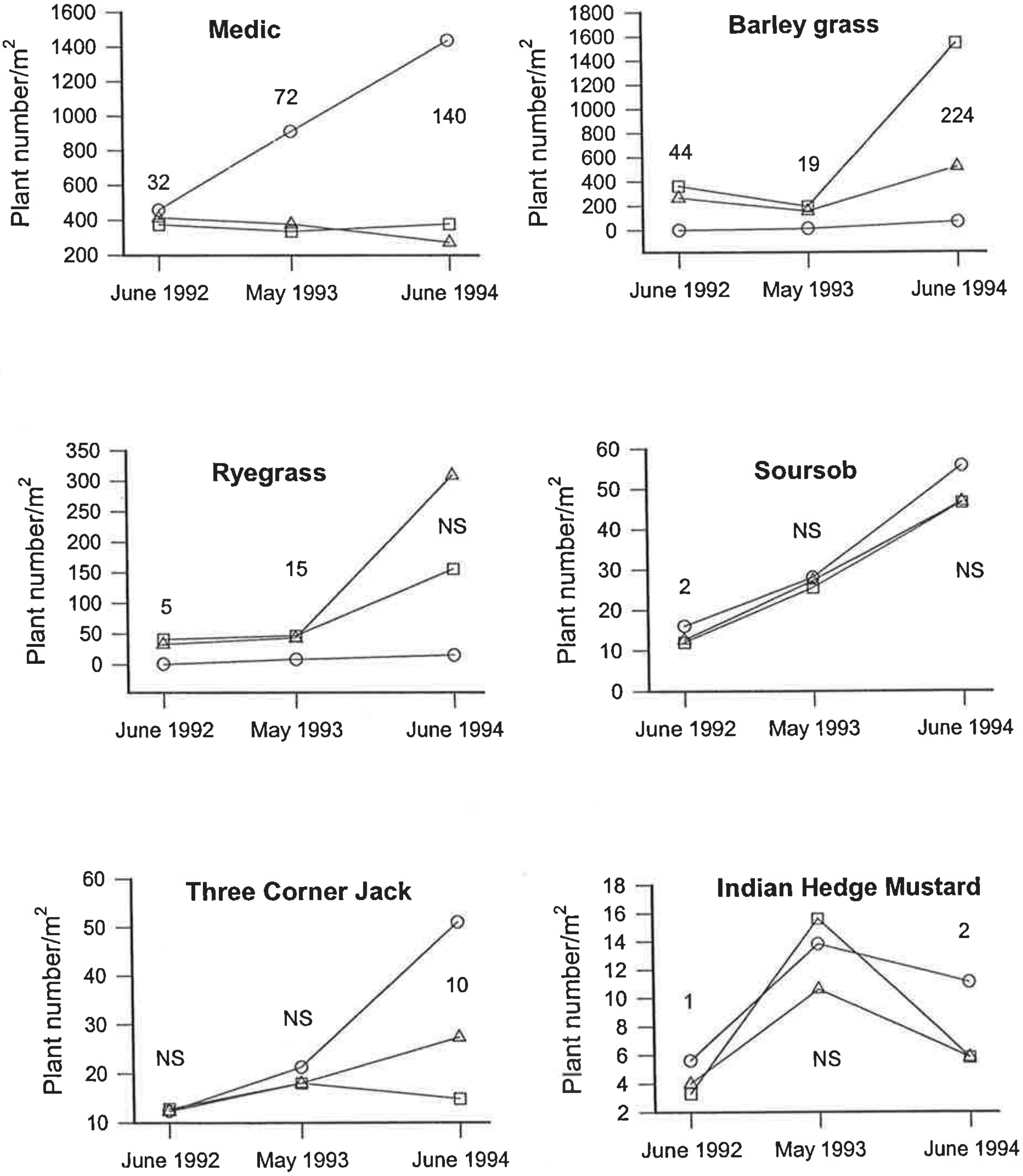

Figure 3.14 Population dynamics of medic, barley grass, ryegrass, soursob, three corner jack and indian hedge mustard for —⊖— Grass-Free Medic —⊟— Grass+Medic and —△— Oat+Grass+Medic from June 1992 to June 1994 (mean of two stocking rates). Numbers next to symbols are Tukey's HSD (P<0.05)

3.4

3.4 DISCUSSION

3.4.1 Pasture 1992

Plant Establishment: The carry-over effect of the 1991 pasture treatments was still obvious at the beginning of this experiment. The higher medic plant numbers in the grass-free medic treatment could be attributed to a combination of the previous year's pasture treatments, which were identical to the 1992 ones and the reduced competition from the removal of grasses. The reduction in barley grass density in the high stocking rate treatments is further evidence that the effect of previous pasture treatments on grass plant density persisted, even though the initial plant population in 1992 had been killed with herbicide and the plots re-seeded. Initial plant counts in 1991 (see Roberts 1991) showed an average barley grass density of 52 plants/m^2. Grass biomass was not large (840kg/ha) at the end of 1991 but it is not known how many seeds were set. The grass plant numbers at the break of the season in 1992 were extremely high which could suggest an almost complete germination or high soil seed bank level. It is well documented that the awned caryopses of barley grass become unpalatable to sheep as they approach flowering (Smith 1967; Cocks 1975), although high stocking rates can reduce barley grass awn density (Campbell *et al.* 1972; George 1972; Pearce 1973). Sheep in the low stocking rate treatments in 1991 would have avoided barley grass at maturity allowing a large number of seeds to mature, creating treatment differences for 1992.

Available Pasture and Botanical Composition: Early in the season (July 1992) the higher yields with the addition of oats suggest that available resources for plant growth were under-utilised by the existing species. The removal of the annual grasses further reduced resource utilisation and thus yield in the grass-free medic pasture type. The oat component therefore became an addition to rather than a substitution for the grass and medic components. While this extra DM from oats allowed the introduction of grazing 11 and 21 days before the grass+medic and grass-free medic pasture types respectively it did not have a suppressing effect on the volunteer grass until harvest 6 at the high stocking rate. In contrast the medic component was retarded from the second harvest onwards (July 29) indicating the inability of the medic to compete successfully against these gramineous species. As these measurements are conducted with the influence of grazing it is likely that the palatability of the medic was also an influencing factor. This suppression effect is very important as it is the yield of legume in pastures that determines the usefulness of the pasture phase throughout the rotation, the amount of nitrogen fixed and available to be returned to the soil being directly proportional to legume growth (Butler and Ladd 1985a; West and Wedin 1985; Hossain *et al.* 1995). The reduced total available dry matter in the grass-free medic treatment was similar to that reported by Thorn and Perry (1987) and Stephenson (1993) when they selectively removed grasses from annual clover in their experiments. The lower rate of grass accumulation over time with the addition of oats to the pasture (Figures 3.1 and 3.2) suggest the oat component was also affecting grass production; however there was little effect of stocking rate on the slope of these lines, even though available grass DM was significantly different. This reduction in grass component from competition and grazing, while encouraging as a low cost option for grass control, did not reduce grass biomass to a level where it did not have an effect on medic growth or associated take-all carryover in the following wheat crop. The lack of early differences between the grass-free medic and grass+medic pasture type in terms of total production agrees with the findings of Latta and Carter (1993) comparing grass-free medic with a grassy control. A similar situation occurred in this experiment where medic growth was replaced with grass and broad leaf weeds in the grass+medic treatments, such that the total production was not different in the early harvests. Whilst the question of increased medic density competing with grass and broadleaf weeds at emergence is not answered by this experiment, it is possible that at very high medic seedling numbers the medic may have competed more favourably. The agronomic expertise and cost of establishing and maintaining these high levels of plant numbers without some form of herbicide intervention may seem to preclude this as an option, since Latta (1994) concluded in the low rainfall study at Walpeup that a medic plant density of 600 plants/m^2 was not sufficiently high to out-compete annual ryegrass and barley grass.

The higher broadleaf weed in the grass-free treatments reflect their lower palatability and/or the reduced competition provided by medic against these weeds compared to the combination of grass+medic and oat+grass+medic. This disadvantage has been noted before by Barrett *et al.* (1973), Venn (1984), Latta and Carter (1993), Little *et al.* (1993) and Stephenson (1993). Similar results of sheep avoiding broadleaf weeds in other grazing experiments have been recorded by Broom and Arnold (1986) and the results agree with Rossiter (1966) and Curtis *et al.* (1989) that sheep preferentially select gramineous species. Except for soursob the broadleaf weeds in this experiment could be easily and inexpensively controlled in a commercial situation by the spray grazing technique of using sub-lethal rates of hormone herbicides, combined with intensive stocking rates for seven to ten days to graze out the weeds. The increase in broadleaf weeds is therefore not considered a problem provided they are weeds that can be controlled using appropriate management strategies.

The lack of a significant stocking rate effect on available medic and grass until August – September indicates that the greater consumption at the higher stocking rate may have been balanced by another factor such as a lower level of senescence. The effect was most pronounced in the grass-free medic pasture type under the high stocking rate with availability rapidly decreasing by harvest 6 (October 23) to below 1800 kg/ha. In contrast the higher medic availability, equivalent to the grass-free pasture type at high stocking rate, in the oat+grass+medic at the higher stocking rate treatment at harvest 6 (Figure 3.3b), was accompanied by a lower yield of oats. This suggests sheep preference for oats which may have reduced competition from oats on medic. The sheep may have been selecting the oat components either because of palatability or because it was easier to forage (Broom and Arnold 1986). If this could be exploited further it would be an advantage in maintaining legume biomass, growth and seed set.

Pasture Growth Rate: Previous authors (Amor 1965; Crawford *et al.* 1989) have commented on the poor early growth of annual legumes and this was reflected throughout this experiment in the grass-free medic treatment where growth rates were lower in winter compared to treatments with oats and volunteer grasses. Pasture growth rates of the grass-free medic pasture type were on average 3.5 times higher over the experimental period measured than the 15 kg/ha/day suggested by Crawford *et al.* (1989) as common for medic pastures in South Australia. Little *et al.* (1993) reported pasture growth rates of 7 and 15 kg/ha/day up to May for grass removed and grassy control subclover pastures respectively. The differences between these results and this experiment are a combination of deferred grazing of the pastures until approximately 1 t/ha of DM and the excellent growing conditions experienced in 1992. The effect of different stocking rates was minimal until the end of the growing season when pasture growth could not keep up with consumption at the high stocking rate. High plant density, particularly of the medic in the grass-free medic treatments would have also contributed to these excellent growth rates.

Seed Production: The well above average growing season rainfall (Appendix Table A.1) extending into November would account for the high herbage and seed yields in 1992 (Cocks 1995). The higher seed yield in the grass-free medic pasture was a result of high medic growth and lack of competition from grasses and agrees with studies by Latta (1994) who showed that increasing grass production decreased medic seed production. Seed yield was closely related to pod numbers (Figure 3.5); the high correlation between pod number and seed yield also reported by Cocks (1988a) and Muyekho *et al.* (1993a). At the high stocking rate the grass-free medic was reduced to 1500 kg/ha of DM and consequently seed production was reduced as the reproductive nodes were being removed by grazing (Tow and Alakailah 1981; Muyekho *et al.* 1992; 1993b). This capacity to set large seed yields and regenerate in later years is very important in pasture-cereal rotations as it provides a very cost effective method of establishing high density legume pastures. One interesting point in this experiment was that the higher stocking rate produced a greater percentage of soft seeds (Table 3.8). A possible explanation is that the greater number of sheep/ha scarified the pods and seed coat by trampling. There is not direct measure of this but it was significantly ($P<0.05$) evident across all pasture types.

Sheep Body-weight: Sheep body-weight gain did not significantly differ among treatments even though there were large variations between available forage for the three pasture types at the introduction of grazing. This is in contrast to McKinney (1972) whose model predicted pasture availability at the beginning of winter as the most important variable in determining sheep body-weight. This may be explained by the fact that grazing in the present experiment did not commence on each pasture type until approximately 1 t/ha of DM was available and available forage was presumably not limiting thereafter. The experiment by Roberts (1991) which regularly measured sheep growth rate on the same pastures showed no decline in body-weight as long as pasture DM levels were greater than 1 t/ha. The effect of stocking rate in this experiment was consistent across all pasture types and the fact that forage was not limiting (Figure 3.3a,b) for the time the sheep were grazing translated into live-weight gains/ha 1.5 times higher for the high stocking rate. The liveweight gain of 128 g/sheep/day is significantly less than the approximate 263-294 g/lamb/day reported by Brand *et al.* (1991) grazing medics in South Africa. This is however, higher than Brownlee and Denney (1985) who could only achieve 74 g/lamb/day grazing a range of medic cultivars in NSW. The differences may be attributable to the use of different medic cultivars and availability of feed on offer. There is little data on the differences in feeding values of various cultivars. Medic breeding programs are almost exclusively devoted to agronomic characteristics such as DM production and seed yield and as such differences in feeding value are often not apparent or measured.

Importantly in this experiment there did not appear to be any penalty for sheep grazing medic dominant, grass-free stands, where the sheep actually achieved higher weight gain/day, suggesting that the quality of the medic pasture was superior to the other pasture types. The literature review suggested that some digestive and nutritional problems may occur (redgut, bloat etc.) however none were evidenced in this experiment. This agrees with Little *et al.* (1992; 1993) who in a series of experiments with both grazing merino wethers and lambs have shown that liveweight is either equal or higher with grass removal on subclover pastures. This is in contrast to Dunlop and Thorn (1984) who showed that sheep live weight gain was up to 6 kg less from grazing grass-free subclover compared to a grassy control. The difference in results can be explained by the 30% reduction in available pasture DM that occurred with grass-removal in their experiment and the introduction of sheep onto all treatments at the same time. However later in a similar experiment Thorn and Perry (1987) showed that while sheep grazing grass-free subclover had lower liveweights compared to subclover plus grass during winter, compensatory gains, due to the improved quality of feed on offer enabled them to finish with higher liveweights by spring. This ability of sheep (Graham and Searle 1979; Thornton *et al.* 1979; Graham 1982) and cattle (Bird *et al.* (1980) to make compensatory growth allows short periods of inadequate pasture quantity and/or quality to be tolerated early in the season, provided there is a following period of adequate pasture of excellent nutritional quality for the animals to utilise. As live weight was not measured continuously in this experiment it is possible that any early differences in live-weight were eliminated at the final weighing due to compensatory growth.

Water Use-Pasture 1992: The grass-free medic pasture at the high stocking rate used less water to flowering, reflecting the lower above ground DM for this treatment compared to the low stocking rate. This was also consistent with water moving down the profile in this treatment and probably leaching below the root zone (Figure 3.8b). The greater water use between flowering and maturity for the grass-free medic pasture type at both stocking rates is a reflection of the later senescence of medic compared to the grasses and corresponding transpiration. This is confirmed by the higher total water use and the greater depth at which water was utilised in the grass-free medic pasture types (Figure 3.8b) even though total DM production was higher in the oat+grass+medic pasture types (Table 3.10). This is in contrast to Blumenthal and Ison (1993a and b) who showed that *M. murex* seed yield was negatively correlated with water use. It is unclear why their result was different but is likely to be a result of the high rainfall associated with the 1992 season in this experiment compared to the lower rainfall at the end of their experiment and the poor productivity of the *M. Murex* stands they were experimenting with. Water use efficiency (Table 3.10) for DM was higher than that suggested by Puckridge and French (1983) who estimated figures of 20-25 kg DM/ha/mm. They also estimated seed yields of 1-2 kg/ha/mm which were easily achieved in this experiment in the grass-free medic pastures; however the other two treatments struggled to achieve half of this. The higher DM figures may be related to the extended growing season provided by late finishing rain in 1992. The method of estimating water use efficiency utilises total rainfall in its equation and makes no distinction between the usefulness of the timing of rainfall events. Rainfall towards the later part of the growing season can be utilised more efficiently than at the beginning due to the higher temperatures, available light energy and more advanced nature of the plants (greater leaf area intercepting a greater proportion of the available light) contributing to higher photosynthetic potential/land unit area.

Soil Nitrogen-March 1993: The high soil nitrate level in the grass-free medic at the low stocking rate (Table 3.11) reflects the higher legume DM production of the 1992 pasture of this treatment. At the time of sampling nitrate had not moved down the soil profile (Table 3.12), although this is the result of two years of pasture. This contrasts with Stephenson (1993) who did not find any differences in soil nitrate, after one year, between grass-free subclover and barley grass-subclover pastures. Stephenson's (1993) result is unusual and is not representative of other results involving high density legume dominant pastures. It is possible in that experiment that the high background nitrate levels (141-168 kg N/ha in the 0-70 cm soil profile) masked any nitrogen fixing ability by the subclover. Due to the high available N the subclover may have used the soil available nitrogen replenishing only what it took rather than adding to the available pool. Alston and Graham (1982) suggested that high soil available N could inhibit N fixation in medics and similarly this is likely to have occurred in Stephenson's study. The lack of correlation between soil nitrate and total soil nitrogen and organic carbon levels found in this experiment has also been noted by White *et al.* (1994) in their studies with grazed medics. Alston and Graham (1982) also reported no correlation between total nitrogen and mineral nitrogen after an examination of soils which had undergone medic-cereal rotations. As suggested before, the available N was the most important factor in determining N_2 fixation in their experiment.

Root Diseases Bio-assay: The soil bio-assay on June 2nd 1992 for take-all produced results that agree with those from published work by MacLeod *et al.* (1993), MacNish and Nicholas (1987), Cotterill and Sivasithamparam (1988a and b), showing higher take-all levels in the soil from the grass+medic and oat+grass+medic pasture types than the grass-free pasture type. CCN levels were negligible, as in the previous year (Roberts 1991) confirming the absence of host plants and the inability of the nematode to significantly multiply on the predominant grasses, ryegrass and barley grass (Rovira 1990). Studies by researchers of the effects of root lesion nematode are in their infancy and consequently it is not known if the levels recorded in this experiment constitute damaging numbers. There appeared to be no relationship between take-all and *Pratylenchus neglectus* in this experiment. Yet, other researchers (Taheri *et al.* 1994) have found a negative effect of *Pratylenchus* spp. on take-all infection in wheat.

The consequences of these bio-assay results are that the following wheat crop would be likely to be affected by take-all in the grass+medic and oat+grass+medic pasture types. The level of yield reduction would depend on the spring rainfall incidence as shown by Roget and Rovira (1991).

3.4.2 Wheat 1993

Wheat Biomass, Plant Nitrogen, Grain Yield and Quality: Wheat grown after the grass-free medic pasture type had a distinct advantage in all measured plant attributes, compared to the other two treatments. The higher dry matter after grass-free medic pasture was also associated with an increased percent plant N (Figure 3.10) suggesting that the higher soil nitrogen levels were a contributing factor to the improved grain yield. Evidence for this was the increase in the number of wheat ears/m^2 after the grass-free medic pasture type, a result of both increased plant density and a greater number of tillers surviving to anthesis (Table 3.17). Although number of grains/ear was reduced in the grass-free medic compared to the grass+medic treatment, grain weight and protein percentage (Figure 3.12) were significantly higher than in either of the other two treatments. Nitrogen is a major nutrient in tiller survival and wheat head retention and has been shown to increase tillers, grains per spikelet and grain protein (Halse *et al.* 1969; Smith and Levick 1974; Whingwiri and Kemp 1980; Blacklow and Incoll 1981). However high nitrogen levels are only useful to the crop provided that other factors such as root diseases and weeds are not limiting crop growth. The very low grass weed numbers in the grass-free medic plots and the significant reduction in take-all would have allowed the full utilisation of nitrogen. Forcella (1984) demonstrated that in mixtures of wheat and ryegrass, if nitrogen was not in adequate supply in early growth, ryegrass would attain a competitive advantage because of its ability to utilise nitrogen more effectively at all stages of growth. This is likely to have been a problem in the grass+medic pasture type treatments.

The increase in grain yield with delayed sowing (Figure 3.11) could be attributed to the reduction in the numbers of weeds by cultivation (Table 3.15). The effect of the previous stocking rate on grain yield (higher yield following low stocking rate) is likely to be the result of higher N input from the higher medic growth at the low stocking rate in 1992. Thorn (1985; 1992) explained an increase in grain yield after clover pasture with higher stocking rate due to a decrease in grass numbers and reduced take-all; however this effect was not present in this experiment. The discrepancy in this argument is the reduced yield in the oat+grass+medic pasture type at the high stocking rate in the second time of sowing, even though it had higher levels of soil nitrate than the corresponding low stocking rate treatment. The higher grain protein (Figure 3.12) after this treatment suggests that nitrogen was not limiting, hence another factor was limiting yield, possibly take-all. It is common for wheat crops infected by take-all to have reduced yield but higher protein levels because the plant available nitrogen is distributed amongst less wheat grains raising the protein levels.

Weed Density: The large amount of barley grass that germinated and emerged late in the season in plots that were previously the grass+medic treatment shows there was a large amount of barley grass seed in the soil. Surprisingly after killing the initial emergence of barley grass seedlings the numbers of plants that emerged again was still high. This contrasts with McGowan (1970) who showed that 91%-97% of barley grass seeds germinated within 61 to 76 days of the opening rains. As seed set was not restricted in 1992 (except by grazing) a very large number of grass seeds could have been set, thus building up the seed bank to a high level. As previously mentioned, sheep will preferentially graze other species besides grasses towards the end of head formation. Surprisingly there was no significant stocking rate effect on grass numbers as reported by Pearce (1973), Reeves and Smith (1975) and Dowling and Wong (1993). The high levels of grass in the wheat crop after the grass + medic treatment would have reduced the wheat yield as barley grass cannot be controlled in wheat with herbicides.

Root Diseases: The high levels of take-all in plots that previously had grass+medic and oat+grass+medic pasture types were highly correlated with the barley grass density in these pasture types (Figure 3.13) and agreed with the results of MacNish and Nicholas (1987) and MacLeod *et al.* (1993). The results also agree with Cotterill and Sivasithamparam (1988b) who reported take-all was more severe after grass- infested medic stands than after pure medic. Inwood *et al.* (1991) and Inwood and Roget (1993) have shown that barley grass is the main host for take-all. The levels of take-all in a crop are also affected by climatic conditions in the previous season, as take-all prefers wet soil (Cook and Papendick 1972). Roget and Rovira (1991) have also shown that rainfall in September greater than 61 mm increases the severity of take-all damage on wheat plants; a situation that occurred in 1992 and 1993 (Appendix Table A.1), and would have increased the severity of take-all (Roget 1993).

This experiment suggests that the increased wheat grain yield and quality following grass-free medic pasture type, compared to the other two treatments is due to a combination of increased plant density, reduced grass competition, reduced take-all levels and higher availability of soil nitrogen. Wheat following grass-free pastures exhibited superior attributes in all yield components measured compared to the other treatments; hence no obvious single parameter was responsible for the yield advantage or disadvantages experienced by the other treatments. This highlights the importance of the systems type of approach used in this experiment to compare the effect of these pastures on wheat and measuring multiple parameters that may influence results.

The results agree with those of other researchers who have conducted similar experiments on grass-free annual legume-crop rotations; all reported increased grain yields associated with grass-free pastures when compared to grassy pastures (Thorn 1985; MacLeod *et al.* 1993; Stephenson 1993). Of the experiments using medic based pastures, Venn (1984) showed an increase of 53% in wheat grain yield with grass removal in the previous pasture and Latta (1994) reported a 20% increase in wheat grain yield and 1% protein increase when the preceding year's annual grass level was reduced to less than 10%. These researchers could not clearly define the exact reasons for the increase in wheat yields, suggesting a combination of the factors mentioned above contributing to the increase in yield. As there are no previous experiments in which oat/legume treatments have been compared in rotations to pure legume or grassy pasture stands for yield and wheat quality; it would appear that the addition of oats in grassy pastures does have a positive impact by improving the yield and quality of following wheat crops but only minimal compared to the large advantage that grass-free medic pastures offer, although this is the only available information on the topic.

Water Use: Water use efficiency for both dry matter and grain yield of wheat was greater following the grass-free pasture type, due to greater yield of biomass and grain for the same water utilised. This approached Puckridge and French's (1983) WUE estimate for DM production of 30-35 kg/ha/mm and WUE of grain yield of 10-12 kg/ha/mm; however the other treatments were well below this, confirming that other factors (see above) than water availability were limiting their production. Connor *et al.* (1992) have also reported similar WUE results for grain yield under rain-fed conditions. French and Schultz (1984) have suggested a maximum WUE of 55 kg/ha/mm for dry matter and 20 kg/ha/mm for grain yield of wheat. The difference between Puckridge and French (1983) and French and Schultz (1984) is likely to be due to the way they calculated potential yield. In addition Siddique *et al.* (1990) have shown that water use efficiency has improved in new wheat cultivars and this may have contributed to the improved water use figures quoted by French and Schultz (1984) after the new analysis was conducted.

3.4.3 Medic and Weed Regeneration in 1994 following the wheat crop

Population dynamics: There was a positive correlation between seed yield measured in March 1993 and medic plant density in June 1994 (Figure 3.7) suggesting that recent seed yield was the most important factor contributing to seedling density. This is also an indication that initial medic seed reserves were low (Tow 1989). The regeneration density of medic seedlings after wheat was more than 1400 plants/m^2 in plots that were previously grass-free medic. These values reflect the high level of seed production in 1992 in these treatments and are comparable to results of Cocks (1994) with *M. rigidula* and *M. polymorpha,* using similar tillage equipment, and of Carter and Fulwood (1993). These results must be interpreted in the context of not only of grass removal but also the above average 1992 rainfall and an extended growing season, seed yield being directly related to rainfall (Cocks 1994). There was also no grazing of pods over summer, a practice which can often remove large quantities of seed (Carter 1980). However regeneration of medic seedlings was poor in other treatments, below the 1000 plants/m^2 suggested by Puckridge and French (1983) for highly productive pasture and well below the 3000 plants/m^2 required to maximise early season dry matter production (Abd El-Moneim and Cocks 1986). None the less Carter (1982), Amenziane *et al.* (1988) and Tow (1989) have reported adequate establishment with 500-600 plants/m^2 and Carter (1982) has suggested a minimum of 400 plants/m^2 in low rainfall environments, with plant density being the most important factor affecting early pasture growth rate (Williams 1978; Abd El-Moneim and Cocks 1986). If medic density is not sufficient then the addition of oats as a supplementary species has a role. The addition of oats was shown in this experiment to compensate for low medic density as oats have a higher potential growth rate per plant than medic seedlings. In this experiment oat/medic combinations were superior in early DM production to grass-free medic and volunteer grass+medic treatments, which explains why farmers often adopt this practice.

The massive increase in both ryegrass and barley grass plants in 1994 (Figure 3.14) is evidence of these species' ability to rapidly dominate pastures if left uncontrolled (Dowling 1988). The barley grass : ryegrass ratio in July 6 1993 was 1.93 for the grass+medic pasture type compared to 1.48 for the oat+grass+medic pasture type (Table 3.15). This slight advantage in plant numbers plus the inability to control barley grass with a selective herbicide in wheat, allowing seed set, may explain the differences between the grass+medic and oat+grass+medic treatments in 1994 with a higher barley grass density compared to ryegrass which was not an issue in the grass-free medic pasture type. Cocks (1969) suggests that barley grass gains a competitive advantage over ryegrass in situations where the barley grass is germinating from the surface and when periods of light rain occur. Rainfall conditions in 1994 (Appendix Table A.1) were similar to this with the paddock left uncultivated until the plant counts were made and this together with the higher seed numbers would explain why barley grass was dominant in regeneration in the grass+medic pasture type plots..

Importantly grass control in all years of the grass-free medic pasture type meant that very low levels of grasses were experienced in this treatment in 1994, suggesting the seed bank had been exhausted. This is in agreement with Mathews (1994) who showed that annual ryegrass and barley grass populations can be almost eliminated after three years of preventing seed set. The addition of oats did contribute to barley grass reduction through competition but was not as effective as the grass selective herbicide and would not be suitable as a grass control method.

3.5 CONCLUSION

The addition of oats to medic based pastures increased early forage production available for grazing but subsequently suppressed medic, annual ryegrass and barley grass. The effect of medic suppression was carried through to seed set so that the ability of the medic to provide a dense regenerating pasture after one year of wheat was jeopardised. The increase in early production offered by introducing oats into the pasture allowed livestock to be introduced onto the pasture 21 days earlier but did not offer any advantages in increasing total liveweight or any improvements in animal health, probably due to the ability of the sheep to compensate in growth on grass-free medic.

The effects of high levels of grass in the pasture on the following wheat yield and quality were demonstrated in this experiment and agree with the results of other researchers who have compared grass-free legume pastures with grassy pastures. Wheat yield was severely reduced by up to 53% both from the root disease take-all and competition from the grasses where grass control was not present in the previous pasture year. The inability of the oat-medic mixture to suppress the grass to a level where it did not affect the following wheat crop by competition or take-all carry-over was also demonstrated.

The practical outcomes from this experiment suggest that the addition of oats in medic based pastures is dependant on management priorities and associated economics of the farming rotation. If the requirement is for a balanced diet with early feed for livestock production then the addition of oats may be beneficial. However, if the aim is to produce a high yielding, high protein wheat crop in the year following the pasture then a grass-free medic pasture is desirable. In order for the addition of oats to be profitable in the rotation the extra available forage would need to be turned into additional saleable livestock produce and balanced against the associated loss in wheat yield and protein. Thus this farming system is dictated as much by economics as agronomic practicalities. The major outcome from this experiment is that the medic component suffers from the addition of oats. In addition grass-free medic pastures have clearly been shown to provide high soil nitrogen levels and improved water use in following wheat crops. The use of a systems approach has highlighted why it is important to examine more than one component of the rotation in pasture-cereal production. Future experiments should be aimed at improving the competitive ability of the medic such that DM and medic seed yield is optimised, along with the associated N fixation.

