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ENVIRONMENTAL AND AGRONOMIC FACTORS AFFECTING SEED PRODUCTION IN ANNUAL MEDICS

by

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ABSTRACT

Annual medics (*Medicago* spp.) are important pasture plants in the ley farming systems of southern Australia and other Mediterranean-type environments of the world. High seed production is necessary for the regeneration of dense pastures and to maximise profit on commercial seed farms. In many annual medic cultivars, as in other forage legumes, the potential seed yield (defined as the number of flowers per unit area) is high, but commercial yields are much lower than expected. Mean seed yields of rainfed medic in South Australia for example, range from 50 to 600 kg/ha both within and between seasons (Australia Bureau of Statistics 1979-89) although individual farmers occasionally have achieved yields exceeding 1200 kg/ha. The agronomic and physiological factors responsible for the large difference between potential and actual seed yield, and the large variation within and between seasons and between cultivars, have not been adequately studied. The studies reported in this thesis sought to define some of the constraints to seed production and to suggest management strategies to improve the yield of annual medic. Six field experiments and one glasshouse experiment were carried out.

To identify the constraints to seed yield within a cultivar, the relationship between vegetative growth and seed yield was examined in the field. The experiment involved two sowing dates (27 May and 27 June), five sowing rates (1, 5, 25, 125, 625 kg/ha) and two cultivars of *Medicago truncatula* (Parabinga=early-flowering, Paraggio=late-flowering). Seed yields were highest with early sowing and at sowing rates of 5 or 25 kg/ha and were related to the number of pods per m^2 at maturity. Delayed sowing reduced seed yield through a reduction in the number of flowers produced in the early part of the season and a shorter period for seed growth. The highest sowing rates produced the highest number of flowers/m^2 but seed yield at 125 and 625 kg/ha was significantly reduced by poor percentage pod set because of the occurrence of complete self-shading (LAI above 4) prior to the start of flowering. At sowing rates of 5 and 25 kg/ha, complete self-shading occurred at different times after the start of flowering but pod set was similar for both sowing rates. It was postulated that methods for improving seed yield in annual medics should be based on strategies which encourage early flower production and which improve pod retention by increasing light penetration into the sward during the early flowering period.

In order to test the hypothesis that poor light penetration through the sward during the early flowering period was responsible for low seed yields, two shading experiments were conducted on swards of annual medics sown at 20 kg/ha. Undefoliated swards of *M. scutellata* cv. Sava and *M. truncatula* cv. Paraggio were given 30% shading at different stages of growth in 1989, and in 1990 swards of Paraggio barrel medic, defoliated at the start of flowering or undefoliated throughout the growing season, were given 30% or 60% shading at various times during flowering. In 1989, 30% shading did not significantly reduce seed yield in either species. In 1990, 60% shading throughout the flowering period reduced seed yield by a half, whereas shading in the first half of flowering reduced yields by a quarter in both the defoliated and undefoliated swards. No significant reduction in seed yield was found after 60% shading up to the start of flowering or by shading in the second half of flowering. Reductions in medic seed yield with shading were due to a low proportion of flowers that formed mature pods. The hypothesis that increased light penetration during the early flowering period increased seed yield through improved pod set was confirmed because the reduction below the potential yield was greater following 60% shading during early flowering than after 30% shading or unshaded control or when shading occurred during other stages of reproductive growth.

From the above experiments it was concluded that early flower production, a long reproductive period and better light penetration through the sward during the early flowering period are important for high seed production in annual medics. The length of the reproductive period within a cultivar depends much on the opening rains and the end of rains in spring both of which are beyond farmers' control. Low light transmission before the start of flowering in many commercial seed crops is common. Commercial seed producers use a low sowing rate (c. 10 kg/ha), graze the swards or use low rates of herbicides to restrict vegetative growth prior to the start of flowering, but published studies do not show that mechanical defoliation or grazing can increase seed yield in annual medics. In order to gain a better understanding of the influence of defoliation on seed yield, two experiments involving different levels of severity, frequency and timing of defoliation were carried out in a lower-rainfall area (Korunye, mean rainfall 360 mm p.a.), and higher-rainfall area (Waite Institute, mean rainfall 620 mm p.a.).

The herbage production (DM) and number of flowers per m^2 at the Waite Institute was 2 to 3 times greater than at Korunye, but the highest seed yields at each site were similar (863 kg/ha for Waite Institute and 936 kg/ha for Korunye). The higher DM at the Waite Institute was due to more growing season rainfall (586 mm) than at Korunye (274 mm), but the low rainfall (7.6 mm) during the middle of the flowering period (October) at the Waite Institute, in comparison to 20 mm at Korunye, reduced seed yield through poor pod set (2 to 3 times lower than at Korunye). In the lower-rainfall area grazing in July only, i.e. before the start of flowering, resulted in greater seed yields than grazing in July plus severe defoliation at the start of flowering. Seed yield was related to the number of pods/m^2 and DM production. In the higher-rainfall area, however, severe defoliations up to the start of flowering increased seed yields. The numbers of pods/m^2 were not significantly different from the undefoliated control, but the number of seeds per pod and mean seed weight increased thereby contributing to significant increases in seed yield. Percentage pod set was not always related to seed yield. The results highlight the importance of severity and time of final defoliation in relation to season or site, whereby in a lower-rainfall area where DM production was low, defoliation at the start of flowering reduced seed yield, but in a higher-rainfall area where DM production was high, severe defoliations up to the start of flowering increased seed yield. The study also showed that the components that most determine seed yield will vary with site, season and management. At the Waite Institute, low rainfall during October resulted in severe moisture stress during the middle of the flowering period. Defoliation reduced plant water stress and increased seed yield by increasing mean seed weight and number of seeds per pod. In contrast, at Korunye seed yield was limited by the small number of flowers per m^2 but high pod set increased seed yield.

The response of seed yield to defoliation at early flowering under different moisture regimes was tested in a glasshouse experiment. Both water stress and defoliation reduced seed yield but there was no Defoliation x Moisture stress interaction. Reductions in seed yield as a result of defoliation 3 weeks after start of flowering were smaller than those caused by water stress. The reduction in seed yield with water stress was due to fewer pods per m^2 as a result of reduced flowers per m^2 and lower percentage pod set. However, with defoliation, improved percentage pod set partly compensated for the fewer flowers per m^2 and, as a result, yields were better than those caused by water stress. The study, however, failed to show that the level of plant water stress was reduced by defoliation: this result was in contrast to the field studies.

To test if the potential benefit of defoliation prior to flowering is generally applicable to a wide range of cultivars, a field experiment involving 10 cultivars was carried out at the Waite Institute. Cultivars were chosen which differed in maturity, ability to produce flowers, number of seeds per pod and mean seed weight. The reasons for choosing these cultivars were also to find out the extent to which seed yield is limited by the number of flowers/m^2 and percentage pod set. The extent to which percentage pod set is limited by time to first flower or the potential sink size (potential sink size=number of flowers per raceme x mean pod weight (Cocks 1990a,b) at each flowering node and the improvements that could be obtained by defoliation were also investigated.

Seed yields differed significantly between cultivars but not between defoliation treatments (defoliation at a height of 3 cm or 6 cm up to the start of flowering or undefoliated), indicating that yields may be little affected by defoliation in most medic cultivars if it ceases at an early stage of growth. The most important factor contributing to high seed yields was setting a large number of pods/m^2 (r=+0.63***). This was achieved via early flowering (r=+0.63***) and high percentage pod set (r=+0.54**) but no single attribute accounted for the differences in pods/m^2 between cultivars. Percentage pod set was greater in early-flowering cultivars but negatively correlated (r=-0.56**) with the potential sink size at each flowering node between cultivars indicating that high pod set is determined by more than one attribute. Seed yields were not simply related to cultivar maturity or to herbage yield at the end of flowering: therefore it may be possible to select for high herbage production and high seed yields together. Selection of cultivars in a wide range of environments may be one of the ways in which higher yielding cultivars over a wide range of seasons can be obtained.

In conclusion, the study shows that the reproductive potential of the annual medic seed crop is set by the number of flowers. The degree to which this potential is realised in terms of seed yield mainly depends on the proportion of the flowers that produce mature pods. The study shows that over 60% of the flowers fail to form mature pods. The physiological reasons for this could not be readily resolved in this experimental program as there is little information on the proportion of florets that are sterile, those that are fertile but are not successfully pollinated or fertilised, or those that become fertilised but abort. Agronomic studies in this thesis show that management strategies that maximise flower production and improve light penetration before the onset of severe soil moisture stress late in the season can improve pod set and seed yield. Management practices which restrict the amount of vegetative growth, such as strategic grazing/defoliation, or the use of low rates of herbicides, may increase seed yield. However, the success of these practices need to be modified to suit local environmental conditions and therefore need to be tested over a range of sites and seasons before more general recommendations can be made. The study also showed that high herbage production may not reduce the genetic potential to produce high seed yields and hence it is possible to select cultivars that have the ability to give both high herbage production and high seed yields.

STATEMENT

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CHAPTER 1

1. GENERAL INTRODUCTION

High seed production of annual medics (*Medicago* spp.) is critically important to the success of ley farming systems in large areas of southern Australia and in some other Mediterranean-type climatic areas of the world because seed reserves are the basis of dense legume swards during the pasture phase. The legume-dominant sward provides nitrogen in the soil for the next cereal crop, minimises the cereal root diseases associated with grassy pastures and provides a large amount of high-quality feed for livestock during the growing season while the dry residues and pods are excellent feed during the summer-autumn period (Callaghan and Millington 1956; Carter 1978, 1987; Puckridge and French 1983). Large quantities of seed are also important to maximise profitability in commercial seed production. The studies reported in this thesis concentrate on how to increase seed yield for commercial purposes.

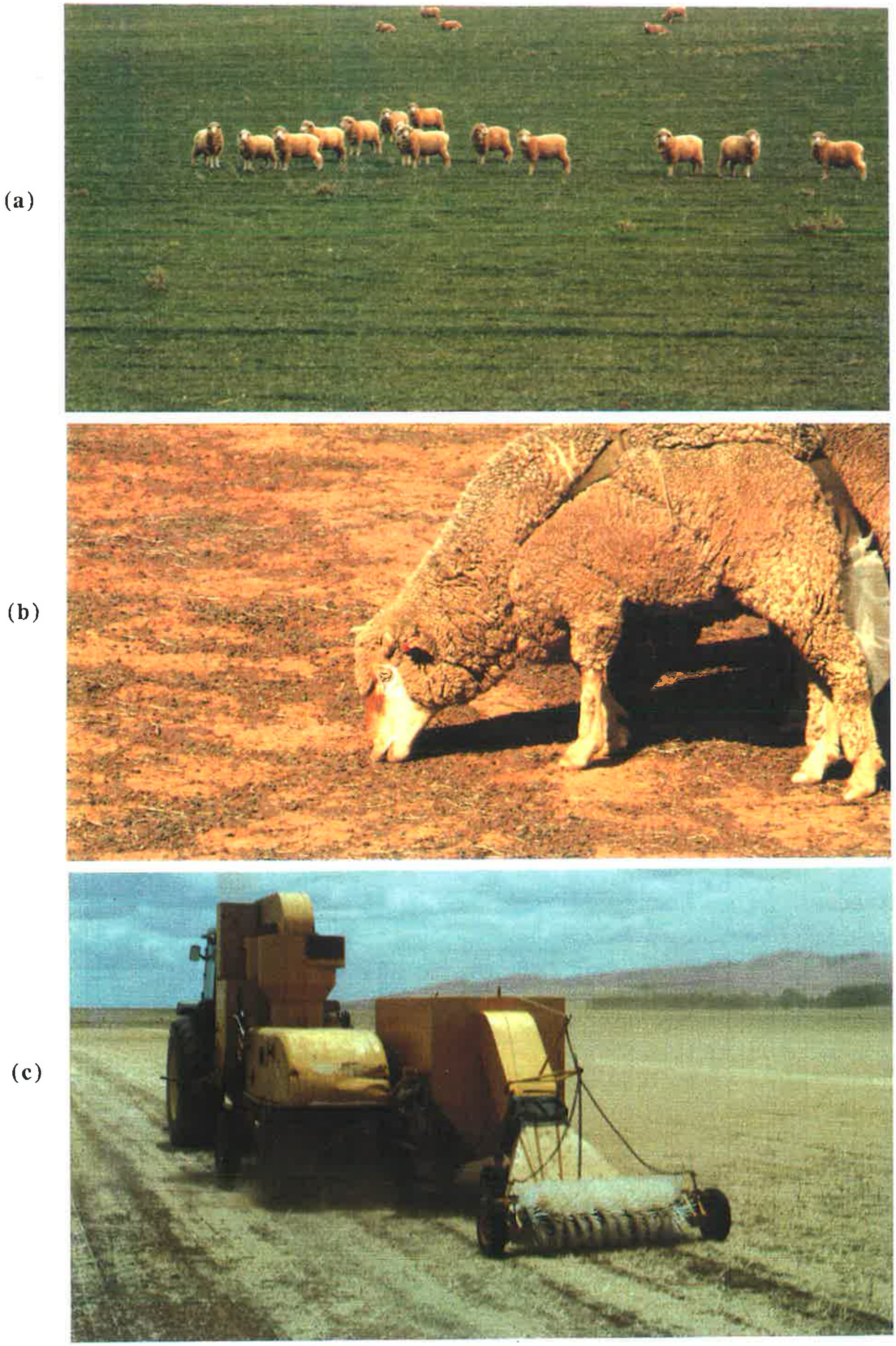
South Australia has been the world's main producer and exporter of annual medic seeds but both Victoria and Western Australia now have substantial production of medic seeds/ (Carter *pers. comm.*). Yields in South Australia for the 11-year period (1979-89) averaged 300 kg/ha, with a range from 50 kg/ha to 600 kg/ha between seasons, locations and cultivars (Australia Bureau of Statistics 1979-1989). Assuming a harvest efficiency for medics of 50% (Cocks 1988) these yields approximate 100 kg/ha to 1200 kg/ha in experimental plots. In fact Carter (1989) has recorded yields of 1469 kg/ha from a five-cultivar medic mixture at the Waite Institute. Ragless (1973) reported that commercial yields of between 110 kg/ha and 440 kg/ha are more common in annual medics than those above 440 kg/ha. However, recent studies by Cocks (1988) show that if yield potential is defined as the number of flowers (or potential seed sites) per unit ground area of crop at the end of the flowering period, then most of the medic cultivars have the potential to produce commercial yields in excess of 1000 kg/ha. There is limited research data on whether the low yields and the variation within and between cultivars in South Australia is due to limitations imposed by climate, management strategies or by lower genetic capacity of the cultivars grown.

A fundamental objective in pasture and forage crop seed production is to increase yield without jeopardising the genetic potential for production of large quantities of herbage. Previous studies show that annual medic cultivars differ considerably in potential for high production of herbage and seed (Cocks 1988, 1990b; Ababneh 1991), but very little detailed analysis of the relationship between total dry matter yield and seed yield has been reported. Samaroo (1988) working with accessions of *Pisum sativum*, *Vicia sativa*, *Lathyrus sativus*, *Medicago aculeata* and *M. rigidula* indicated that total dry matter yield at the beginning of pod formation and seed yield at maturity behave to a large extent as independent variables. The author suggested that selection for genotypes combining high seed yield and dry matter yield should not offer major difficulties. In contrast, in the winter cereals grown in Mediterranean environments, high vegetative growth can result in lower grain yields (e.g. Fischer and Wood 1979). In order to gain a better understanding of the relationship between dry matter production and seed production, the components of yield which contribute greatly to high seed yields need to be identified. The studies should be replicated in time and space so that the ability of a cultivar to produce high seed yields over a wide range of environments or seasons can be assessed. Current information on annual medic seed production indicates that seed yield is mainly determined by the number of pods produced per unit area (Adem 1977; Cocks 1988, 1990a,b; Ababneh 1991). However, except for the recent studies by Cocks (lit. cit.), which have shown that seed yield is partly limited by the number of flowers that survive to form mature pods, most of the other reported studies have concentrated on the measurement of final pod numbers, seed yield and seed yield components (e.g. Amor 1966; Poole 1970; Adem 1977; Ababneh 1991) without adequate information on how these are achieved.