Chapter 4

4. EXPERIMENT 2 - EFFECT OF SIMULATED AUTUMN AND WINTER TEMPERATURE ON OAT-MEDIC GROWTH AND COMPETITION

4.1 INTRODUCTION

Amor (1965) suggested that early rainfall in autumn favours medic establishment over grasses, as the seedlings are able to start branch development before winter. However in late rainfall breaks to the season the annual grasses grow more rapidly than medic due to their superior response to low temperatures and shortened day-length. The introduction of oats into medic based pastures is often practised in seasons when the opening rains, greater than 13 mm over a 7-day period (Cocks 1969), are delayed into late autumn/early winter, in order to increase the available forage for grazing animals. Experiment 1 (chapter 3) confirmed the increase in early available forage with this technique, however the results have also shown a reduction in medic growth and seed set. It is unknown whether the apparent reduced competitiveness of the medic component in medic-oat mixtures is a result of the lower temperatures associated with late starts to the season.

The study by Clarkson and Russell (1979) using *M. scutellata* and *M. truncatula* with a range of temperatures from 12/5°C (day/night) to 30/23°C showed that with the cv. Jemalong the days from planting to the first branch increased from 25 to 39 when the temperature dropped from 18/11°C to 12/5°C. It has also been shown by Taylor (1972) and Cocks (1973) that young spaced plants of subterranean clover responded positively to an increase in temperature up to 25°C. Mitchell (1956) and Morley (1958) concluding the optimum temperature for spaced subclover plants was between 20 and 25°C. Fukai (1974), Fukai and Silsbury (1976), Greenwood *et al.* (1976), Silsbury *et al.* (1984) and Silsbury and Hancock (1990) also working with subclovers, but in swards, showed that temperatures as low as 10/5°C (day/night) reduced subclover growth. In contrast Davidson *et al.* (1970) working with subclover swards reported that growth was not significantly affected by temperature (12°C vs 22°C).

The conclusion from these experiments is that low temperatures associated with winter establishments may reduce medic growth, but to an unknown extent. Furthermore the degree to which temperature will affect competition in oat-medic mixtures is not known. Should low temperatures associated with late establishments affect the growth and/or competitive ability of the medic in oat-medic mixtures then this would have an important bearing on the timing of sowing of this mixture.

The hypotheses of this chapter is that reduced winter temperatures common to Mediterranean environments place medic at a competitive disadvantage when grown in mixtures with oats.

Hence the aim of experiment 2 (chapter 4) was to determine if the temperature differences associated with autumn (early) and winter (late) establishment affect the productivity of oat-medic mixtures and more importantly the growth and competitive ability of medic.

4.2 MATERIALS AND METHODS

An examination of the long term mean maximum and minimum temperatures for The University of Adelaide, Roseworthy Campus (Appendix Table A.1) showed that the mean autumn (April and May) temperatures were: Max. 20.7°C and Min. 9.7°C and that the mean Winter (June and July) temperatures were: Max. 15.3°C and Min. 6.2°C.

4.2.1 Design of Experiment and Treatments

The experimental design was a randomised complete block design with five density ratios, two temperature regimes and 4 replications.

Treatments were: five oat-medic density ratios (Table 4.1)
two temperatures, autumn day/night 20/10°C and winter 15/8°C.

It was not possible to hold the growth cabinet temperature at 6°C, similar to the winter minimum, so the temperature was raised to 8°C for this treatment. The replacement series design was chosen to allow an estimation of competitive ability in each treatment. As per de Wit *et al.* (1966) experiments with legumes and grasses, two medic plants were equated to one oat plant. This is based on experience with previous experiments (Roberts 1990;1991), where early season growth is limited in medics compared to the faster growing oats, so in order to provide a more balanced mixture, the legume density is doubled. The sum of the relative plant frequencies still equals 1 (table 4.1).

Table 4.1 Replacement series planting ratios (seedlings/pot) for temperature simulation experiment.

Medic		Oats	
Plants	Relative plant frequencies	Plants	Relative plant frequencies
16	1	0	0
12	0.75	2	0.25
8	0.5	4	0.5
4	0.25	6	0.75
0	0	8	1

4.2.2 Seed Preparation, Establishment and Maintenance

Medic (cv. Paraggio) and oat (cv. Marloo) seeds were graded for uniformity of size. Scarified medic and oat seeds were pre-germinated on agar medium and incubated at 25°C upside-down to grow straight radicals. Seedlings were established in 22 cm diameter × 40 cm height PVC tube cylinders lined with a polythene bags and filled with steam sterilised University of California potting mix (Appendix C.1 and Table C.2). Seedlings were spaced equi-distant from each other in the ratios shown in Table 4.1. The ratios were chosen based on de Wit *et al.* (1966) where two pasture legumes were equated to grass pasture plant. Seedlings were inoculated at establishment with *Rhizobium* strain CC169. A sliding sleeve of plastic mesh was placed over the cylinders to confine the plant shoots to the same area as that of the cylinder surface. Alkathene beads (3 mm diameter) were placed on the cylinder surface to minimise evaporation.

Plants were placed in identical controlled environment growth cabinets with one temperature regime set to autumn simulation and the other winter simulation. The photoperiod was 11 hrs and changes in temperature coincided with the beginning and end of the photoperiod. Photosynthetic quantum flux at pot level was maintained at 340 μE m^{-2} s^{-1}. This light intensity is approximately 15% of full light conditions and approximately 50% of maximum photosynthetic rate in sub clover (Fukai and Silsbury 1977). These authors also showed that the ranking for CO_2 exchange rate in differing monoculture densities did not change with increasing light intensities except at very low LAI (2.1). The cylinders were watered to 90% field capacity at the start of the experiment and returned to this level every 7-10 days by weighing the cylinders to allow a measurement of evapotranspiration. Positions of cylinders were re-randomised at watering times. Nutrients above those in the potting mix were supplied by applying 60 g/pot of the slow release granular fertiliser Osmocote® (nutrient analysis Appendix Table C.3), 16 days after establishment.

4.2.3 Measurements

Harvest 1 was taken 47 days after establishment and regrowth harvest 2 taken 78 days after establishment. Plants were cut to 3 cm above the soil surface, oven dried at 80°C for 24 hrs and weighed. Evapotranspiration was calculated by weighing the cylinders and adding the appropriate amount of water to return the weight to the starting point of 90% field capacity. An estimate of soil water evaporation was made by measuring water use of cylinders with no plants but alkathene beads, at both temperature regimes. Transpiration was estimated as total evapotranspiration - evaporation but did not take into account the differential effects of the plant species on shading.

Plants were sprayed with LeMat ® (omethoate) to control an infestation of blue green aphids which were more prevalent in the high temperature regime.

An attempt was made to examine differences between nitrogen fixation in treatments using the acetylene reduction technique (Hardy and Holsten 1977) *in situ* to allow re-growth. Preliminary results did not detect any differences between the medic monocultures and the medic 4 : 6 oat plant sowing ratio, hence further examination was abandoned. The inability to detect differences in ethylene concentrations between the two treatments was probably due to the large volume of soil and the high amount of acetylene required to flood the cylinders minimising any detectable differences.

4.2.4 Analysis of Data

Analysis of variance was conducted on data using the statistical program Genstat V. The experiment was analysed as randomised complete block design for density ratios. It was not possible to replicate the temperature treatments, but as there were replicates within each growth cabinet and the variation between these was similar, this was used to provide a measure of error for temperature comparisons. In addition replacement series analysis was used to further investigate the effects of competition in oat-medic mixtures. A simple iterative method (W. Bowden pers. comm.) similar to that used by de Wit (1960) and de

Wit and van den Bergh (1965) was used to estimate curves for the change in dry matter per pot over the densities tested in the replacement series. The model had the form of

$$\mathrm{O}ij = \frac{\mathrm{yMax}\ i \times\ ki\ \times\ \mathrm{Density}\ i}{(1 + ki \times \mathrm{Density}\ i + kj \times \mathrm{Density}\ j)}$$

Where

$\mathrm{O}\ ij =$ yield per pot of species i grown with species j
$\mathrm{yMax}\ i =$ maximum yield of species i when grown in monoculture
$ki =$ constant for species i
$\mathrm{Density}\ i =$ density of species i
$kj =$ constant for species j
$\mathrm{Density}\ j =$ density of species j

The k coefficients are taken as a measure of the competitiveness of one species relative to another. The higher the k coefficient the more competitive the species is within the mixture. The ratio of the ki against kj can be used to measure the competitive ability of i relative to j within the environment where the plants were grown and hence can be used to compare values across environments provided the same species and replacement density ratios are used. Parameters ki, kj, yMax i were estimated by minimising the sums of squares of deviations of observed data from the fitted model estimates.

In addition relative yield totals (RYT) and relative yield ratios (RY ratio) were calculated for each mixture utilising the following formula (as per de Wit *et al*,1966).

$$\mathrm{RY}i = \frac{\mathrm{Y}ij}{\mathrm{Y}i} \quad \text{and} \quad \mathrm{RY}j = \frac{\mathrm{Y}ji}{\mathrm{Y}j}$$

$$\mathrm{RY}ij\mathrm{ratio} = \frac{\mathrm{RY}i}{\mathrm{RY}j}$$

$$\mathrm{RYT} = \mathrm{RY}i + \mathrm{RY}j$$

Where

$i =$ species one
$j =$ species two
$\mathrm{Y}i =$ yield of species i when grown in monoculture
$\mathrm{Y}j =$ yield of species j when grown in monoculture
$\mathrm{Y}ij =$ yield per pot of species i grown with species j
$\mathrm{Y}ji =$ Yield per pot of species j grown with species i

In general:

If RYT = 1, the two species are mutually exclusive, and the mixture does not outyield the highest yielding monoculture. If RYT > 1, the two species are not competing for exactly the same resources, and certain mixtures may outyield both mixtures. If the RY ratio increases from one harvest to the next, this is a measure of the degree by which one species is replacing another.

4.3 RESULTS

4.3.1 Dry Matter Yields

Species:

Harvest 1: Both species were still in a vegetative state at this time. Dry matter was influenced significantly ($P<0.05$) by both density ratio (relative frequency) and temperature. Both oat and medic DM increased as their respective densities increased (Table 4.3). Medic DM was 37% higher in monoculture and 15% higher in the 12:2 Medic:Oat density mixture with the high temperature regime. There was no effect of temperature on oats. Total harvested DM increased with increasing oat proportion and was maximised with the oat monoculture, producing 2.8 times more DM than the medic monoculture at the high temperature. The effect of the higher temperature environment was to increase total DM of the mixtures slightly although only the 12:2 Medic:Oat density mixture yielded significantly higher.

Harvest 2 regrowth: Both species were still in a vegetative state at this stage. Defoliation reduced the oats ability to regrow, but inline with a similar severe defoliation that would occurred under intensive grazing, if this had been a grazing situation. There were significant ($P<0.05$) density ratio and temperature effects for both oat DM, medic DM and combined harvests DM (Table 4.3). Increasing temperature increased DM production of both oat and medic components as monocultures. The oat monoculture DM was significantly higher in the high temperature environment. There was a trend for both oat and medic DM to increase with increasing plant density. Medic DM was significantly higher in the higher temperature environment in monoculture and mixtures except for medic 4:6 oat. There were significant ($P<0.05$) density ratio and temperature effects on total DM (Table 4.3). The most productive treatment was the 12:2 mixture in the high temperature environment (significantly higher than both monocultures).

Total dry matter: Total combined species DM for both high and low temperatures increased significantly ($P<0.05$) with increasing proportion of oats in the mixture (Table 4.3). Oat monoculture the highest at both temperatures. There was also a significant ($P<0.05$) temperature effect for total combined species harvests and medic DM, the higher temperature producing the highest DM yields in both cases. As expected total combined medic DM growth was significantly ($P<0.05$) higher in monoculture. The temperature effect was not evident in the total combined oat DM harvests, however the oat monoculture did yield significantly ($P<0.05$) higher than mixtures.

4.3.2 Relative Yield Total and Competitive Ability

Temperature had little effect at harvest 1 on competitive ability of the mixtures (Figure 4.1). The model fitted the data well with the relative yield total (RYT) 1 and the observed data RYT's similar. The almost linear lines show that competition was scarcely occurring between the two species although the *k* coefficient ratios (Table 4.2) indicate that oats was between 2 and 2.4 times more competitive, even at that stage. At harvest 2, the model RYT's were still close to 1, in contrast to observed RYT's as high as 1.24 at densities of medic 8:4 oats in the low temperature environment, showing over-yielding did occur (Figure 4.1). At the low temperature, oats were highly competitive (Table 4.2) but this competiveness and dominance were decreased with the higher temperature.

Table 4.2 Estimated *k* coefficients and *k* ratio for the density model for two temperature environments and two harvests.

Treatment	*k*Oat	*k*Medic	*k*Oat:Medic Ratio
Harvest 1 Low 15/8°C	2.02	1.0	2.02
Harvest 1 High 20/10°C	3.13	1.31	2.39
Harvest 2 Low 15/8°C	13.7	1.13	12.12
Harvest 2 High 20/10°C	1.49	0.23	6.48

Relative yield ratios (Table 4.3) changed very little between harvests at the winter temperatures, but increased from harvest 1 to harvest 2 at autumn temperatures. This showed that medic tended to be more competitive, replacing the oats, at the higher temperatures, in terms of DM yield.

Table 4.3 Mean dry matter production (g/pot) for harvest 1, harvest 2 and total biomass at five medic:oat sowing ratios and two temperature environments.

	Low 15/8°C					High 20/10°C						
	Medic:Oat					Medic:Oat					Tukeys HSD (P<0.05)	
	16:0	12:2	8:4	4:6	0:8	16:0	12:2	8:4	4:6	0:8	Ratio	Temp.
Oat DM harvest 1	-	3.0	7.1	9.5	12.0	-	3.1	7.2	9.8	12.4	0.8	n.s.
Medic DM harvest 1	3.2	2.6	2.0	0.8	-	4.4	3.0	2.1	0.8	-	0.6	0.3
Total DM harvest 1	3.2	5.6	9.1	10.3	12.0	4.4	6.0	9.3	10.6	12.4	0.8	0.5
Relative yield ratio H1	-	0.87	0.28	0.08	-	-	0.96	0.29	0.03	-		
Oat DM harvest 2	-	3.6	5.1	5.8	5.3	-	3.4	4.4	6.4	7.2	1.4	1.0
Medic DM harvest 2	4.4	2.5	1.5	0.2	-	6.9	5.0	3.2	0.7	-	1.1	0.5
Total DM harvest 2	4.4	6.1	6.6	6.0	5.6	6.9	8.3	7.6	7.1	7.2	0.9	0.5
Relative yield ratio H2	-	0.69	0.29	0.03	-	-	1.47	0.73	0.11	-		
Oat DM harvest 1 and harvest 2	-	6.6	12.2	15.4	17.6	-	6.4	11.6	16.2	19.6	1.2	n.s.
Medic DM harvest 1 and harvest 2	7.6	5.0	3.5	1.0	-	11.3	7.9	5.3	1.5	-	1.6	1.3
Total DM combined harvests	7.6	11.6	15.7	16.3	17.6	11.3	14.3	16.9	17.7	19.6	1.0	0.7

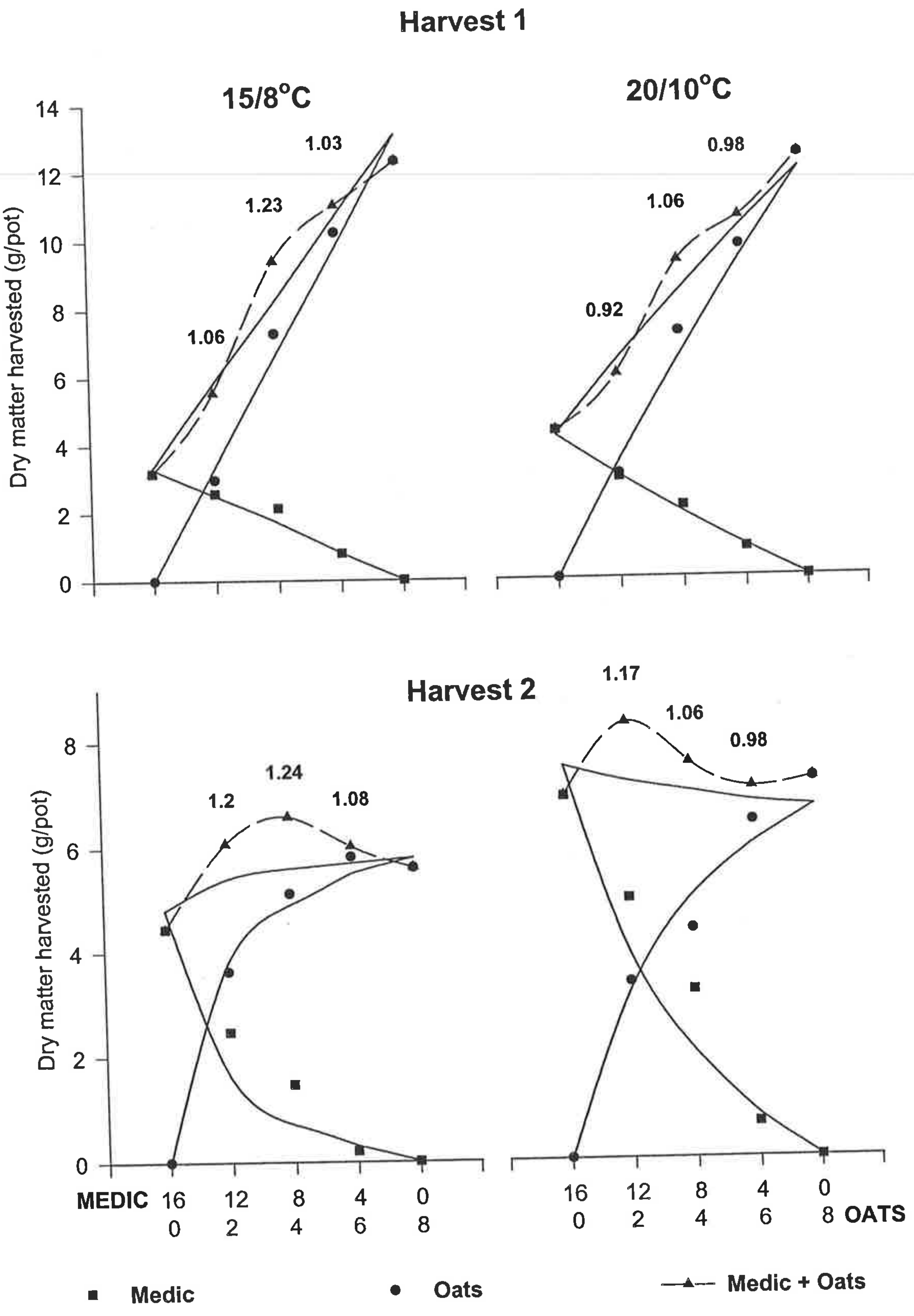

Figure 4.14 Replacement series diagrams for medic and oats on dry matter yield per pot for two temperature environments and two harvests in 1994. Symbols are observed data and continuous lines are fitted from the model. Relative yield totals shown above mixtures are for observed data.

4.3.3 Transpiration and Transpiration Efficiency

Estimated evaporation from bare pots for each temperature environment was: high = 38.2 ml/day and low = 33 ml/day. There was a significant ($P<0.05$) linear relationship between dry matter production and transpiration for both harvests (Figure 4.2). Initial linear regression showed a high standard error around the origin for both harvests so regressions were extended through to the y axis and are represented by the following equations:

Harvest 1 Evapotranspiration (ml) = 1663 + 231 (±8) Dry matter (g) $r^2 = 0.88$

Harvest 2 Evapotranspiration (ml) = 1124 + 161 (±22) Dry matter (g) $r^2 = 0.74$

Transpiration: Oat density had the largest influence on transpiration. There was a significant ($P<0.05$) density ratio and temperature effect for transpiration to harvest 1, transpiration between harvest 1 and harvest 2 and total transpiration (Table 4.4). To harvest 1, transpiration increased as oat density increased, with oat monocultures having the highest transpiration. The higher temperature environment also increased transpiration. Between harvests 1 and 2 the highest transpiration was recorded in medic-oat mixtures and in the medic monoculture at the high temperature. Combined total transpiration for the two harvests increased as oat density increased and was higher for the high temperature environment.

Transpiration Efficiency: There was a significant ($P<0.05$) density ratio and temperature effect for transpiration efficiency (TE) at harvest 1 and a significant ($P<0.05$) density ratio × temperature interaction for TE at harvest 2 and total TE (Table 4.4). To harvest 1 TE was highest in the low temperature environment, the medic monoculture being the most efficient overall. Between harvests 1 and 2, TE was similar in all treatments with 12:2 medic:oat mixture at low temperature and medic monoculture at the high temperature the least efficient. There were no differences in total TE for the high temperature environment however the 12:2 medic:oat mixture was the least efficient at the low temperature environment.

Table 4.4 Mean transpiration and transpiration efficiency for harvest 1, harvest 2 and total biomass at five medic:oat sowing ratios and two temperature environments (TE= transpiration efficiency).

	Low 15/8°C					High 20/10°C						
	Medic:Oat					Medic:Oat					Tukeys HSD (P<0.05)	
	16:0	12:2	8:4	4:6	0:8	16:0	12:2	8:4	4:6	0:8	Ratio	Temp.
Transpiration to harvest 1 (ml)	649	1399	2118	2159	2483	914	1458	2284	2632	2963	313	120
Transpiration between harvest 1 and harvest 2 (ml)	629	913	770	800	636	995	1095	916	999	826	122	55
Combined harvest 1 and harvest 2 transpiration (ml)	1278	2312	2888	2959	3119	1909	2553	3200	3630	3789	346	478
TE harvest 1 (mg/m1)	5.0	4.1	4.3	4.8	4.8	4.8	4.1	4.1	4.1	4.2	0.5	0.2
TE between harvest 1 and harvest 2 (mg/m1)	7.1	6.5	8.5	7.5	8.8	6.9	7.5	8.2	7.1	8.7	0.9	0.8
TE combined harvest 1 and harvest 2 (mg/m1)	6.0	5.3	6.4	6.2	6.8	5.9	5.9	6.2	5.6	6.5	0.6	0.5

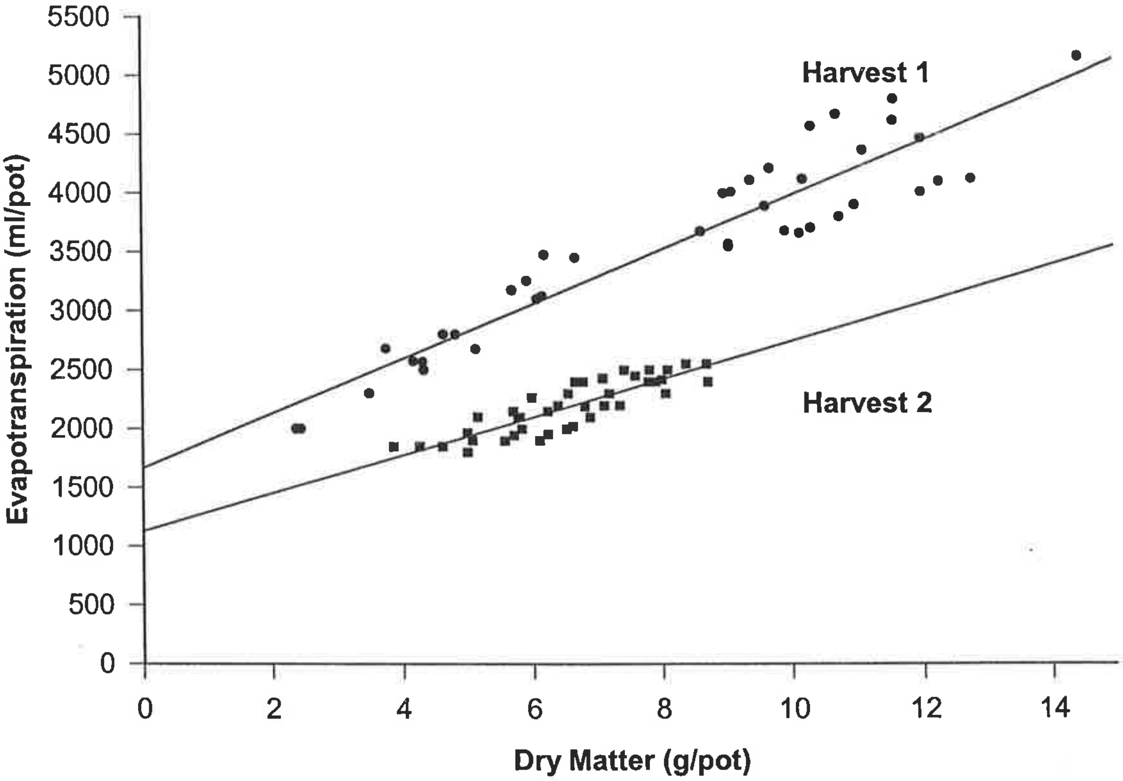

Figure 4.2 Relationship between combined medic and oat dry matter and evapotranspiration for harvest 1 and harvest 2 in growth cabinets. Mean of two temperature environments.

4.4 DISCUSSION

The major findings from this study were that the density ratio of oats is the most important parameter for early total production and that temperature has only a secondary role, mainly influencing medic growth and competitive ability after defoliation.

The effect of increasing temperature from 15/8°C to 20/10°C (day/night) was to increase growth of the medic component slightly in the first 47 days without an associated change in oat production. However, after defoliation and subsequent regrowth the higher temperature was advantageous to both oat and medic DM production. Medic benefited from higher temperatures in all mixtures as well as monocultures. Oats showed a much greater capacity than medic to produce early dry matter in either monoculture or mixture but increasing temperature did improve medic growth in general, although at harvest 1 it was marginal. The temperatures used in this experiment were probably below optimum as the majority of temperate grasses and legumes have optimum temperatures for vegetative growth between 20-25°C. However, young plants tend to have a higher temperature optimum, which decreases with age because of the increasing importance of dark respiration (McWilliam 1978). This is possibly due to the higher requirement for the daily photosynthetic assimilate being used for growth purposes, rather than maintenance, in younger plants (Hay and Walker, 1989). In contrast this temperature optimum can be altered with low light intensities (similar to this experiment) displacing the optimum temperatures for photosynthesis towards the lower end of the range (Larcher 1995).

The increased growth of medic at higher temperatures found in this experiment agree with research by Clarkson and Russell (1979) who studied medic development as a function of temperature, and showed that increases in mean daily temperatures accelerated medic development; however there was no measure of dry matter in their experiment. The results also agree with research by Mitchell (1956), Morley (1958), Taylor (1972) and Cocks (1973) who showed that production of spaced subclover plants increased with increasing temperatures up to 20-25°C. The low medic dry matter production relative to oat dry matter agrees with results of other researchers who have studied grass/legume relationships at low temperatures although in this experiment oat monocultures were more productive than medic at both high and low temperatures. Williams (1970) and Davidson and Robson (1986) and Davidson *et al.* (1986) have shown that perennial clovers are generally less productive than companion grass species at low temperatures, except in situations of low nitrogen availability where the clover can out yield the grass species by supplying its own nitrogen. Davidson and Robson (1986) studied competition using replacement series analysis and aggressitivities (McGilchrist and Trenbath 1971). They found that perennial ryegrass was highly aggressive and a superior competitor to white clover at low temperatures. It therefore seems likely that from this experiment and the limited published data available on the growth of annual legume pasture plants, that medic growth and possibly competitive ability are reduced at low temperatures, similar to those experienced with late plantings in winter. Kemp (1975) working with subclover swards also established that it is important to establish the sward before the cold of winter. It was possible to equal nitrogen fertilised oats in DM production if the sward was established at the right time (temperature wise) with sufficient moisture. However in these experiments oats always outyielded the subclover in early DM production, similar to the way oats outyielded medic in this and other experiments.

Regrowth after defoliation was affected by both temperature and seeding rate. After the first harvest, production of both oat and medic were higher with the higher temperature treatment, although medic responded to a greater degree with a 56% increase in yield in monoculture and 66% increase in the 12:2 medic:oat mixture suggesting it had improved competitive ability at the higher temperature. McWilliam (1978) states that regrowth of temperate legumes and grasses following defoliation is temperature dependant, the results being influenced by the temperature prior to defoliation, the age of the plants and the time interval between defoliations. His review of research showed that the optimum temperature for maximum dry matter production declined after the initial harvest and also with increasing age and duration of the cutting interval. One of these experiments, Leach (1971) using the perennial lucerne, found an increase in regrowth, when the temperature prior to defoliation was increased from 15 to 20°C. The increase in regrowth of both oats and medic with increasing temperature in the present experiment agrees with the previous work on annual pasture plants. Greenwood *et al.* (1976) working with subclover swards and repeated defoliation also reported similar response to temperature increases although Davidson *et al.* (1970) (also with subclover) did not. Silsbury (1971) using perennial ryegrass has also reported increases in plant growth associated with higher temperatures and concluded that seedling growth of perennial ryegrass was strongly dependant on temperature. There were no negative effects of increasing temperature on plant growth as reported by Greenwood *et al.* (1976) who showed that after five weeks, subclover growth responses to temperature changed from positive to negative. Fukai (1974) also demonstrated that maximum yield of subclover was inversely related to temperature over the range of 15-30°C although during the early stages of growth canopy development of the swards were favoured by higher temperatures. Both of these experiments used swards rather than spaced plants as in this experiment, and were grown for longer periods over a greater range of temperatures, hence it is unclear whether the same results would have occurred if the temperature ranges were higher and further harvests were conducted.

Transpiration effects are not a direct measure of competition, because they are pot based and therefore measure the transpiration rate of both species when in mixtures, however they do provide an indication of water use efficiency between the various mixtures and monocultures. This is important information for determining biomass production in limited seasonal rainfall conditions and the efficiency of such mixtures at early sowings (warmer temperatures) compared to later sowings (cooler temperatures) in field situations is desirable knowledge.

The increase in transpiration associated with increasing oat density was directly related to dry matter production. Transpiration efficiency was greater in the medic monocultures than mixtures at harvest 1 but this was reversed by harvest 2 such that the combined transpiration was slightly higher with the addition of oats. The difference in transpiration and associated transpiration efficiencies between treatments suggests that medic monocultures are more efficient at utilising water at establishment. The reason for the reversal of this result after defoliation is unclear but may have been an artefact of the method of estimating pot surface evaporation. The assumption in the calculation of transpiration efficiency in this experiment was that surface evaporation was constant across all treatments only affected by temperature, however in reality this is unlikely to be the case. The accuracy of estimating surface evaporation would decrease as canopy cover increased altering the evaporation potential at the pot surface. Canopy cover is influenced by the individual species or mixtures grown in each pot; medic being a prostrate species and oats erect providing different shading intensities, and the stage of development of these plants may be critical in determining the level of surface evaporation. It is likely that at harvest 1 there was a higher proportion of soil surface exposed which may account for the differences in the Y intercept values between the two harvests in figure 4.2. The transpiration efficiency may also increase because the plants have stopped leaf expansion and lengthening before cutting and after cutting regrowth occurs very rapidly due to a well established root system with a large number of branch and growing points for regrowth to occur. Richards (1993) suggested that compensatory growth after defoliation can increase the leaf and tiller growth rate. This enhanced leaf and tiller growth can persist for a few weeks after defoliation.

There are several important differences between the artificial environment of the growth cabinet and the field conditions under which these monocultures and mixtures would normally be grown that may override the isolated effect of temperature studied in this experiment. These are density, light intensity and day length and soil temperature. As has been previously shown by Davidson *et al.* (1970) and Cocks (1973), optimum temperature declines as density increases although Cocks (1973) found the effect was related to leaf area index rather than actual plant density. The plant density in this experiment was relatively low and as such in the early stages the plants could have considered to be growing in isolation and competition intensity would be at a low level, assuming space for root growth was not limiting; hence any differences in the beginning can be attributed to treatment effects. Competition between the species for the available resources was at a low intensity at harvest 1. However by harvest 2 the medic had improved its competitiveness, particularly at the higher temperature. This even resulted in overyielding, suggesting the mixtures (oat and medic) were able to improve production with the limited resources available. The competition was likely to be root induced, as limited shading occurred in this experiment but there is no way to confirm this. Examination of the root profiles after the experiment showed intermingled medic and oat roots in the mixtures confirming their close soil space proximity.

The light intensity and day length were not altered in this experiment, in order to isolate the effect of temperature; however in the field the ambient temperature, day length, total energy and irradiance would all be different for the two periods simulated in this experiment. Ludlow (1978) has suggested that day length has little effect on early plant growth with a much larger effect on flowering; however differences in total energy and irradiance would certainly affect the plants growth. Black (1955) working with subclover also suggested that light and temperature interacted to determine growth rate and concluded that temperature alone had only a small influence on growth. Temperature does however, affect rate of leaf appearance and root growth, and hence growth of the plant. Generally the higher the temperature up to an optimum, the faster the plant growth (Milthorpe and Moorby 1988).

Another important difference between plants grown in field conditions and growth cabinets is the increased soil and root temperature associated with the growth cabinet conditions. McWilliam (1978) in reviewing experiments where soil temperature was controlled independently from aerial temperature suggested optimum soil temperature for top growth was similar to optimum air temperature but the optimum temperature for root growth may be substantially lower. Yet Sumner *et al.* (1972) working with subclover showed that the greatest reduction in rate of leaf development occurred when both root and shoot temperatures were lowered together. It is possible in this experiment that shoot growth temperatures were below optimum but the plants were able to compensate by increased root growth which may have been at optimum temperature. As the pot size was relatively large, root competition intensity may have been at a low level up to the first harvest, allowing the plants to behave in a similar manner to monocultures.

4.5 CONCLUSION

The initial aim of this experiment was to assess if reduced medic growth and competitiveness in medic-oat mixtures was affected by lower ambient temperatures often associated with winter establishment. The results support the hypothesis that increased temperatures associated with autumn establishment improves medic growth both in monoculture and mixture with no associated penalty to oat growth. The effect is most pronounced after defoliation and a period of re-growth. When temperature is the influencing parameter and other resources are non limiting, there appears to be little competition between the two species at an early stage. Competition becomes evident as the plants grow and root space becomes limited and it is at this stage that improved medic growth and competitive ability is noticed at higher temperatures. However, under a sward situation in field conditions the results may be different where competition for light, nutrients and water may markedly alter the results. The recommendation from this experiment is that early establishment in autumn, as opposed to winter, of medic both as pure stands or in mixture with oats will maximise medic production. More importantly, other factors such as the medic-oat sowing ratio are likely to have a greater influence on medic and total dry matter production early in the season than temperature alone. In this experiment the best sowing ratio was 12 medic: 2 oat plants, in terms of providing early production, yet maintaining a reasonable level of medic proportion.

Chapter 5

5. EXPERIMENTS 3 and 4 - MANAGEMENT OF OAT-MEDIC MIXTURES TO MAXIMISE MEDIC PRODUCTION

5.1 INTRODUCTION

Experiment 1 (Chap 3) highlighted the competitive disadvantage to medic in oat/medic mixtures. The addition of oats and other grasses was shown to limit the ability of the medic to achieve high productivity and seed yield. Maintaining a high medic component is essential as both the quantity and quality of the feed on offer and the amount of biologically fixed nitrogen are related to medic growth (Dahame 1978; Crawford *et al.* 1989; Hossain *et al.* 1995). Once high medic production has been achieved the next most important aim (in ley farming systems) is seed production, which though influenced by many other factors, also requires the plant to attain a physiological stage of growth and maturity.

It therefore seemed appropriate that investigations should be conducted which involved the manipulation of the oat/medic mixtures to try and improve medic productivity in the mixture either by improving medic competiveness or reducing the competitiveness of the oats.

Sowing rates: Under a normal pasture situation medic growth would be influenced firstly by initial plant densities of individual species and then by competition both between species and within the species. Superimposed on this is the effect of defoliation by the grazing animal which can significantly alter growth and composition of the pasture throughout the growing season. High initial plant densities of annual pasture legumes are considered imperative to achieve high growth rates. This important relationship between early medic growth and initial plant density has been established by researchers working in both pure medic stands Chaichi (1995) and annual clovers (Cocks 1973; Collins *et al* 1983; Ru *et al* 1997; Evans *et al* 1992; Evans *et al* 2002). It is less clear whether a mixture of medic and an annual cereal, such as oats, would result in the same response.

Khan (1991) showed that at very high seeding rates of 100 kg/ha, equivalent to excellent regenerating pasture, medic could compete successively with oats in a mixture. Much of Khan (1991) and Kahn *et al.* (1989) work was, however aimed at total forage production in the absence of grazing and was conducted with taller growing annual legumes including *Medicago scutellata* and *Vicia benghalensis.* As these experiments were conducted without grazing and the influence of selective defoliation that sheep provide, it cannot be inferred that these results will hold true in grazed systems.

Dry matter production throughout the growing season is the primary purpose of maximising the medic component, however sufficient seed set also allows the medic to regenerate in subsequent years providing a low cost method of continuous pasture establishment. Muyekho *et al.* (1993a) showed that high seeding rates in pure medic swards increased the number of flowers/m^2 but pod set was reduced due to self shading (LAI above 4) before the start of flowering. He concluded that to improve pod retention, light penetration needed to be adequate during the early flowering period. It is assumed that competition for light from other plants for example oats, could also be important in maintaining high seed yields. Higgs (1987) also suggested that eliminating plants that could shade the legume during flowering would promote higher seed yields. Rhodes and Stern (1978) suggested that plant communities with erect foliage are the most productive under management practices that maintain a high leaf area index.

Defoliation: Vickery (1981) discussed the problems of trying to optimise a management strategy for either a forage or pasture system, alluding to the problems of working in complex ecosystems with all the associated interactions. One management approach is to use defoliation frequency, intensity and timing to obtain a suitable balance between species. Generally, a more frequent and intensive defoliation reduces total herbage yield (Harris 1978). Frequency of defoliation can be set either by specific time interval, or more usefully, by phenological growth stage of the plant. Fortune (1985) argues that by adjusting defoliation for the growth stage of the plant, genotype and environmental effects on growth rates will be taken into account and cutting will not occur at a critical stage of plant development. Unfortunately pastures may be placed in a grazing system where this flexibility is not always available and over-grazing can occur. Intensity is dependent on both the quantity of the plant removed at a given time and the time this takes. The quantity removed is usually equated with a given cutting height, while the time factor is the grazing duration. With grazing, the plant is subjected to the effects of defoliation over a longer period which often complicates the regrowth process as opposed to instantaneous cutting by hand or machine (Fortune 1985).

Increasing cutting frequency and lowering cutting height have been shown to reduce production in annual medics (Taylor *et al.* 1979). However it may also be a useful management tool in reducing the competitive effects of an associated grass species, allowing improvements in light penetration, given that grasses are more erect in their growth habit.

Nitrogen: Winter cereals, such as oats, are highly responsive to nitrogen (Spurway *et al.* 1974). The effect of nitrogen on medic growth is less pronounced than for cereals. It would be expected that high soil available nitrogen levels would favour oat production in oat/medic mixtures as nitrogen is frequently a limiting nutrient in cereal cropped soils. The medic with its ability to fix its own nitrogen requirements would be less responsive to high nitrogen levels. Nitrate has the effect of reducing fixation in medics (Butler 1988) but this is of less consequence in high soil nitrate situations where the medic will utilise the available nitrogen first. In contrast the addition of nitrogen fertiliser has been reported to increase the forage yield of autumn-sown oats significantly (Crofts 1966a; 1966b; Spurway *et al.* 1974; Brown 1975). Adjusting soil nitrogen levels may be a simple method of reducing the growth potential of the oats and therefore reducing the competition by the oats on the medic in the mixture.

With the above factors in mind two experiments were designed with the objectives of improving the medic component in medic/oat mixtures.

Experiment 3 was designed to evaluate the effect of oat-medic sowing ratios, nitrogen application and defoliation timing on dry matter production and botanical composition.

The hypothesis examined was:

> That oat-medic sowing ratio, available soil nitrogen and defoliation timing, and their interactions affect the amount of total dry matter and/or medic growth in medic/oat mixtures. Consequently, medic proportion and growth can be improved by modifying the relationship between sowing ratio, soil nitrogen status and defoliation timing.

In experiment 1 described in chapter 3, oats and medic were established together at the beginning of the growing season. Both grass and broadleaf weeds were also present providing an opportunity to assess the ability of the medic/oat combinations to compete against these weeds. However with the medic having to compete against both the annual grasses (predominately barley grass) and oats at the same time may have created excessive competition for the medic.

Experiment 4 was designed to examine the impact of placing oats in established high density medic pastures under different grazing intensities with minimal additional competition from weeds.

The hypotheses examined were:

1) That oats provide additional dry matter in early winter when sown into established, high density medic pastures.

2) That stocking rate affects the proportion and production of medic in medic/oat mixture and with these, sheep productivity.

5.2 EXPERIMENT 3 - EFFECT OF NITROGEN APPLICATION AND DEFOLIATION TIMING ON THE PRODUCTION AND COMPOSITION OF OAT-MEDIC MIXTURES

5.2.1 Materials and Methods

5.2.1.1 Site of Experiment

The experiment was conducted at The University of Adelaide Roseworthy Campus; paddock North West 4. Soil description is presented in Chapter 3 section 3.2.1 and climate data for 1994 in Appendix Table A.1. Previous paddock history was barley in 1993 and wheat in 1992. Soil samples taken to 20 cm depth in March 1994 revealed mean soil nitrate levels of 9.3 mg/kg.

5.2.1.2 Design of Experiment

The design of the experiment was a 5 × 2 × 2 split plot with five oat-medic sowing ratios and two nitrogen application rates as main plots and two defoliation timings as sub plots. There were four replicates with sowing ratios and nitrogen application arranged in the main blocks and the timing of defoliation split across these treatments.

The main plots were: five sowing ratios (Table 5.1) and two nitrogen treatments: 0 and 34kg/ha of N applied as ammonium nitrate (34% N).

The sub plots were: two defoliation timings: early and late (late =10 days later than early treatment). This 10 day interval was kept constant at each harvest.

Plot size was 20m × 2m.

It was clear from previous experiments that high density medic populations are required to be competitive with oats. To simulate a high density regenerating medic population it was decided to start of with a high seeding rate (100 kg/ha) which would provide very high plant densities. To complement this oats were also sown at a relatively high population of 100 kg/ha to generate a high biomass situation. This would allow the best possible medic stand available in the field to be compared to a highly productive oat forage crop along with the associated combination of mixtures in-between.

The defoliation timings and severity were based on the assumption that previous experiments have shown that oats can provide DM earlier than medic and as such would be available to graze earlier by livestock. At high stocking rates the livestock would graze the oats quite severely (as they would be the main source of food on offer) and hence the initial defoliation was severe on the oats.

Table 5.1 Replacement series sowing ratios (kg/ha of pure germinating seed) for sowing ratio, nitrogen and defoliation timing experiment in 1994.

Oats		Medic	
Kg/ha	Relative plant frequencies	Kg/ha	Relative plant frequencies
0	0	100	1
25	0.25	75	0.75
50	0.5	50	0.5
75	0.75	25	0.25
100	1	0	0

5.2.1.3 Establishment

The experimental site was cultivated on April 29 with an offset disc to promote germination of volunteer grasses and broadleaves. Volunteer weeds were sprayed with 1.5 l/ha of glyphosate (450g/l) on May 20. The experimental site was rolled on June 4 and sprayed again on June 25 with 1.5 L/ha of SpraySeed® (paraquat 125 g/l + diquat 75 g/l) to control a second emergence of volunteer weeds. The experiment was sown on July 2 with an 8-row cone seeder with 15 cm row spacing. The experiment was planted later than originally intended due to a combination of poor establishment rains and weeds emerging. Germination tests were conducted on seed of both medic and oats and sowing rates adjusted accordingly to match the appropriate pure germinating seed ratios in Table 5.1. Oats cv. Marloo were sown at a depth of 4 cm with 100 kg/ha of triple superphosphate (20% P, 1.5% S). Medic cv. Paraggio was sown immediately after at a depth of approximately 1cm. Nitrogen treatments were applied as ammonium nitrate (34%N) with a small trial spreader to the soil surface the day after sowing. The experimental site was rolled again to improve the seed to soil contact. Plants emerged on July 12 and were sprayed with LeMat® (omethoate) at 50 ml/ha on July 20 to control red-legged earthmite (*Halotydeus destructor*) and lucerne flea (*Sminthurus viridis*). Broadleaf weeds, three corner jack (*Emex australis*), Indian hedge mustard

(*Sisymbrium orientale*) and three-horn bedstraw (*Galium tricornutum*) were controlled on July 25 by applying 25 g/ha of Broadstrike® (flumetsulam 800g/kg) plus 2% Uptake® spraying oil. Defoliation treatments were conducted with a spin mower and catcher to 4cm in height and herbage was removed from the plots.

5.2.1.4 Measurements

Plant Establishment Counts: Plant establish counts (plants/m^2) of emerged medic and oat plants were conducted on August 10. Four 0.3m × 0.5m quadrat counts (taking in two rows) were made in each plot.

Herbage Harvests: Three harvests were taken to determine the available dry matter and botanical composition of the mixtures; harvesting times are presented in (Table 5.2). Quadrat size was 0.3m × 0.5m, taking in two rows per plot and plants cut to ground level. One quadrat cut was taken per plot on each sampling and a new position randomly selected each successive harvest.

Table 5.2 Harvest dates and days after emergence for sowing ratio, nitrogen and defoliation experiment in 1994.

	Early Defoliation		Late Defoliation	
	Date	Days after emergence	Date	Days after emergence
Harvest 1	August 21	40	August 31	50
Harvest 2	September 12	62	September 22	72
Harvest 3	October 4	84	October 14	94

Medic Pod and Seed harvests: Due to the growing season being extremely short and the severe defoliation treatments applied, regrowth by the end of the growing season was extremely poor. While the medic plants did flower, pod set was extremely poor and as a consequence pod and seed measurements were abandoned due to insufficient and highly variable yields.

5.2.1.5 Analysis of Data

Analysis of variance was conducted on data using the statistical program Genstat V. The experiment was analysed as a 5× 2 × 2 split plot. Comparison of means was made using the Tukey's honestly significant difference range test (HSD) (Steel and Torrie 1960). Where appropriate, regression analysis was conducted to determine significant relationships between treatments and DM yield. Tests to compare improvements over the linear model were conducted by comparing the variance ratios between linear, quadratic and cubic functions. If the higher order model was significantly better, then this was used.

In addition relative yield total (RYT) and relative yield ratio (RY ratio) were calculated for each mixture utilising the following formula (as per de Wit *et al*, 1966).

Relative Yields $RYi = \frac{Yij}{Yi}$ and $RYj = \frac{Yji}{Yj}$

$$RY\,ij\,\text{ratio} = \frac{RY\,i}{RY\,j}$$

Where

$i =$ species one
$j =$ species two
$Yi =$ yield of species i when grown in monoculture
$Yj =$ yield of species j when grown in monoculture
$Y\,ij =$ yield of species i grown with species j
$Yji =$ yield of species j grown with species i

$$RYT = RYi + Ryj$$

5.2.1.6 Actual establishment ratios

Once plants emerged and could be counted, actual establishment ratios were calculated by taking the plant establishment count in the pure stands and dividing the other ratios into this. Hence the ratios are not equated to the number of plants in the mixed population but rather a ratio against the maximum as determined by the highest seeding rate for each species.

5.2.2 Results

5.2.2.1 Plant establishment

Good plant establishment was recorded on August 10 with a significant (P<0.05) difference between sowing ratios for both medic and oats (Table 5.3). There was no effect of the nitrogen treatment on plant populations and defoliation treatments had not been conducted at this stage.

Table 5.3 Mean plant emergence density (plant/m^2) of Medic and Oats on August 10 1994 (mean of two nitrogen rates and two defoliation timings).

Medic:Oat ratio	Medic	Oats	Actual established ratios
100:0	1958	0	100:0
75:25	1548	22	79:13
50:50	805	69	41:40
25:75	545	120	28:69
0:100	0	174	0:100
Tukeys HSD (P<0.05)	89	15	

5.2.2.2 Herbage harvests

An examination of the rainfall data for 1994 (Appendix A.1) shows that growing season rainfall was 44% below the long term mean and pan evaporation 20% above the long term. This combination contributed to severe water stress and reduced the ability of the plants to recover from defoliation. Harvests were also delayed past early winter and could not be considered in the context of early feed. The objective of examining early DM was not able to be achieved in this experiment, never-the-less the pattern of growth could be considered similar to a year with an earlier start except more compacted in time.

Harvest 1:

Medic DM: there were significant ($P<0.05$) sowing ratio × defoliation, sowing ratio × nitrogen and nitrogen × defoliation interactions (Table 5.4). Medic 25: oat75 had the lowest yielding production with the other two sowing ratio's yielding similar medic DM production

Oat DM: there was a significant sowing ratio × nitrogen × defoliation ($P<0.05$) interaction; late defoliated, unfertilised monoculture oats yielding the highest (Table 5.5).

Total medic + oats DM: There were significant ($P<0.05$) sowing ratio × defoliation and sowing ratio × nitrogen interactions for total combined DM for harvest 1 with late defoliated oat monoculture yielding the highest (Table 5.6). With early defoliation medic monocultures yielded only 10 g/m^2 lower than oat monocultures (Table 5.7) . However delaying defoliation improved oat DM considerably. The addition of oats and delaying defoliation significantly improved DM production in all cases. Examining the relationship between sowing ratio and nitrogen (Figure 5.1, a) shows that as the proportion of oat increased and medic decreased in the mixture, there was a linear increase in total DM. Even though the analysis of variance for total DM provides a significant interaction between sowing ratio and nitrogen the regression analysis of total Harvest 1 DM against sowing ratios provided was not statistically different (in slope or intercept) between treatments that had + and – nitrogen. There was also no statistical improvement in fitting quadratic or cubic relationships to the DM yield data. The lack of response to nitrogen at this stage is probably due to the low rainfall incidence.

Percentage medic: Further examining the effect on medic production (Figure 5.1, b) shows that as the ratio of medic to oats decreased the percentage medic decline is not linear but of a sigmoidal nature, with a rapid initial decline, plateau then decline due to zero medic. There was no significant difference in medic percentage with or without nitrogen. Delaying defoliation increased total DM with an associated sigmoidal response to sowing ratio. Thus all mixtures yielded similarly, with monoculture oats yielding the most. Early defoliation reduced overall total production with monocultures and mixtures yielding similarly (Figure 5.1, c). Early defoliation did however improve the percent medic in the total mixture slightly (Figure 5.1, d).

Relative yield total: The addition of nitrogen had the greatest effect on relative yield total (RYT) (Table 5.10). RYT was significantly greater than 1 with the addition of N, except medic 75:oats 25 and early defoliation when it was only 0.99. This nitrogen effect was also evident on the medic component as well but mainly with the early defoliation treatment.

Table 5.4 Mean dry matter (g/m^2) and relative yield of Medic for harvests 1, 2 and 3 and total cumulative Medic dry matter in 1994 at Roseworthy.

	Medic100:0 Oats				Medic 75:25 Oats				Medic 50:50 Oats				Medic 25:75 Oats				Tukeys HSD (P<0.05)			
	Early		Late		Early		Late		Early		Late		Early		Late					
	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	R×D	R×N	N×D	R×N×D
Harvest 1	66	54	61	49	22	27	32	36	23	30	31	24	11	16	24	20	7	8	7	n.s.
RY	-	-	-	-	0.33	0.50	0.52	0.73	0.35	0.56	0.51	0.49	0.17	0.30	0.39	0.41				
Harvest 2	94	64	91	94	36	50	41	40	31	30	34	37	25	22	38	22	-	-	-	17
RY	-	-	-	-	0.38	0.78	0.45	0.42	0.33	0.47	0.37	0.39	0.27	0.34	0.42	0.23				
Harvest 3	81	84	60	67	44	51	40	55	33	34	41	39	29	31	32	26	9	7	n.s.	n.s.
RY	-	-	-	-	0.54	0.61	0.67	0.82	0.41	0.40	0.68	0.58	0.36	0.37	0.53	0.39				
Total	242	204	213	211	103	129	113	131	88	95	108	100	66	70	95	64	-	-	-	27

R = Sowing ratio, D = Defoliation treatment, N = Nitrogen treatment; RY = Relative yield

Table 5.5 Mean dry matter (g/m^2) and relative yield of Oats for harvests 1, 2 and 3 and total cumulative Oat dry matter in 1994 at Roseworthy.

	Medic 75:25 Oats				Medic 50:50 Oats				Medic 25:75 Oats				Medic 0:100 Oats								
	Early		Late		Early		Late		Early		Late		Early		Late		Tukeys HSD (P<0.05)				
	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	R	N	D	R×D	R×N×D
Harvest 1	20	34	65	67	49	48	63	94	49	49	71	87	70	69	138	115	-	-	-	-	21
RY	0.29	0.49	0.47	0.58	0.70	0.70	0.46	0.82	0.70	0.71	0.51	0.76	-	-	-	-					
Harvest 2	70	60	66	60	60	70	55	54	88	81	49	66	97	121	71	66	-	-	-	19	n.s.
RY	0.72	0.50	0.93	0.91	0.62	0.58	0.77	0.82	0.91	0.67	0.69	1.00	-	-	-	-					
Harvest 3	36	42	32	34	29	45	29	36	35	35	35	32	50	43	43	53	-	-	-	-	7
RY	0.72	0.98	0.74	0.64	0.58	1.05	0.67	0.68	0.70	0.81	0.81	0.60	-	-	-	-					
Total	127	135	163	162	139	163	147	185	172	165	155	185	217	233	252	234	14	10	11	n.s.	n.s.

R = Sowing ratio, D = Defoliation treatment, N = Nitrogen treatment; RY = Relative yield

Table 5.6 Mean dry matter (g/m^2) of combined Medic and Oats for harvests 1, 2 and 3 and total combined dry matter in 1994 at Roseworthy.

	Medic 100:0 Oats				Medic 75:25 Oats				Medic 50:50 Oats				Medic 25:75 Oats				Medic 0:100 Oats				Tukeys HSD (P<0.05)	
	Early		Late		Early		Late		Early		Late		Early		Late		Early		Late			
	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	R×D	R×N
Harvest 1	66	54	61	49	42	62	97	103	72	78	95	118	60	65	96	107	70	69	138	115	16	14
Harvest 2	95	65	91	94	107	110	107	100	92	100	90	92	113	104	87	84	97	121	71	66	20	n.s.
Harvest 3	81	84	60	67	80	93	72	89	63	80	70	75	64	67	68	59	50	43	43	53	10	10
Total	242	204	213	212	230	265	277	293	227	259	256	285	238	236	250	250	217	233	252	234	25	28

R = Sowing ratio, D = Defoliation treatment, N = Nitrogen treatment

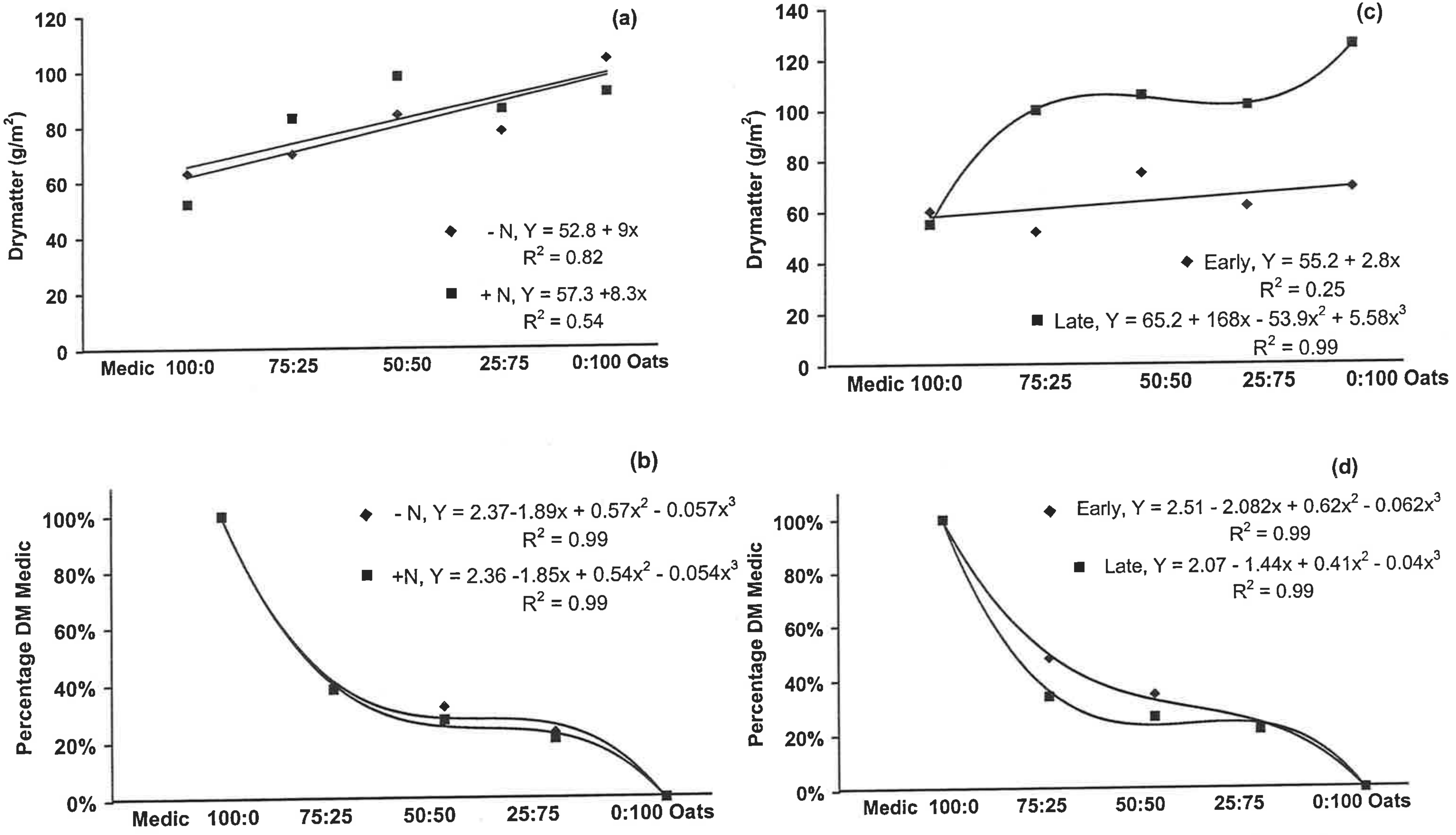

Figure 5.1 Total (medic+oats) dry matter production (g/m^2) and medic percentage at harvest 1 1994 for five medic-oat sowing ratios.(a) and (b), effect of nitrogen level and (c) and (d), effect of defoliation timing.