In order to obtain high seed yields in an indeterminate plant like annual medic, events that determine the establishment of yield potential (i.e. flowers), the developmental processes of pollination, fertilization and seed growth, which determine the number of pods per unit area, number of seeds per pod and mean seed weight, need to be known. Furthermore, the way in which these events interact with the environment or how they can be modified by management strategies in order to optimise seed yields needs to be clearly described.

Cocks (1988, 1990a,b) in Syria showed that medic pod set is partly limited by the failure of many flowers and young pods to form mature pods. He also demonstrated that there is genetic variability between species and cultivars, both in the number of flowers produced and those that set mature pods. The extent to which seed yield in the cultivars currently grown by South Australian farmers is limited by poor percentage pod set has not been adequately examined. Similarly, the extent to which flower and young pod abortion is influenced by inadequate photosynthetic supply as a result of competition from existing developing pods, or from vegetative growth, is still to be studied. Furthermore, the extent to which management practices that enhance photosynthate partitioning to reproductive rather than to vegetative growth influence pod set, and the extent to which such management strategies can reduce yield potential by reducing the number of flowers produced per unit area have not been adequately investigated. The hypothesis that certain stages of reproductive growth are more sensitive to environmental or management stresses that reduce crop growth than others have not been investigated for annual medics.

The work reported in this thesis was therefore undertaken to investigate some of the constraints to seed yield in annual medics. Constraints related to hormones or mineral nutrients will not be considered. Firstly, information on crop growth and the interactions between herbage production and seed yield were investigated. The influence of the major environmental factors (water availability, light and temperature) during the growing season on seed yield was also quantified in the first Experiment in order to facilitate further work. Secondly, it was necessary to know the sensitivity of reproductive growth to reduced light penetration through the sward at different stages of growth so that management strategies such as grazing and mechanical defoliation, which increase light penetration, could be devised. Thirdly, mechanical defoliation studies were carried out to test whether seed yields could be increased by allowing better light penetration into the sward or whether such strategies could limit seed yield through limiting flower production. Interactions between defoliation and water stress were studied in the glasshouse to supplement the observations made in the field experiments. The differential response of various cultivars and species to mechanical defoliation and the genetic variability in terms of herbage yield and components of reproductive growth were investigated in a field study.



Well-grazed medic pastures (a) lead to good seed production for summer grazing (b) and seed harvesting (c).

CHAPTER 2

2. LITERATURE REVIEW

This review of literature will examine the role of annual medics in the ley farming system of southern Australia and the importance of high seed production. A description of a medic plant is presented and the major environmental factors and important agronomic practices that affect vegetative growth and seed yield in annual medics and subterranean clover legumes are reviewed. Limitations of knowledge to annual medic seed production is identified to facilitate further research. Reference to other forage legumes and grain legumes, especially those grown in the temperate environments, has only been made to illustrate some aspects where information is deficient in medics and subterranean clovers.

2.1. THE ROLE OF ANNUAL MEDICS IN LEY FARMING SYSTEMS OF SOUTHERN AUSTRALIA

Australia has some 40 Mha of crop and sown pasture lands that rely on introduced pasture legumes to maintain or improve levels of soil nitrogen, control cereal diseases and provide high quality livestock feed. Pastures dominated by annual self-regenerating medics (*Medicago* spp.) and clovers (*Trifolium* spp.) each year occupy some 27 Mha (Carter 1987; Thorn 1989) and are worth at least US$ 2,500 million each year to the crop and livestock industries (Carter 1981). The other 13 Mha is under various crops.

In South Australia, annual, self-regenerating medics and subterranean clovers form the largest proportion of the legumes used in the ley farming system. Annual medics were commercialised in the 1930's after it had been recognised that subterranean clovers were not adapted to the drier regions (250-450 mm annual rainfall) and more alkaline soils of the cereal belt (Carter 1975). In this region of the cereal belt farmers aim to have a pure legume crop (e.g. field peas) or pure legume pasture stands (immediately before a cereal crop) to maximise nitrogen input and reduce the amount of weedy grasses and to minimise cereal root diseases that may be associated with these grasses. The higher-rainfall areas (500-1000 mm), on the other hand, have mainly acidic soils better suited to subterranean clover and other clovers. The aim of pasture management in the higher-rainfall areas is mainly to improve the quality and quantity of livestock feed by growing grass-legume pastures.

The cultivars of annual medic, like most other forage crops currently in use by farmers, have been selected for high herbage production because of the association of yield with increased animal production and nitrogen fixation (Crawford *et al.* 1989). Seed production is also one of the selection criteria,but it is often secondary to herbage production. Despite this, it is important to have high seed yields in annual self-regenerating legumes for the following reasons:

(i) *To maintain the seed bank in the soil.* The success of annual, self-regenerating legume pastures in increasing nitrogen in the soil, minimising cereal diseases and providing large quantities of high quality livestock feed depends on the establishment of a dense pasture, which usually depends on high seed production during the previous pasture phase. Furthermore, pasture growth during the late autumn and winter period is linearly related to seedling density (Carter 1981, 1987, 1990a; Crawford *et al.* 1989), and this is often the period when farmers do not have enough feed for their livestock.

(ii) *To provide summer/autumn grazing.* Medic pods and clover burrs containing seed usually provide feed for livestock during summer and autumn when other feed is scarce (Carter 1982; Carter *et al.* 1982; Crawford *et al.* 1989), so high production of seed will provide feed for livestock as well as adding to the seed reserve for regeneration of new pastures. However, as Carter has warned, overgrazing of medic pods and clover burrs can seriously deplete seed reserves (Carter 1981, 1982; Carter *et al.* 1989; de Koning and Carter 1989).

(iii) *Commercial seed production.* In commercial seed production, high seed yields are important to maximise profitability. South Australia is the major producer of annual medic seed in Australia ,much of which is exported thereby providing a trade link to other countries.

The seed yield of pasture and forage crops depends upon the way in which many factors influence a whole sequence of processes during the vegetative, flowering, seed-setting and seed-growth phases of the pasture and how these processes are synchronised to provide a large quantity of seed available for harvesting at one time (Bean 1971; Humphreys 1979). For forage crops, the yield of viable seed per unit area is a product of the following parameters each of which is controlled by genetic and environmental factors:

(i) the number of shoots which appear per unit area,

(ii) the percentage of these shoots which survive to flowering time,

(iii) the number of reproductive sites differentiated on each shoot,

(iv) the number of flowers differentiated on each inflorescence,

(v) the percentage of the formed flowers that are pollinated and fertilised and develop into mature pods, and

(vi) the seed numbers per pod and the size to which individual seeds grow.

Some of these yield components are more variable than others and more subject to control by the farmer through alterations in the environment by the manipulation of the farming practices during the growing season (Hebblethwaite *et al.* 1980). For example, shoot density, which determines the potential number of inflorescences, is greatly influenced by the light, temperature and moisture regime in a given growing season, but it is also positively associated with sowing rate, weed control, soil fertility and moisture supply, and is modified by cutting or grazing practices.

2.2. DESCRIPTION OF THE MEDIC PLANT

2.2.1. Ecological distribution and plant morphology

In this thesis the word "medic" applies to an annual species of the legume genus *Medicago*. The genus *Medicago* is native to western Asia and the Mediterranean region, although many of its annual species have become naturalised over wide areas in many countries of the world, especially those areas with a Mediterranean-type climate (Heyn 1963). Medics are well adapted on neutral to alkaline soils with annual rainfall of 250-500 mm. Annual medics are also being studied as pasture legumes in the 500-800 mm rainfall zone of dry subtropical eastern Australia (Clarkson 1970; Clarkson and Russell 1979). They grow and persist in this regions as far north as Latitude 23°S, and are very productive in years with adequate cool season rainfall (Russell 1969; Jones and Rees 1972).

All medics are winter annuals. The above-ground vegetative structure consists of herbaceous, weak stems, trifoliate leaves and inconspicuous yellow flowers (Whyte *et al.* 1953; Oram 1990). The lowest node at emergence bears two cotyledons, followed by a monofoliate leaf and trifoliate leaves which are borne at alternate nodes on a petiole on the stem. Depending on medic plant density, all nodes except the cotyledonary and single monofoliate leaf, possess the potential for branching. Leaf longevity, as in other plants, is a function of canopy light relations to some extent. In general, under sward conditions, the cotyledon, monofoliate leaf and the first few trifoliate leaves usually abscise before the commencement of flowering.

2.2.2. Reproductive growth

Annual medic plants are self-pollinated, pollination occurring just prior to, or at, flower opening. The node of first flower varies with species (Cocks 1990a,b) and environment (Clarkson and Russell 1975). There is also a wide genetic diversity in flowering time of annual medics. For example, Crawford (1985) found a 25-day range (99-124 days) in time to flowering among 9 commercial cultivars sown at Adelaide in late April, while Cornish (1985b) found a range of 35 days in genotypes of *M. truncatula* in central New South Wales. Much greater diversity was found in the South Australian Department of Agriculture's *M. truncatula* germplasm collection where the range was 66-148 days (Crawford *et al.* 1989). Devitt *et al.* (1978) also observed major differences according to site and sowing date, as well as agronomically-significant interactions between species, site and sowing date.

Annual medics also tend to hasten their development to flowering following late germination/emergence and there is genotypic variation in the magnitude of hastening

(Aitken 1955; Devitt *et al.* 1978; Cornish 1985b; Hochman 1985). The hastening of development is a reflection of the inter-relationships between temperature promotion, vernalisation (cold treatment) and photoperiod (dark period inhibition), which was suggested by Aitken (1955) and confirmed by Clarkson and Russell (1975) in six annual medic species. Clarkson and Russell (1975, 1979) concluded that vernalisation and long photoperiod were able to substitute for each other to a greater extent and high temperature acceleration of flowering occurred only after vernalisation except in *M. scutellata* where temperature had an overriding influence on flowering.

The growth habit of annual medics is indeterminate, with flowers borne on pedicels at successive reproductive nodes after the first flowering node. The number of flowers per pedicel varies with cultivar and species (Cocks 1990a,b; Oram 1990). Each reproductive node is subtended by a leaf which develops somewhat in advance of flowers. The leaf is almost fully expanded by the time of anthesis of the subtending flower. Pods at different reproductive nodes on an individual plant are not all at the same developmental stage at any one time. Maturing pods, young developing pods and anthesis occur successively, starting from the first flowering node on each branch and progressing towards the distal part of the branch. The number of flowering nodes in a given cultivar can vary depending on the number of branches per plant and the number of nodes developed per branch. The number of nodes per branch and the number of branches are determined by genotype, environmental conditions and agronomic practices under which the pasture sward is grown.

2.2.3. Assimilate partitioning and pod set

Studies on partitioning of assimilates between the vegetative and reproductive growth in annual medics have not been reported: however, studies on indeterminate grain legumes indicate that vegetative plant parts (including the roots) are the only sinks for assimilates prior to flowering but during flowering and fruit set, vegetative and reproductive plant parts become competing sinks (e.g. Pate and Farrington 1981; Jeuffroy and Warembourg 1991). During seed filling and seed maturation, the growing seeds become the major sinks for assimilates.

The pattern of the distribution of assimilates between competing sinks is determined by the rate of photosynthesis, the strength and proximity of the various sinks (modified to some extent by the pattern of vascular connections (Wardlaw 1968) and environmental conditions. In the vegetative plant, the upper leaves export assimilates principally to the apex and young expanding leaves, lower leaves export to roots and middle leaves supply both (Belikov and Kostetskii 1958 cited by Shibles *et al.* 1975; Thaine *et al.* 1959). However, superimposed on this generalised directional pattern there is a strong phylotactic influence. In vegetative plants of soybean Thrower (1962) found the expanding leaf to import more from the second leaf below than from the one immediately below. In the fruiting plant, although export from a leaf is primarily to its own pods and seeds (Belikov 1955; Belikov and Pirskii 1966), the pods and seeds in the axil of the second node below (Blomquist and Kust 1971) and the second above receive more assimilate from a given leaf than do those in the axil immediately above and below.

Some studies have indicated that the high abscission of flowers and young pods in indeterminate grain legumes is due to competition for photosynthetic assimilates on the basis of sink strength. Partial or complete removal of the upper laterals during early flowering has been reported to increase pod set on the main branch of *Lupinus* spp. (Farrington and Pate 1981; Porter 1980, 1982) as did application to developing laterals of a growth retardant (Farrington and Pate 1981). Similarly, removal of developing pods increases the number of pods set higher up an inflorescence (Pate and Farrington 1981 for *Lupinus* spp.; Huff and Dybing 1980 for *Glycine max* (soybean); Aufhammer and Gotz-Lee 1991 for *Vicia faba* (faba beans)). Studies of Jeuffroy and Warembourg (1991) in *Pisum sativum* have shown that flowers and very young pods rely on the immediate subtending leaf for assimilates; however, once the very young pods have passed the stage of abortion, these become stronger sinks, thereby importing assimilates for growth from leaves at the other flowering nodes. In *Lupinus angustifolius*, Pigeaire *et al.* (1992) have defined that stage as when the pods are 10 cm long.

Annual medic cultivars vary in the number of flowers that survive to form mature pods, and as high as 95% of the flowers produced can fail to form mature pods in some cultivars and seasons (Cocks 1988). Mechanical tripping of flowers (Cocks 1987) did not improve pod set in comparison to the control, indicating that pod set in annual medics was possibly not limited by pollination. However, the proportion of medic flowers that are sterile and those that are fertilised but fail to form mature pods, as well as the physiological and agronomic management strategies required to improve pod set, have not been studied in detail.

2.3. ENVIRONMENTAL FACTORS CONTROLLING SEED PRODUCTION

2.3.1. The climate of South Australia

General descriptions of the climate of South Australia are given by Leeper (1970), Gentilli (1971,1972) and Nix (1975). The climate is Mediterranean with hot, dry summers and rainfall concentrated in the cooler, winter-spring growing season (May-October). Rainfall has a marked seasonal and yearly variation due to easterly-moving anticyclones that follow one another across Australia at intervals of a few days (Gentilli 1971; Nix 1975). Summer rainfall is sporadic and usually non-effective for plant growth, hence the most suitable form of agriculture is the growing of short-season crops and annual pastures in autumn, winter and spring. The opening rains, i.e. sufficient rain for substantial germination, emergence, establishment and growth of seedlings, may fall any time from April to June. Rainfall in the winter months (June-August) is usually adequate for plant growth but moisture stress of unpredictable severity, timing and duration can occur any time from mid-September (French and Schultz 1984). The uncertainty in the start and finish of the growing season are the dominant factors in crop and pasture production in South Australia.

Solar radiation ranges from 23 - 27 MJ /m^2/day in summer to 8 - 12 MJ/m^2/day in winter. The low solar radiation in winter limits crop and pasture growth except when high sowing rates are used or regeneration is dense. In general, regenerating pastures emerge in autumn when the mean maximum air temperatures are around 20°C, and crops and sown pastures are sown a month or so later when the temperatures are 12-15°C with mean minimum temperatures occasionally below 3°C during the winter months. Flowering, pod and seed development take place in spring when air temperatures during the day are 20 - 25°C and minimum temperatures are 9 - 13°C.