Table 5.7 Effect of nitrogen and defoliation timing on total combined medic + oat dry matter (g/m^2) for harvest 1, 1994.

	Nitrogen		Defoliation	
	- N	+ N	Early	Late
Medic 100:0 Oat	64	52	60	55
Medic 75:25 Oat	70	83	52	100
Medic 50:50 Oat	84	98	75	106
Medic 25:75 Oat	78	86	63	102
Medic 0:100 Oat	104	92	70	127
Tukeys HSD ($P<0.05$)	14		16	

Harvest 2:

Medic DM: There was a significant ($P<0.05$) sowing ratio × nitrogen × defoliation interaction for medic DM (Table 5.4). Medic monoculture yielded the highest with all other mixtures showing significant reductions in DM. At this stage medic production had improved in both monoculture and mixtures but was still behind oat DM production.

Oat DM: There was a significant ($P<0.05$) sowing ratio × defoliation interaction for oat DM (Table 5.5). Nitrogen still had little effect on changing total production or composition of the mixtures. In general treatments that had high initial DM growth at harvest 1 showed a reduced amount of DM at harvest 2. This effect was most noticeable in the oat monoculture treatments.

Total medic + oats DM: The combined medic + oat total was only significantly ($P<0.05$) affected by a sowing ratio × defoliation interaction (Table 5.8). This effect was to reduce total DM as the sowing proportion of oats increased with the late harvest

(Figure 5.2, c). In comparison DM was relatively constant with early defoliation in mixtures (Table 5.8).

Percentage medic: Similarly to harvest 1 the pattern of medic production for the different sowing ratios followed a sigmoidal decline (Figure 5.2, b). Early defoliation provided the most DM at harvest 2, however, the later defoliation did advantage the percentage of medic in the lower medic sowing ratios (Figure 5.2, d). Similar to harvest 1 the composition is constant over all mixtures with medic % varying very little.

Relative yield total: In general the late defoliation treatments had a higher RYT compared to the early defoliation (Table 5.10). All but one treatment had a RYT close to or significantly greater than 1.

Table 5.8 Effect of defoliation timing on total combined medic + oat dry matter (g/m^2) for harvest 2, 1994.

	Defoliation	
	Early	Late
Medic 100:0 Oat	80	93
Medic 75:25 Oat	108	103
Medic 50:50 Oat	96	91
Medic 25:75 Oat	109	86
Medic 0:100 Oat	109	69
Tukeys HSD (P<0.05)	20	

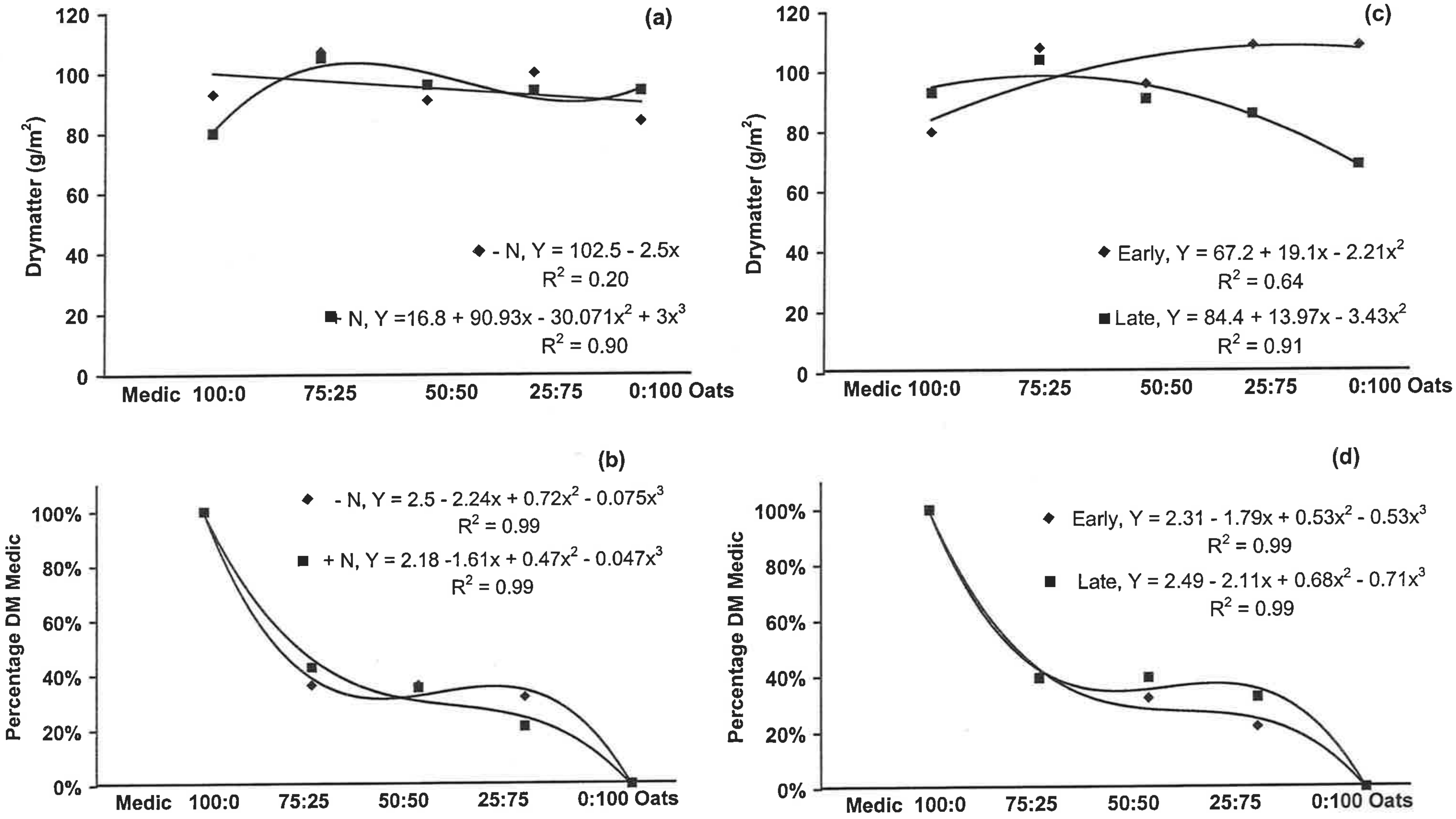

Figure 5.2 Total (medic+oats) dry matter production (g/m^2) and medic percentage at harvest 2 1994 for five medic-oat sowing ratios. (a) and (b), effect of nitrogen level and (c) and (d), effect of defoliation timing.

Harvest 3:

Medic DM: There was a significant (P<0.05) sowing ratio × defoliation and sowing ratio × nitrogen interaction for medic DM (Table 5.4). Monocultures still yielded the highest amount of medic DM with the Medic 75: Oats 25 sowing ratio significantly higher than the other two mixtures.

Oat DM: There was a significant (P<0.05) sowing ratio × nitrogen × defoliation interaction for oat DM (Table 5.2). The addition of nitrogen significantly increased total DM for the Medic 75: Oat 25 and Medic 50: Oat 50 treatments (Table 5.9) but as the sowing proportion of oat increased in the mixture there was a negative curvilinear response (Figure 5.3, a). Without the addition of nitrogen this negative response was linear. Defoliation reduced DM as the proportion of oats increased in the sowing ratio's. The response was a linear decline with early defoliation and curvilinear with late defoliation. The highest yielding treatment was Medic 75: Oats 25 (Figure 5.3, c).

Total medic + oats DM: There was both a significant (P<0.05) sowing ratio × defoliation and sowing ratio × nitrogen interaction for total combined oat+medic DM (Table 5.6). Both medic monocultures and oat/medic mixtures outyielded the oat monoculture at this stage.

Percentage medic: The highest percentage of medic was recorded at harvest 3 and followed the same sigmoidal patterns as previous harvests (Figure 5.3 b and d). Neither addition of nitrogen nor defoliation timing had a significant impact on medic percentage. Once again medic proportion was similar for all sowing ratios

Relative yield total: Relative yield totals were all close to or significantly greater than 1 (Table 5.10).

Table 5.9 Effect of nitrogen and defoliation timing on total combined medic + oat dry matter (g/m^2) for harvest 3, 1994.

	Nitrogen		Defoliation	
	- N	+ N	Early	Late
Medic 100:0 Oat	71	76	83	64
Medic 75:25 Oat	76	91	87	81
Medic 50:50 Oat	67	78	72	73
Medic 25:75 Oat	66	63	66	63
Medic 0:100 Oat	47	48	47	48
Tukeys HSD (P<0.05)	10		10	

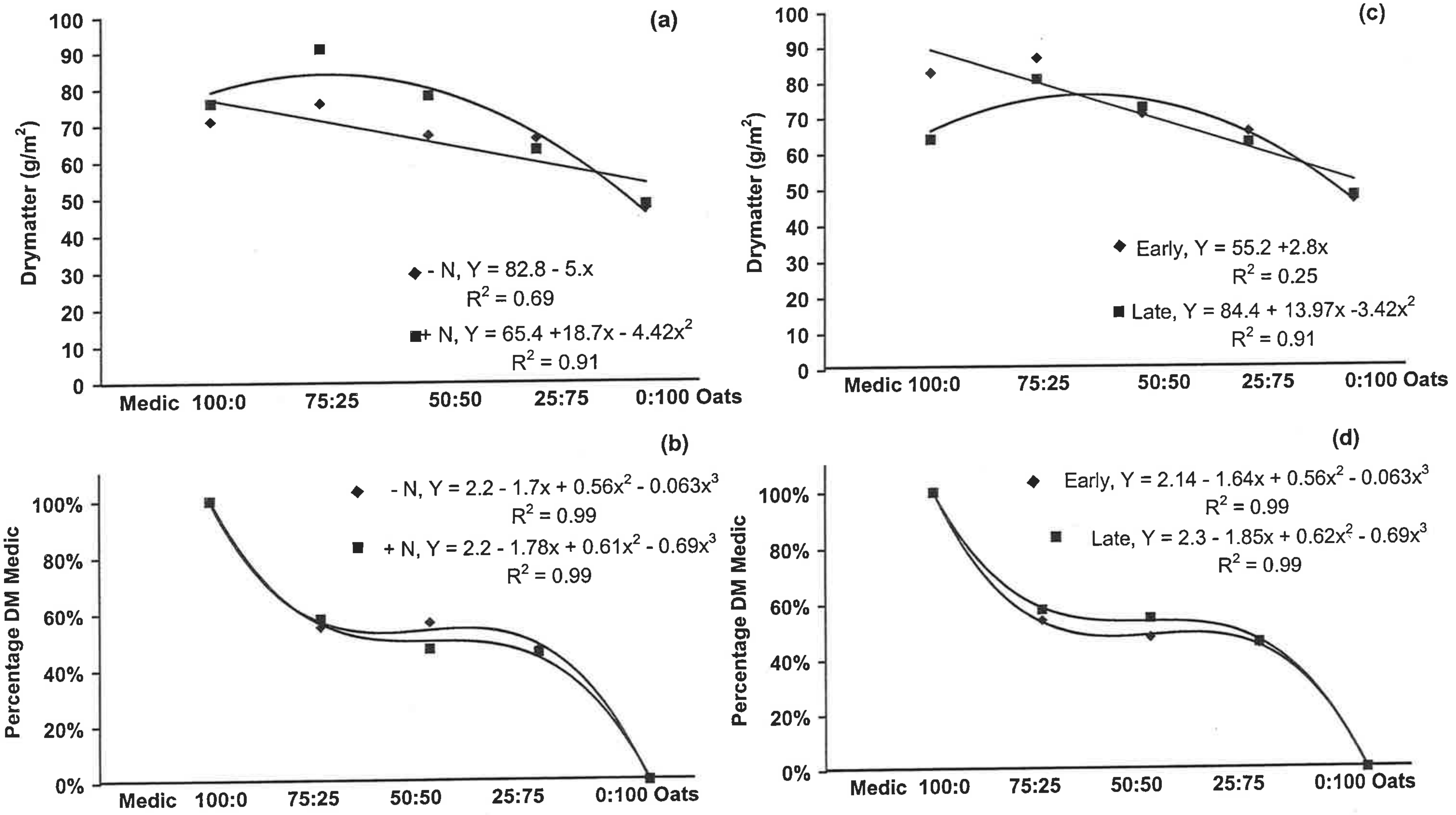

Figure 5.3 Total (medic+oats) dry matter production (g/m^2) and medic percentage at harvest 3 1994 for five medic-oat sowing ratios. (a) and (b), effect of nitrogen level and (c) and (d), effect of defoliation timing.

Total Cumulative Production: Results of the combined three harvests show that maximum DM production occurred with a medic 75: oat 25 sowing ratio, applied nitrogen and late defoliation and the lowest production (31% lower) with monoculture medic, applied N and early defoliation (Table 5.6 and Figure 5.4). There were both significant ($P<0.05$) sowing ratio × defoliation and sowing ratio × nitrogen interactions (Table 5.6). Cumulative DM production for mixtures was similar for all treatments, with medic being substituted by oats in general. Medic/oat mixtures were in general more productive than monocultures. The effect of nitrogen increased both medic and oat production in most treatments. The effect of defoliation was more treatment specific with the 75 medic: oat 25 sowing ratio having the greatest benefit from late defoliation and nitrogen application. In general the medic DM component was slightly enhanced in mixtures with late defoliation (Figure 5.4).

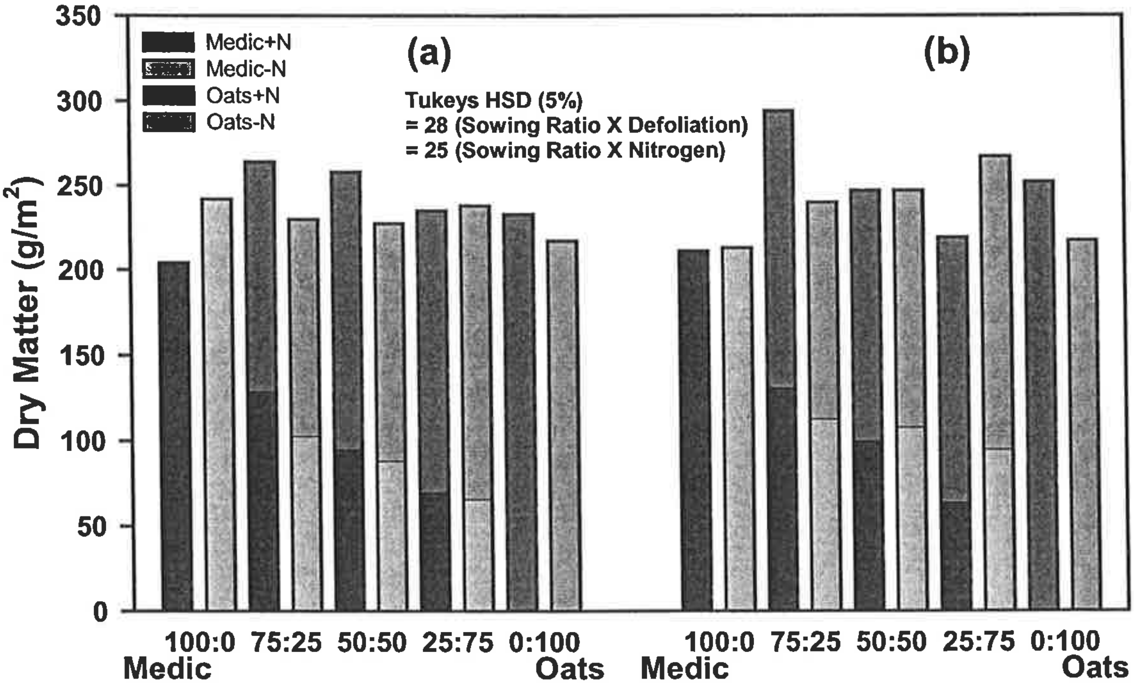

Figure 5.4 Mean dry matter (g/m^2) of 3 harvests combined medic + oats for five sowing ratios, with and without nitrogen and (a) early and (b) late defoliation.

Table 5.10 Relative yield totals of medic and oats for harvest 1, 2 and 3 dry matter in 1994 at Roseworthy.

	Medic 75: 25 Oats				Medic 50:50 Oats				Medic 25:75 Oats			
	Early		Late		Early		Late		Early		Late	
	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N
Harvest 1	0.62	0.99	0.99	1.31	1.05	1.26	0.97	1.31	0.87	1.01	0.90	1.17
Harvest 2	1.10	1.28	1.38	1.33	0.95	1.05	1.14	1.21	1.18	1.01	1.11	1.23
Harvest 3	1.26	1.59	1.41	1.46	0.99	1.45	1.35	1.26	1.06	1.18	1.34	0.99

5.2.3 Discussion

The aim of this experiment was to determine if a favourable interaction between sowing ratio, soil nitrogen status and defoliation timing could be found that improved the medic production, particularly in the early season. A 3:1 medic:oat ratio was the highest yielding mixture in terms of total cumulative DM for this experiment but this sowing ratio only marginally improved the percent medic at each harvest (Figures 5.1, 5.2 and 5.3).

Initially (harvest 1) early dry matter was highest with the oat monoculture or medic/oat mixtures confirming that oats produce more dry matter in winter than medic. At this early stage, delaying defoliation slightly improved the proportion of medic at the higher sowing ratios of medic 75:25 and 50:50 oats (Figure 5.1). These results agree with previous field experiments conducted by Naidu (1979), Gargano *et al.* (1990), Roberts (1990) and Khan (1991) in that mixtures with medic and oats increase total herbage production compared to monocultures. The medic-oat mixture seems to be able to utilise the available environmental resources more effectively than monocultures alone. It is likely that the legume is able to source another form of nitrogen, i.e. its own biologically fixed N possibly accounting for the increases in total yield. Other researchers working with grass legume mixtures in replacement series designs (de Wit *et al.*1966; Harris and Thomas 1972; Harris 1973) have often hypothesised and attempted to show that the legume has the ability to transfer nitrogen to the grass and improve the growth of the grass and that this may be a reason for the increased yield from the mixtures. The large nitrogen rate utilised as one treatment in this experiment should have maximised both oat and medic growth without the need for the oat to benefit from associated transfer during the season.

Total production was not increased greatly by the addition of nitrogen, which is probably as much a reflection on the reduced rainfall for the season as anything else, however, the use of the relative yield (RY) and relative yield total (RYT) allowed some interesting results to be revealed. At harvest 1 the RYT was always greater with the addition of N and with only two exceptions significantly higher than 1 (Table 5.10). This suggests that the species were not mutually exclusive and probably competing for some different resources. The initial assumption was that the oat component with its ability to utilise the additional nitrogen would be the main contributor to an RYT greater than 1. The RY values confirmed this when late defoliation was the applied treatment but not with early defoliation, with most values similar (Table 5.3). In addition the medic component also had increased RY values with the addition of N suggesting that it was also utilising some of the N for increased growth as well. Unfortunately neither the DM results or RY values provide a consistent pattern when examined across defoliation time or sowing ratio to further investigate this.

The increase in oat/medic mixture productivity over monocultures may simply be a function of improved photosynthetic potential per unit area. The combination of an erect grass with a prostrate growing legume utilises all the available space and probably maximises leaf area as there is more than one surface plane to capture sunlight.

The impact of additional nitrogen was minimal in this experiment and it was surprising not to see a greater response to the applied nitrogen; however it is likely that the dry conditions limited the ability of the plants to respond. The positive response in growth of oats to nitrogen is well documented (Moreira 1989) with increases as much as 50% with 67 kg/ha N recorded by Spurway *et al* (1974). The slight increase in medic DM with additional nitrogen when grown in mixtures suggests that the medics could not adequately fix all their own nitrogen requirements. This trend was not consistent across all treatments, particularly with late defoliation, but does invite the question of whether competition can decrease medic × rhizobium efficiency. Also the dry conditions experienced throughout the growing conditions of this experiment may have also contributed to a change in the nitrogen fixation potential of the medic.

The results of this experiment must be considered in the context that 1994 was an extremely dry year with the growing season rainfall 44% below the average. This induced water stress would have reduced the ability of the plants to regrow after each harvest and accounts for the low dry matter production. There are no published data that suggest water stress will differentially affect the two species tested, although it has been suggested by Johns (1972) that temperate grasses are less affected by dry conditions than temperate pasture legumes. In the review by Wilson (1988) of shoot and root competition, there was little evidence to suggest that a reduction in resources, including water, increased competition intensity. In many cases the opposite was true, hence no assumption is made as to which of the two species tested in this experiment was advantaged or disadvantaged by the dry conditions. In addition the low level of soil nitrate at the beginning of the experiment may have altered and increased as rainfall and temperatures changed throughout the growing season minimising the response to N. Available nitrogen fluctuations have been recorded in many soil types (Rochester *et al.* 1991) and it would be common to see an increase in mineral nitrogen throughout the growing season (Fillery 2001). However the preceding period of continuous cropping with cereals should have exhausted most of the available nitrogen supply.

The establishment technique used in this experiment was simply to plant the two species together based on kg/ha seeding rates. An alternative approach to utilising sowing ratios in which kg/ha of seed varied the plant populations would be to use higher than required seeding rates, then hand thin the plant populations back to the desired level. This would have the advantage of being able to improve the accuracy of the sowing ratio treatments. Hand thinning plots this size with such high plant populations would have been extremely time consuming and beyond the resources available for these studies. DM production with medics is particularly influenced by plant populations as shown by Chaichi (1995) in which three seeding rates (3, 15 and 75 kg/ha) were used and differences of between 400-500 kg/ha DM in early harvests were recorded. There was however, an interaction between seeding rate and continuous versus delayed defoliation with delayed defoliation producing more initial DM but continuous defoliation producing higher total DM production over the growing season. Due to the high seeding rates, and large differences between rates, in this experiment it is unlikely that the results would have been markedly different if exact plant populations had been used as the sowing ratios. This is because, over time plants will adjust their size in accordance to the space given them and leaf area/unit area is probably more important for DM production.

In addition to the dry growing season conditions the late timing of establishment for this experiment provides information on establishing medic/oat mixtures in situations that are less than desirable for medic based on the low temperatures experienced during mid winter (see Chapter 4). However the maximum and minimum temperatures experienced during the winter period in 1994 were considerably higher than the long term mean (Appendix Table A.1) which may have helped the medic, although soil water was also limiting.

In summary total production was higher from medic/oat mixtures compared to monocultures alone. Sowing ratios that strongly favoured medic (i.e. > 3:1) helped maximise the medic contribution to the total mixture although in this experiment there was little difference between 3 fold differences in seeding rates in terms of medic percentage contributing to the cumulative production. Maximum medic percentage (approx 56%) only occurred at harvest 3 in the Spring period suggesting growth patterns of the two species affect the components of the mixtures more than sowing ratios. The effect of additional nitrogen was minimal, however delaying defoliation did improve medic growth slightly in harvest 1.

This experiment also confirms the same findings of other researchers in that high medic seeding rates are essential for early DM production, however, oats always provide additional early DM, more than medic alone. The most important finding from this study was the confirmation that the medic: oat sowing ratio must be biased towards the medic component if the desired outcome is a medic dominant mixture.

5.3 EXPERIMENT 4 - THE EFFECT OF THREE STOCKING RATES ON PASTURE PRODUCTION, COMPOSITION AND SHEEP GROWTH IN OAT + MEDIC AND GRASS-FREE MEDIC PASTURES

5.3.1 Materials and Methods

5.3.1.1 Site of experiment

The experiment was conducted at The University of Adelaide Roseworthy Campus; paddock North West 4. Soil description is presented in chapter 3 section 3.2.1 and climate data for 1995 in Appendix Table A.1. The experimental site was the same as used by a previous researcher in 1993 (Chaichi 1995), who examined the effects of deferred grazing on medic production. Establishment counts on medic and soursob, conducted on May 21, 1995 (refer to section 5.3.2.1), revealed that the plant populations were suitably even across all treatments averaging over 1200 plants/m^2. Since this is at the top of the density yield curve for medic (Muyekho 1993; Chaichi 1995) it was deemed appropriate to use this experimental site without having to resort to covariance statistical methodology.

5.3.1.2 Design of experiment

As fencing was already established, the design of the experiment was kept the same even with its limitations of being unreplicated. The design was an unreplicated split-plot with stocking rates as whole plots and pasture types as subplots. The three stocking rates were:

Low = 10 sheep/ha
Medium = 20 sheep/ha
High = 30 sheep/ha

The two pasture types were:

grass-free medic

grass-free medic + oversown oats (medic+oats).

Six sheep were allocated to each paddock of these treatments and stocking rate was adjusted via the paddock size. Paddock sizes were 150m × 40m for Low, 150 × 20m for Medium and 150 × 13.3m for High. Each experimental plot was subdivided into 10 strata for stratified pasture sampling. Stocking rates were based on the previous experiments in this thesis and prior work by Tow (1989), Tow and Alkailah (1981), Roberts (1990, 1991) and Chaichi (1995). The aim being to go below and above suitable pasture utilisation stocking rates for this climate.

5.3.1.3 Establishment

Volunteer barrel medic cv. Paraggio, annual grasses and broadleaf weeds emerged on May 2 and were sprayed with the grass herbicide Fusilade® (fluazifop-P 212 g/L) applied at 500 ml/ha plus 2% wetter and 1% oil on May 26 to control volunteer grasses across all treatments. LeMat® at 50 ml/ha (omethoate) was also added to control red-legged earthmite (*Halotydeus destructor*) and lucerne flea (*Sminthurus viridis*). Oats cv. Marloo were sown into the medic+oat treatment at 50 kg/ha with 100 kg/ha of triple superphosphate fertiliser (20% P, 1.5% S) on May 30 using a John Shearer Trash Culti Drill® plot seeder with narrow points and press wheels. The tyne spacing was adjusted from conventional 15 cm spacing to 30 cm to provide minimal disturbance to the established medic plants. 100 kg/ha of triple superphosphate fertiliser was also drilled into the grass-free medic plots using the same technique so as to reduce any effect of fertiliser or soil disturbance as a contributing factor to treatment differences. The broadleaf weeds three corner jack (*Emex australis*) and indian hedge mustard (*Sisymbrium orientale*) were controlled on June 20 by applying 25 g/ha of Broadstrike® (flumetsulam 800g/kg) plus 2% Uptake® spraying oil.

<u>*Sheep selection, allocation and management*</u>: An initial flock of 50, 3 year old Merino weathers were weighed according to the method of Moule (1965). This involves ranking the sheep in descending order of body-weight. Six sheep were allocated to each of the six pasture treatments based on body-weight such that each pasture treatment received a mean body-weight similar to the mean of the flock according to the method of Roberts (1975) (see chapter 3 materials and methods). Three sheep were kept as spares.

Sheep were introduced to the pasture after overnight fasting and weighed on July 4 and then subsequently weighed on July 18, August 7, August 23, September 9, September 25 and October 12. Sheep in the high stocking rate treatments had to be removed after September 25 due to lack of available pasture for feed.

5.3.1.4 Measurements

Plant Establishment Counts: Counts were taken of emerged medic, ryegrass, barley grass, soursob, three corner jack and indian hedge mustard on May 21. Two $0.1m^2$ quadrats were counted in each of the ten strata in each plot.

Herbage Harvests: Harvests were taken to determine the available dry matter, total growth and botanical composition of the six pasture treatments. To determine pasture growth rates between harvests four 0.7m × 0.7m square and 1m tall secured cage exclosures were placed randomly in each pasture plot and placed on the pasture before the introduction of the sheep. The 'open' and 'closed' quadrat method of McIntyre (1946) was used to determine pasture availability and cumulative growth (see chapter 3 section 3.2.4). Quadrat size was 0.6m × 0.6m and plants were cut to ground level. At harvest 1 cage exclosures were secured randomly in the paddock and a quadrat cut that visually represented growth and composition inside the exclosure was taken outside and adjacent to each exclosure. This was termed an "open" cut. At the second harvest the pasture was cut inside the exclosure (termed "closed" cut) before it was shifted randomly to a new area and secured. The visually matched "open" cut for the second harvest was then taken outside the cage. The four quadrats were combined for each plot for statistical analysis. Pasture growth and growth rates were then calculated as follows:

$$\text{Pasture growth} = (\text{H}n{+}1 \text{ closed}) - \text{H}n \text{ open}$$

where n = harvest number

$$\text{Pasture growth rate} = \frac{((\text{H}n + 1\,\text{closed}) - \text{H}n\ \text{open})}{\text{No.of days between harvest}}$$

Total pasture growth for the season was estimated by adding together the pasture growth between harvests. Harvests were conducted before the introduction of the sheep (which was July 4), on July 3, August 6, September 3, September 27 and October 11. After harvest 5 the cages were shifted to a new position and left secured until the sheep were removed on November 12, to compare the effects of additional grazing and protection on medic seed components. Botanical composition was determined on both "open" and "closed" quadrat samples by hand separation into oats, medic and soursob in the laboratory. Herbage samples were dried in a forced-draught dehydrator for 24 hrs at 85°C.

<u>*Medic Pod and Seed Harvests*</u>: Two medic pod samplings were conducted, the first was conducted after harvest 5 (sheep had been removed on high SR but pods still had opportunity to mature) and the second on November 25 after the end of the experiment. Galvanised metal infiltrometer rings measuring 29.5 cm in diameter were placed randomly along each of the 10 strata in each plot and pushed into the ground to define the sample area. A portable electric vacuum cleaner was used to extract the medic pods off the surface of the soil. Samples were sieved to remove excess dirt and medic vine residue before being washed with Perclean® (perchlorethlene) by the method of Carter *et al.* (1977). An attempt was made to remove pods from the previous year which appeared darker in colour due to weathering; however the majority of pods from the previous year (1994) were buried and were not collected in the sampling procedure.

Medic pod samples were weighed and counted. A random sub sample of ten pods per sample was taken and the pods dissected by hand and seeds removed and counted. Yield components measured from the seed harvest included: number of pods/m^2, number of seeds/pod, mean seed weight, total seed yield.

5.3.1.5 Statistical analysis

One way analysis of variance was conducted on data using the statistical programme Genstat V. Comparisons of pasture types at each of the three stocking rates were analysed first, and if these were not significantly different the data were combined to compare between stocking rates. Regression analysis was used to determine relationships between specific variables relating pasture and sheep production. Linear regression models for the same relationship were tested to determine if they were two distinct lines, two parallel lines or one common line by comparing the observed variance ratios against F tables. As there were no replicates, the stocking rate × pasture type interaction could not be examined statistically. Standard errors were calculated for each mean presented in figures and tables by calculating this from the variance of the number of samples taken per plot or the number of sheep per treatment. So in the case of pasture, 10 strata, and the sheep, six individual's weights.

5.3.2 Results

5.3.2.1 Plant establishment

Plant density counts taken in May 21 showed no significant differences between treatment plots for any of the plant species. The mean plant density of medic was 1210 (±49) plants/m^2, barley grass 13.2 (±1.1) plants/m^2, ryegrass 5 (±0.6) plants/m^2, soursob 7.4 (±0.5) plants/m^2, three corner jack 4.2 (±0.3) plants/m^2 and indian hedge mustard 1.8 (±1.3) plants/m^2. Plant density counts of oats taken on June 16 showed no significant differences between treatments with a mean of 56 plants/m^2. By harvest 1 on July 3 all volunteer grasses, and broadleaf weeds except soursob, were dead from the herbicides applied and did not contribute to the pasture.

5.3.2.2 Available pasture yield and botanical composition

Data for the available pasture yield of three components and botanical composition are presented in Appendix Tables D.1, D.2 and D.3. and Figure 5.5.

Medic DM: At each harvest there was no significant difference between pasture types for available medic yield (Figure 5.5). In the low SR medic DM increased from harvest 1 to harvest 4 by a mean (both pasture types) of 875 kg/ha before declining by 480 kg/ha to 1945 kg/ha at harvest 5. In the medium SR treatment medic DM peaked earlier at harvest 3 with a mean increase (both pasture types) of 415 kg/ha before resulting in a decrease of 501 kg/ha at harvest 5 to 1494 kg/ha. There was however a massive decrease from harvest 1 to harvest 5 in available medic DM for the high SR treatment of 983 kg/ha (mean both pasture types) (Appendix Table D.1).

Soursob DM: The only remaining broad leaf weed after herbicide application was soursob which contributed to the botanical composition of the pasture on offer until the final two harvests when it had senesced naturally (Figure 5.5). There was little differences between SR until harvest 4 when the high SR treatment had reduced soursob availability to only 80 kg/ha (mean two pasture types) (Appendix Table D.2).

Oat DM: The oat component of the pasture in the oat+medic treatments only contributed a small amount at each harvest compared to the medic component (Figure 5.5) and as a percentage of the DM available peaked at 16% at harvest 2 in the low SR treatment (Table

5.11). At harvest 5 the sheep at the high SR had completely consumed all oat DM and none was recorded. Both low and medium SR treatments had only 100-115 kg/ha at this stage (Appendix Table D.3). As a percentage of the pasture the oat component was only affected by SR at harvest 5. (Table 5.11).

Table 5.11 The percentage of oat and medic available dry matter yield for three stocking rates (mean of two pasture types) for five harvests in 1995.

Stocking Rate	Species	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5
Low	Oat	9%	16%	12%	9%	5%
	Medic	72%	68%	80%	83%	91%
	Soursob	19%	16%	8%	8%	4%
Medium	Oat	8%	15%	13%	9%	6%
	Medic	72%	70%	78%	82%	89%
	Soursob	20%	15%	9%	9%	5%
High	Oat	9%	13%	11%	8%	0%
	Medic	70%	70%	75%	79%	96%
	Soursob	21%	17%	14%	13%	4%

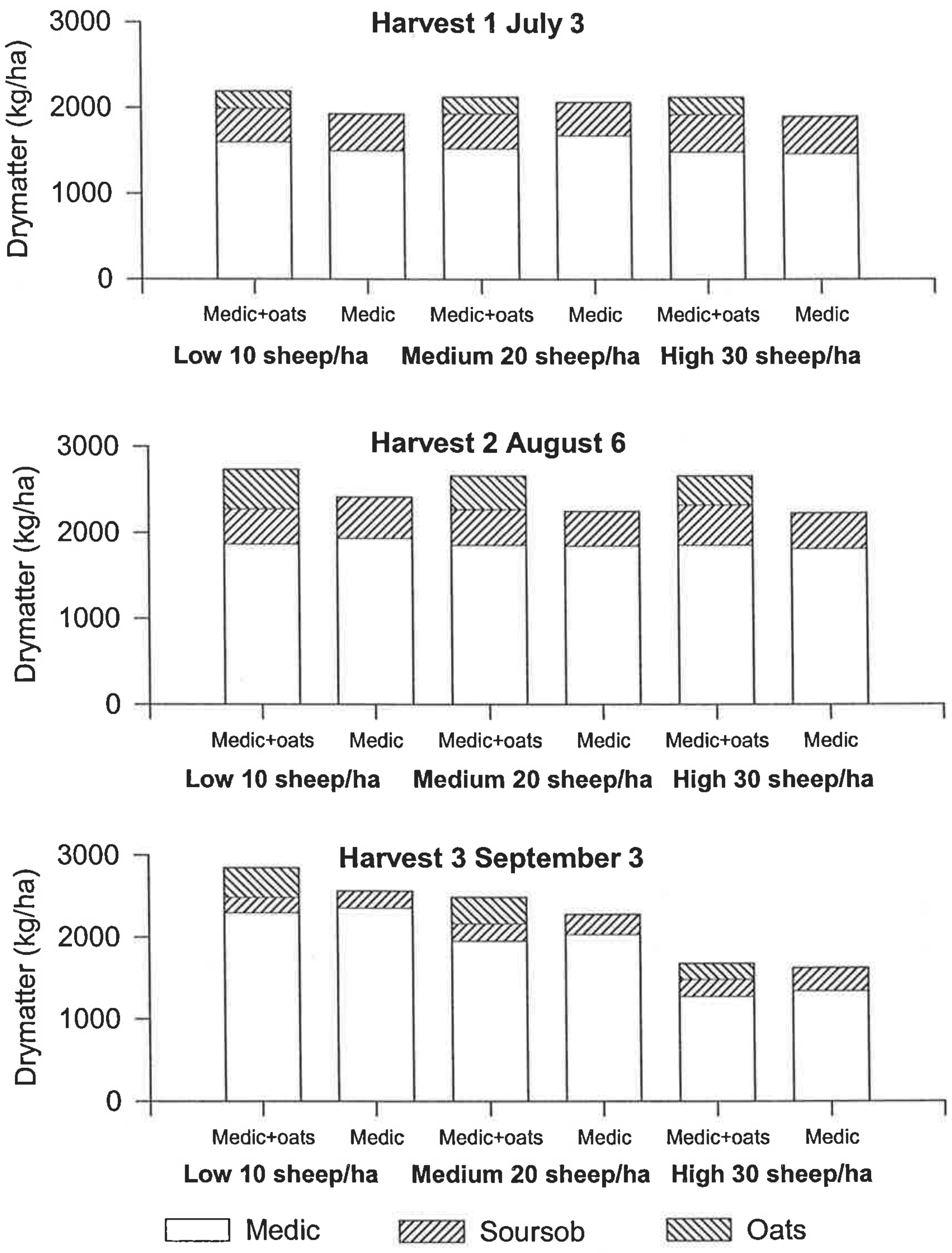

Figure 5.5a Available dry matter yield (kg/ha) of medic, soursob and oats at Harvest 1, Harvest 2 and Harvest 3 for 1995.

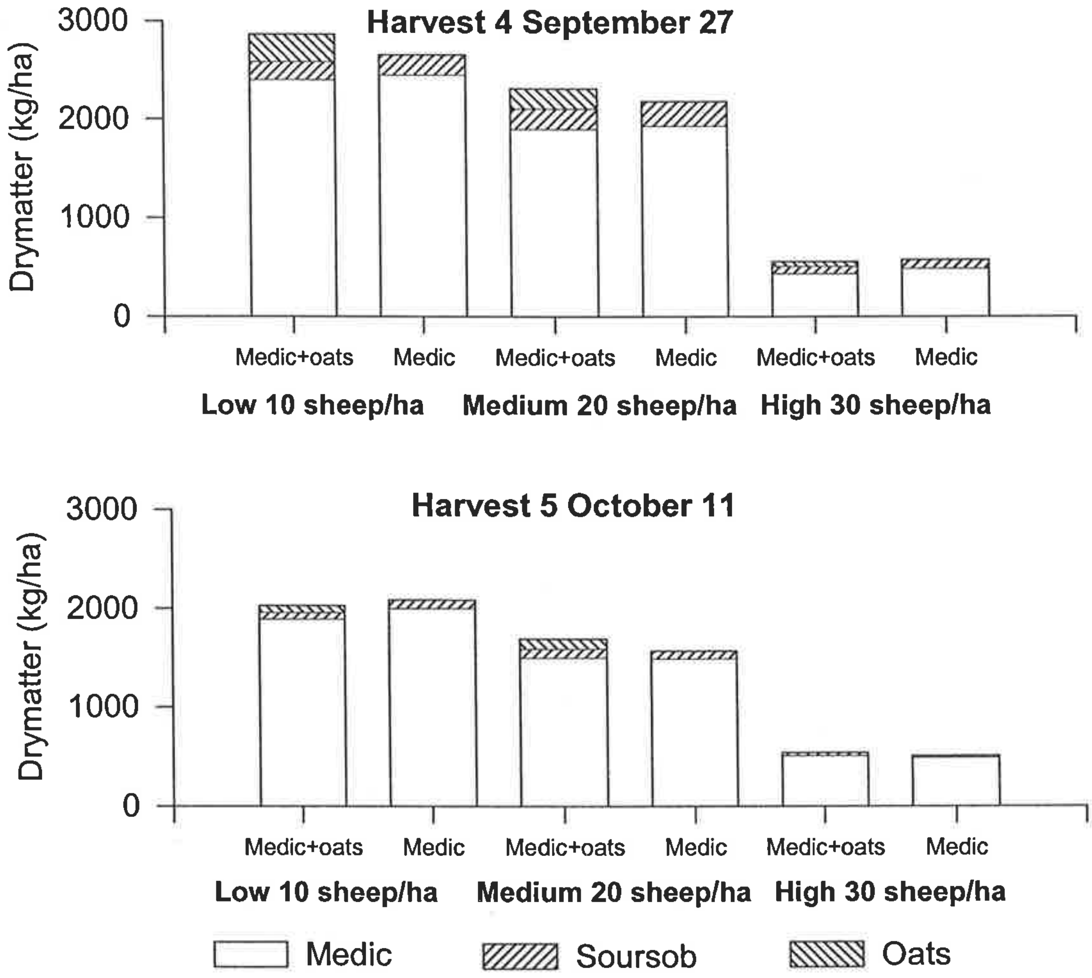

Figure 5.5b Available dry matter yield (kg/ha) of medic, soursob and oats at Harvest 4 and Harvest 5 for 1995.

5.3.2.3 Total available pasture production

Total available DM increased at all stocking rates from harvest 1 to harvest 2 (96 days after emergence). Then the high SR treatment showed a rapid decline in availability (Figure 5.6), which was only halted by the removal of the sheep after harvest 4. Both the low and medium SR treatments only showed a significant decline 148 days after emergence.

Total available DM on offer was only significantly ($P<0.05$) different between pasture types at harvest 2 when the average of the three SR oat+medic treatments yielded 145 kg/ha more DM than the medic treatment (Table 5.12). In all other harvests this difference was not evident.

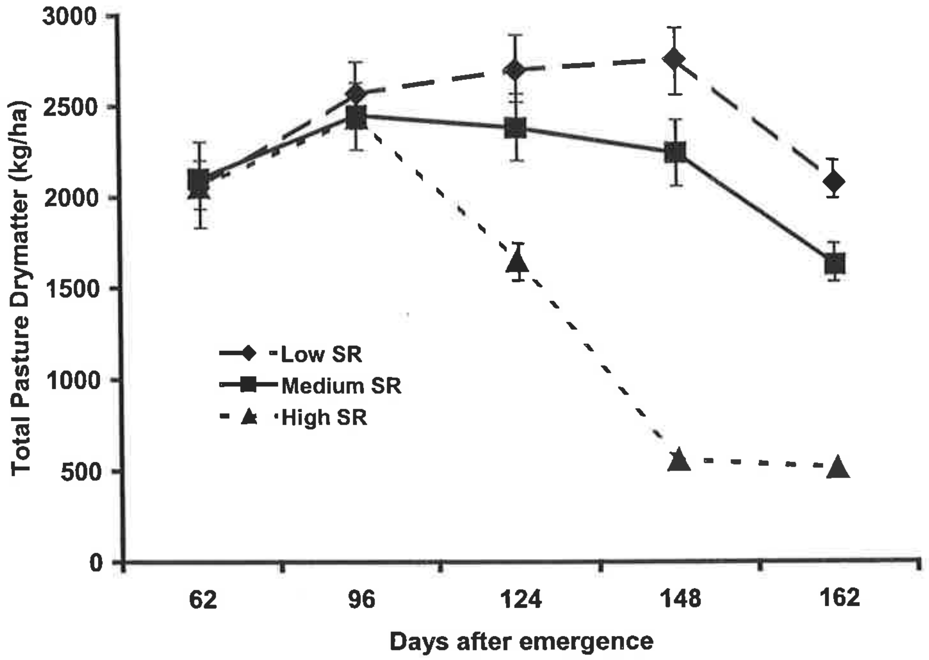

Figure 5.6 Total available pasture DM (kg/ha) over time for Low (10 sheep/ha), Medium (20 sheep/ha) and High (30 sheep/ha) stocking rates (SR) in 1995 (means of two pasture types). Vertical bars indicate standard errors.

Table 5.12 Mean total available dry matter yield (kg/ha), for three stocking rates and two pasture types at five harvests in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
Harvest 1 Jul 3	2190	1923	2123	2078	2120	1996
	±200	±196	±214	±211	±198	±201
Harvest 2 Aug 6	2731	2412	2658	2245	2655	2225
	±227	±232	±234	±210	±216	±225
Harvest 3 Sep 3	2843	2561	2486	2279	1679	1623
	±223	±230	±249	±234	±191	±195
Harvest 4 Sep 27	2864	2656	2311	2179	555	574
	±257	±243	±222	±236	±43	±58
Harvest 5 Oct 11	2073	2085	1689	1567	536	504
	±166	±176	±121	±132	±65	±54

5.3.2.4 Total production of five harvests

Total production was affected by two components, SR and the addition of oats. The effect of the high SR was to reduce total DM produced, most notably by a halving of the medic component compared to the other stocking rates (Table 5.13). The medium SR treatment appeared to be the optimum for DM production, producing 892 kg/ha (average both pasture types) more DM than the low SR treatment. The addition of oats to medic significantly ($P<0.05$) increased total DM production at all stocking rates when compared to medic alone, providing a mean increase of 781 kg/ha across all stocking rates.

Table 5.13 Mean total pasture species production (kg/ha) for medic, soursob and oats from July 3 to October 11 for three stocking rates and two pasture types in 1995. Numbers below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
Medic	6589 ±302	6592 ±313	7581 ±301	7611 ±323	3046 ±289	3189 ±299
Soursob	728 ±145	759 ±134	778 ±139	792 ±121	680 ±111	717 ±116
Oats	960 ±110		902 ±105		738 ±98	
Total Production	8277 ±386	7351 ±345	9261 ±314	8403 ±311	4464 ±358	3906 ±311
Oat % of Total Production	11.5%		9.7%		16.5%	

5.3.2.5 Pasture growth rate

As with pasture availability and total pasture growth, medic growth rates were lowest at the highest SR from the start of the measurements (Table 5.14). Grazing at the medium SR had the effect of maximising medic growth rate from August onwards with a 59% (average both pasture types) increase over the low SR by the end of the experiment. There were no significant differences in growth rates between pasture types for medic production. Hence the main treatment effect was stocking rate on medic growth with large differences occurring by the end of spring allowing 20 sheep/ha to be maintain sheep growth rates virtually as high as 10 sheep/ha. Oat growth rates were reduced dramatically from early

August onwards (Table 5.15); however there appeared to be little effect of SR treatments. The addition of oats to the medic did provide significantly ($P<0.05$) higher total pasture growth rates (39.6 compared to 28.8 kg/ha/day, mean of the three SR's) in the period from July 3 to August 6 but this difference between pasture types did not continue after August 6 (Table 5.16).

Table 5.14 Mean medic growth rate (kg/ha/day) between five harvests at three stocking rates and two pasture types in 1995. Numbers below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
July 3-Aug 6	31.4 ±3.2	34.3 ±3.1	32.8 ±3.0	28.6 ±2.9	13.7 ±1.1	14.6 ±1.2
Aug 6-Sept 3	33.3 ±3.3	34.0 ±3.2	40.9 ±3.8	42.5 ±3.9	8.4 ±0.9	13.9 ±1.0
Sept 3-Sept 27	24 ±2.2	22.3 2.6	48.6 ±4.2	48.6 4.3	9.4 ±0.8	9.3 0.8
Sept 27-Oct 11	32.7 ±3.5	27 ±3.3	73.3 ±4.9	72.6 ±4.8	7.3 ±0.5	7.5 ±0.6

Table 5.15 Mean oat growth rate (kg/ha/day) between five harvests at three stocking rates and two pasture types in 1995. Numbers below means are standard error of means.

	Low 10 sheep/ha	Medium 20 sheep/ha	High 30 sheep/ha
	Oat+Medic	Oat+Medic	Oat+Medic
July 3-Aug 6	12.1 ±1.1	11.5 ±0.9	11.5 ±1.1
Aug 6-Sept 3	3.5 ±0.2	3.8 ±0.25	2.4 ±0.24
Sept 3-Sept 27	2.8 ±0.21	1.2 ±0.13	1.3 ±0.11
Sept 27-Oct 11	3.7 ±0.3	5.1 ±0.2	2.9 ±0.2

Table 5.16 Mean total pasture growth rate (kg/ha/day) between five harvests at three stocking rates and two pasture types in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
July 3-Aug 6	45.3 ±3.8	37.5 ±3	46.7 ±4.1	32.2 ±3.8	26.8 ±2.9	16.7 ±2.1
Aug 6-Sept 3	40.3 ±4.0	36 ±3.7	47.8 ±3.8	46.4 ±3.2	12.8 ±1.7	16.6 ±1.8
Sept 3-Sept 27	30 ±3.0	25.3 2.6	52.6 ±4.3	51 3.9	13.6 ±1.8	13 1.7
Sept 27-Oct 11	38.8 ±3.4	27.7 ±3.1	80.9 ±4.7	74.8 ±4.8	12.3 ±0.9	9.8 ±1.0

5.3.2.6 Medic seed harvest

Medic seed yield and yield components (pod numbers, pod weight, seeds/pod and seed weight) were all greater in the low and medium SR treatments compared to high SR (Table 5.17). As a result seed yield was severely reduced with high SR. Seed yields were mostly related to pod number/ha, however there was a reduction in mean seed weight for the high SR treatment. The addition of oats did not significantly affect medic yield components. As sheep were removed from the high SR treatment after September 25 two medic pod samplings were conducted for the Low and Medium SR treatments. The comparison between the first (Table 5.17) and second (Table 5.18) medic yield component samplings, show that a large reduction in medic pod numbers occurred for the medium SR with an additional month of grazing. This resulted in a 22% decrease in seed yield. The effect appeared to be less pronounced with the pasture type that had oats.

Table 5.17 Mean pod number (pods/m^2), pod weight (mg), seeds/pot, seed weight (mg) and seed yield (kg/ha) from pasture grazed to October 11 for three stocking rates and two pasture types in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
Pod number/m^2	4137 ±365	4692 ±349	4626 ±280	4724 ±295	2563 ±180	2446 ±189
Mean pod weight (mg)	62 ±3	68 ±2.2	72 ±3.4	68 ±3.6	51.8 ±2.5	56 ±1.4
Number seeds/pod	4.8 ±0.3	5.2 ±0.2	5 ±0.2	4.5 ±0.3	4.2 ±0.3	4.4 ±0.2
Mean seed weight (mg)	4.2 ±0.2	4.5 ±0.1	4.5 ±0.2	4.2 ±0.3	3 ±0.1	3.4 ±0.1
Seed yield (kg/ha)	833 ±96	1098 ±124	1041 ±93	893 ±68	323 ±38.8	366 ±10.4

Table 5.18 Mean pod number (pods/m^2), pod weight (mg), seeds/pot, seed weight (mg) and seed yield (kg/ha) from pasture grazed to November 12 for two stocking rates and two pasture types in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic
Pod number/m^2	4137 ±380	4074 ±321	3815 ±183	3428 ±132
Mean pod weight (mg)	54 ±2.4	60 ±1.9	50 ±2.4	60 ±3.5
Number seeds/pod	4.8 ±0.3	5.3 ±0.2	4.9 ±0.2	4.5 ±0.3
Mean seed weight (mg)	4.1 ±0.2	4.3 ±0.1	4.4 ±0.2	4.2 ±0.3
Seed yield (kg/ha)	834 ±100	946 ±120	864 ±78	654 ±55

5.3.2.7 Sheep body-weight gain

Sheep gained the most weight in the low and medium SR treatments with only small gains in the high SR treatment (Table 5.19). There was no significant difference in body-weight between sheep grazing grass-free medic or oat + medic at any sampling date when combining the SR's as replicates for analysis.

Table 5.19 Mean sheep body weight (kg/sheep) and total weight gain at three stocking rates on medic and oat+medic pastures in 1995.

	Weighing times (grazing days from start)							
Treatment	0	15	36	51	68	84	101	Weight Gain (kg/sheep)
Medic								
Low (10 sheep/ha)	48.8	50.8	52.8	56.8	58.4	60.1	62.8	14
	±2.3	±1.7	±2.5	±3.2	±3.5	±3.7	±3.7	±3.6
Medium (20 sheep/ha)	48.6	50.8	53.8	55.3	57	58.2	60.3	11.7
	±1.5	±0.8	±1.0	±1.8	±1.9	±1.8	±1.7	±0.5
High (30 sheep/ha)	48.8	51.1	53.7	52.2	51.9	52.3		3.5
	±1.9	±2.1	±1.2	±1.3	±1.2	±1.5		±0.9
Oat+Medic								
Low (10 sheep/ha)	48.9	50.9	54.8	56.1	58.5	61	62.7	13.8
	±1.8	±1.7	±1.5	±1.7	±1.8	±2.1	±2.0	±1.9
Medium (20 sheep/ha)	48.8	50.7	53.4	55.2	57.3	58.8	60.6	11.8
	±1.4	±2.4	±2.1	±1.7	±1.0	±0.8	±0.9	±0.8
High (30 sheep/ha)	48.3	53.3	54.5	54	53	52.7		4.4
	±1.5	±0.4	±1.4	±2.6	±2.3	±1.2		±2.2

As the low and medium stocking rates were not significantly different the data were combined for comparison over time. There was a linear increase in sheep body-weight over time for sheep grazing at low and medium SR. However, sheep grazing at the high SR increased body weight for approximately 35 days, then reduced body weight for the next 50 days (Figure 5.7).

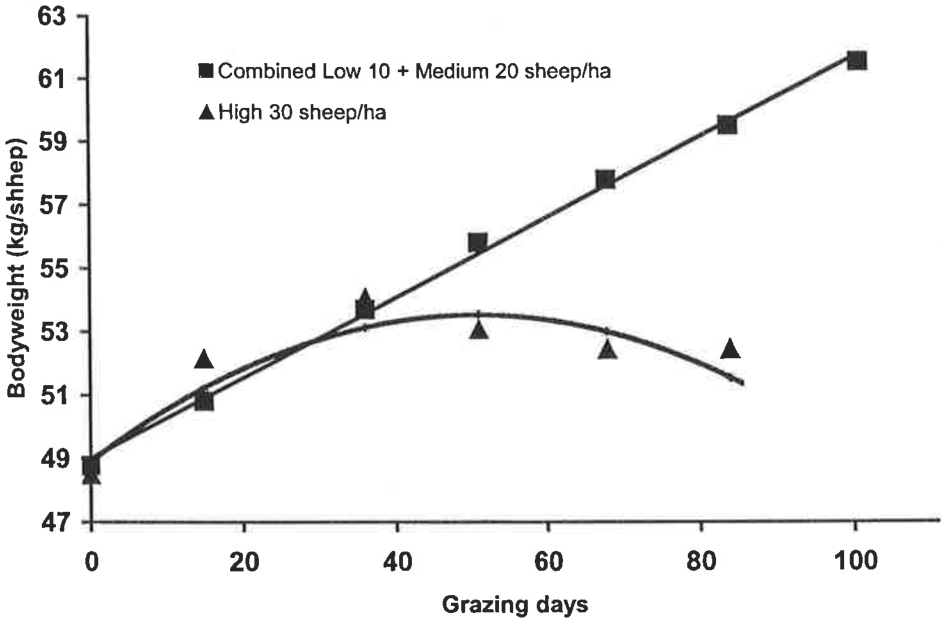

Figure 5.7 Effect of stocking rate on bodyweight gain per sheep (kg/sheep) over 100 days in 1995 (mean of two pasture types, data combined for low and medium stocking rates).

The significant ($P<0.01$) relationships between body weight and time for the three stocking rates were:

Combined Low 10 + Medium 20 sheep/ha
body weight = $49 + 0.138(\pm 0.0038)\ X$ ($R^2 = 0.99$)
Where X = Grazing days

A cubic polynomial gave a significantly better fit ($R^2 = 0.99$) than the quadratic for the high SR over the period tested, as sheep liveweight had stopped decreasing by day 84. However if the sheep had been retained on this treatment longer they would have continued to lose weight, altering the relationship. Since the cubic polynomial relationship made no biological sense, as sheep can not lose then gain weight with decreasing food on offer, the data were transformed by taking the natural log of the reciprocal of the bodyweights according to the following general equation as shown by Ratkowski (1983)

$$\ln(1/y) = a + bx + cx^2$$

The data were solved for this equation and back transformed to actual bodyweight data to provide points for the trend line. A quadratic equation was then fitted to this and had the form of:

High 30 sheep/ha

Body weight = $49.1 + 0.182(\pm0.0496)\,X - 0.0018(\pm0.0006)\,X^2$ ($R^2 = 0.83$)

Where X = Grazing days

These trend lines are shown in Figure 5.7

The low SR treatment achieved the highest sheep body-weight gain/day, but when converted to a body-weight gain/ha the medium SR rate was 40% higher (Table 5.20). Comparing the body-weight gain/ha/day shows that while the medium SR was still the most productive, both low and high SR were comparatively similar (Table 5.20).

Table 5.20 Mean body-weight production growth rates (kg/ha/day) for three stocking rates from July 4 to November 12 1995 (mean of two pasture types).