Crop and pasture growth and seed production in this Mediterranean-type environment of southern Australia is therefore determined by:

(i) the timing of the opening rains,

(ii) the duration of the mid-winter depression in temperature and radiation,

(iii) the timing of flowering to avoid frost damage and heat stress, and

(iv) the rapid increase in temperature and moisture deficit during the spring season.

Environmental factors may act individually or in combination to influence vegetative and reproductive growth. This review shows how each of the major environmental factors (light, temperature and soil moisture) influences plant growth and reproductive development in the absence of other environmental constraints, mineral nutrient supply or physiological constraints such as dormancy and environmental shock.

2.3.2. Influence of light on plant growth and seed yield

Plant morphology, the rate of dry matter accumulation and seed production are influenced by the interception and utilization of light. Moreover, success and survival of individuals in communities depends upon how they intercept, compete for and respond to light. Comparatively, the control which light interception exerts on current photosynthesis during the reproductive phase appears to have a more significant effect on seed production than during the vegetative phase (Shibles and Weber 1966; Meadley and Milbourn 1971).

2.3.2.1. Plant morphology

The effects of light energy on rate of leaf appearance on a single stem are not clear. Some workers have found a high rate of leaf appearance under high light energy conditions (Ludlow 1978), while others reported no effects of light energy on the appearance rate (Bean 1964). However, leaf area increases with increased light energy (Ludlow 1978). Leaf thickness also increases with increased light energy whereas the specific leaf area (leaf area divided by leaf dry weight per unit area) is reduced by increased light energy. Lateral branching is similarly promoted by high light energy whereas internode length and plant height is reduced (Fukai and Silsbury 1977c; Ludlow 1978). The rate of leaf senescence is increased under very low light energy (McCree and Troughton 1966b). Woledge (1972), working with ryegrass, found a rapid aging of leaves under very low light energy (21W/m^2 PAR (Photosynthetically Active Radiation) or 10% of full light). Lower leaves in a canopy are often in advanced senescence due to low light energy (Brougham 1958).

2.3.2.2. Canopy growth and dry matter accumulation

The reviews of Blackman and Black (1959), Donald (1963), Brown and Blaser (1968) and Ludlow (1978) indicate that, provided temperature is not limiting and water and nutrients are in adequate supply, the rate of growth is dependent on the amount of radiation intercepted by the canopy. Pasture growth rate per unit area increases as LAI (Leaf Area Index) increases until most of the incident light is intercepted. The LAI value when nearly all the available light (95% of incident light) has been intercepted is called the optimum LAI and is usually around 3 to 4 in subterranean clover and medic swards. The concept of the "optimum" leaf area index states that when the LAI is below the optimum, crop growth rate would be dependent upon the LAI and would be depressed owing to incomplete interception of the available solar radiation, whereas when LAI is above the optimum, crop growth rate would be depressed due to increased respiratory losses (Brown and Blaser 1968). However, there are only a few crops for which this very simplified analysis predicts the pattern of growth rate with success (Hay and Walker 1989). Studies of undefoliated swards of subterranean clover and annual medics established at different plant densities and different times of the year by Silsbury and Fukai (1977) and Silsbury *et al.* (1979) for example found no optimum relationship between crop growth rate and LAI, as had been claimed by previous workers (e.g. Davidson and Donald 1958). However, in the Davidson and Donald studies, canopy closure occurred at an LAI value of 3 to 4 and swards grew at near-constant rate up to an LAI of 6. These results support the concept of critical LAI which states that crop growth rate increases with LAI up to critical LAI value (LAI at which light interception is complete) and above which a relatively constant, maximum value of crop growth rate is maintained (Hay and Walker 1989).

The concept of light interception and LAI also holds that the optimum or critical level of LAI declines as the amount of incident light decreases. At low light intensities less leaf area is required to intercept the available light, and if LAI exceeds this requirement, the foliage is below the light compensation point. Low LAI values are beneficial at certain periods because they favour tiller or branch initiation (Brown and Blaser 1968).

2.3.2.3. Canopy photosynthesis

The rate of net photosynthesis of the canopy is an integration of the rates of photosynthesis of each component leaf. Leaves in canopies are more light-limited than leaves of isolated plants due to self-shading and mutual shading as leaf area and average leaf angle increases (de Wit 1965; Brown and Blaser 1968; Leaf 1972). Therefore, except for leaves at the top of canopies, most leaves are light-limited most of the time, and the degree of limitation increases with depth. Maximum efficiency of light utilization for leaf net photosynthesis occurs at an illuminance of about 10% of full sunlight (Ludlow and Wilson 1971) and for canopy photosynthesis when all leaves are uniformly illuminated at this level. Further support for this concept is given by Fukai (1974) and Fukai and Silsbury (1977c) who observed that net photosynthesis of subterranean clover communities at high light flux density increased with increase in LAI, the increase being very small once an LAI of 3 (representing 95% of light interception) was attained. Ludlow and Charles-Edwards (1980) also reported net and gross photosynthetic rates of *Setaria/Desmodium intortum* swards subjected to different cutting heights and frequency of defoliation to approach a constant value in the LAI range of 3 to 5.

2.3.2.4. Seed yield

Seed yield in pasture legumes and grain legumes is particularly affected by light intensity changes during the period from anthesis to seed development (Shibles and Weber 1966; Meadley and Milbourn 1971; Collins *et al.* 1978). In a field trial in Western Australia Collins *et al.* (1978) found a marked decrease in seed yield of three cultivars of subterranean clover (Woogenellup, Clare and Seaton Park) when subjected to shading treatments (70% or 45% of daylight) from the beginning of flowering onwards. Seed yield of the cultivar Woogenellup fell from 200 g/m^2 to approximately 50 g/m^2 when daylight was reduced by 70%. The reduction in seed yield was mainly through a reduction in the number of inflorescences per unit area.

Similarly, shading of cowpea (*Vigna ungniculata* L. cv. Prima) to approximately 50% of full daylight throughout the growth period (from emergence to pod maturity) and from first flower to maturity reduced seed yield by 25% because fewer pods were formed (Summerfield *et al.* 1976). Plants shaded throughout the vegetative and reproductive phase produced significantly fewer pods than either unshaded plants or those shaded from first flower to mid pod fill only. Shaded plants had a greater seed:pod (weight) ratio than unshaded plants, suggesting that shading at some time from after the first flower alters the distribution of assimilates between pods and seeds. The authors proposed that when carbohydrate supply from leaves is limited by shading, the seeds, being a more powerful sink, presumably leave little carbohydrate to be accumulated in the pod wall.

The major source of dry matter for vining pea (*Pisum sativum*) yield is the photosynthate produced after commencement of flowering rather than from dry matter translocated from roots or stems following storage during the vegetative period (Meadley and Milbourn 1971). A reduction of incoming daylight by 50% throughout the vegetative and flowering period or from commencement of flowering to maturity significantly reduced pea yields by equal amounts. This occurred even though peas grown in full daylight until commencement of flowering had many more fertile branches and therefore a greater reproductive potential in terms of flowers than those shaded at the commencement of flowering. The reduction in yield with shading coincided with the loss of flowers and pods during the flowering and pod-filling stage. Conversely, when plants where shaded up to the time of flowering (vegetative stage only), the crop was able to compensate and yields approached those of peas grown entirely in full daylight. This was mainly due to a reduced abscission of flowers and pods so that the majority of pods formed on the main stem contributed to final yield.

It is well established that shading at some time from first flowering onwards alters the production and distribution of photosythate within the plant. In subterranean clover for example, shading during flowering (Collins *et al.* 1978) invariably reduced weight per seed, the number of seeds per burr and number of burrs per inflorescence. Sixty one days after the beginning of flowering the number of inflorescences in the cultivar Seaton Park had fallen from 183 to 52 per dm^2 with 70% shading. Seed development was also retarded. Even when shading was imposed 42 days after the beginning of flowering, seed yield was still considerably below the unshaded control (70 g/m^2 compared with 170 g/m^2). Collins *et al.* (1978) argued that a sudden restriction in photosynthate production towards the end of the flowering period, when the number of inflorescences was high but before seed development was very far advanced, was responsible for the reduction in seed yield. Further evidence of alteration in the distribution of assimilates between the vegetative and different components of reproductive organs is seen from the work of Meadley and Milbourn (1971), where shading imposed during flowering reduced the number of peas, and from that of Summerfield *et al.* (1976) where seed weight, seed number and fruit number per plant were reduced by 20 - 30% in cowpea by shading.

Some reports indicate that shading after the start of flowering does not affect individual seed weight although seed yield may be reduced. It is suggested that the seeds are a more powerful sink than other organs when the photosynthate from leaves is limited by shading (Summerfield *et al.* 1976; Gifford and Evans 1981). However, in these circumstances seed number per pod is obviously reduced at the expense of seed weight. For instance, mean seed weight was maintained in subterranean clover cultivars shaded 42 days after the beginning of flowering but the number of seeds per burr was significantly reduced (Collins *et al.* 1978).

Work to date has shown that the major source of assimilate for seed yield is the photosynthate produced during the reproductive period (after the emergence of the first flower), since a reduction in light intensity at this time markedly reduces the final seed yield. In annual medics, it is well established that seed yield is determined by the number of pods per m^2 (Adem 1977; Cocks 1988, 1990a,b) and that the number of pods is reduced by flower and pod abortion (Cocks 1988, 1990a,b). However, whether this is due to the inability of the canopy to supply sufficient photosynthate during the reproductive period has not been investigated. Furthermore, the question as to whether some stages of the reproductive period are more sensitive than others or whether species differ in their response to light intensities has not been reported.

2.3.3. Influence of temperature on plant growth and seed yield

Temperature can increase or decrease the rate of growth and development of pasture swards by speeding up or slowing down particular morphological and physiological processes, mainly through its control of biochemical reactions (Milthorpe and Moorby 1974). However, the optimum temperature for growth and/or development of particular organs depends on the interaction between temperature, other environmental factors and the genetic potential of the plants (Amen 1963).

The influence of temperature on vegetative growth, even within a species, is complex because most growth processes are influenced simultaneously and the effects may be modified by the age and stage of development of the plant as well as other environmental influences. For reproductive growth, temperature affects floral induction, anthesis, pollen germination as well as seed setting, seed development and maturation (Humphreys 1979; Hill 1980). The influence of temperature on seed development mainly occurs by preventing the formation of viable pollen and by causing flower abscission before seed set (Nitsch 1965). This review attempts to analyse some of the major effects of temperature on growth and development of annual forage legumes and some temperate grain legumes.

2.3.3.1. Plant morphology

Temperature can markedly affect the morphology of plants, and thereby influence their ability to adapt to altered temperature conditions or survive in competition with other members of the community (McWilliam 1978). Studies with subterranean clover (Fukai 1974; Fukai and Silsbury 1976) showed that increasing temperature not only brought about increases in the rate of leaf appearance, but also favoured a high death rate in the canopy so that leaf numbers did not accumulate faster at high temperature than at low temperature. Leaf longevity (i.e. the time which a leaf can contribute to the photosynthetic gain of the whole community) was found to be higher at low temperatures (15°C) than at high temperatures (30°C) and was also reduced with plant age. Leaf size and specific leaf area were also responsive to temperature. The optimum temperature for leaf size was 20°C, which was similar to what Mitchell (1956) reported in isolated plants. Specific leaf area, on the other hand, had a higher optimum temperature (25-30°C) than leaf size, suggesting that temperature influenced leaf thickness, cell number per unit area or the cell contents. Low temperatures hasten the production of branches (Fukai and Silsbury 1976; McWilliam 1978) and this is attributed to a high percentage of water-soluble carbohydrate in plants at low temperature (Robson 1972; McWilliam 1978).

2.3.3.2. Canopy growth and dry matter accumulation

The effects of temperature on dry matter production of annual self-regenerating legumes have been examined extensively in controlled environments (Cocks 1973; Fukai 1974; Fukai and Silisbury 1977a,b; Ababneh 1991). For many cultivars, the optimum temperature for both dry matter accumulation and leaf extension growth lies around 20-25°C. Severe limitations to growth below 4.4°C and above 24°C have been reported (Fitzpatrick and Nix 1970). Temperatures below the optimum reduce the rate of germination, emergence, early vegetative growth, and the growth rate of heavily-grazed pastures (Reed and Cocks 1982), whereas most temperate species cease growth in the temperature range of 30-35°C (McWilliam 1978).

The growth of plants in response to temperature depends to some extent on the stage in ontogeny. Young plants tend to have a higher temperature optimum, which declines with age because of the increasing importance of dark respiration (Fukai 1974; Fukai and Silsbury 1977a,b; McWilliam 1978; Ababneh 1991). Also, because of restrictions imposed by other environmental factors, the response of plant communities to temperature differs from the response observed in single plants. This effect of plant density has been demonstrated in *T. subterraneum* (Davidson *et al.* 1970; Cocks 1973; Greenwood *et al.* 1976). Cocks (1973), for example, found that the optimum temperature of swards of Mt. Barker subterranean clover declined from a day/night temperature of 22/17°C at low density (LAI=0.2) to 17/12°C at high density (LAI=5.5). Davidson *et al.* (1970) suggested that once the canopy becomes mature with full light interception, there is no need for further development of leaf area and hence the advantage of high temperature for growth disappears partly due to increased respiratory loss.

Variation in optimum temperature for growth between species has also been reported. Ababneh *et al.* (1989) and Ababneh (1991) studied the effects of three contrasting temperatures (10, 15 and 20°C) on the growth rates of two annual medic cultivars widely used in southern Australia, viz. *M. scutellata* cv. Sava and *M. truncatula* cv Paraggio, and also two annual medic genotypes from the colder areas of west Asia viz. *M. rigidula* sel #716 and *M. rotata* sel #1943. The cold-tolerant genotype *M. rigidula* sel #716 showed the highest growth rate at low temperature and growth rate decreased with an increase in temperature beyond 15°C, while Sava became more productive as the temperature increased from 10°C to 20°C.

Most of this temperature response data has been obtained under controlled-environment conditions. The extent to which these results reflect the actual behaviour of sown pasture communities in the field was studied by Silsbury and Fukai (1977). They concluded that whether subterranean clover swards are grown in controlled environment or in the field, the influence of temperature on growth rate depends on the amount of dry matter present.

2.3.3.3. Canopy photosynthesis

The optimum temperature for canopy net photosynthesis increases with an increase in either CO_2 concentration or irradiance, which suggests that temperature operates primarily through its effect on the biochemical reactions involved in carbon fixation and that these are the important rate-limiting steps under these conditions (Ludlow and Wilson 1971; McWilliam 1978). Under high irradiance and ambient CO_2 concentration, net photosynthesis has a broad temperature optimum, similar, in most respects, to the optimum temperature for the growth of shoots in both temperate and tropical species. This optimum, as for growth, changes with age and stage of development and it may shift according to the plant's previous history (McWilliam 1978).

For most species, the rate of dark respiration increases almost exponentially with increasing temperature, particularly at low temperatures (McWilliam 1978). In *T. subterraneum* communities grown under controlled conditions, Fukai (1974) and Fukai and Silsbury (1977a,b) have shown that the rate of dark respiration per gram of DM increases linearly with increases in growth temperature. As well, when temperature is held constant, respiration increases linearly with increases in plant dry weight. Reduced crop growth rate at high levels of herbage DM is therefore due to higher respiration rate. However, the temperature coefficient of dark respiration (Q_{10}) decreased with higher growth temperatures, from 1.8 at 12°C to 1.5 at 24°C. The high Q_{10} induced by a low growth temperature may be the result of increased carbohydrate accumulation in leaves (Woledge and Jewiss 1969). This implies that plants grown at a low temperature will lose relatively more dry matter through dark respiration when temperatures are suddenly elevated. This situation may arise quite regularly with pasture swards when high temperatures are experienced following a period of cool weather in the field especially during the early spring season.