	Low (10 sheep/ha)	Medium (20 sheep/ha)	High (30 sheep/ha)
Sheep body-weight gain (kg)	13.9	11.75	3.95
Grazing days	101	101	84
Body-weight gain (kg/sheep/day)	0.137	0.116	0.047
Total body-weight gain/ha (kg/ha)	139	235	118.5
Body-weight gain/ha/day (kg/ha/day)	1.37	2.32	1.41

5.3.3 Discussion

Plant establishment and Pasture yield: There was excellent medic establishment in this experiment. High plant densities have been shown to be of critical importance to achieve high herbage yields in winter for annual legumes (Adem 1977; Abd El-Moneim and Cocks 1986; Carter 1987; Dear and Jenkins 1992). Oat establishment was equally good and the objective of establishing a weed-free oat/medic mixture was almost achieved. The only weed to contribute to the total pasture production in this experiment was soursob. This weed has become rare in rotations with frequent cereal crops due to its high susceptibility to the sulfonylurea class of herbicides. In a commercial medic: cereal rotation, soursob would have been eliminated in the previous seasons by the use of metsulfuron-methyl within the cereal phase and would not normally be a problem. The ability to utilise herbicides to eliminate the majority of grass and broadleaf weeds before planting the oats, proved that it is possible to achieve almost pure medic-oat pasture with the correct management. The usual method of establishing oat/medic mixtures is to plant both species at the same time at the break of the season. This has the advantage of early growth in warmer climatic conditions but the disadvantage of competition from weeds. The medic may also be at a competitive disadvantage (see chapter 4). In this experiment the effect of adding oats to the medic pasture had no impact on medic DM availability. Total production was increased with the addition of oats; however oats were additive to the pasture rather than substitutive. The delay in planting the oats placed them at a significant disadvantage and they only provided an additional total of 781 kg/ha of DM for the course of the experiment. As a result oats represented less than a fifth of the total production (Table 5.11) which is significantly less than measured in previous field experiments in this thesis (Chapter 3) and others including Naidu (1979), Roberts (1990; 1991) and Kahn (1991). The oat component contributed a slightly higher percentage in the high SR treatment suggesting that high grazing pressure may have allowed it to grow at a faster rate. This was not, however, supported by the growth rate analysis (Tables 5.14 and 5.15). A number of contributing factors may have altered the medic/oat competition in this experiment. The high density medic plant numbers that were established prior to the oats being drilled in at a low rate may have allowed the medic to compete more favourably. This hypothesis is supported by the previous experiment 3 which showed that high medic plant populations compared to oats, allowed the medic component to contribute substantially more to the mixture. It is also possible that the change in sowing rate configuration from 15 cm to 30 cm row spacing may have contributed to reduced oat growth. Certainly the medic was less disadvantaged by this planting system, as there was reduced shading for the medic.

In this experiment the optimum stocking rate in terms of sustainable pasture production, seed yield and sheep live-weight gain was 20 sheep/ha. The low SR of 10 sheep/ha allowed more DM accumulation which was under-utilised. It is possible that the under-utilization resulted in death of shaded plant growth, thus lower net growth rate. Conversely the high SR of 30 sheep/ha created a situation in which the growth rate of the pasture was greatly reduced and was unable to replace what the sheep consumed.

The design of this experiment does not permit examination of whether the oat component of the pasture was actively targeted and grazed by the sheep in preference to the legume. It is, however, clear that the oat component was not avoided by the sheep given that at the low SR they had adequate feed to avoid eating the oat DM. The available DM production (Figures 5.5a and b) show that the sheep were consuming the oats and the percentage of oats in the pasture did alter significantly between SR's (Table 5.11).

Seed yield: As with pasture availability, medic seed yield components were optimised with the medium SR and severely reduced in the high SR treatment. The seed yields in the low and medium SR treatments were excellent and illustrate the value of high medic densities in pastures to maximise seed yield for subsequent regeneration. The greater pod numbers/m^2 for the medium SR treatment compared to the low SR treatment may be the result of improved canopy structure at flowering and pod filling time. Muyekho (1993) clearly demonstrated that at high seedling densities, a degree of defoliation is useful in limiting self shading, thus optimising flower numbers and subsequent pod numbers/ha. The findings of this experiment also agree with Chaichi's (1995) result of maximum medic seed yield in his grazing experiments with 20 sheep/ha. Chaichi's (1995) spring grazing experiment examined the effect of stocking rate and grazing time on medic DM and seed yield using three stocking rates, with a similar experimental design to this experiment. (although his three stocking rates were 20, 40 and 60 sheep/ha which are considerably higher than this experiment). He attributed the main differences in seed yield to correlations between SR and branches/plant, nodes/plant, flowers/plant and pods/plant.

The low seed yields associated with the high SR treatment in this experiment are in agreement with the results of Muyekho (1993) and Chaichi (1995) who showed that low dry matter production was associated with low seed yield. As with the available DM production, there was no noticeable effect of the addition of oats on pod or seed yield in this experiment.

Sheep body-weight: When pasture availability was adequate, as with the low and medium stocking rates, sheep body-weight increased in a linear fashion over time (Figure 5.7). When pasture availability became limiting, as in the high SR, body-weight began to decline as expected. The sheep were removed from this experiment before serious body-weight decline occurred, as pasture availability had declined to approximately 500 kg/ha DM. At such low DM yields there is substantial bare ground visible, with little leaf left on medic plants and a considerable reduction in flowers and pods. The reduction in sheep body-weight when pasture availability falls below 500 kg/ha DM agrees with results of Chaichi (1995) in grazed medic studies and Smith *et al* (1972; 1973) grazing subclover.

The addition of oats to medic had little effect on sheep body-weight. There was, however, a trend for sheep grazing the oat+medic pasture type at the high SR to have higher body weights up to day 51 but it was not significant (Table 5.19). The body-weight gains of 137 and 116 g/sheep/day are similar to those recorded in experiment 1 (chapter 3) but are higher than values of approximately 100 g/sheep/day at 20 sheep/ha SR, recorded in some of Chaichi's (1995) grazing experiments. The differences may be due to the short grazing periods and high (58 kg) starting body-weight of the sheep used in Chaichi's (1995) experiments.

There were large differences in the body weight gain per hectare on these pastures with the three different stocking rates. The medium stocking rate appeared to come close to optimisation of three important components; pasture production, seed production and sheep production. The importance of matching stocking rate to pasture availability is clearly evident in this experiment.

5.4 CONCLUSIONS (sections 5.2 and 5.3)

The two experiments described in this chapter were designed to examine management options to improve total productivity and the medic component of oat/medic mixtures. These results of these experiments highlight the importance of medic seedling density at establishment. High medic density and delaying defoliation i.e. later sheep introduction, are the most effective methods of maximising medic growth. The use of low soil nitrogen levels as a way of reducing oat competition against the medic component is of little value.

In terms of sheep productivity the results suggest that high medic density and delaying the introduction of the sheep onto the pasture is the most important attribute in maintaining body weight gain per hectare. The grazing experiment in 1995 (section 5.3) has shown that in situations where there is an early start to the season, and provided there is high medic density, the extra DM offered by the addition of oats is not required. The advantage of having additional oat DM in medic based pastures in seasons with early growing season starts, provided high density medic stands exist, are minimal, although this situation may change with differing ratio's of medic and oats.

Chapter 6

6. EXPERIMENTS 5 and 6 - EVALUATION OF ANNUAL *MEDICAGO* GENOTYPES FOR INCREASED COMPETITIVENESS WITH OATS

6.1 INTRODUCTION

The results of previous experiments (chapter 3, 4 and 5) have shown that the medic cultivar Paraggio is at a competitive disadvantage in oat/medic mixtures, even when management options designed to increase its productivity are utilised. A medic genotype that is more competitive in its early growth stage would be an advantage in oat/medic mixtures and may help to capitalise on management options designed to favour medic growth in these mixtures. Large genetic diversity exists within the annual *Medicago* genus and collection expeditions to Mediterranean regions of the world have accumulated over 17,500 annual medic genotypes (Crawford *et al.* 1989; Auricht 1990). These genotypes have been characterised and evaluated under field conditions at Parafield, South Australia providing the information to create a database on both morphological and agronomic characteristics. Examination of this data base has shown large differences amongst species and within species for traits desirable in competitive medics. Selection and evaluation of these genotypes for their competitiveness would determine if genetic improvement over the current cultivars is available for oat/medic mixtures. Grime (1979) claims that plants with a high relative growth rate at an early stage of growth and inter-plant interference would confer a competitive advantage. Hence looking for medic plants with enhanced early vigour may provide one strategy in improving the medic component in oat/medic mixtures.

Legume growth is a combination of plant × rhizobium strain interactions and several authors including Brockwell and Hely (1966), Brockwell and Holliday (1988) and Howieson and Ewing (1989) have shown considerable variation in both medic species and individual genotypes to form effective host × rhizobium strain relationships. This research suggests that to optimise medic growth, particularly of new untested medic accessions, appropriate rhizobium strains may be required for each accession or species. Some species (i.e. *M. ciliaris, M. blancheana, M. turbinata, M. intertexta*) appear to have never been evaluated for rhizobia requirements. To ensure new, untested species and genotypes are not disadvantaged in competition evaluations, appropriate *Rhizobium meliloti* strains should be utilised. The aim of experiment 5 was to evaluate genotypes selected for increased competitive ability (based on early vigour) with *R. meliloti* strains to determine appropriate host × strain relationships, should further evaluation be required.

The results from experiment 2 (chapter 4) and an experiment by Clarkson and Russell (1979) have shown reduced medic growth at low temperatures with cultivars of both *M. truncatula* and *M. scutellata*. Other researchers (Taylor 1972; Cocks 1973; Greenwood *et al.* 1976; Silsbury *et al.* 1984; Silsbury and Hancock 1990) have also shown low temperatures impede sub clover growth. Comparison of these experiments indicate that medics may be even more sensitive to low temperatures. All of these experiments were conducted with commercially released available cultivars at the time of the experiment. Recent selection and breeding have provided medic genotypes that are supposedly more vigorous in their early stages of growth; that is, faster growth and dry matter production at low temperatures, assuming growth is assessed at low temperatures (I. Kaehne pers. comm.). A comparison of the competitive ability in oat/medic mixtures between these genotypes and the cultivar Paraggio is required to determine if the cold tolerance genetic trait is useful. The aim of experiment 6 was to compare three new cold tolerant genotypes with Paraggio in competition with oats at two defoliation times to determine if these genotypes are more competitive.

6.2 EXPERIMENT 5 - EVALUATION OF EARLY VIGOUR *MEDICAGO* GENOTYPES WITH SIX RHIZOBIUM STRAINS

6.2.1 Materials and Methods

An examination of the Australian Medicago Genetic Resource Centre (AMGRC) database was conducted to identify *Medicago* accessions with increased early vigour. Early vigour was defined as the average of the first two subjective herbage ratings relative to the control cv. Jemalong when the plants were first grown at Parafield Plant Introduction Centre, South Australia. Selection was further narrowed by selecting accessions with attributes suitable to the requirements of medic plants adapted to low rainfall, alkaline soil regions of southern Australia. These were: mean annual rainfall less than 400 mm, pH greater than 7.0 (water), altitude close to sea level, days to flowering less than 110 and pod spininess less than the control cv. Jemalong. Breeders utilise these characteristics along with final herbage seed yield to select suitable genotypes for commercial release. Final selections from the database comprised 16 accessions from 12 different species.

Selection of *Rhizobium meliloti* strains consisted of the current commercially released recommended strain (CC169), four isolated strains (WSM 826, WSM 540, CC 2103 and NA 39) and a mixture of related ICARDA M strains (ICARDA M1, ICARDA M17, ICARDA M36 and ICARDA M44) supposedly suitable for *M. rigidula* (Brockwell and Holliday 1988) all provided by CSIRO Division of Plant Industry, Canberra.

6.2.1.1 Design of experiment and treatments

The design of the experiment was a 18 × 7 factorial with 4 replicates.

Treatments were: Sixteen annual *Medicago* accessions and two control cultivars Jemalong and Paraggio (Table 6.1)

Six rhizobium strains and a nitrogen control given mineral N to provide a standard to judge the effectiveness of symbiotic N fixation (Table 6.1).

Uninoculated nitrogen free controls were included as checks for cross contamination.

6.2.1.2 Seed preparation, establishment and maintenance

Seed Preparation: *Medicago* seed was graded for uniformity of size and held in a dessicator for 24 hrs before scarification and surface sterilisation by immersion in concentrated sulfuric acid for 5 mins. Seeds were washed in sterilised water then allowed to imbibe for two hours before being placed on agar medium to germinate. Seeds were incubated at 25°C with the agar dishes inverted to allow radicles to grow straight down from the gel.

Establishment: Five seedlings per 12.5 cm diameter pot were established in steam sterilised 2:1 sand:vermiculite mixture pH(w) 7.0. The seedlings were inoculated seven days after establishment by applying 20 ml of a suspension of rhizobium in 0.085% physiological saline to the surface of each pot. After inoculation the surface of the pots was covered with 3 mm diameter alkathene beads to minimise evaporation and reduce splash contamination between pots. Pots were arranged in randomised blocks in a glasshouse with maximum temperature of 25°C over the winter/spring period. Uninoculated controls were scattered randomly amongst the blocks to check for potential rhizobium contamination.

Maintenance: A nitrogen-free basal nutrient solution was applied every 28 days as follows (mg/pot): KH_2PO_4 ,110; K_2SO_4 ,97; $Mg(SO_4)_2$,45; $CuSO_4$,1.2; $ZnSO_4$, 2.4; Na_2MoO_4, 0.14; and $FeSO_4$, 5.44. Nitrogen treatments were watered with 25 mg of NH_4NO_3 every 14 days. Pots were rotated every seven days within blocks to minimise glasshouse edge effects.

6.2.2 Measurements

Plant shoots were harvested 64 days after establishment, oven dried at 60°C for 24 hours and weighed before being ground for nitrogen analysis. The four replicates were combined for nitrogen analysis; two sub samples per treatment were analysed using the Kjeldahl method. Percent shoot nitrogen was multiplied by shoot dry weight to give total shoot nitrogen per pot. Soil was washed from the roots before oven drying at 80°C for 24 hours and weighing. Roots were also examined to see if nodulation had occurred.

6.2.3 Statistical Analysis

Analysis of variance was conducted on data using the statistical program Genstat V. The experiment was analysed as a 16×7 factorial design. Comparison of means was made using the Tukey's honestly significant difference range test (HSD) (Steel and Torrie 1960). Because not all medic accession × rhizobium combinations could be tested due to poor germination, separate ANOVA's were conducted for each complete set of medic accession × rhizobia results. This is shown Tables 6.1 and 6.2 where each separate ANOVA and HSD value is for the species and columns above the horizontal lines.

6.2.4 Results

Seeds of some accessions did not readily imbibe, possibly because the level of scarification was insufficient or long term storage may have reduced their viability. Due to the limited amount of seed available (1 gram) it was not possible to conduct a preliminary experiment on scarification time. This resulted in a reduced number of seedlings available for establishment and so not all medic accession × rhizobium combinations could be examined.

There was no significant ($P<0.05$) correlation between the AMGRC subjective herbage rating and shoot dry weight of accessions. There was also no significant relationship between seed weight of the accessions and AMGRC subjective herbage rating or shoot dry weight. By harvest time, uninoculated controls were either dead or severely stunted and yellow, indicating nitrogen deficiency. Root examination showed no or very few nodules on these plants indicating low levels of contamination. Plants from most other accessions had good nodules although nodule number and size varied considerably and appeared to be random as replications of the same treatments produced different nodulation patterns (e.g. some had a few big nodules and others a smaller size but greater number scattered throughout the rooting structure). No attempt was made to assess this, due to the randomness of the results.

6.2.4.1 Dry weight

There was a significant (P<0.001) medic accession × rhizobium interaction for both shoot dry weight and combined shoot+root dry weight (Table 6.1 and Table 6.2). Nitrogen controls in general had higher dry weights than inoculated accessions. In general, shoot + root DM weights followed shoot DM weights in the same pattern. Only two accessions SA 6183 (*M. polymorpha*) and SA 10638 (*M. ciliaris*) with the rhizobium strain CC169 produced higher shoot dry weight (although not significant) than the cv. Paraggio with its preferred strain CC169. SA 10638 also appeared to form a successful symbiotic relationship with rhizobium strain CC2103 but this was not significantly greater than other effective combinations. The current commercial strain of rhizobium CC169 was, overall, the most consistently effective, SA 17298 (*M. littoralis*) being the only accession failing to form an effective symbiotic relationship with it, or any of the strains tested.

The medic accession SA 10638 appeared to have excellent growth potential with its nitrogen control yielding 75% higher than Paraggio and the highest DM yield with rhizobium strain CC169 of all accessions tested (Tables 6.1 and 6.2).

6.2.4.2 Total Shoot Nitrogen/Pot

Shoot nitrogen percentage ranged from 0.8% to 3.7% with a mean of 2.3%. Low shoot nitrogen % was generally associated with low dry weight. Total shoot nitrogen/pot was mainly influenced by dry weight in accessions that formed effective symbiotic relationships (Table 6.3). Accession SA 10638 again much higher than all others. Nitrogen controls and

CC169 gave similar N yields, suggesting symbiotic associations with the strain CC169 provide adequate N fixation.

Table 6.1 Mean shoot dry weight yields (g/pot) and AMGRC herbage ratings for 18 *Medicago* accessions inoculated with six *Rhizobium meliloti* strains and nitrogen controls.

			1	2	3	4	5	6	7
Species	SA Line[a]	Herbage[b] rating	Nitrogen Control	CC169	WSM 826	CC 2103	WSM 540	NA 39	M mixture
truncatula	Paraggio	NA	4.24	4.15	2.39	2.58	2.63	1.63	1.54
truncatula	Jemalong	10	3.21	3.3	2.73	3.21	2.66	1.94	2.38
truncatula	4303	21	4.08	3.29	2.75	3.07	3.42	2.61	2.76
truncatula	27778	17	3.81	3.33	2.60	2.19	3.77	1.54	1.98
littoralis	17298	NA	4.6	0.383	0.54	0.54	0.338	1.36	1.31
rigidula	27849	14	2.55	3.38	1.37	2.2	1.91	1.46	0.43
polymorpha	6183	19	3.7	4.76	0.39	3.56	3.32	0.38	0.43
rotata	2645	14	4.28	3.02	2.45	1.97	2.28	3.88	2.14
Tukeys[c] HSD ($P<0.05$) = 1.77 (Columns 1-7)									
ciliaris	5866	19	3.59	2.79	0.24	3.03	2.24		
ciliaris	10638	21	7.45	4.95	0.29	4.26	2.53		
blancheana	2341	16	5.80	3.47	2.81	3.18	3.74		
polymorpha	17792	25	3.04	3.06	0.44	2.99	3.07		
turbinata	23330	13	3.7	3.27	3.06	2.64	1.46		
aculeata	17398	16	3.62	2.29	1.93	1.88	1.62		
Tukeys[c] HSD ($P<0.05$) = 1.79 (Columns 1-5)									
intertexta	24816	24	3.70	3.6	0.57	2.71			
ciliaris	2364	23	4.32	3.66	0.37	3.48			
Tukeys[c] HSD ($P<0.05$) = 1.79 (Columns 1-4)									
intertexta	5788	20	2.90	3.26	0.39				
rugosa	3503	20	3.56	2.79	0.426				
Tukeys[c] HSD ($P<0.05$) = 1.68 (Columns 1-3)									

[a] SA line is the official accession number given by the AMGRC.

[b] Herbage rating is the subjective score given by the AMGRC relative to the cv. Jemalong rated at 10.

[c] Tukey's value corresponds to accession × rhizobium strain interaction for all values in the columns above the Tukey's value.

Table 6.2 Mean combined shoot and root dry weight yields (g/pot) and AMGRC herbage ratings for 18 *Medicago* accessions inoculated with six *Rhizobium meliloti* strains and nitrogen controls.

			1	2	3	4	5	6	7
Species	SA Line[a]	Herbage[b] rating	Nitrogen Control	CC169	WSM 826	CC 2103	WSM 540	NA 39	M mixture
truncatula	Paraggio	NA	8.07	6.2	4.31	4.55	4.13	3.07	2.54
truncatula	Jemalong	10	7.79	7.78	7.41	6.63	6.35	4.24	5.83
truncatula	4303	21	7.17	5.89	5.22	4.97	5.54	4.83	4.83
truncatula	27778	17	6.39	5.7	4.22	4.41	5.92	2.87	3.48
littoralis	17298	NA	7.22	0.95	1.17	1.31	0.71	2.38	2.31
rigidula	27849	14	4.96	5.97	2.35	3.56	4.08	2.67	1.0
polymorpha	6183	19	6.13	7.45	0.91	6.02	5.61	0.93	1.06
rotata	2645	14	8.94	5.87	4.23	4.12	4.93	6.83	4.23
Tukeys[c] HSD ($P<0.05$) = 2.97 (Columns 1-7)									
ciliaris	5866	19	6.59	4.95	0.64	5.45	3.78		
ciliaris	10638	21	13	7.25	0.84	6.89	4.7		
blancheana	2341	16	8.56	5.33	4.11	4.58	5.76		
polymorpha	17792	25	8.6	7.03	1.31	6.42	7.13		
turbinata	23330	13	8.75	5.97	6.2	4.65	2.95		
aculeata	17398	16	7.38	4.87	3.78	4.06	2.85		
Tukeys[c] HSD ($P<0.05$) = 3.07 (Columns 1-5)									
intertexta	24816	24	6.11	5.42	1.25	4.58			
ciliaris	2364	23	8.11	5.70	0.99	5.09			
Tukeys[c] HSD ($P<0.05$) = 3.08 (Columns 1-4)									
intertexta	5788	20	5.71	5.18	0.93				
rugosa	3503	20	6.86	5.03	1.12				
Tukeys[c] HSD ($P<0.05$) = 3 (Columns 1-3)									

[a] SA line is the official accession number given by the AMGRC.

[b] Herbage rating is the subjective score given by the AMGRC relative to the cv. Jemalong rated at 10.

[c] Tukey's value corresponds to accession × rhizobium strain interaction for all values in the columns above the Tukey's value.

Table 6.3 Mean shoot total nitrogen (mg/pot) for 18 *Medicago* accessions inoculated with six *Rhizobium meliloti* strains and nitrogen controls (Combined N analysis of four replicates).

Species	SA Line[a]	Nitrogen Control	CC169	WSM 826	CC 2103	WSM 540	NA 39	M mixture
truncatula	Paraggio	88.6	108	70.6	64.8	46.8	38.8	29.9
truncatula	Jemalong	75.2	70	58	71.9	43.6	40.2	56
truncatula	4303	89	74.1	60.5	70.8	68.3	63	61
truncatula	27778	83.6	90.4	66.2	56.7	75	32.7	43.1
littoralis	17298	92.9	4	10	6.4	3.8	26	25.1
rigidula	27849	82.8	91.8	39.4	66.3	50	29.8	4.7
polymorpha	6183	63.2	111	3.7	108	87	3.45	3.8
rotata	2645	104	77.8	70	62.5	63.8	120	58.4
ciliaris	5866	88.1	99	3	94.4	74.3		
ciliaris	10638	166	164	4.5	148	69.6		
blancheana	2341	115	104	73.9	95.8	92.7		
polymorpha	17792	64	98	4.5	95.2	81.3		
turbinata	23330	80	97.9	91.6	58.8	28.6		
aculeata	17398	90.2	70.6	36.7	51.6	29.4		
intertexta	24816	72.9	92	6.1	94.3			
ciliaris	2364	112	117	4	130			
intertexta	5788	71.8	107	3				
rugosa	3503	101	95.5	5.9				

[a] SA line is the official accession number given by the AMGRC.

6.2.5 Discussion

The aim of this experiment was to identify superior medic genotype × rhizobia combinations that might be more competitive when grown with oats. The results suggest that two accessions SA 6183 and SA 10638 produced slightly higher (but not significantly) shoot and root dry weight than the cv. Paraggio when inoculated with strain CC169. Jemalong also had higher root+shoot dryweight but this was mostly a result of higher root dryweight rather additional shoot growth. The majority of accession × rhizobium interaction dry weights were below the yield of the nitrogen controls suggesting that nitrogen fixation efficiency was not maximised, particularly with SA 10638 achieving only 55% of the nitrogen control combined shoot and root dry weight. However it produced the same total shoot N as the N control, which contradicts the poor nitrogen fixation hypothesis.

Total shoot nitrogen/pot reflected dry weight suggesting that once an effective symbiotic relationship between legume and rhizobia had been formed there was small variation in efficiency of nitrogen fixation.

The results support the findings of Brockwell and Hely (1966), Howieson and Ewing (1986) and Denton *et al.* (1996) that specific host × rhizobium associations exist for annual *Medicago* species. Importantly some accessions failed to form effective symbiotic relationships with the strains of rhizobia used in this experiment confirming the importance of identifying suitable rhizobia for new species and untested genotypes. Of particular concern was the inability of SA 17298 (*M. littoralis*) to form an effective symbiotic relationship with any of the strains used. Denton *et al.* (1996) have also commented on this species high strain-specific requirement. In general the current commercial strain (CC169 at the time of the experiment) showed broad compatibility with all accessions except SA 17298.

The lack of correlation between the AMGRC relative herbage rating and accessions grown in this experiment suggests that selecting accessions for early vigour from the data base on this characteristic alone may not be suitable. A possible reason for this is that not all accessions are grown in the same year when they are initially evaluated, resulting in dry weight yield fluctuations based on climatic variability. A comparison of the actual DM yields between years of the check (control) cultivar Jemalong was used to reduce this variability when selecting accessions. However individual accessions may respond to yearly climatic stresses in different ways. Also numerous indigenous soil rhizobia at Parafield SA (the site of initial field testing) would have colonised the roots of the accessions, possibly preventing more suitable or aggressive rhizobium strains form forming symbiotic relationships. In this experiment each accession had only one rhizobium strain applied and if the symbiotic relationship was not satisfactory the plants suffered nitrogen deficiency. These two factors would have markedly influenced the comparison between the optimal environment of a glasshouse versus field condition evaluation.

The data generated from this experiment did not identify any outstanding new accessions × rhizobium combinations that were significantly better than the current commercial cultivar Paraggio and rhizobium inoculant strain CC169. While this experiment was not exhaustive in its capability to examine all different species of medics or rhizobium strains, a diverse range was tested. It is also difficult to foresee what new type of analysis could be conducted to identify better competitive medic accessions. It would therefore appear that experimenting with current commercial cultivars is still the most appropriate strategy in trying to improve the medic component in oat/medic mixtures.

6.3 EXPERIMENT 6 - EVALUATION OF COLD TOLERANT *MEDICAGO* GENOTYPES FOR INCREASED COMPETITIVENESS AGAINST OATS WITH EARLY AND LATE DEFOLIATION.

6.3.1 Materials and Methods

Three new cold tolerant *Medicago* accessions SA 21876 (*M. truncatula*), SA 17722 *(M. aculeata*) and SA 16358 (*M. polymorpha*) were supplied by the South Australian Research and Development Institute, Northfield to evaluate their competitiveness against oats. These cold tolerant lines were selected on overseas collection expeditions from known cold climates and showed promise when regrown in the South Australian medic selection program. Whilst cold tolerance does not necessarily equate to early vigour, these particular lines were selected because they showed promise in their ability to provide early dry matter production. Given that experiment 2 in chapter 4 showed that cooler conditions reduced the ability of Paraggio medic to compete, the hypothesis was proposed that lines adapted to cool conditions may be better at competing with oats. As these new accessions were not available for the previous experiment 6, there was no opportunity to identify the most appropriate accession × rhizobium strain combination; however the broad adaptability of CC169 suggested that it would be suitable.

6.3.1.1 Design of experiment and treatments

The design of the experiment was a 9 × 2 factorial with 4 replicates.

Treatments were: Monocultures of medic accessions SA 21876, SA 17722, SA 16358, and cv. Paraggio, Marloo oats and 50/50 combinations of each medic accession with oats. Once again the assumption made by de Wit *et al.* (1966) is that 2 medic plants are equated to one oat plant.

Two defoliation treatments, "early" and "late" were imposed 11 days apart to ascertain any differences in competitiveness under varying defoliation regimes. Two harvests were then conducted.

6.3.1.2 Seed preparation, establishment and maintenance

Medic and oat seeds were graded for uniformity of size and the medic seed scarified using sand paper to scratch the seed coat. Medic and oat seeds were pre-germinated on agar medium and incubated at 25°C with agar dishes inverted to allow radicles to grow straight down from the gel. 16 medic seedlings were sown in medic monoculture pots, 8 medic seedlings and 4 oat seedlings in mixture pots and 8 oat seedlings in oat monoculture pots. Seedlings were spaced to be equi-distant from each other. Pots were free draining and 25 cm in diameter and filled with steam sterilised University of California potting mix (nutrient analysis Appendix C.1 and Table C.2). Seedlings were inoculated at establishment with rhizobium strain CC169. Pots were arranged in randomised blocks and grown outdoors during Spring (temperature range Min. 7.8°C to max 21.8°C). Extra nutrients were supplied by applying 50 g/pot of the slow release granular fertiliser Osmocote® (nutrient analysis Appendix Table C.3), 16 days after establishment. Watering was conducted as demand required.

6.3.1.3 Measurements

There were two dry matter harvests with plant tops cut to 3 cm above the soil level. Harvest 1 was conducted 35 days after establishment for the early defoliation and at 46 days for the late defoliation. Harvest 2 was conducted on the regrowth 39 days after emergence for the early defoliation treatment and 50 days for the late defoliation. Shoots were oven dried at 80°C for 24 hrs and weighed.

6.3.1.4 Analysis of data

Analysis of variance was initially conducted using the statistical program Genstat V to determines any yield differences and interactions between cultivar, ratio and timing of defoliation for medic. Analysis of variance was then conducted on the total DM for each variety. Additional analysis of data was conducted using the methodology described in chapter 4 for analysing the competitive ability of species in binary mixtures in replacement series designs. The model took the form of the following:

$$Oij = \frac{\text{yMax } i \times ki \times \text{Density } i}{(1 + ki \times \text{Density } i + kj \times \text{Density } j)}$$

Where

$O\,ij$ = yield per pot of species i grown with species j
yMax i = maximum yield of species i when grown in monoculture
ki = constant for species i
Density i = density of species i
kj = constant for species j
Density j = density of species j

6.3.2 Results

The three-way interaction of variety × ratio × timing of defoliation was not significant, however, analysis of variance showed that there were significant two-way interactions between accessions, time of defoliation and sowing ratio. Table 6.4 presents the data for variety × sowing ratio and Table 6.5 the data for variety × defoliation interactions just for the medic component. Decreasing the sowing ratio of the medic reduced medic DM at both harvests. There were also significant cultivar differences with the two best cultivars Paraggio and SA 16358 producing significantly more DM at both harvests (Table 6.4). Delaying defoliation by 11 days increased DM in all cultivars and at both harvests and once again there were significant cultivar differences (Table 6.5) with Parragio and SA 16358 producing the highest DM. Cultivar SA 17722 was consistently the lowest ranked throughout the experiment and does not appear to be able to produce as much DM as the other three cultivars.