2.3.3.4. Seed yield

Temperature has an important effect on all stages of reproductive growth, from the initiation of flowers through to the setting of pods and seed growth. The rate of inflorescence development and differentiation is increased by temperature. Taylor and Palmer (1979) subjected *Trifolium subterraneum* cv. Daliak to three temperature treatments from the commencement of flowering and found that the mean time interval between the production of successive inflorescences increased from 3.1 days at 24/19°C day/night to 4.2 days at 18/13°C and 5.4 days at 12/7°C.

High temperature can reduce seed yield both during the early flowering and/or during the seed growth period. In swards of *T. subterraneum* cv. Daliak, Greenwood *et al.* (1976) found that increasing temperature from 5/10°C day/night temperature to 25/20°C day/night temperature after the commencement of flowering stimulated the rate of growth of reproductive structures at the expense of vegetative growth. When temperatures were increased during seed growth, overall rates of growth of the tops, including reproductive plant parts, fell drastically. Although seed yield at maturity was not measured, the authors suggested that high temperatures during the early flowering period can reduce seed yield through reduced vegetative growth, whereas during the later reproductive period reductions in yield could occur through reductions in mean seed weight and number of seeds per burr. Reduction in mean seed weight with increased temperatures were also demonstrated by Taylor and Palmer (1979) who showed that increasing temperature from 12/7° to 24/19°C reduced the mean seed weight.

In narrow-leaved lupin *Lupinus angustifolius* L. Downes and Gladstones (1984a) have shown that temperatures of 21/16°C during the reproductive phase is most suitable for high grain yield. Cooler conditions favoured vegetative growth rather than seed growth, although individual seed weight was greatest at the lowest temperature (15/10°C). Seed yield at temperatures higher than 21/16°C was limited by the failure of the flowers to produce pods and the lack of seed production per pod, despite appreciable total dry matter of the plants at the beginning of flowering. From experiments where *L. angustifolius* was subjected to different temperature and defoliation treatments, Downes and Gladstones (1984b) concluded that at higher temperatures, temperature was more important than low current assimilate in reducing pod set.

The findings were in agreement with those of Lambert and Link (1958) where increasing temperature from 27°C to 29°C and 32°C reduced fresh weight and number of peas (*Pisum sativum* L.). The overall reduction in yield was greater when the treatments were imposed 5 days after bloom. Lambert and Link proposed that high temperatures may have reduced pea yields by causing an increase in respiration, decreasing the concentration of nutrients needed for ovule development, or by reducing translocation of materials into the pods and peas.

This review indicates that temperature affects vegetative growth, pod and seed setting, rate of seed growth and mean seed weight. In general, although a substantial amount of work has been reported on the effects of temperature on floral induction, very little research has been conducted to determine the optimum temperature for higher pod set and seed growth in annual medics.

2.3.4. Influences of soil moisture on plant growth and seed yield

The influence of soil moisture deficit on plant growth and reproduction has been extensively reviewed (Henckel 1964; Slatyer 1967; Kaufmann 1972; Hsiao 1973; Turner and Begg 1978). It is generally accepted that water stress affects reproductive growth through the influence it exerts on plant morphogenesis such as leaf area development, branching, root growth and physiological processes such as stomatal behaviour, photosynthesis, respiration and distribution of assimilates. However, there is no simple and general relationship between soil moisture condition and all aspects of plant functioning. Some plant processes are relatively insensitive to increasing moisture stress over the available range while others are distinctly affected. It is possible that stress at one period of plant growth may 'harden' the plant to stress at a later period, i.e. plants can adjust to a particular moisture regime (Denmead and Shaw 1960).

Plants, especially during the flowering and seed development period, are particularly sensitive to shortage of water in the soil. Slatyer (1974) has divided the general effects of water stress on the reproductive process of plants into three categories: (i) the effects of water stress on floral initiation and inflorescence development when potential fruit number is determined; (ii) the effects on anthesis and fertilisation when the potential yield is fixed, i.e. seed set, and (iii) the effects on fruit maturation during which fruit or seed weight progressively increases. In general the influence of plant water stress on final seed yield is a primary function of the degree and duration of stress, the stage of plant growth when stress is imposed and the species or cultivar involved.

2.3.4.1. Morphological effects of water deficits

The growth and development of a plant depends on continuing cell division, on progressive initiation of primordia and on the differentiation and enlargement of cells, all of which are affected by water stress in some way (Slatyer 1973). Cell division is generally regarded as being less sensitive to water deficits than cell enlargement (Clements 1964; Gates 1964; Slatyer 1967; Hsiao 1973).

Although there are limited data for forage legume species, leaf enlargement in grasses generally shows a marked decrease at values of leaf water potential below -0.4 MPa (Turner and Begg 1978). For example, Ludlow and Ng (1976) showed an 80% reduction in leaf elongation rate of *Panicum maximum* var Trichoglume when the leaf water potential fell from -0.4 to -0.7 MPa, and elongation ceased at -1.0 Mpa. However, as Watts (1974) clearly showed, sensitivity to water deficit depends largely on growth conditions, which influences both the osmotic potential of the tissue and the gradients in potential between the measured and expanding leaf tissue.

One of the most important consequences of the sensitivity of cell enlargement to small water deficit is the marked reduction in leaf area, and the resulting reduction in crop growth rate, particularly when there is incomplete light interception. Water stress can also affect leaf area by reducing branching and by hastening the death of leaves and branches (Turner and Begg 1978).

2.3.4.2. Physiological effects of water deficits.

Water deficit affects most physiological processes associated with the photosynthetic supply in plants through the influence it exerts on stomatal closure (Turner and Begg 1978). It is generally recognised that the stomata do not respond to changes in leaf water potential or in relative water content (RWC) until a critical threshold level is reached, below which stomatal closure occurs over a narrow range of leaf water potential or RWC (Begg and Turner 1976).

The critical leaf water potential for stomatal closure depends on the age of plants, whether the plants were grown in the field or in a controlled environment, the position of the leaf in the canopy and the stress history of the plant. Leaves low in the canopy of dense communities close at a higher leaf water potential than those higher in the canopy (Turner and Begg 1973; Millar and Denmead 1976).

In plants that have undergone several cycles of stress or in which water deficits have developed slowly, the leaf water potential for stomatal closure is lower than in plants quickly dehydrated or with no history of stress (McCree 1974; Turner and Begg 1974). Many of the differences in the leaf water potential for stomatal closure can be accounted for by differences in the osmotic potential or osmotic adjustment of the plants (Turner 1974; Begg and Turner 1976).

Since stomata regulate CO_2 exchange, water deficits that close stomata must also depress photosynthesis. Additionally, the transfer and fixation of CO_2 internal to stomata may be affected by water deficits. The initial reduction in photosynthesis due to an increase in plant moisture stress is generally considered to arise from changes in conductance of CO_2 through the stomata (Slatyer 1973). Consequently, the changes in net photosynthesis with leaf water potential follows that of the stomatal conductance.

Dark respiration appears to be depressed whenever the water deficit is sufficient to close the stomata and decrease photosynthesis, but the relative decrease in the dark respiration is less than that of net photosynthesis. For example, in *P. maximum* var Trichoglume, the rate of dark respiration decreased by 60%, but the photosynthetic rate fell 100% as the leaf water potential decreased from -0.4 to -1.2 MPa (Ludlow and Ng 1976).

Water stress can influence translocation and the distribution of assimilates by affecting the rate of assimilation, the rate of utilisation, the loading and unloading of sieve elements and/or the movement of assimilates in the phloem (Turner and Begg 1978). Assimilates will preferentially move to those tissues/organs that are most rapidly growing and the rate and pattern of distribution will vary with the timing and severity of stress. For example, when *Lolium temulentum* was stressed at the vegetative stage, assimilates moved preferentially to young leaves, sheaths and roots, but when wheat was stressed at the grain filling stage a reduction in photosynthesis resulted in assimilates moving from the lower leaves, stems, roots and crown to the ear (Wardlaw 1967, 1969). Wardlaw (1968) concluded that a reduction in translocation and changes in assimilate distribution under water stress results from a reduction in source or sink activity rather than from any direct effect on the conducting system.

2.3.4.3. Seed yield

The components that determine seed yield have been listed in section 2.1. These parameters are related to the rate of plant growth, plant nutrient uptake, photosynthesis and translocation of assimilates, all of which are directly affected by soil water stress.

Water stress during flowering and seed setting affects seed yield through the influence it exerts on the development of floral primordia into fertile flowers, fertilisation, abortion of fertilised ovaries and fruit abscission (Kaufmann 1972; Slatyer 1974; Hsiao *et al.* 1976). Although the effects of water stress on delaying floral initiation are not common to all plants, available evidence suggests that water deficits reduces the number of flowers produced (Kaufmann 1972). Flower and early fruit abscission are also generally increased and seed or fruit set is often decreased by plant water stress. Whereas it is difficult to separate the effects of temperature and other factors from those of water stress on early fruit abscission, it is generally recognised that fruit abscission results from the interactions of these environmental effects with internal physiological processes such as respiration and carbohydrate supply to the fruit. More specifically, Hsiao *et al.* (1976) have pointed out that if water stress occurs during flowering, it could diminish source intensity (assimilates) by causing stomatal closure and by inhibiting the biochemical steps of CO_2 assimilation. Slatyer (1967, 1973) also states that stomatal closure caused by water stress retards transpiration and increases leaf temperature and may reduce photosynthesis through its effects on CO_2 exchange. Dry conditions, can also directly limit fertilisation through excessive dehydration of pollen or the stigma (Kaufmann 1972).

Both fruit cell division and enlargement appear to be progressively inhibited by water deficits, although cell enlargement generally ceases before cell division (Slatyer 1974). If water stress occurs during seed maturation the effects are concentrated on the source and translocation of assimilates, mainly mineral nutrients and carbohydrates. However, if the period from flowering to fruit maturation is short, water stress may have little effect: alternatively, seed size, viability and dormancy may be seriously affected (Slatyer 1974).

Clarkson and Russell (1976) studied the effects of water stress on the phasic development of five annual *Medicago* species. Four water stress treatments were imposed throughout the growing season by allowing the soil water content to fall to 28% (mild stress), 23% (moderate stress) and 19% (severe stress) before re-watering to the level of the control, which was maintained at soil water content of 49%. The re-watering cycles were repeated continually. The length of the flowering period was significantly reduced in *M. truncatula* and *M. tornata,* as was the time between the appearance of the first flower and the first mature pods in *M. polymorpha, M. littolaris* and *M. truncatula.* Seed set was prevented at the most severe stress and seed yield was reduced in all species. From these observations Clarkson and Russell (1976) suggested that *Medicago* species lack mechanisms for evading adverse seasonal conditions by flowering earlier. However, under the environment of southern Australia, water stress during floral induction and early flower production is unlikely as there is usually adequate rainfall during this period.

Andrews *et al.* (1977) studied the effects of withholding water during flowering on seed production in two cultivars of subterranean clover (*Trifolium subterraneum* L.). Water withheld over the whole of the flowering period reduced yield of viable seed by 80 percent in both Northam A and Geraldton cultivars. Seed yields were 33 g/m^2 and 23 g/m^2 respectively as compared to 133 g/m^2 and 139 g/m^2 for the controls. These treatments also shortened the duration of flowering and lowered individual seed weight in both cultivars. The effects of withholding water for short periods only during flowering varied with cultivar. Although there was no reduction in seed yield when stress was applied towards the end of flowering in Northam A, which has a long duration of flowering, a significant reduction occurred in the cultivar Geraldton which has a short duration of flowering. Reduced seed production in

Geraldton was mainly due to a reduction in the number of inflorescences per unit area in stressed swards, owing to a shorter duration of flowering and a slower rate of inflorescence production. This agreed with the work of (Clarkson and Russell 1976) in annual medics where water stress reduced the duration of flowering. The lower individual seed weight in Northam A and Geraldton was attributed to the reduced growth which could have resulted in a smaller photosynthetic surface, thus further reducing the amount of assimilate available for growth and also to the shorter seed-filling period.

Further evidence on the adverse effects of moisture stress during the flowering and seed development stage on seed yield of subterranean clover cultivars is provided by the work of Collins (1981). Reducing the growing season by three weeks by withholding water supply led to a 50% reduction in seed yield of Seaton Park and Midland B swards, whereas a reduction of five weeks led to more than 75% reduction in seed yield. The reductions in seed yield were ascribed to a reduction in the number of mature burrs produced and to a lesser extent in mean weight per seed.

Wolfe (1985) reported a study in which he imposed four durations of water stress on micro-swards of two subterranean clover cultivars, Northam A and Daglish, and two annual medics, Cyprus and Harbinger. The swards were subjected to water stress 14-35 days after flowering (WE), 28-49 days after flowering (WM), 42-63 days after flowering (WL), or not stressed. Water stress during the later period of seed development (WM and WL) resulted in considerable reductions in seed yield of both medic and clover cultivars. However, when water stress was applied early after the start of flowering (WE), seed yields of medic cultivars were not reduced significantly, whereas clover yields were 40% less than those of the control. The effect of WE was to reduce the number of medic pods produced but these were almost compensated for by the production of more seeds per pod and heavier seeds. From this study and field experience, Wolfe (1985) concluded that annual medics are better than subterranean clovers in withstanding aridity during the reproductive development when moisture stress occurs at flowering (WE) but not during the main period of seed development (WM and WL). Similarly, Amoabin *et al.* (1987) imposed two cycles of soil moisture deficit on swards of *Trifolium subterraneum* cv. Nungarin, *Medicago truncatula* cv. Cyprus and *Medicago* *polymorpha* cv. Serena during the reproductive phase at 94-108 and 116-126 days from sowing. Water deficits, as expected, depressed leaf area, shoot dry weight, number of flowers, burrs and seed yield in Nungarin and Serena relative to the control. However, in Cyprus there was an increase in all these components except shoot dry weights. These increases in flower production and seed yield in Cyprus were unexpected, and in the absence of further investigations it raises the question as to whether different species/cultivars of annual medics differ in their tolerance to moisture stress during the reproductive phase.

In plants of *Lupinus angustifolius* L. cv. Unicrop, which displayed daily short-term wilting for most of the flowering period, Biddiscombe (1975) observed seed yield reductions of 47% as compared to well-watered plants. Reductions in yield were caused entirely by decreased number of seeds and pods per plant as a result of decreased plant size which resulted in fewer flowering nodes and increased flower abortion. Although flower losses were serious, even under favourable moisture conditions, in plants that were subjected to water stress for most of the flowering period, the number of flowers that aborted increased by 15%. However, moisture stress did not affect seed number per pod or weight of individual seeds, as plants displayed some compensatory growth in the surviving flowers and pods, probably assisted by early development of a deep root system (i.e. 150 cm by mid September) which appeared to ramify through the soil and to sustain a considerable leaf area when favourable water supply was resumed. On the contrary, moisture stress during the post-flowering period had a less marked effect, reducing seed yield by only 20% as compared to the control. This was mainly due to a reduction in the number of seeds per plant.

In some forage crops, a short period of moisture stress at flower initiation or at early flower appearance is considered to be beneficial (Humphreys 1979). This is entrenched, for example, in the thinking of ryegrass seed producers in southern Australia, who follow this check to growth by irrigating fully during blooming to accelerate flowering (Humphreys 1979). Research support for this kind of practice is limited to few crops. Taylor (1965) observed that moisture stress during the period of initiation to flowering increased flower numbers in Geraldton and Daliak cultivars of *T. subterraneum* but not in *T. cherleri and T. hirtum.* Similar stresses applied during flowering gave reduced flower numbers and increased seed weights in each cultivar of *T. subterraneum* but in *T. cherleri* and *T. hirtum* the number of flowers and seed weights were reduced. The increased flower production in the cultivars of *T. subterraneum* when moisture stress was applied between initiation and flowering was attributed to reduced leaf canopy which in turn allowed better light penetration into the sward.

Sinha and Singh (1986) reported a field study in which the physiological basis of water requirements at different critical stages (at regeneration, flower initiation, full bloom, seed initiation and advanced seed development) in relation to seed production in Berseem clover (*Trifolium alexandrinum* L.) were investigated. Eight irrigation treatments were made at the various physiological stages. By analysing the relative water content, proline content, photosynthetic pigments in leaves and water-soluble sugar in the reproductive organs, it was observed that irrigation at full bloom enhanced further flowering, efficient functioning of the photosynthetic pigments and the build up of sugar in the reproductive organs, while irrigation at seed initiation favoured the accumulation of substrate (sugars) in seeds of Berseem clover. Irrigation at advanced seed development stage did not appear to be useful to increase seed yield. This agreed with the work of Collins and Quinlivan (1980) with subterranean clover where moisture supply during the final stages of seed development did not increase seed yield.

In general, water stress affects flowering by influencing the inductive process of the leaves, the translocation of floral stimuli and inhibitors, and subsequent differentiation of inflorescences. During the period of flowering, water stress affects the number of fertile flowers, pollen viability and germination, meiosis of the gametes and carbohydrate translocation (e.g. Hsiao *et al.* 1976). During the period of pod and seed development soil moisture supply may influence number and weight of seeds and subsequent seed yield through accumulation of sugars in the seed (Slatyer 1974; Sinha and Singh 1986). Under the environment of southern Australia water stress is more likely to occur during the reproductive phase (September to November) than during the vegetative and flower-initiation phase of annual medics. In determinate annual crops where the reproductive stages are clearly demarcated, there is considerable evidence that seed yield is most sensitive to water deficits from the time of floral initiation and during flowering than during fruit and seed development (Salter and Goode 1967). However, in indeterminate annual forage legumes like medics, where flower production and seed development overlap for a considerable period of time, research information to identify the most sensitive stages is limited. Also, pasture management systems in southern Australia are such that swards are grazed during the winter period and, depending on season or site, swards ranging from sparse to dense can occur during the reproductive period after winter grazing. Research data on the growth of the sward and the efficiency of water use for reproductive growth of different sward canopies in relation to soil moisture stress which may occur at any time during the spring period has not been reported for annual medics. Furthermore, not much work has been reported on the variability between different cultivars/species to water stress during the reproductive phase.

2.4. AGRONOMIC FACTORS

The varieties of herbage grasses and forage legumes currently in use by livestock farmers have been selected specifically for high herbage production and persistence; seed production has been a secondary consideration (Humphreys 1979; Hebblethwaite *et al.* 1980; Crawford *et al.* 1989). In herbage grasses, considerable variation in components of seed yield exists (Griffiths *et al.* 1966) and these components will respond to selection (Bean 1972) resulting in higher yields. However, it has been suggested that selection for the highest possible seed production may incur some reduction in forage-producing potential (Burton and De Vane 1953). In annual self-regenerating forage legumes like medics, where persistence in the pasture phase depends on large hard seed reserves and previous high seed yields, Crawford *et al.* (1989) stressed that selection for high seed yields should be the principal criterion in breeding programmes. Annual medic genotypes differ in the time to first flower (e.g. Crawford *et al.* 1989), number of flowers per raceme and per unit of herbage dry weight (Cocks 1988, 1990a,b; Oram 1990) and the ability to set pods from the flowers produced (Cocks 1988, 1990a,b). Thus, there is considerable genetic variation available for components that together constitute a good seed yield and would be amenable to selection.

However, little attention has been paid to selection for higher seed yields, and this is often reflected in higher seed prices.

Improved seed production is not a major breeding objective in many forage legume programs, therefore increases in seed yields will be largely dependant on identifying those agronomic practices necessary to maximise seed production (Humphreys 1979; Hebblethwaite *et al.* 1980). Sowing rate, sowing time, defoliation or grazing are some of the important farming practices that influence seed yield in herbage crops in the absence of nutritional factors, weed problems, pests and diseases.

2.4.1. Influence of density on plant growth and seed yield

2.4.1.1. Influence of plant density on plant growth

Seedling density is of particular importance during the autumn/winter period as early growth per unit area is directly related to plant numbers. In a self-regenerating medic pasture seedling density is related to the amount of seed in the top 5 cm soil and this amount of seed may vary greatly depending on seed production during the pasture phase, grazing management during the summer/autumn period or tillage practices during the cereal phase of cropping (Carter 1982). A seedling density of 500 plants per m^2 in a regenerating pasture has been recommended in commercial practice by Carter (1982) and Tow (1989). In order to achieve such a seedling density for barrel medic, seed reserves of 200 kg/ha are needed (Carter 1982; Tow 1989), assuming that 10% of the seed reserve is soft seed (Carter 1981). In sown pastures farmers have some control of plant density by basing their sowing rates on percentage pure germinating seed, proper seed-bed preparation, depth and method of sowing in relation to the cost of seed. The recommended sowing rate under such circumstances is 10 to 20 kg/ha. However, even with the smaller-seeded annual medics these sowing rates will give densities of only 200 to 400 plants per m^2 in most sowing conditions.

The effects of plant density on the pattern of growth of annual medics and subterranean clover communities are well established (Donald 1951, 1954; Stern 1965; Adem 1977; Silsbury and Fukai 1977; Silsbury *et al.* 1979; de Koning 1990; Squella 1992). Early winter growth is directly related to density over a wide range of sowing rates, but, except at low density, spring growth is independent of density because of canopy closure. In favourable growing seasons and weed-free conditions even the lowest sowing rates can attain DM final yields similar to those of higher sowing rates (Davidson and Donald 1958; Adem 1977; Silsbury and Fukai 1977). The ability of low-density swards to eventually attain similar yields to that of high-density swards can be attributed to higher growth rates later in the season than for the high-density swards (Donald 1951). Variation in seedling density can thus result in different growth rates initially but a similar final yield of dry matter.

Higher plant densities result in higher growth rates during the winter season because increased leaf area due to plant numbers overcomes the limitations to growth imposed by low solar radiation and temperature (Cocks 1973; Fukai and Silsbury 1977a,b, c; Ababneh 1991). Later in the season, growth rates at higher densities are reduced because of increased respiratory loss caused by higher plant dry weights in comparison to low-density swards. The ways in which light and temperature influences plant growth have been reviewed in sections (2.3.2 and 2.3.3).

Although final dry matter yield may be the same over a wide range of densities, the stage at which competition for growth factors (i.e. light, water, nutrients) begins and its severity varies with density. Donald (1954) examined the growth of subterranean clover (cv. Mt. Barker) over a wide range of densities and showed that individual plants grown at the lowest density (12 plants per m^2) were the largest (31.3 g per plant) and the plants became progressively smaller as density increased, until at the highest density (18,510 plants per m^2) individual plants only weighed 0.04 g. The final DM yields were not significantly different between 269 plants per m^2 and the highest density (18,510 plants per m^2). Racemes per plant, seeds per plant and weight of seed per plant followed similar trends as plant density increased. In addition to reduced individual plant weight at higher plant density, self-thinning also increases as plant density increases and the two mechanisms enable some plants in high-density swards to reach maturity (Yoda *et al.* 1957). Stern (1960) found that for high-density swards of subterranean clover (36 plants per dm^2) the ceiling leaf area index (LAI) was reached 100 days after emergence as compared with 146 days for plants grown at the low density of 4 plants per dm^2. The medium density (16 plants per dm^2) was intermediate and the ceiling LAI was reached at 123 days. He also found that individual plant weight increasingly became a function of density after 34 days, the largest plants being found at the lowest density. The highest LAI and DM at the end of the growing season between the three densities was achieved at the medium density. He attributed the high LAI and DM to the survival of branches and less leaf senescence at the medium density in contrast to the highest density where the number of branches per plant were decreased and leaf senescence was high. Both the studies by Donald (1954) and Stern (1960) showed that high densities greatly reduced the individual plant size, therefore intermediate densities used by both researchers were best in terms of increasing and maximising dry matter production per unit area.

Plant density also interacts with cultivar maturity in determining the early winter growth and hence the stage at which plant competition sets in. Yates (1961); Dear and Loveland (1984) and de Koning (1990) working with cultivars of subterranean clover of differing maturity found that the dry matter production of early-maturing cultivars was higher than that of late-maturing cultivars at lower plant density, but as density increased the differences between cultivars were reduced.

In general, plant density influences the stage at which competition commences between and within species. As density increases, the growth stage at which competition begins will be earlier (Donald (1951). Competition is often for light, usually when other factors such as water and nutrients are abundant (Donald 1954).

2.4.1.2. Influence of plant density on seed yield

The relationship between plant population and yield per unit area has been reviewed for many crops, annual pastures and forage legume species (Holliday 1960; Donald 1963; Wiley and Heath 1969). When yield relates to reproduction such as seed, yield increases with density to an optimum and falls at very high densities.

The optimum plant density for seed production in annual self-regenerating forage legume species appears to be determined through various pathways. In studies with subterranean clover cv. Mt. Barker and annual ryegrass cv. Wimmera, Donald (1954) reported that the optimum density for seed yield is determined by the inter- and intra-plant competition. For example, when subterranean clover was sown at densities of 12, 79, 269, 1931 and 18,510 plants per m^2, seed yield was greatest at intermediate densities (269 and 1931 plants per m^2) and decreased at the highest density. The high seed weights and numbers of seeds per inflorescence at intermediate densities were attributed to differences in the time at which inter- and intra-plant competition became effective. In low density stands many inflorescences per plant are initiated because there is little competition at this stage but this does not compensate for the fewer plants per m^2. At the later stages of seed set, the large numbers of inflorescences suffer from intra-plant competition, resulting in reduced seed yield per head (both numbers of seed and weight per seed are reduced) which gives low yield per plant and this, together with fewer inflorescence per m^2, results in low seed yield per m^2 at low density. At a high density, both inter- and intra-plant competition operate at the time of inflorescence initiation so only a small number per plant are formed. The larger number of plants per m^2 could not compensate for the reduced number of inflorescences per plant resulting in a reduced seed yield per m^2. At moderate density inter-plant competition became operative at the time of inflorescence initiation. The number of floral primordia laid down or developed by each plant is considerably reduced, but this reduced number of inflorescences was within the capacity of the plant to support as interplant competition intensified. The result is a moderate number of heads of good size which gives maximal seed yield per plant. Similarly the moderate number of inflorescences per plant at intermediate density together with the number of plants per m^2 results in a large number of inflorescences per m^2 which gives the highest seed yield per m^2.

Other factors apart from competition may also account for the response of seed yield to plant density. Yates (1961) working with a number of subterranean clover cultivars at densities of 5, 25, 123, 617 and 3086 plants per m^2 at two sites in the Western Australian wheat belt showed the optimum density for seed-set in cultivars with a fairly well developed burr burial habit: early-maturing cultivars produced higher yields at sowing rates higher than late-maturing cultivars because of improved burr burial which increased total seed yield and mean seed weight. The late-maturing cultivars produced less seed irrespective of plant density due to the unfavourable soil moisture conditions for burr penetration at the time of burr development. These findings suggest an alternative to Donald's 1954 proposal of varying degrees of intra- and inter-plant competition as an explanation of his results with Mt Barker subterranean clover, which has an intermediate burial habit.

Cocks (1988, 1990b) working in Syria with annual medics also showed that medic may behave differently to Mt. Barker subterranean clover used by Donald (1954). Cocks demonstrated that a marked reduction in the number of inflorescences per plant as density increased is more than compensated by increased plant numbers per m^2. High-density swards produced the greatest number of flowers per m^2 but seed yields are low mainly because fewer flowers survive to form mature pods. At the optimum density, percentage pod set is high and the number of flowers per m^2 is also moderately high compared to swards at the lower plant density, thereby resulting in the highest seed yields. Changes in mean seed weight and/or number of seeds per pod with increasing sowing rate have also been shown to vary with species rather than density *per se* (Cocks 1988). For example, in *M. rotata* neither mean seed weight nor number of seeds per pod was affected by sowing rate, while in *M. rigidula* mean seed weight was lowest at high density.

The plant density at which the highest seed yield occurs varies with maturity of the genotype. Cocks (1988, 1990b) while conducting a series of studies in north Syria involving several species of *Medicago* at varying plant densities concluded that there were strong interactions between ecotypes and density in both seed yield and number of seed per pod. For example, in a study involving seven species at two sowing rates (10 kg/ha and 200 kg/ha), *M. polymorpha* cv. Tah and *M. truncatula* cv. Jemalong gave high seed yields at high density while *M. noeana* cv. 15845 and *M. rigidula* cultivars yielded more only at low densities. *M. noeana* selection 1938 failed to produce seed at high density. Variation in seed yield at high density was attributed to variation in flowering time. The early-flowering species like *M. polymorpha* cv. Tah and *M. truncatula* cv. Jemalong gave high seed yields at high density because of the greater number of flowers produced and higher flower survival to form mature pods. The late-flowering species yielded more at the lower density because of the reduced percentage pod set at higher density. Flower production was greater at high density suggesting the stress that limited seed yield operated through the survival of flowers to form mature pods rather than through flower production.

The relationship between density and seed production within a cultivar will not always be constant from season to season or location to location. Williams and Vallace (1982) while growing *M. truncatula* cv. Jemalong at different sowing rates (1 to 625 kg/ha) on a sandy loam soil at Walpeup in the Victorian Mallee (with an average annual rainfall of 350 mm) reported increases in dry matter, seed yield or pod numbers up to sowing rates of 16 kg/ha. In Syria at Tel Hadya (annual rainfall of 382 mm) Cocks (1988, 1990b) found the highest seed yields for *M. truncatula* cv. Jemalong to occur at sowing rates in excess of 20 kg/ha. The increases in seed yield at higher sowing rates at Tel Hadya was associated with the production of more flowers and greater percentage pod set. At the lower sowing rates percentage pod set was higher but flower production was low as a result of poor vegetative growth due to frost. In contrast, working with the same cultivar on a red brown soil at the Waite Institute South Australia (average annual rainfall of 600 mm) Adem (1977) observed no significant differences in dry matter production, seed yield or pod numbers with sowing rates which ranged from 1 kg/ha to 1000 kg/ ha. In Adem's study all sowing rates resulted in similar dry matter yields at the end of the flowering period, indicating that yield was not limited by flower production. This was attributed to good rains during the spring period.

The existence of an optimum density for seed production means that this factor is important in the production of higher seed yields in annual medics. This review shows that density influences the stage at which competition begins and its severity. However, the research data on plant density in annual medics has mainly focused on herbage production and final seed yield in Australia. Little attempt has been made to examine the effect of plant density on flower production, pod set and seed development in relation to the Australian environment. Moreover, interactions between plant density and time of sowing, cultivar maturity and the environment in terms of seed yield have not been extensively studied. Most of the studies that have been carried out have been done on undefoliated swards and no specific experiments have been conducted to compare the effect of sowing rate on seed yield in defoliated (or grazed) and undefoliated swards of annual medics despite the fact that grazing during the winter season is a common practice and regeneration of plant densities in excess of the recommended sowing rates is common under favourable seasons. Future investigations should therefore provide detailed data on the interrelationships between seed yield, herbage yield, reproductive growth and environmental conditions in both defoliated/grazed and undefoliated swards in order to gain a better understanding of the factors influencing pod set in annual medics.