Table 6.4 Mean dry weight (g/pot) for 3 new accessions and Paraggio medic at two sowing ratios at two harvests. Tukeys HSD values are for the variety × sowing ratio interaction at each harvest.

	Sowing Ratio	
	Medic:Oat	Medic:Oat
Species and cultivar	16:0	8:4
Harvest 1		
Parragio	5.24	1.50
SA 16358	5.32	1.37
SA 17722	3.30	0.70
SA 21876	4.11	0.95
	Tukeys HSD (P<0.05) = 0.4	
Harvest 2		
Parragio	7.08	2.02
SA 16358	7.64	2.18
SA 17722	4.79	0.93
SA 21876	6.37	1.20
	Tukeys HSD (P<0.05) = 0.79	

Table 6.5 Mean dry weight (g/pot) for 3 new accessions and Paraggio medic at two defoliation timings at two harvests. Tukeys HSD values are for the variety × time of defoliation interaction at each harvest.

	Timing of defoliation	
Species and cultivar	Early	Late
Harvest 1		
Parragio	2.37	4.37
SA 16358	2.38	4.31
SA 17722	1.24	2.76
SA 21876	1.80	3.26
	Tukeys HSD (P<0.05) = 0.4	
Harvest 2		
Parragio	3.05	6.06
SA 16358	3.73	6.08
SA 17722	1.87	3.84
SA 21876	3.01	4.56
	Tukeys HSD (P<0.05) = 0.79	

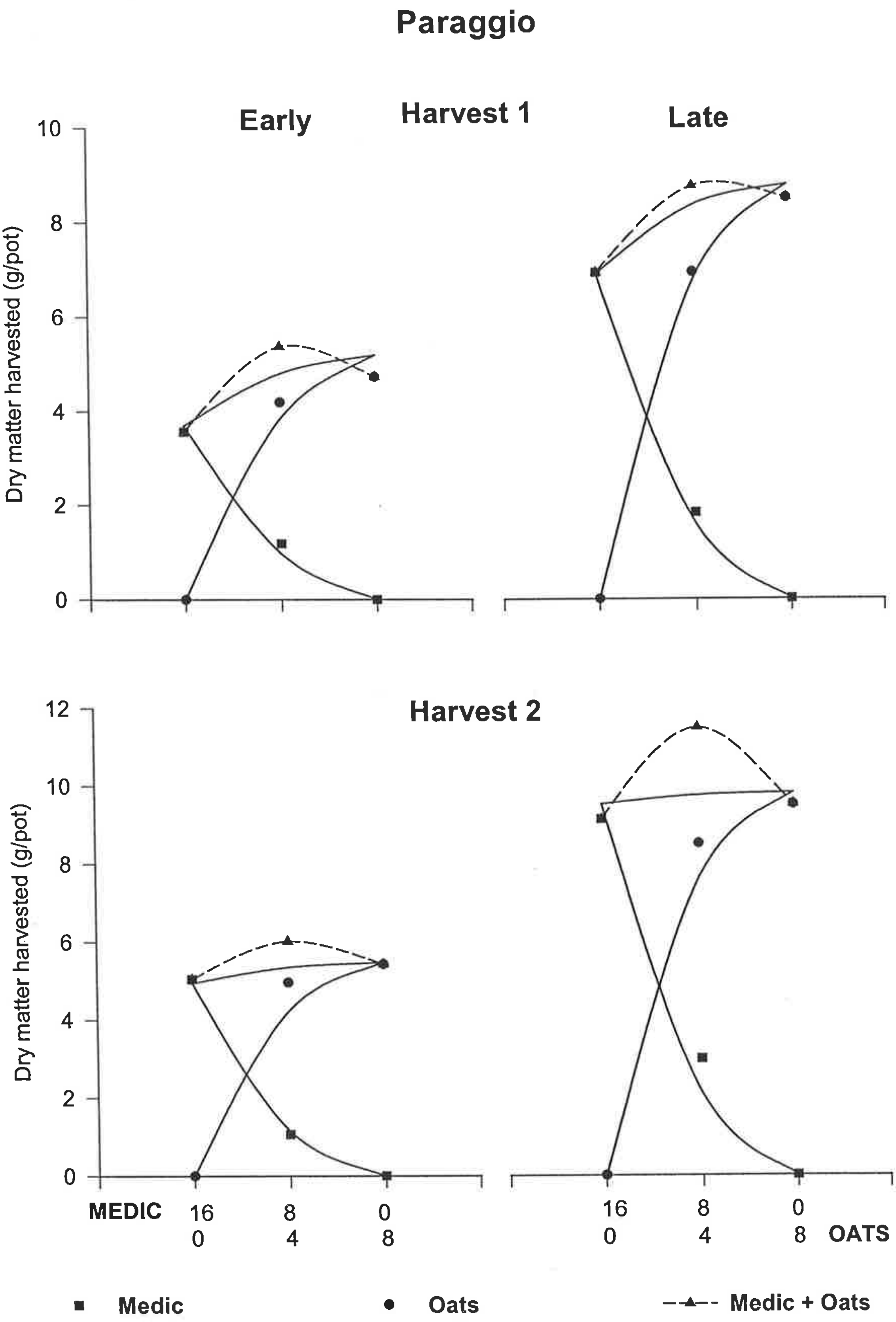

Figure 6.1 Replacement series diagrams for *Medicago truncatula* cv. Paraggio and oats on dry matter yield (g/pot) for two defoliation timings and two harvests in 1993. Symbols are observed data and continuous lines are fitted from the model. Dashed line with triangles are the actual yields of the mixture.

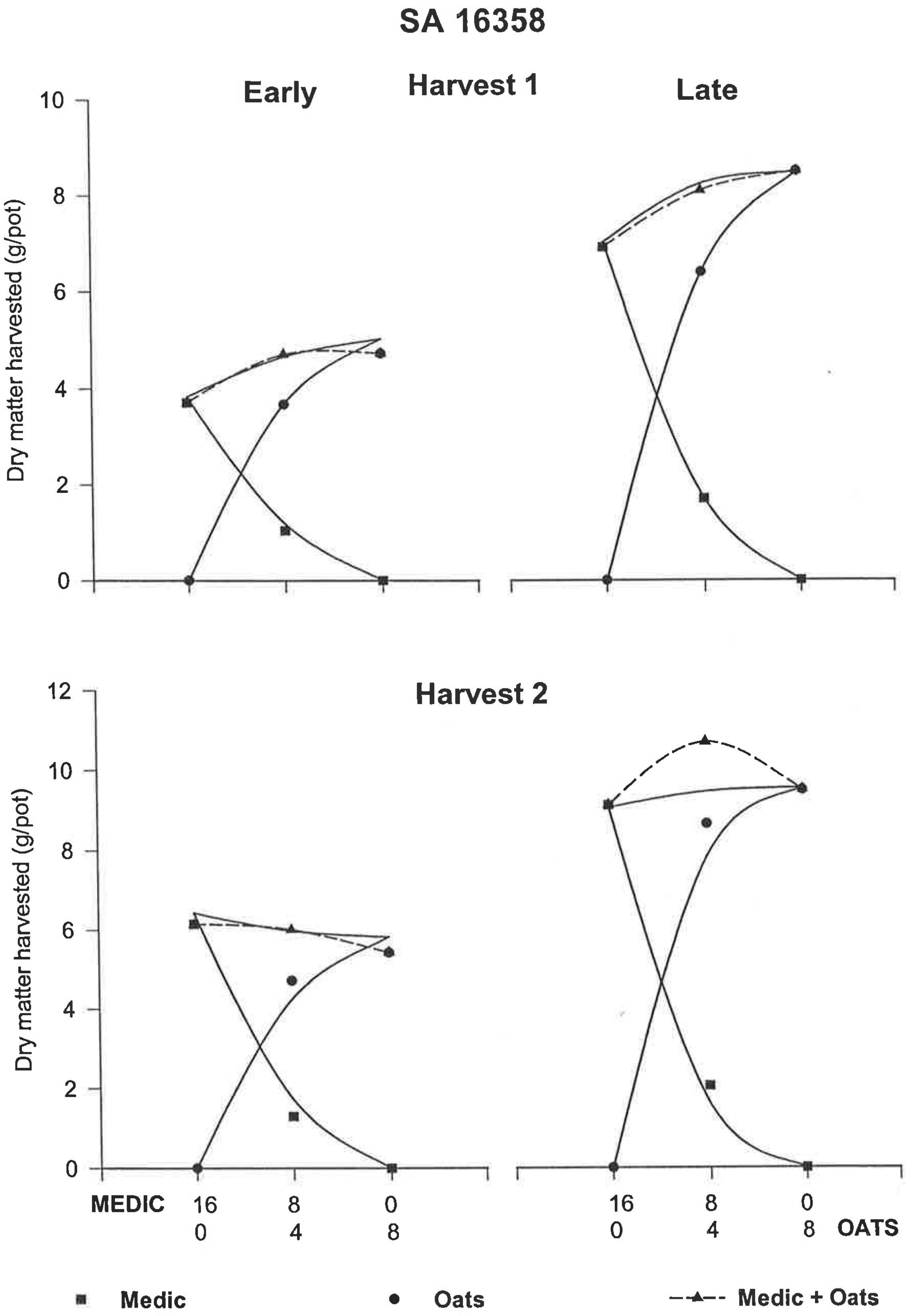

Figure 6.2 Replacement series diagrams for *Medicago polymorpha* SA 16358, and oats on dry matter yield (g/pot) for two defoliation timings and two harvests in 1993. Symbols are observed data and continuous lines are fitted from the model. Dashed line with triangles are the actual yields of the mixture.

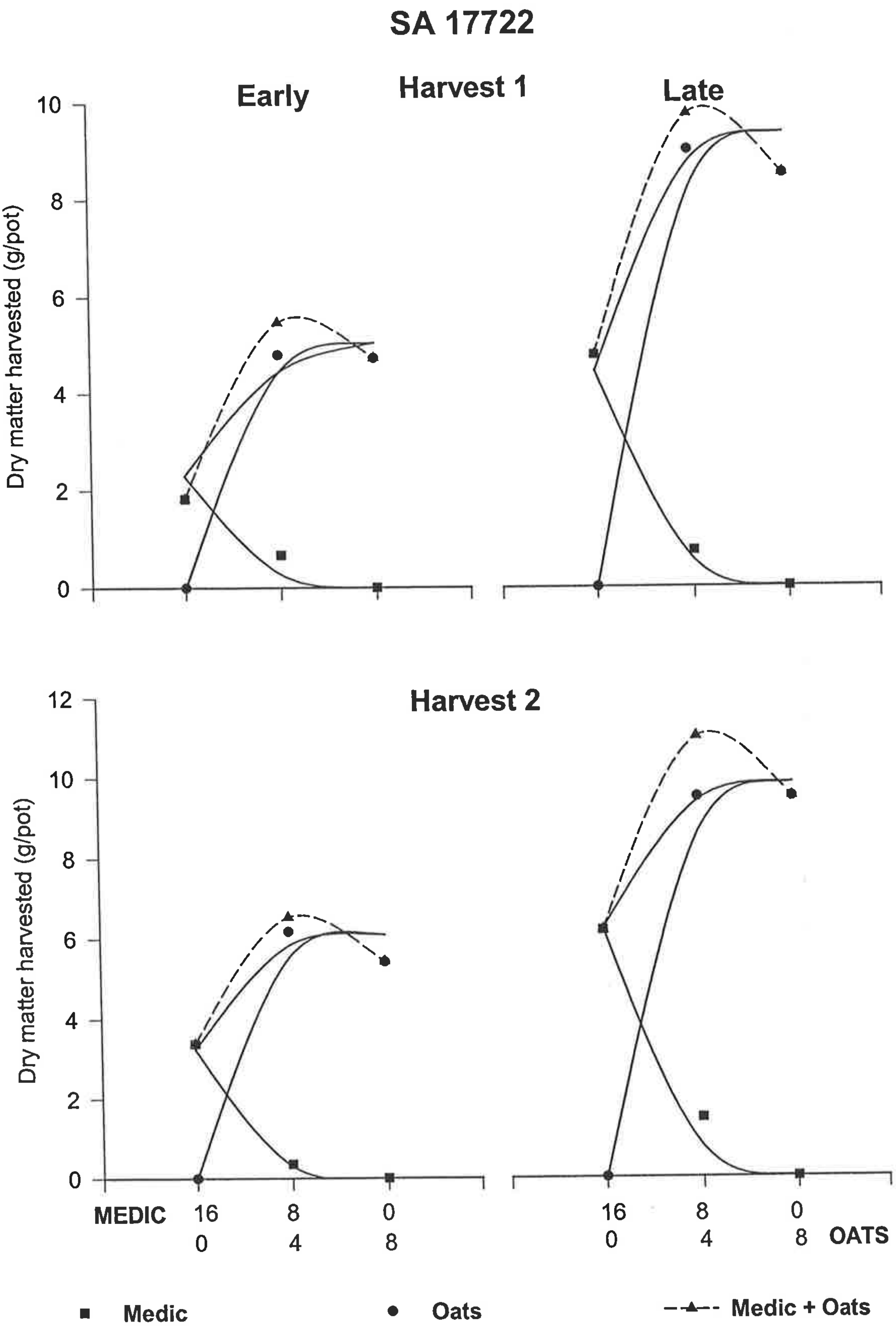

Figure 6.3 Replacement series diagrams for *Medicago aculeate* SA 17722, and oats on dry matter yield (g/pot) for two defoliation timings and two harvests in 1993. Symbols are observed data and continuous lines are fitted from the model. Dashed line with triangles are the actual yields of the mixture.

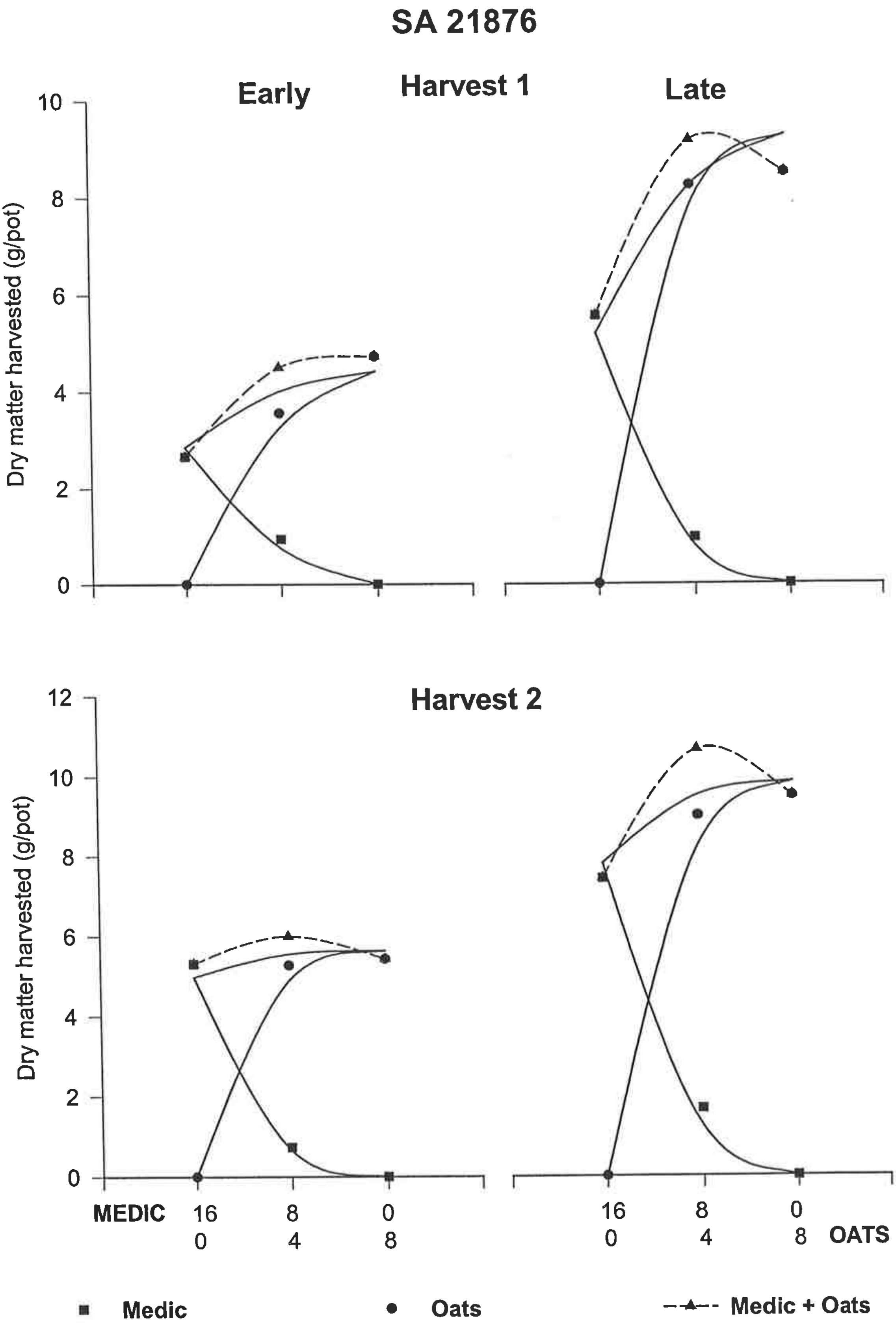

Figure 6.4 Replacement series diagrams for *Medicago truncatula* SA 21876, and oats on dry matter yield (g/pot) for two defoliation timings and two harvests in 1993. Symbols are observed data and continuous lines are fitted from the model. Dashed line with triangles are the actual yields of the mixture.

Figures 6.1 - 6.4 examine the competitive relationship between the three medic accessions and cv. Paraggio and oats. All medic cultivars were at a competitive disadvantage in relation to oats when grown in mixtures. The shape of the lines predicated by the model in Figures 6.1 - 6.4 clearly show this disadvantage. Delaying defoliation improved competitiveness of the medic slightly but the regrowth (harvest 2) curves still followed a similar pattern to harvest 1. Oats produced more DM than medic at all stages except in the cultivars Parragio at harvest 2 for both defoliation timings (Figure 6.1), SA 16358 at harvest 2 and both defoliation timings (Figure 6.2) and SA 21876 harvest 2 the early defoliation timing (Figure 6.4).

In comparing the oat:medic *k* coefficients, the larger the oat:medic *k* coefficient ratio, the more competitive the oats are in the mixture (Table 6.6). The cultivar SA 17722 was clearly less competitive than the other cultivars. None of the new accessions were more competitive or productive than Paraggio, in either monoculture or mixtures.

Table 6.6 Estimated *k* coefficients and *k* ratio for the replacement series model for two defoliation timings and two harvests.

Treatment		*k*Oat	*k*Medic	*k*Oat:*k*Medic Ratio
	Paraggio			
Harvest 1	Early	0.8	0.1	8.0
	Late	5.0	0.7	7.14
Harvest 2	Early	1.3	0.15	8.6
	Late	6.0	0.8	7.5
	SA 16358			
Harvest 1	Early	0.65	0.11	5.9
	Late	4.0	0.6	6.6
Harvest 2	Early	4.0	0.7	5.7
	Late	6.0	0.6	10.0
	SA 17722			
Harvest 1	Early	3.0	0.15	20.0
	Late	8.0	0.5	16.0
Harvest 2	Early	5.0	0.2	25.0
	Late	8.0	0.5	16.0
	SA 21876			
Harvest 1	Early	7.0	1.2	5.8
	Late	5.0	0.4	12.5
Harvest 2	Early	6.0	0.4	15
	Late	8.0	0.7	11.4

6.3.3 Discussion

The aim of this experiment was to determine the relative differences between Paraggio and three cold tolerant genotypes in their competitive ability against Marloo Oats. The replacement series design of de Wit (1960) was chosen as it was a simple method of comparing the relative competitive ability of the four genotypes. Other more complex methods as previously described in chapter 2 would have allowed a more thorough analysis of competition between species and with in species however they would have also required more treatments (i.e. varied densities). As seed supply of the three cold tolerant genotypes was restricted this was not possible. Hence results are only relevant to the conditions and density at which the experiment was conducted. By comparing the shapes of the curves in Figures 6.1 -6.4 and the oat:medic *k* coefficient ratios an estimation of the competitive ability of the medic cultivars is obtainable. In all instances the shape of the curves as depicted by Harper (1977) suggest the medic is disadvantaged when grown with oats, even after defoliation and regrowth. The results are similar to the small plot experiment by Litav and Zeligman (1977) in which oats were the dominant competitive species against medic. Two *M. polymorpha* medics were used in that experiment with neither cultivar improving the competition of the medic against oats. The authors concluded that oat density was the most important variant in determining both total DM and the ratio of plant DM in the mixtures.

From these results though it would appear that the cultivar SA 16358 is as least as competitive against oats as the common variety Parragio but no better. Cultivars SA 21876 and SA 17722 did not perform as well in this experiment and did not produce as much DM as the other two even when grown in monoculture. There appears to be no significant advantage over Paraggio of the three cold tolerant accessions in competitive ability. Although this experiment was conducted in late Winter-Spring, when daylight hours were increasing not reducing as in autumn. It is possible this could have influenced the results but since this experiment had a known standard, Parragio, it seems unlikely. Examination of the temperature data (Appendix Table A.1) shows that mean minimum and maximum temperatures over the period the experiment was conducted were lower than for autumn; hence the low temperature requirement for this experiment was satisfied. It is therefore unlikely that the medic accessions tested were disadvantaged by temperature unless they tolerate very low temperatures in which oats would be at a growth disadvantage and they at an advantage.

Even though line SA 16358 appears to be at least as good as the industry standard, Paraggio, it is doubtful if pursuing this strategy is any more useful than concentrating on agronomic management of a well adapted cultivar such as Paraggio.

6.4 CONCLUSIONS

The genetic variability of available *Medicago* genotypes with early winter growth potential suitable for direct commercial application is limited. It is possible that other untested accessions and rhizobium strains may be suitable. However breeding may be required to remove undesirable characteristics. The cultivar Paraggio used in the previous experiments in this thesis would appear to rate relatively highly in terms of its competitive ability and adaptability. It is however possible that if more effective rhizobia strains were available or had been evaluated other accessions may have performed better. While the pursuit of cultivars and effective rhizobium strains is desirable, improved management of the existing cultivars will provide immediate benefits.

Chapter 7

7. GENERAL DISCUSSION

7.1 OVERVIEW OF EXPERIMENTATION

The initial aims of this experimentation were to assess the role that grazed oats could contribute to medic-cereal based pastures. The methodology used was to examine the system in its entirety, then identify the specific problems associated with the outcomes (chapter 1, Figure 1.1). In this thesis the first experiment (Chapter 3) compared grass+medic, grass-free medic and oat+grass+medic pastures in their ability to provide early grazing for sheep. An important component of the experiment was the associated affect that each of the pastures had on a following wheat crop. Thus an examination of the whole system, albeit one type of rotation, as it would occur in the southern Australian wheat belt was attempted.

The results from the first experiment can be divided three sections; available pasture production, effect on sheep growth and effect on the following wheat crop. The addition of oats to a grass+medic pasture initially provided more available grazing DM than either a grass-free medic pasture or grass+medic alone. The effect in winter was that the oats was an addition rather than substitution which allowed the pasture to attain 1 t/ha of DM 21 days earlier than the grass-free medic and 11 days earlier than the grass+medic pasture types along with the introduction of grazing. This ability to allow the introduction of sheep onto the oat+grass+medic pasture earlier would be an advantage in reducing the days of supplementary feeding required in the Autumn period. It is clear from this experiment that medic pastures without grass control are disastrous in terms of the ability of medics to compete and contribute effectively to the mixture. Even when medic is sown at high rates (18 kg/ha), such as in this experiment, the annual grasses have the ability to quickly establish themselves and out-compete the medic. Utilising grazing pressure by increasing the stocking rate did not alter this balance which is in contrast with some other grazing experiments that measured the annual grass component. For example the experiments of Carter (1968), Lloyd Davies and Greenwood (1972), FitzGerald (1976), Carter and Lake (1985), Curtis *et al.* (1989) and Latta (1994) all showed that increasing stocking rate decreased grass biomass and helped favour the legume component. It is likely that the exceptionally high winter rainfall and growing conditions experienced in 1992 combined with the initial high grass plant populations allowed the grasses to establish a competitive advantage early and maintain this through the growing season. It is also clear that the High stocking rate (19.8 sheep/ha), which although considered high for the environment, was not sufficient to induce a stocking rate affect early enough to alter the grass/medic balance. A more appropriate response may have been to adjust the High stocking rate even higher although this may have created difficulties in comparing the two stocking rates as one would have been altered without the other during the course of the experiment. The danger of increasing one or both is that the season may turn unfavourable, with the possibility of then having to remove some sheep again. Once this occurs then the experimental design changes from the original aims and reconsideration of the objectives is required.

The addition of oats may have a role in reducing grass numbers through competition. The results in chapter 3 show linear reductions in grass dry matter over time (Chapter 3, Figures 3.1, 3.2 and 3.3) through the addition of oats. This was surprisingly independent of stocking rate but probably due to the previously mentioned reasons. This has been noted before by Roberts (1991) and while minimal in the overall context of the outcomes of the experiment, it may be of use in an integrated weed management (IWM) approach in which the entire rotation must be considered when controlling grass weeds. In IWM approaches that use competition has been suggested as one method of helping reduce the grass seed bank (Medd *et al.* 1985; Wilson *et al.* 1995). Lemerle *et al.* (1995) have also shown that oats rank as one of the most competitive cereals in relation to ryegrass. Further evidence that this approach would be useful is the plant density counts of ryegrass and barley grass over time (Chapter 3, Figure 3.14) which shows that the oat+grass+medic treatment had significantly lower populations (only barley grass statistically lower) over time compared to the grass+medic pasture type. This competitive effect was not noted with the broadleaf weeds and they remain a significant problem in grass/legume mixtures, often increasing in number over time. Some new herbicides, e.g. flumetsulam, do offer potential control of some weeds, particularly cruciferous weeds, and selective use of these herbicides may be appropriate in some occasions.

An examination of the pasture growth rates (Chapter 3, Table 3.6) confirm that grass-free medic pastures are slower at producing biomass in winter than pastures with volunteer grasses or sown oats. It is possible that this growth rate may have been improved with a higher established plant population (> 458 plants/m^2) but nevertheless confirms the suggestion of previous authors, Taylor *et al.* (1979) with medics and Smith *et al.* (1972) with subclover, that the annual legumes struggle to provide critical herbage weight for grazing in early winter compared to annual grasses. In this experiment the delay in attaining critical herbage weight with grass-free medic pasture only reduced the number of available grazing days. It did not affect sheep production. In fact actual growth rate (kg/sheep/day) was on average 22% higher with the grass-free medic pasture type compared to either grass+medic or oat+grass+medic. This compensatory growth was presumably a function of the improved quality (nutrients, digestibility, metabolisable energy) of feed on offer from the legume (Doyle *et al.* 1993; Ru 1996) and has been noted before e.g. (Thorn and Perry 1987). There is one significant problem though that continually plagued the experimentation in this research and that is the ability to provide early pasture growth available for grazing in early winter. The experiments conducted in this thesis only examined the period from when germinating rains occurred and pastures reached a significant level, to allow grazing or pasture DM measurements to occur. In farming systems the livestock would still have to be fed on some form of alternative feed supplement. Traditionally this has involved grazing cropping stubbles with the addition of supplementary feed (grain, hay or silage) up to the time sufficient pasture has grown. Unfortunately this is totally dictated by opening season rainfall events. This thesis makes no attempt to examine the period before pasture growth occurs and as such on many occasions, as in experiment 1, early winter growth was not obtained.

In this experiment, the resulting wheat yield and grain quality can be directly related to the previous pasture types and highlights the important problems volunteer grasses can create for following cereal crops. As expected wheat yield and protein percentage was highest after grass-free medic pasture types. This can be related to reduced grass numbers, eliminating weed competition, and reduced take-all incidence (Chapter 3, Figure 3.13) from lack of suitable hosts in the pasture year. In addition the increased wheat yields after the grass-free medic pasture with a low stocking rate can be attributed to the higher available nitrogen from this treatment. However the reduced yield in wheat in the high stocking rate treatments is evident across all pasture types (Chapter 3, Figure 3.11) cannot be explained entirely by reduced available nitrogen. It is possible that another unidentified factor is responsible, as it does not appear to be related directly to the variables measured in this experiment. One possibility is soil compaction, resulting from sheep grazing in a very wet year, but this was not measured.