2.4.2. Influence of time of sowing on plant growth and seed yield

2.4.2.1. Influence of time of sowing on plant growth

The effects of time of sowing or regeneration on the pattern of growth of annual medics and subterranean clover communities under rainfed conditions has been extensively studied (Poole 1970; Adem 1977; Silsbury and Fukai 1977; Silsbury *et al.* 1979; de Koning 1990). Early establishment results in high dry matter yield and LAI early in the growing season but the final dry matter yields may be similar to that from later establishment as long as sowing is not delayed until very late in the season. For example, Adem (1977) and Silsbury *et al.* (1979) found no difference in final dry matter yield at the Waite Institute, South Australia under rainfed conditions when time of sowing was delayed from April to June, whereas Poole (1970) found a significant difference at Lancelin in Western Australia when time of sowing was delayed from 1 May to 1 July. The similarity in final DM yield between early-sown and late-sown swards at the Waite Institute is attributed to the long wet growing season compared to the studies at Lancelin in Western Australia.

2.4.2.2. Influence of time of sowing on flowering

Time of establishment has a major effect on the number of days to flowering and the effect will vary with species/cultivars. Later establishment usually shortens the period from sowing to flowering because of the early onset of long photoperiod and warmer temperatures (section 2.2.2). The reduction in the number of days from establishment to flowering with delayed sowing is more pronounced in the late-flowering cultivars than in the early-flowering cultivars. This has been demonstrated in *M. polymorpha* var. brevispina where the reduction in time of flowering in a field experiment at Kojonup Western Australia was only 5 days in the early-flowering cultivars when sowing was delayed from 30 April to 6 July but was 40 days in the late-flowering cultivars when sowing was delayed over the same period (Thorn and Laslett 1992). The authors proposed that early-flowering cultivars are less sensitive to high temperature and/or long photoperiod than the late-flowering cultivars.

2.4.2.3. Influence of time of sowing on seed yield

The effects of environmental stresses on the seed yield of annual self-regenerating legumes is largely due to the stage of development at which stress occurs. Matching the phasic development of the seed crop to seasonal conditions so that stress at critical times is minimised is an important strategy for improving yields. Time of sowing in relation to environmental conditions influences seed yield through inflorescence initiation, number of flowers per unit area, percentage of the initiated flowers that form pods, number of seeds per pod and mean seed weight.

Studies on time of sowing in annual medics and subterranean clover have generally shown that late sowing results in low seed yields. At Lancelin, Western Australia, Poole (1970) working with three *Medicago* species (*M. truncatula* cv. Jemalong (barrel medic), *M. littoralis* cv. Harbinger and *M. tornata* cv. Tornafield), observed a steady decline in top growth, pod and seed yield in all species when sowing was delayed from May 1 to July 10. The author argued that the decline was possibly due to moisture stress during the reproductive phase in the late-sown treatments.

In northern Syria, a comparison of native genotypes and cultivars of *Medicago* species from Australia sown at different rates and times (31 October=early and 6 December=late), Cocks (1988) found that seed yield of the late-sown plots was on the average, less than 40% of the early-sown plots. Native species that were early flowering produced more seed than the late-flowering genotypes or cultivars from Australia. The increase in seed yield in the native and early-flowering cultivars was due to a greater production of flowers early in the season (before April) which were more likely to give mature pods than late-produced flowers.

Tagging flowers at 7 day intervals from first flower appearance showed that in *M. rigidula* (native but early-flowering) and *M. noeana* (native but late-flowering) pod setting was higher in flowers appearing soon after flowering commenced than for those flowers appearing later. In contrast, pod setting in *M. truncatula* cv. Jemalong (Australian cultivar) was low irrespective of when flowers appeared. The very low pod set and seed yield of Circle Valley and Jemalong (Australian cultivars) was attributed to frost and the disease (*Phoma medicaginis* Malbr. & Roum) respectively. The effects of time of sowing on the seed yield components varied with cultivar. For example, with late sowing, seeds of *M. rigidula* and *M. polymorpha* cv. Circle Valley were heavier but the number of seeds per pod were fewer, whereas mean seed weight and number per pod in *M. rotata* were not affected by time of sowing. These results demonstrate that time of sowing interacts with cultivar maturity and environment in determining pod set and seed yield components.

Further evidence on the interaction between cultivar maturity and time of sowing is provided by the studies at Kojonup in Western Australia by Thorn and Laslett (1992) who reported significant reductions in annual medic seed yield when sowing was delayed from 30 April to 6 July and by sowing late-maturing cultivars. Similar trends have been reported for subterranean clover cultivars (Quinlivan *et al.* 1973, 1974; Dear and Loveland 1984). From the studies of Poole (1970); Cocks (1988) and Thorn and Laslett (1992) it can be postulated that in dryland farming where the reproductive period is limited by adverse environmental conditions a combination of early sowing and use of early-flowering cultivars will increase seed yield in ungrazed swards of annual medics.

This review shows that time of sowing interacts with environmental conditions and cultivar maturity to influence pod and seed production in annual forage legumes. Most of the reported work on annual medics has dwelt on the effects of time of sowing on flowering time and final pod and seed yield. Little research work has been done to understand the effects of time of sowing on flower production, pod set, seed development and the interrelationships with the environmental conditions in southern Australia. Furthermore, because of the variation in the time of sowing or regeneration under dryland farming, an understanding of the relationship between time of sowing, cultivar maturity and defoliation/grazing is vital in order to maximise seed production.

2.4.3. Influence of defoliation on plant growth and seed yield

The effects of defoliation on plant growth and seed production is usually characterised by its frequency and severity, its timing in relation to developmental stages or environmental conditions, and the species or cultivar being defoliated. Humphreys (1979), and Humphreys and Riveros (1986) categorised these effects on pasture seed production in terms of:

(i) altered patterns of apical dominance which influence the rates of leaf and inflorescence differentiation,

(ii) removal of bud sites and inflorescence,

(iii) variation in assimilate supply to inflorescence due to altered leaf area,

(iv) shifts in the duration and timing of flowering and

(v) secondary effects in mixed swards which change the balance of plant competitive relations.

It is difficult to generalise on the importance of these effects on seed yield for all species/cultivars or environments. Therefore, to develop defoliation management strategies directed at maximising commercial seed production or dual use of crops for seed and forage, local experience is necessary.

2.4.3.1. Restoration of leaf surface after defoliation

The rate of restoration of the leaf area after defoliation depends on the carbohydrate reserve of the plant and the residual leaf area (Ward and Blaser 1961; Davidson and Milthorpe 1966; Humpreys and Robinson 1966). The extent to which residual leaf area influences regrowth after defoliation depends on the amount of leaf area left, their photosynthetic capacity, the density of the leaves which are still capable of expansion, the density of buds present and their further expansion and differentiation. The proportion of young leaves and growing points left after defoliation depends on the growth habit, severity of defoliation, age and density of the sward. In prostrate plants like subterranean clover young swards will recover much faster than older swards because a lower percentage of photosynthetic material is removed in young swards (Brown and Blaser 1968; Davidson and Birch 1972).

The photosynthetic capacity of the residual leaves reflects the light environment in which they have developed. Leaves formed in the lower levels of the sward have a higher specific leaf area,but this advantage is offset by a lowered photosynthetic capacity (Ludlow and Wilson 1971). The mature, shade-adapted leaves in the lower levels of the sward usually have a low photosynthetic capacity for some time (Ludlow and Wilson 1971; Wolf and Blaser 1972; Ludlow and Charles-Edwards 1980) and this retards regrowth in comparison to young leaves.

2.4.3.2. Influence of defoliation on flowering

The effects of defoliation on flowering or flower re-appearance is well documented in subterranean clover but not in annual medics. Collins and Aitken (1970) while studying the effects of leaf removal on flowering time of subterranean clover (*Trifolium subterraneum*) reported that removal of fully expanded leaves before floral initiation delayed the flowering time of the cultivar Mt. Barker sown at Melbourne by up to 30 days, mainly by reducing the rate of leaf appearance. Similarly with cv. Woogenellup, Hagon (1973) found that defoliation prior to floral initiation (FI) delayed FI although the time from sowing to flowering was not altered compared with the undefoliated control. However, defoliation after FI advanced flowering by 10 days. This was attributed to the 20-30% increase in rate of leaf appearance between FI and flowering which was in agreement with the results reported earlier by Rossiter (1972). The most likely explanation for these increases is that once leaf area index (LAI) values above the optimum level (which ranges from 3 to 4) has been reached, defoliation stimulates leaf production because of greater light penetration into the canopy (Davidson and Donald 1958). On the contrary, Collins (1978) found that the time of commencement of flowering in swards of Seaton Park, Yarloop and Midland B subterranean clover defoliated at weekly intervals from 1 month after emergence until the onset of flowering, was little affected despite a delay in flower initiation. He attributed the absence of delay in flowering to the lower severity of his defoliation treatment, since the basal height of 1.5 - 2 cm used did not result in the removal of all expanded leaves as compared to the severe cutting treatments used by Collins and Aitken (1970) where defoliation before FI delayed flowering in a sward of Mt. Barker. These studies support the idea that the stimulus necessary for floral initiation is first produced in the leaves and then translocated to the shoot apex. These also show that the effects of any defoliation on the flowering of a sward will depend not only on whether the time of FI is changed but also on how the LAI is altered in relation to the optimum for a particular environment.

2.4.3.3. Influence of defoliation on seed yield

The effects of defoliation on seed production of pastures will vary with severity, frequency, time of final defoliation, the species or cultivar being defoliated and the environmental conditions after defoliation. Seed production may be increased by removing apical dominance, increasing branch density, providing more sites for inflorescence development and allowing better light penetration and hence photosynthetic supply. Seed production may also be decreased by poor vegetative growth following poor rains after defoliation and/or removal of inflorescences if defoliation is done late in the flowering period.

Frequent defoliation prior to the commencement of flowering has been reported to enhance seed production in subterranean clover cvv. Seaton Park, Yarloop and Midland B (Collins 1978, 1981; Collins *et al.*, 1983). For example, Collins (1978) observed that defoliation at weekly intervals prior to commencement of flowering increased seed yield by at least 30% compared with the uncut control. This effect was attributed partly to increased inflorescence numbers and partly to increases in other yield components as a consequence of the burial of a large proportion of burrs. When cutting was continued until midway through flowering (with cutting height progressively raised) the seed yield in Yarloop and especially in Midland B was much lower than that obtained when cutting was stopped at the beginning of flowering; in Seaton Park there was no reduction. With further cutting until the end of flowering, seed yields were less than when cutting was stopped midway through flowering. However, there was a significant Cultivar x Defoliation interaction with respect to seed yield in the experiment which evidently arose primarily because cultivars reacted differently when cutting was continued beyond the onset of flowering.

Collins (1978) suggested that the frequent removal of leaves through cutting during flowering undoubtedly restricted the amount of assimilate available for seed production. In Yarloop and Midland B this was reflected in reductions in the number of mature burrs formed (as a consequence of a reduction in the number of inflorescences produced), number of seeds per burr and weight per seed. In contrast with Yarloop and Midland B cultivars, Seaton Park appeared to be less responsive to defoliation during flowering. Further work by Collins *et al.* (1983) with Seaton Park demonstrated that the weight of leaves per unit area present at the end of flowering was highly and positively correlated with final seed yield, indicating that seed yield reductions with late defoliations were related to the photosynthetic surface after defoliation. The fact that the seed yield increased when defoliation was done prior to commencement of flowering, shows that the LAI increased to optimum after cutting.

The effects of infrequent defoliation (cutting at intervals of 3 weeks or more) on seed production in subterranean clover cultivars has similarly been investigated by some research workers (Rossiter 1961; Scott 1971; Hagon 1973; Walton 1975): however, it is difficult to draw any general conclusions from these studies. Rossiter (1961) found that swards of two cultivars (cvv. Yarloop and Dwalganup) responded similarly to infrequent defoliation: cutting prior to flowering increased the seed yield compared with uncut controls (largely because of an increase in the number of inflorescences produced), while with further cutting during flowering the seed yield was decreased. Scott (1971), using six cultivars of subterranean clover showed that the effects of defoliation on seed production varied markedly between cultivars, ranging from a large increase to a decrease in seed yield. In two other studies (Hagon 1973; Walton 1975) found that infrequent cutting up to early flowering had no effect on seed production.

Reports on the effects of defoliation on seed production of annual *Medicago* species are fewer. In a field trial at the Waite Institute, South Australia (Carter *et al.* 1988 and Carter 1989) demonstrated that hay making involving a single mowing at early flowering reduced seed yield in a mixed stand of medic cultivars from 1469 to 784 kg/ha but had little effect on seed yield of subterranean clover cultivars. Among the medic cultivars, the reduction in seed yield was much more pronounced in *M. scutellata* cv. Sava and *M. polymorpha* cv. Serena than in *M. truncatula* cvv. Jemalong and Paraggio and *M. rugosa* cv. Sapo (Carter 1989). The variation in seed yield among the medic cultivars following a single hay cut could be attributed to the growth habit and flowering time since all cultivars were sown at the same time, and mowing was done at the start of flowering of the late-flowering cultivars (cvv. Jemalong and Paraggio). The seed yield reduction in Serena was possibly due to flower removal as a result of being early flowering, whereas the reduction in Sava was probably both due to flower removal and poor recovery because it is early flowering and erect growth in habit.

In another experiment at Roseworthy College, Tow and Al Alkailah (1981) examined the effects of five cutting heights (Uncut control, 1 cm, 2 cm, 5 cm and 8 cm) at early flowering on flower and seed production of *M. truncatula* cv. Jemalong. Their results demonstrated that the number of inflorescences removed increased with intensity of cutting, and pod and seed yields were similar in the Uncut, 5 cm and 8 cm treatments but significantly more than in treatments cut to 1 cm and 2 cm. Cutting at 1 cm and 2 cm resulted in seed yields which were 67 per cent lower than in the Uncut control. The fact that pod and seed yields were not reduced significantly by cutting to 5 cm at early flowering led them to suggest that lenient grazing could continue during early flowering without a significant loss of seed yield. However, since annual *Medicago* species vary in growth habit from prostrate to erect types, more research is warranted in terms of height and frequency of defoliation and stage of final defoliation and the relationship between leaf dry weights and final seed yield on a range of species and cultivars if more precise recommendations are to be developed.

Mowing and other forms of cutting are rapid and non-selective, while grazing animals selectively remove herbage: not only is there selection between which plants to consume, but also between plant parts (leaves in preference to stems, green herbage in preference to dry). Even the type of grazing animal has some influence. For example, sheep graze close to the ground while cattle graze further from the ground. The grazing animal not only removes foliage, but can indiscriminately damage the pasture by treading, causing poaching and pugging (Carter and Sivalingham 1977).

In grazed pastures in Mediterranean-type environments there is a complex soil-plant-animal interrelationship. Pasture yield and botanical composition can be greatly modified by grazing pressure and as a result legume seed production is also affected (Carter 1968a,b, 1977, 1987, 1990b). For example, at low stocking rates seed yields can be reduced because of suppression of annual forage legumes by weeds whereas, at higher stocking rates, seed yield can be low because of poor recovery of the sward. Even in a pure annual forage legume sward, species and cultivars differ in their response to grazing during the reproductive phase in terms of seed yield. De Koning and Carter (1987) in a study involving five cultivars of subterranean clover (Yarloop, Trikkala, Clare, Mt.Barker and Larisa) grazed during spring at three stocking densities (Low, Medium and High) observed that cultivars differed in their response to grazing in terms of seed yield. Early-maturing cultivars with an erect growth habit (Yarloop and Clare) suffered more from heavy grazing and treading when soils were waterlogged and hence resulted in reduced seed yield compared with the other, later-maturing cultivars. Similarly, Taylor and Rossiter (1974) found that the proportion of rose clover (*Trifolium hirtum*. All) that set seed in a mixture with subterranean clover declined in grazed pastures compared with ungrazed pastures, partly because the erect seed heads of rose clover were readily grazed. Working with a range of annual legumes Bolland (1987) similarly reported that imposing a moderate grazing pressure had no effect on seed production of some species (e.g. *T. globosum* L.) as compared with ungrazed swards, but reduced seed production of other species (e.g. *T. balansae*. Boiss) by up to 50 per cent.