The conclusions from this initial experiment are that well managed grass-free medic pastures leave a very positive legacy; low grass weeds numbers for the following year, low cereal root disease levels, high available nitrogen and excellent seed production capable of producing excellent self-regenerating pastures (up to 1400 plants m^2). Annual grass-medic pastures fail in all the above criteria except in their ability to produce early dry matter production. The use of sown oats as an addition to a grass+medic pasture, while enhancing early dry matter production even further and helping reduce annual grass dry matter and seed numbers through competition, do not provide the equivalent benefits of a grass-free medic pasture. The inability of the medic to compete against both grass and oat species is the most limiting factor associated with these mixtures. It is also unlikely that simply increasing the medic plant density alone will solve the problem as Latta (1994) has already shown this to be unsuccessful.

The approach shown above could be classified as a "top down" systems approach which in itself is not original but is unique for pasture research involving medic in Australia. This approach involves examining the sum of the interacting components first then separating out the components that are not understood clearly and conducting research on these components individually. Many of the individual components have been examined before, such as density (Latta 1994; Chaichi 1995), ecology and productivity (Adem 1977; Ababneh 1991), effects of defoliation (Muyekho 1993, Chaichi 1995) and seedling dynamics (Cocks 1993; Taylor 1996). Some attempt has been made to examine results in the context of the total system as in the work of Quigley (1988) looking at the effect of cereal straw residues on medics, and of Latta (1994) with the applied approach to understanding the low success of medics in the low rainfall mallee region of Australia. Often much has been inferred from these experiments about the associated effects on following cereals, but, little has been measured, mainly because it was outside the scope of the studies. In addition the majority of studies have involved pure medic and rarely involve medic/grass mixtures. The advantages of conducting a systems type of experimentation allows the research to build on what is already known and piece components together so that the research outcome is directly applicable to the associated industry.

Following the major finding from the initial rotation experiment that the medic component is at a competitive disadvantage in medic/grass combinations, further experiments were designed to examine the possible effect of management factors in enhancing the medic component in medic/oat mixtures.

There is much anecdotal evidence and some published, e.g. (Taylor *et al.* 1979), that as the temperature decreases from autumn to winter, annual medic grows more slowly and struggles to provide adequate DM for grazing purposes. Experiment 2 (chapter 4) examined this hypothesis, in the context of the pressure of competition from oats at low winter temperatures. It was clear that medic growth and competitive ability were enhanced when grown at higher temperatures similar to those experienced in autumn, compared to the reduced temperatures associated with winter. This was particularly evident after defoliation, in the regrowth period.

The temperature influence on medic growth is important and highlights the need to have oat/medic mixtures established as early as possible in autumn. Examination of the long term temperature records for Roseworthy (Appendix A.1) show that the maximum and minimum temperatures are 5°C and 3°C respectively warmer in the April-May period compared to June-July. Although establishment is influenced mostly by rainfall, which is less reliable in the autumn period, having high seedling populations established at the break of the season, such as self-regenerating pastures, increases the chance of this occurring. Experiment 3 clearly showed that late establishment in a dry year is detrimental for the medic component in oat/medic mixtures. Neither adjusting the sowing ratio, defoliation timing or soil nitrogen levels could improve the medic component to an acceptable level of production in oat/medic mixtures under these conditions. Conversely the stocking rate experiment (Chapter 5, section 5.3) where the early establishment of a high density medic pasture enabled it to compete extremely well with oats sown at 50 kg/ha 28 days later. In this experiment the oats did not contribute greatly to the available dry matter for grazing and made no difference to sheep body weight gain; nor did they extend the grazing period. This shows that for a high stocking rate adequate DM can be provided relatively early in the season with high density self-regenerating medic stands. The delay in sowing the oats in order to control the annual grasses did not allow the seedling establishment comparison to occur and it is likely that with this scenario a higher plant population of oats would be beneficial. Stocking rate had no affect on oat production, suggesting the sheep were selectively eating oats. At the low stocking rate where the sheep had the greatest opportunity to be selective and avoid consuming the oats if they chose, oat drymatter was similar to he higher stocking rate even though food on offer was more than required. The lack of difference between pasture types in sheep body weight reconfirms the findings from the first experiment (Chapter 3) in that sheep grazing almost pure medic are not at a disadvantage compared to sheep with a gramineous species in their diet.

Throughout this thesis a common conclusion has been the importance of medic:oat sowing ratios that favour the medic component as much as possible. The majority of experiments in this thesis involve the oats established with the medic at the same time. In the grazing experiment in Chapter 5 the oats were sown in 28 days after the medic emerged. The suppressive effect of the oats on the medic as seen in the other experiments was not evident in this case. It is therefore possible that seedling competition is more important than the sowing ratio of the two species. Certainly a medic:oat sowing ratio in the order of 3 to 1 plants or higher maximises the medic component in the mixture, but the medic is still at a disadvantage. The experiment on the effect of nitrogen and defoliation timing in oat/medic mixtures (Chapter 5, section 5.2) examined if low soil nitrogen and/or timing of defoliation could improve medic production in medic/oat mixtures. Soil available nitrogen levels would have to be extremely low (< 4 mg N /kg) to ensure that oat production was limited by nitrogen. This is possible after a period of continuous cropping (Evans *et al.* 2001) but likely to be highly variable. Delaying defoliation can help medic production early but selective defoliation may be of more benefit. Selective defoliation would involve oats being defoliated but not the medic component. In commercial grazing this would require livestock to actively target the oat component early while leaving the medic, to grow. While livestock such as sheep can be selective (Carter 1987), there was no evidence in the two grazing experiments reported in this thesis for a major preference of one species over another. Stocking rate is often cited as a method of reducing the grass component in annual legume/grass pastures, but increasing the stocking rate reduces the selectivity of the grazing animal forcing it to defoliate the sward more evenly. This is likely to favour the more prostrate species such as medic by reducing grass biomass, as it is easier to forage. However in practice selective defoliation of just oats is unlikely to occur in oat/medic mixtures.

As with many grass/legume mixtures (Trenbath 1974), total production was also greater with a mixture compared to monoculture throughout this thesis. This is in agreement with previous experiments involving oat/medic mixtures by Litav and Zeligman (1977), Naidu (1979), Khan (1991), and Roberts (1990; 1991). In each case where this research was field based, spring was the period where rapid medic growth occurred and the medic component contributed significant dry matter production to the mixture. This was also reconfirmed throughout the field experiments in this thesis. It is also likely that oat productivity declines after two or more defoliations, which would help reduce competition in mixtures.

In many problematic areas of crop and pasture production, agriculturalists turn to genetic diversity and breeding to solve specific problems. Examples of this with the *Medicago* genus are provided by Crawford *et al.* (1989) where disease and insect tolerance/resistance were priorities in helping to improve persistence of the genus. The use of genetic diversity is only useful if the traits required are easily identifiable and readily transferable to germplasm that is well adapted to the growing environment. Not all attributes are quickly or efficiently improved with breeding alone. In the case of the annual medics, selecting accessions that are more compatible/competitive with oats appears from present experiments to be without merit. This may be because the genus simply does not have highly competitive attributes within its gene pool or it may be difficult to identify competitiveness as a trait. The experiment in Chapter 6 (section 6.2) used an average of the first two subjective herbage ratings relative to a control, cv. Jemalong, made in initial small plot testing at Parafield, South Australia. This may not have been a suitable method of identifying early vigour or competitiveness, however, discussion with the curators could not identify more appropriate methods. An additional problem is the rhizobium × host interaction. Suitable rhizobium strains are critical for medics to perform to their optimum potential. The most striking example of this has been the selection of acid tolerant rhizobium strains for medics in Western Australia (Howieson and Ewing 1986; Howieson *et al.* 1988; Dilworth *et al.* 2001).

Thus in summary after examining the initial research to find the accessions to conduct experiments in Chapter 6, and the results of all experiments, it is concluded that management techniques that improve early medic growth are likely to yield greater benefits, than new medic × rhizobium combinations. This is not to say that more suitable combinations to compete against oats don't exist but that improved management of existing cultivars will provide immediate productivity gains.

7.2 FUTURE RESEARCH REQUIRED

The initial experiment in this thesis consisted of three pasture types, grass-free medic, grass+medic and oat+grass+medic. By adding the oats to a grass+medic pasture type allowed the examination of the potential for grass reduction through competition by the oats. However because the grass component was not reduced to low enough levels, there were significant negative effects on the following wheat crop. In practice it is likely that some annual grasses will be present unless winter grass cleaning using selective herbicides has been practised or a weed-free cropping phase has been completed. An additional experiment would be the use of oats and medic without grasses compared to grass-free medic. This was achieved in the second grazing experiment in Chapter 5 but the effects on a following wheat crop were not measured. By conducting such an experiment a true examination of the impacts of an oat/medic mixture in a rotation could be identified. Kirkegaard *et al.* (1996) found that oats preceding wheat yielded similarly to continuous wheat despite lower levels of take-all and similar preceding N and available water levels. It is therefore possible that oat/medic mixtures may not be appropriate preceding a cereal phase.

The grazing experiment (experiment 4) in Chapter 5 also highlighted an interesting point - seedling competition between medic and oats. It is clear from the cutting experiments involving sowing ratios that even when the medic:oat sowing ratio is highly in favour of medic, there appears to be initial competition at the seedling stage that the medic cannot overcome. Establishing the oats after the medic has established appears to overcome this problem. Future experiments examining this aspect may be warranted, however if high medic density pastures are established then practically there may not be a requirement to have oats at all.

If further investigation was conducted on this topic the use of other cereals with cereal cyst nematode and take-all resistance may also be appropriate. Barr (1989) has shown that barley can provide more early DM than either oats or wheat over the first 8 weeks after establishment. However barley is also known to be highly competitive (Mathews *et al.* 1996) which would not improve early medic competition. Triticale, which has similar disease resistance attributes to some cultivars of oats, may be a possibility worth investigating. While oats respond well to defoliation and grazing it may be more advantageous to use a gramineous species that establishes well and provides early DM then dies after repeated defoliation allowing the medic component to take over.

7.3 PRACTICAL APPLICATIONS OF THESE RESULTS

This thesis was designed to examine a practical problem – the low grazing productivity in early winter of grass-free annual medic pastures. A summary of the research findings can help decipher the most important practical and applied attributes of this research:

1. Volunteer grass control in the pasture phase is a very important factor in determining the amount of medic production in the pasture year as well as the level of take-all and grass weeds inherited by the following cereal crop. The combination of medic, oats and high grazing pressure while reducing grass biomass was still not capable of reducing the grass component to a level that would not reduce yield and quality of the following wheat crop in the initial experiment in chapter 3. It appears that the introduction of oats into the pasture system without volunteer grass control has the following effects. It:

    a) increases early available feed on offer which has the potential to increase livestock production/hectare and profitability of the pasture phase.

    b) does not suppress grass weeds sufficiently to limit grass seed and take-all carryover to the following year.

    c) does not provide following wheat yields and grain quality as high as those following a grass-free medic pasture.

    d) reduces overall profitability of the rotation compared to a grass-free medic pasture rotation when economics favours wheat production.

2. The results of experiment 2 (chapter 4) demonstrate that early medic establishment, when the day/night temperatures are significantly warmer, improves medic growth and the productivity of the mixture. Although competitiveness of the individual species is affected by temperature and individual species growth is enhanced at

higher temperature regimes. This suggests that timing of establishment is important from the competitive ability of the individual species in oat-medic mixtures, as well as density. This is supported by Roberts (1990) who showed in an additive experiment over three harvests that medic dry matter was constant across a range of increasing oat densities with constant medic density. The practicality of these findings is that increased medic sowing rates combined with early autumn establishment will maximise the productivity of medic both in a pure sward or oat/medic mixtures.

3. The capacity to manipulate medic/oat mixtures to encourage the medic component was not shown in the experiments reported here. Severe defoliation of the pasture did not reduce the adverse effect of oat competition on medic at the seedling stage. The experiment have shown that the ratio of 75% medic and 25% oats is the most appropriate ratio mixture for maximising total production. This mix would also seem to be the most appropriate in terms of maximising nitrogen input into the soil as N input is directly related to top growth. Alternatively establishing the medic first then sowing in oats may be an option, but, this does not improve the ability to provide early grazing feed.

4. The genetic variability of available *Medicago* accessions for early winter growth and for direct commercial application appears limited. Other untested accessions and rhizobium strains may be suitable for this purpose but would require breeding to remove undesirable characteristics. Until further research is conducted the use of management techniques to maximise early medic growth will be of more strategic importance than relying on genetic variability.

What is clear from the systems approach used in this thesis is that it is important to decide on the main purpose of the pasture phase in a medic-cereal rotation. If the requirement is for a balanced diet with early feed for livestock then the addition of oats will be beneficial. However if the aim is to produce a high yielding, high protein wheat crop in the year following the pasture then a grass-free medic pasture is desirable. The type of management applied to the pasture will depend on the answers to these questions. Current economics suggest the emphasis should be placed on producing high yielding, high protein wheat, even at the expense of livestock production. This research suggests that livestock grazing can be brought forward by approximately 21 days with the addition of oats at the beginning of the season compared to a grass-free medic pasture, however sheep production is not necessarily improved, just a reduction in the time required to provide supplementary feed. The penalty however, for the following wheat crop can be a reduction in wheat yield of 53% if grass is a significant component in the pasture.

The results of this thesis suggest that pure medic stands are likely to be the easiest to establish and maintain and have the highest positive impact in a medic-wheat system. Hence it is suggested that grass-free medic pastures be promoted (along with strategic spray topping to limit herbicide resistance) and that only in special situations of low grass numbers should oats be introduced in conjunction with the medic. If a mixture was required to improve early winter productivity and potential grazing time then a 75:25 mixture would be the maximum amount of oats allowed in the mixture. Any greater proportion of oats could affect the ability of the medic to contribute to the mixture until spring, there-by minimising the amount of high quality feed on offer and biologically fixed nitrogen.

There are two suggested scenarios for introducing oats into a medic based pasture.

1. If volunteer grass numbers are low in the preceding year or grass control is achieved in the first year of the pasture then it would be appropriate to introduce cereal cyst nematode resistant oats into the pasture and selectively spray or graze them out before the end of July to control any volunteer grasses and maximise medic seed set. However there are withholding periods for livestock with grass herbicides and in late establishment seasons, competition from the oats will severely reduce medic production due to cold, low light conditions.

2. Alternatively a cereal cyst nematode resistant oat/medic pasture may be applicable at the beginning of a pasture phase where minimal medic seed set is required and grass control is not essential. Assuming a second year of pasture, grass control can be achieved before the end of July to eliminate grasses and maximise medic seed set before proceeding with a cereal crop.

7.4 CONCLUSIONS

After observing four years of experiments, each with different climatic seasons, it would appear that in early establishment years, with early rainfall and warmer autumn temperatures, medics establish readily and grow quickly to sustain some grazing pressure. The aim is therefore to have high plant populations to maximise ground cover as quickly as possible. Delayed defoliation [including grazing, Chaichi (1995)] has been shown to enhance the ability of medic to maintain production throughout the growing season and should be common practice. In these years the addition of oats, while slightly improving early winter feed is of little gain and only acts to compete against the medic. Delayed sowing of oats reduces seedling competition but adds little to the early productivity of pasture minimising the advantage oats have in providing early grazing feed. In late establishment seasons when medic productivity is reduced due to low temperatures, the use of sown oats will improve early production but unfortunately competition decreases medic production irrespective of management treatments to prevent this.

If legume dominant pastures are to be a feature of our farming systems it would appear that practical ways of overcoming the problems of low herbage availability in early winter may therefore need to be addressed in managerial ways other than the introduction of gramineous species. These would include lambing in July/August to reduce stock pressure in autumn/early winter, and delaying grazing. Stock could be lotfed as Carter *et al* (1993) have suggested preserving both the medic seed bank and allowing the medic plants to establish themselves. It may also be appropriate to examine other perennial type species including saltbush (*Atriplex* spp.), tagasaste (*Chamaecytisus palmensis*) and native acacias (*Acacia* spp.) that can serve the dual purpose of windbreaks and standing fodder reserves on broadacre livestock producing enterprises. It may also be time to re-evaluate the perennial pasture species we have available that are suitable for lower rainfall, alkaline soil environments, such as new improved lucerne cultivars, and assess their possible role in providing extra production through the critical early winter period. It is common in Australia and throughout the USA for example to use oats in association with lucerne and vast amounts of agronomic research has been conducted on this mixture (Schmid and Behrens 1972; Brink and Marten 1986; Nickel *et al*. 1990; Lanini *et al*. 1991; Simmons *et al*. 1995).

In answering the four objectives at the beginning of this thesis (Chapter 1) the results suggest that a gramineous species would not be required for sheep production and can have negative effects on following wheat crops when in mixtures with medic; there was no gain by the addition of oats except 21 days of extra grazing in which the sheep grazing grass-free medic were able to compensate for. Higher Autumn temperatures, and delayed defoliation can improve early medic growth but doesn't appear to improve the competitive ability of the medic markedly. There may be more productive early winter competitive accessions and accessions × *rhizobium* combinations. However, initial evaluation of accessions available did not identify any that were more competitive or better adapted than the current commercial cultivar Paraggio.

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9 APPENDIX A

Appendix Table A.1 Mean monthly temperature and rainfall and evaporation data for The University of Adelaide Roseworthy Campus 1992-1995.

Mean Temperature (°C)

Months	1992			1993			1994			1995			**Long Term Mean**		
	Max.	Min.	**Mean**	Max.	Min.	**Mean**	Max.	Min.	**Mean**	Max.	Min.	**Mean**	**Max.**	**Min.**	**Mean**
January	27	12.8	**19.9**	28.2	13.9	**21.1**	27.4	14.2	**20.8**	33.7	17	**25.4**	29.8	14.6	**22.1**
February	30.8	15	**22.9**	31.3	15.6	**23.4**	29.2	15.5	**22.4**	33.3	15.4	**24.4**	29.6	14.8	**22.2**
March	28.3	24.5	**26.4**	26.9	13.8	**20.4**	27.3	13.3	**20.3**	25.5	12.6	**19**	27.4	13.3	**20.3**
April	23.8	11.6	**17.7**	26	11.5	**18.8**	23.7	12.5	**18.1**	21	10.4	**15.7**	22.7	10.7	**16.6**
May	18.8	9.8	**14.3**	21.8	9.6	**15.7**	19.7	9	**14.4**	19	9.2	**14.1**	18.8	8.9	**13.8**
June	16.2	7.3	**11.8**	15.6	7.1	**11.4**	23.7	12.5	**18.1**	16.9	8.9	**12.9**	15.8	6.7	**11.3**
July	17	6.9	**12**	16	7.2	**11.6**	17.2	7	**12.1**	14	7.2	**10.6**	14.8	5.8	**10.3**
August	15.7	5.4	**10.5**	18.8	7.4	**13.1**	15.5	5.9	**10.7**	17.7	6.6	**12.1**	16.1	6.1	**11.1**
September	15.5	6	**10.8**	19	7.8	**13.4**	18.5	7.4	**12.9**	19.3	7	**13.2**	18.9	7	**12.9**
October	20.3	9.1	**14.7**	21.8	8.9	**15.4**	22.7	10.7	**16.7**	23.6	10.4	**17**	22	8.9	**15.4**
November	21.9	9.8	**15.9**	27.1	12	**19.5**	24.4	12.1	**18.2**	26.9	11.8	**19.4**	25.6	11.4	**18.5**
December	26.2	14.7	**20.5**	28.5	14.3	**21.4**	31	14.5	**22.8**	26	11.3	**18.7**	28	13.5	**20.7**

	Monthly Rainfall (mm)					Monthly Pan Evaporation (mm)			
Months	1992	1993	1994	1995	**Long Term**	1992	1993	1994	**Long Term**
January	0	44.4	21.8	18.2	**21**	273	216	230	**259**
February	20.4	7.1	12	29	**19**	237	242	198	**212**
March	54.6	11.8	0.6	14.1	**20**	176	181	220	**180**
April	25.5	3.1	12.6	27.1	**38**	103	112	132	**112**
May	52.9	21.3	14.8	44.9	**49**	56	68	110	**69**
June	41.6	44.9	12.6	55.1	**53**	34	50	58	**48**
July	31.3	37.5	32.8	87.5	**49**	56	57	87	**43**
August	106.5	40	10.4	16.7	**52**	42	103	88	**58**
September	121.6	63.7	8.6	18.7	**46**	72	88	120	**86**
October	56.6	89.4	24.8	49.2	**43**	97	132	180	**117**
November	83.9	20.2	34	7.6	**27**	143	189	200	**178**
December	49.1	23.6	6.6	8.1	**23**	148	239	306	**224**
TOTALS	537.5	407	197	376	**440**	1437	1675	1929	**1586**

Appendix Table B.1 Plant emergence counts (plants/m^2) of medic, grass and other (broadleaf) on the experimental site on March 15, 1992 before spraying with glyphosate

	13.2 sheep/ha			19.8 sheep/ha			Tukeys HSD (P<0.05)		
Species	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Grass-Free Medic	Grass+ Medic	Oat+Grass +Medic	Pasture	SR	Pasture × SR
Medic	594	227	225	582	375	309			22.6
Grass	10	282	259	4.7	198	142			37.2
Other	16	10.4	9.4	19.1	12	10.1	1	0.88	n.s.

Appendix Table B.2 Mean available DM yield (kg/ha) of medic for three pasture types at two stocking rates at six harvests (July 18 - October 23) in 1992.

	13.2 sheep/ha			19.8 sheep/ha		
Harvest	Grass-Free Medic	Grass+ Medic	Oat+ Grass+ Medic	Grass-Free Medic	Grass+ Medic	Oat+ Grass+ Medic
Harvest 1 July 18	185	172	176	202	182	173
Harvest 2 July 29	518	226	217	513	218	200
Harvest 3 Aug 8	828	297	370	791	238	415
Harvest 4 Aug 31	1167	344	548	1025	258	614
Harvest 5 Sep 26	2546	565	652	1265	308	1083
Harvest 6 Oct 23	3957	453	801	1252	494	1143

Tukeys HSD ($P<0.05$) Pasture × SR × Harvest = 62

Appendix Table B.3 Mean available DM yield (kg/ha) of grass for three pasture types at two stocking rates at six harvests (July 18 – October 23) in 1992.

	13.2 sheep/ha			19.8 sheep/ha		
Harvest	Grass-Free Medic	Grass+ Medic	Oat+ Grass+ Medic	Grass-Free Medic	Grass+ Medic	Oat+ Grass+ Medic
Harvest 1 July 18	0	190	154	0	179	169
Harvest 2 July 29	0	597	551	0	573	541
Harvest 3 Aug 8	0	946	883	0	812	963
Harvest 4 Aug 31	0	1343	1214	0	1253	1177
Harvest 5 Sep 26	0	3004	1290	0	2609	1518
Harvest 6 Oct 23	0	3585	2419	0	2626	1778

Tukeys HSD ($P<0.05$) Pasture × SR × Harvest = 102

Appendix Table B.4 Mean available DM yield (kg/ha) of broadleaf weeds for three pasture types at two stocking rates at six harvests (July 18 – October 23) in 1992.

	13.2 sheep/ha			19.8 sheep/ha		
Harvest	Grass-Free Medic	Grass+ Medic	Oat+ Grass+ Medic	Grass-Free Medic	Grass+ Medic	Oat+ Grass +Medic
Harvest 1 July 18	285	269	270	285	260	254
Harvest 2 July 29	231	170	253	228	183	191
Harvest 3 Aug 8	288	141	200	369	160	272
Harvest 4 Aug 31	330	109	154	596	151	385
Harvest 5 Sep 26	352	107	136	746	133	399
Harvest 6 Oct 23	678	109	136	523	137	88

Tukeys HSD (P<0.05) Pasture × SR × Harvest = 46.8

Appendix Table B.5 Mean available DM yield (kg/ha), totals for three pasture types at two stocking rates at six harvests (July 18 – October 23) in 1992.

	13.2 sheep/ha			19.8 sheep/ha		
Harvest	Grass-Free Medic	Grass+ Medic	Oat+ Grass+ Medic	Grass-Free Medic	Grass+ Medic	Oat+ Grass +Medic
Harvest 1 Jul 18	470	631	991	487	622	1004
Harvest 2 Jul 29	750	994	1631	741	976	1538
Harvest 3 Aug 8	1116	1385	2453	1161	1211	2324
Harvest 4 Aug 31	1498	1797	3463	1622	1664	2921
Harvest 5 Sep 26	2898	3677	4904	2011	3051	3686
Harvest 6 Oct 23	4635	4148	4252	1776	3258	3189

Tukeys HSD (P<0.05) Pasture × SR × Harvest = 132

Appendix Table B.6 Calibration equations and bulk density at four depths for paddock North 4A at Roseworthy

Equations		Bulk Density (g/cm^3)
(0-20cm) : θ_v(mm/mm) = -0.150 + 0.973 × count ratio,	($r^2 = 0.969$)	1.36
(20-40cm) : θ_v(mm/mm) = -0.049 + 0.61 × count ratio,	($r^2 = 0.877$)	1.15
(40-60cm) : θ_v(mm/mm) = -0.050 + 0.604 × count ratio,	($r^2 = 0.887$)	1.21
(60-80cm) : θ_v(mm/mm) = -0.112 + 0.692 × count ratio,	($r^2 = 0.721$)	1.26

Where θ_v is volumetric soil water

APPENDIX C

Appendix C.1 University of California Potting Mix

2/3 cubic metre of washed coarse sand is sterilised at 100°C for 30 minutes in a sterilising mixer. One bale of peatmoss (1/6 cubic metre expands to 1/3 cubic metre) is added and mixed for 10 seconds. The combined temperature drops to 75°C. A further 10 minutes of cooling is allowed before the following fertilisers are added and mixed for 20 seconds. The pH is approximately 6.5.

Fertilisers

700 gm	Calcium hydroxide
480 gm	Calcium carbonate
600 gm	Nitrophoska

Appendix Table C.2 Nitrophoska Analysis

Total Nitrogen	15.0%	
		5.0% NH_4 Ammonium
		4.0% No_3 Nitrate
		1.0% NH_2 Amide
		5.0% IBDU
Total Phosphorous	3.9%	
		3.9% Citrate soluble, of which
		1.2% water soluble
Potassium sulphate	12.4%	
Magnesium carbonate	1.25%	
Dicalcium phosphate	3.4%	
Sulphates	5.3%	
Iron Oxide	0.3%	
Copper Oxides	0.0002%	
Zinc Oxide	0.007%	
Calcium borate	0.01%	
Molybdenum oxide	0.0003%	

Appendix Table C.3 Osmocote Nutrient Analysis

Nitrogen as ammonium form	7.25%
Nitrogen as nitrate form	7.25%
Phosphorous as water soluble	4.40%
Phosphorous as citrate soluble	1.30%
Potassium as potassium nitrate	6.00%
Potassium as potassium sulphate	4.00%
Magnesium as magnesium oxide	1.40%
Sulphur as sulphates	3.00%
Total calcium as calcium phosphate and calcium sulphate	3.00%
Total Iron as iron sulphate and iron chelate	0.15%
Manganese as manganese sulphate	0.06%
Copper as copper sulphate	0.05%
Molybdenum as sodium molybdate	0.02%
Boron as boric acid	0.02%
Zinc as zinc sulphate	0.015%
Organic resin coating as vegetable oils	7.10%

Appendix Table D.1 Mean available dry matter yield (kg/ha) of medic for three stocking rates and two pasture types at five harvests (July 3 – October 11) in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
Harvest 1 Jul 3	1601	1500	1523	1638	1489	1478
	± 189	±176	±166	±169	±165	±176
Harvest 2 Aug 6	1867	1934	1856	1845	1856	1812
	±134	±145	±134	±125	±156	±123
Harvest 3 Sep 3	2300	2356	1956	2034	1278	1345
	±150	±145	±136	±132	±101	±112
Harvest 4 Sep 27	2399	2451	1901	1934	437	488
	±189	±212	±178	±165	±53	±48
Harvest 5 Oct 11	1890	2000	1500	1489	510	489
	±210	±186	±134	±128	±56	±45

Appendix Table D.2 Mean available dry matter yield (kg/ha) of soursob for three stocking rates and two pasture types at five harvests (July 3 – October 11) in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha		Medium 20 sheep/ha		High 30 sheep/ha	
	Oat+Medic	Medic	Oat+Medic	Medic	Oat+Medic	Medic
Harvest 1 Jul 3	389	423	413	400	436	428
	±34	±40	±36	±28	±32	±39
Harvest 2 Aug 6	406	478	413	400	467	413
	±38	±44	±38	±32	±37	±36
Harvest 3 Sep 3	192	205	212	245	206	278
	±33	±30	±39	±34	±32	±35
Harvest 4 Sep 27	187	205	209	245	73	86
	±37	±33	±32	±36	±13	±18
Harvest 5 Oct 11	68	85	88	78	26	15
	±15	±16	±11	±12	±5	±4

Appendix Table D.3 Mean available dry matter yield (kg/ha) of oats for three stocking rates and two pasture types at five harvests (July 3 – October 11) in 1995. Figures below means are standard error of means.

	Low 10 sheep/ha	Medium 20 sheep/ha	High 30 sheep/ha
	Oat+Medic	Oat+Medic	Oat+Medic
Harvest 1 Jul 3	200	187	195
	±31	±27	±25
Harvest 2 Aug 6	458	389	332
	±68	±64	±63
Harvest 3 Sep 3	356	321	195
	±41	±37	±24
Harvest 4 Sep 27	278	201	45
	±39	±32	±6
Harvest 5 Oct 11	115	101	0
	±23	±15	