The period of grazing in relation to the reproductive phase and the grazing pressure on the pure legume sward determines to a large extent whether grazing will be beneficial for seed production in annual forage legumes. Working with seven *Medicago* species comprising seventeen cultivars and two species of *Trifolium subterraneum* at Katanning in Western Australia, Thorn and Revell (1987) found that severe grazing at 16 sheep/ha from 33 days after sowing to the start of flowering reduced dry matter yield from an average of 7.0 t/ha to 3.6 t/ha and seed yield from 582 to 362 kg/ha in all medic cultivars. Continuous grazing beyond flowering reduced dry matter yield and seed yield by more than 75%. Similarly, at Esperance in Western Australia (average annual rainfall 500 mm with 130 mm during the reproductive period), Bolland (1987) found reductions in seed yield of about 30% in cultivars of *M. truncatula* and *M. littoralis* when the swards were continuously grazed at 4 sheep/ha up to approximately three weeks after flowering. Thorn (1989) after reviewing management aspects in annual legume pastures, pointed out that the reductions in seed yield in annual medic pastures grazed up to the start of flowering is associated with poor recovery of swards.

In contrast to the reductions in seed yield observed in annual medics, in a two year study in Western Oregon (USA) with Mt Barker subterranean clover using four grazing practices (Ungrazed, Early grazed, Late grazed and Extended grazing at constant stocking rates of 5 and 7.5 ewes/ha, Steiner and Grabe (1986) observed that extended grazing applied from before flowering until early burr formation increased seed yields over the ungrazed control by 51 and 27 per cent (234 and 223 kg/ha) in 1979 and 1980 respectively. Two grazing treatments of a shorter duration during this period were not as effective in increasing seed yields. The increase in seed yield was attributed to the fact that grazing modified the pasture canopy by removing the established leaves not associated with reproduction. This in turn allowed the leaves, which subtend the reproductive structures to receive more light and hence provide a majority of the photosynthate used by the inflorescence for seed development. Grazing prior to the initiation of flowers did not have the advantage of removing the leaves not associated with reproduction when flowering occurred. The other point that was found to `be beneficial was that grazing from just prior to the start of flowering until the time of early burr fill allowed the plant to enter the period of limited moisture with less canopy material to maintain at the expense of seed development.

This review indicates that defoliation or grazing increases seed yield in some circumstances in subterranean clover and that the increase is through the provision of more sites for inflorescence production and increased photosynthetic supply to the developing reproductive structures due to alteration in the leaf area. On the contrary, the literature available for annual medics does not show that defoliation or grazing can increase seed yield. The fact that annual medics are adapted to drier areas and have a more erect growth habit than most of the subterranean clover cultivars suggests the need for repeated studies on a wide range of cultivars with varying defoliation or grazing frequencies, severity and timing of final defoliation or closure from grazing in order to predict the importance of this strategy in commercial seed production instead of relying on the research findings in subterranean clover. From the review it can be noted that no detailed analysis of the importance of vegetative growth after defoliation, reproductive development and how the two processes interact with environment, has been undertaken. Future research should be directed at understanding the growth characteristics of a range of annual medic species/cultivars when subjected to defoliation/grazing in relation to the environmental conditions during the spring period. Similarly, because of the indeterminate growth habit, attempts should be made to understand the relationship between herbage production and flower production, light transmission and pod set as well as determining whether there is a critical stage for the establishment of a large photosynthetic system so as to limit flower and pod abortion. Also, because moisture stress in dryland farming can occur at any time during the reproductive period, studies are needed to define the vegetative growth that is capable of minimising plant water stress yet maximising seed yields.

2.5. CONCLUDING REMARKS

This review shows that seed yield in annual self-regenerating legumes is dependent on the number of inflorescences produced and the proportion that develop into mature pods. The fact that seed yield is poorly related to mean seed weight indicates that factors limiting high seed yields don't operate during seed maturation, but during the vegetative, flowering and seed-setting phase. Most of the research work reported in southern Australia has concentrated on the final seed yield and only limited work has been done to understand the factors influencing flower production, anthesis, pollination, fertilisation and seed development. For any crop to produce high seed yield, a high percentage of the florets formed must undergo anthesis, be effectively fertilised and develop into seed. Recent work at ICARDA in Syria (Cocks 1988, 1990a,b) has shown that annual medics do not attain their seed yield potential due to the high loss of reproductive structures (flowers and young pods), which can be as great as 95% in some species. The extent to which seed yield in the annual medic cultivars currently grown by farmers in South Australia is limited by the survival of flowers to form mature pods has not been reported.

Grazing and defoliation studies show that reductions in seed yield are associated with reduced dry matter production (Thorn 1989). In contrast, plant density studies show that dense swards produce the greatest number of flowers but seed yield is limited by the survival of flowers to form mature pods within a cultivar (Cocks 1988, 1990b). These studies suggest that there could be a relationship between herbage production and seed production. However, there is no detailed data available on the sensitivity of pod set in annual medics to different levels of vegetative growth at various phenological stages, nor has the mechanisms that determine pod set been adequately investigated.

It has been shown that the supply of water during the reproductive period, controls the yields to be obtained and that inconsistency in yield between seasons and sites is because of the variability in seasonal rainfall (amount and duration during the spring period). Detailed studies to modify the detrimental effects of drought by the use of early flowering cultivars or early sowing to increase the proportion of pod set before moisture stress occurs are limited. Furthermore, most of the studies on moisture stress reported in annual medics have either been conducted on undefoliated or defoliated swards up to the start of flowering. Grazing studies with subterranean clover in Oregon (USA) indicated that dense vegetative growth increases the rate of soil moisture depletion and consequently intensifies water stress for burr set and seed development (Steiner and Grabe 1986). It appears that an understanding of the interacting effects of vegetative growth and moisture stress on the reproductive growth of annual medics in dryland farming may be important for devising management strategies that can minimise moisture stress in different seasons and locations.

In view of this background information this thesis describes a series of studies which were conducted with the aim of:

(i) quantifying the effects of environmental characteristics on flower production and flower and pod retention;

(ii) examining the sensitivity of flower production and flower/pod retention to stress-induced reductions in crop growth rates at different phenological stages;

(iii) examining the influence of defoliation as a management strategy to minimise stress-induced reductions in seed yield; and

(iv) examining the causes of genetic variability in seed yield among the cultivars currently grown by farmers and their sensitivity to defoliation in commercial seed production.

CHAPTER 3

EXPERIMENT 1: EFFECTS OF SOWING DATE AND SOWING RATE ON HERBAGE AND SEED PRODUCTION OF TWO CULTIVARS OF *MEDICAGO TRUNCATULA*

3.1. INTRODUCTION

Two agronomic practices that can greatly affect seed yields in medics are time of sowing and sowing rate (see Review of Literature sections 2.4.1 and 2.4.2). Both of these influence the herbage (DM) production of swards and the growth stage at which competition begins, while sowing time also determines the timing of important phenological stages of development in relation to environmental factors. The importance of DM production and phenology to grain yield in winter cereals is generally well understood (e.g. Fischer and Wood 1979) but such understanding in medics is lacking possibly because of the greater emphasis hitherto placed on herbage production.

An understanding of the relationship between DM production and flower production, pod set and seed development in annual medics may assist in developing management strategies that can minimise stress at critical stages of growth and so improve yields. To further these aims an experiment was undertaken with specific objectives to:

(i) examine canopy development of medics in response to sowing date, density and cultivar;

(ii) examine the effects of herbage DM production on flower production, percentage pod set, also pod and seed growth; and

(iii) relate the response of flower production, percentage pod set, pod and seed growth to environmental conditions at different phenological stages and to the length of the vegetative and reproductive period.

3.2. MATERIALS AND METHODS

3.2.1. Location

The experiment was conducted at the Waite Agricultural Research Institute, Glen Osmond near Adelaide, South Australia (Latitude 34° 58' S, Longitude 138° 38' E, Altitude 122.5 m). Rainfall, temperature and solar radiation for the year, together with the long-term averages are shown in Table 3.1. The soil type is a hard-setting, red-brown earth (Urrbrae loam). The mechanical analysis of the soil reveals a rather silty clay loam with 57% silt, 32.5% clay and 10.0% sand at a depth of 0-15 cm (Williams 1981). The soil pH (in water) is 6.5 in the top layers but becomes alkaline with depth. The land used for the experiment had been under oat/vetch mixture the previous year and barley the year before.

3.2.2. Treatments

Two cultivars of *Medicago truncatula* cvv. Parabinga (early flowering) and Paraggio (late flowering) were sown on two occasions in 1989, 27 May (early sowing) and 27 June (late sowing). Each cultivar was sown at 1, 5, 25, 125, 625 kg/ha (based on pure germinating seed) to generate different canopies during the growing season. These sowing rates represent the range likely to be found under field conditions. The two highest sowing rates simulate the soft seed in the best regenerating medic stands, whereas 5 and 25 kg/ha represent common farm soft seed reserves. The lowest sowing rate (1 kg/ha) represents very poor seed reserves (Carter 1982) following a cropping sequence, especially where seed production in the previous pasture phase was poor and/or where grazing during the summer/autumn period was severe (Carter 1987; Carter *et al.* 1989).

3.2.3. Experimental design

The experimental design was a split plot, randomized complete block with four replicates. Each replicate was split into an early-and late-sown half (main plots). The two cultivars at five sowing rates (i.e. 10 treatments) were randomised within the subplots of each main plot. The main plot measured 10 m x 10 m and each subplot was 2 m x 5 m. A distance of 2 m was kept between replicates and also between main plots (Plan 3.1).

Plan 3.1: Field layout for Experiment 1

EXP. 1: EFFECT OF SOWING DATES AND SOWING DENSITY ON HERBAGE AND SEED PRODUCTION OF TWO CULTIVARS OF *MEDICAGO TRUNCATULA*

FIELD LAYOUT: Split plot design, using sowing dates as main plots. Cultivars and sowing rates forms subplots.

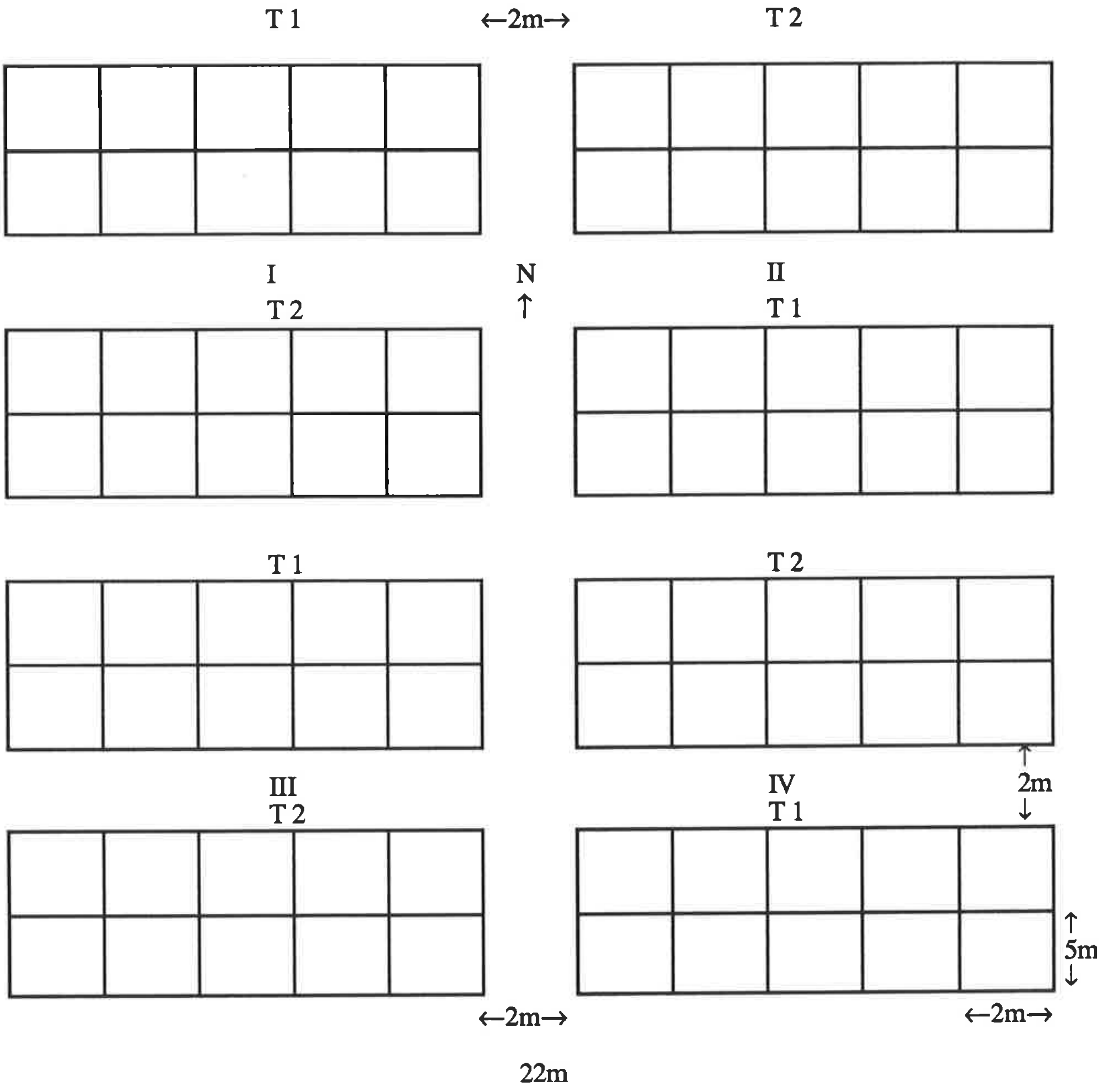


Table 3.1. Rainfall, solar radiation and temperature data for the Waite Agricultural Research Institute.

Month	Mean rainfall (mm)		Solar radiation (MJ/month)	Temperature (°C)			
	1989	1925-89	1989	1989			1925 - 89
				Max.	Min.	Mean	Mean
Jan	2.6	23.4	25.9	27.6	17.5	22.5	22.1
Feb	1.6	24.3	25.1	29.0	17.4	23.2	22.1
Mar	2.8	23.8	15.4	26.8	18.3	22.5	20.6
Apr	54.0	54.9	12.6	22.2	14.0	18.1	17.3
May	97.0	80.3	7.9	18.3	11.7	15.0	14.3
Jun	104.8	74.6	5.7	13.5	7.6	10.5	11.9
Jul	87.0	87.9	6.7	13.7	7.3	10.5	11.0
Aug	88.8	74.8	9.4	13.8	7.3	10.5	11.7
Sep	51.8	61.9	15.2	17.9	9.9	13.9	13.5
Oct	38.2	52.6	17.5	19.6	10.8	15.2	15.6
Nov	33.8	36.9	21.0	25.0	14.3	19.6	18.1
Dec	13.4	29.2	25.2	27.1	16.4	21.8	20.3
Total	**575.8**	**625.3**					

3.2.4. Seedbed preparation and sowing

The experimental field was cultivated twice with a rotary hoe and harrowed once prior to sowing. To control weeds the herbicide trifluralin was sprayed at a rate of 2 L/ha and incorporated into the soil by scarifier two weeks prior to sowing.

Certified commercial medic seeds that contained a range of seed sizes were used. The average seed weight for Parabinga was 3.9 mg and for Paraggio was 4.0 mg. Seed was weighed out, based on pure germinating seed/plot, wet-inoculated with a peat culture of *Rhizobium meliloti*, allowed to dry and broadcast on each plot. At the time of sowing the inoculated seed was mixed thoroughly with slightly moistened sand and 9 kgP/ha (as single superphosphate), 52 kgK/ha (as potassium chloride) and 7 kgN/ha (as urea). The plots were lightly raked before hand broadcasting. The soil surface was again raked after sowing to ensure good coverage of the seed.

3.2.5. Data collection

Plant counts and vegetative growth harvests. The early-sown plots were sampled for plant number and dry matter production 7 times and the late-sown ones 6 times throughout the growing season . The first harvest and plant counts were made 19 days after emergence of the early-sown plots. The second harvest and plant counts were made for both early-sown and late-sown plots 19 days after emergence of the second sowing date. Subsequent harvests were made approximately every 28 days as shown in Table 3.2. The final harvest included the seed harvest and plant numbers were not determined.

Fifteen galvanised wire quadrats (25 x 40 cm) were arranged on each plot shortly after emergence to mark the boundaries of harvest areas. On the first two harvest occasions samples were taken at random beside the pre-arranged quadrats. On each subsequent harvest occasion two quadrats were taken per plot, one from the northern and the other from the southern half of each plot (Plan 3.1).

In the early stages of growth all plants in a quadrat from the sowing rates of 1, 5 and 25 kg/ha were counted directly in the field. At the 125 and 625 kg/ha sowing rates 10 core samples forming a total area of 88 cm^2 were taken beside the quadrats and seedlings within the cores counted at each harvest. Later, as plants at low sowing rates started spreading out of the quadrat and plant densities decreased at higher sowing rates, the swards within each quadrat was cut first, following the shape of the quadrat. The plants within the quadrat were then cut just below ground level so that plants in the harvested sample could be counted. It was assumed that as much sward grows out of the quadrat as grows into the quadrat. The herbage samples were put in plastic bags and stored in a cold room (5°C) until processing. At the three lowest densities all plants in the quadrat were counted, whereas for the two highest densities a sub-sample of 100 plants was removed from the centre of the harvested material, dried and used to calculate the total number of plants from dry weight ratios. After counting, the herbage was sub-sampled to determine leaf dry matter, stem dry matter, leaf area index (LAI) and flower/pod weight during the reproductive period. LAI was determined using an electronic planimeter. The remaining sample was dried at 85°C for 24 hours and weighed.

Table 3.2. Number of harvests, days from emergence and dates for determining plant numbers and herbage yields

Harvest number	Days from emergence		Date of harvest
	Early sowing	Late sowing	
1	19	-	19 Jun
2	47	19	17 Jul
3	75	47	14 Aug
4	103	75	11 Sep
5	131	103	9 Oct
6	159	131	9 Nov
7	187	159	7 Dec

Transmission of PAR. The amount of incident light transmitted through the canopy to the ground was calculated from Saeki (1960) using the relationship:

$$I = I_0 \exp(-k L) \qquad (1)$$

where I is transmitted incident light, I_0 is incident light above the canopy, L is LAI at each harvest and k is the light transmission coefficient. In order to calculate the value of k, measurements of I_0 and I were made on 10 plots using a Licor light meter (sensitive to incident light flux intensity). At the time of the measurements the swards were intercepting about 90% of incident light. The measurements were made on a clear day on 10 October at about midday. From the data, k was found to be approximately 0.9 which was similar to that reported by Davidson and Phillip (1958) in subterranean clover swards. The percentage of incident light transmitted through the sward (I/I_0) at each harvest was calculated using equation (1) and converted to photosynthetically-active radiation (PAR) by multiplying with 0.45 (Monteith 1977; Howell *et al.* 1983).

Radiation use efficiency. The cumulative incident PAR between harvests was calculated by multiplying the cumulative daily solar radiation measurements from the nearby meteorological station at the Waite Institute by 0.45 (Monteith 1977; Howell *et al.* 1983). The cumulative PAR intercepted by the canopy was calculated by multiplying the percentage PAR intercepted at each harvest (equation (1)) by the cumulative incident PAR. Linear regression equations of total shoot dry weight (starting from Harvest 2) on cumulative intercepted PAR were calculated. The slope of each line represents the radiation use efficiency (RUE).

Soil moisture. Gravimetric water content of the soil was estimated for each sowing date, density and cultivar two weeks after the start of flowering (21 September for early sowing and 6 October for late sowing) and towards the end of flowering (23 October). Two soil samples to depths of 0 - 30 cm and 30 - 60 cm were taken from each plot with a Jarret auger which had a diameter of about 82 mm. The soil was sealed in polythene bags and taken to the laboratory where representative soil sub-samples were taken and sealed in tins, weighed, oven-dried in open tins at 105°C for approximately 24 hours and re-weighed. The moisture contents were calculated as a percentage of the weight of oven dried soil using the following formula:

$$\text{Percent soil moisture (\%)} = \frac{\text{wet soil weight - dry soil weight}}{\text{dry soil weight}} \times 100$$

Reproductive growth. The start of flowering was defined as the time when approximately 10% of the plants had flowered in each plot. In the early-sown treatments, Parabinga flowered on 1 September and Paraggio on 6 September 1989, whereas in late-sown treatments Parabinga flowered on 15 September and Paraggio on 19 September 1989.

The number of racemes (which also infers number of reproductive nodes in *Medicago truncatula* since only one raceme is produced per flowering node) were counted from 5 randomly-selected plants in each treatment on three occasions. The areas from where the plants were taken were marked by pegs to avoid herbage or seed harvest from the same spot. The number of flowers per raceme was also estimated by counting the number of flowers on 20 randomly-selected racemes on the three occasions. There were generally two flowers per raceme and the number did not vary with either sowing rate or the time at which they were counted. The total number of flowers was estimated by multiplying the total number of racemes by the number of flowers per raceme, which was two. Percentage pod set was calculated by dividing mature pod numbers by the estimated maximum number of flowers, expressed as a percentage.

The number of branches was counted at the time of peak flowering (10 October) from the samples used to estimate the number of racemes. Only branches that were more than 10 cm long were counted.

Seed harvesting and threshing. Seed was harvested between 5 and 7 December 1989. A metal bar quadrat of 0.25 x 1 m was used to define the sample area. Two random samples were taken from the north and another two from the south of each plot in areas where herbage harvests had not been taken. Dry pasture residues, which included some pods, was removed from the quadrats by hand whereas pods that had fallen on the ground were collected with a vacuum cleaner (Plate 3.1).

In the laboratory, pods were separated from the dry pasture residues. The straw and dead leaves recovered from vacuumed material were oven dried at 40°C for 24 hours and weighed. All pods were cleaned in Genclean (1,1,1 trichloroethane) to remove soil particles (Carter *et al.* 1977). Pods were then air dried and any other material present was carefully removed. Before weighing, these pods were oven dried at 40°C for 24 hours.

Pods from the southern part of the plot were threshed through a medic/subclover seed thresher, pod husks recovered after threshing and small particles that escaped machine threshing were then hand threshed to ensure that all seed was recovered. The threshed material was then carefully separated to obtain clean seed.

Yield components measured from the seed harvest were: harvest index (HI), number of pods (#/m^2), total seed yield (kg/ha), number of seeds per pod, individual seed weight (mg/seed), seed:pod ratio (%) and individual pod weight (mg/pod).

Plate 3.1: Experiment 1: Harvesting medic pods.

Upper: Removing dry herbage residues from a $0.25m^2$ quadrat.

Lower: Collecting pods with a vacuum cleaner.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3.2.6. Data analysis

Analyses of variance were conducted at each harvest on all the data parameters using GENSTAT V. Natural logarithm transformations were made where necessary.

3.3 RESULTS

3.3.1 Plant density

Establishment was generally better after late sowing (Table 3.3) because the soil was more moist at the time of sowing. The differences between cultivars in number of plants were not significant for most of the growing season, whereas early sowing date significantly reduced the number of plants per m^2 for most of the growing season (Fig. 3.1). The greatest decline was after Harvest 3 (Fig. 3.1) and was more severe with early than late sowing. A decline in plant numbers with increasing sowing rate occurred throughout the growing season at 125 and 625 kg/ha sowing rates but was fairly stable at 1 and 5 kg/ha sowing rate (Fig. 3.2). At 25 kg/ha a decline in plant numbers occurred after Harvest 4 (Fig. 3.5). The growth stage at which the greatest decline in plant numbers occurred corresponded to an LAI above 4 or over 90% light interception (Figs. 3.4, 3.5). As expected, the results show that the greatest self-thinning depended on plants numbers in the higher sowing rates and the stage at which intense inter-plant competition for light occurred at lower sowing rates.

3.3.2. Phenological development

As sowing was delayed from 27 May to 27 June, the average time from sowing to beginning of flowering decreased by nearly two weeks. The duration of reproductive growth (flowering to maturity) was similarly reduced with late sowing by two weeks because of adverse environmental conditions at the end of the season. The later-flowering cultivar Paraggio, flowered 6 days later than Parabinga when sown early, and 4 days later when sown late.

Table 3.3. Effects of sowing date, cultivar and sowing rate on the expected and actual plant numbers at emergence.

Cultivar	Sowing rate (kg/ha)	Expected plants/m^2	Actual plants/m^2		
			Early sowing	Late sowing	Mean
Parabinga	1	26	20	20	20
	5	130	67	100	83
	25	651	394	478	437
	125	3255	3265	3608	3437
	625	16275	15548	13563	14556
Paraggio	1	25	14	15	15
	5	125	67	105	86
	25	625	386	465	426
	125	3125	3038	3565	3302
	625	15625	16484	11990	14237

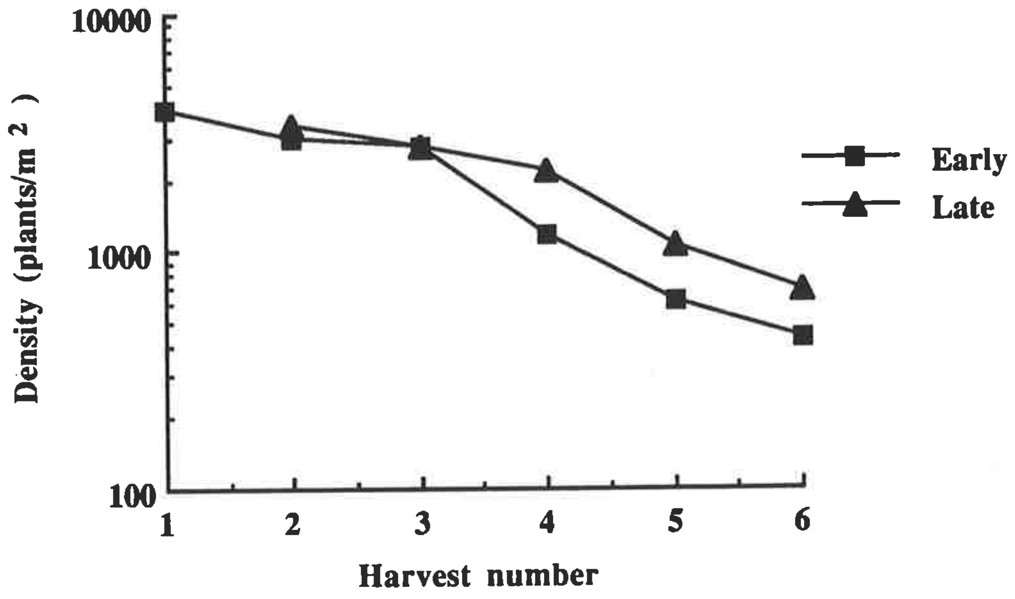


Fig. 3.1. Effects of sowing date on plant density of barrel medic during the growing season. (Each point is the mean of five sowing rates and two cultivars)

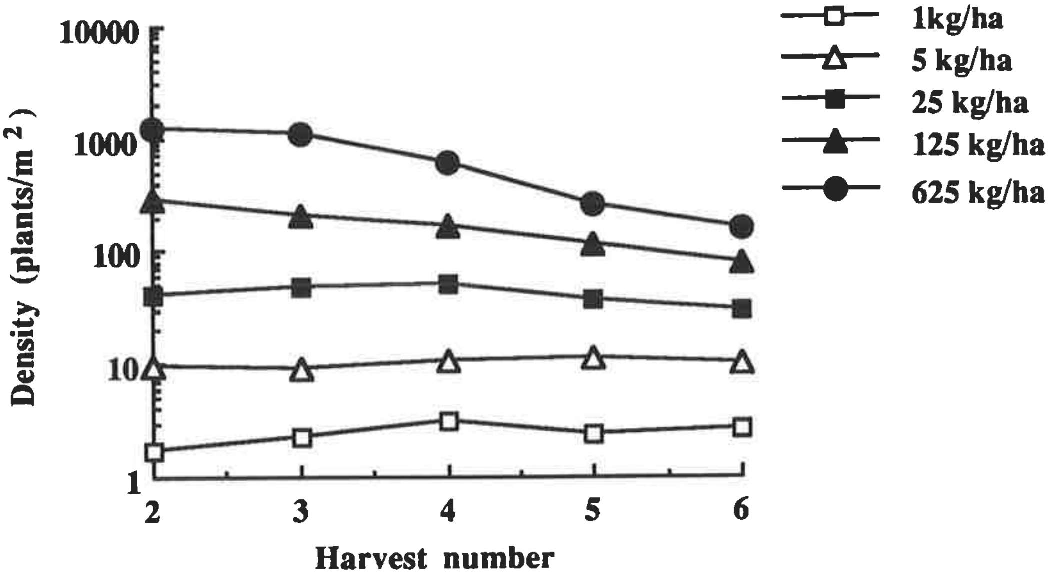


Fig. 3.2. Effects of sowing rate on plant density of barrel medic during the growing season. (Each point is the mean of two sowing dates and two cultivars)

3.3.3. Total herbage production

The summary of the main effects of Sowing date, Cultivar, Sowing rate and their interactions on total shoot dry weight (DM) is shown in Table 3.4.

Early sowing and the use of an early-flowering cultivar increased winter DM (Harvests 1-3) but had no significant main effects on spring DM production (Fig. 3.3, Table 3.4). Sowing rate effects were highly significant throughout the season (Table 3.4). The growth stage at which rapid increase in herbage production occurred was earliest at higher sowing rates than at lower sowing rates due to differences in plant density (Figs. 3.2, 3.3). There was a significant Sowing date x Sowing rate interaction early in the season (Table 3.4). At 125 and 625 kg/ha a rapid increase in DM occurred before the start of flowering for both sowing dates. At 25 kg/ha a rapid increase in DM occurred at the start of flowering when sown early but before the start of flowering when sown late, while at 1 to 5 kg/ha this occurred after the start of flowering when sown early but at the start of flowering when sown late (Fig. 3.3).

The growth stage at which the maximum crop growth rate occurred was earliest with higher sowing rates and delayed sowing; the highest maximum growth rate was 19 g/m^2/day at 5 and 25 kg/ha sowing rate. By the end of the flowering herbage yields were generally highest at the 5 and 25 kg/ha sowing rates and lowest at 1 kg/ha (Table 3.19 , Fig. 3.3). There were significant differences between 25 and 125 kg/ha sowing rates (Table 3.19). The results suggest that although the stage of rapid increase in herbage production is earlier at higher sowing rates, swards with plant density between 80 and 3,000 per m^2 at emergence (Table 3.3) are likely to achieve final DM yields that are higher than those with plants above 3000 per m^2 (Tables 3.3, 3.19).

3.3.4. Leaf area index

Leaf area index (LAI) was affected mainly by sowing rate; both sowing date and cultivar had significant effects at only a few harvests (Table 3.5). Early leaf area production was mainly enhanced by early sowing and high sowing rates but the main effects of sowing date disappeared before the start of flowering. When swards were sown at 125 and 625 kg/ha, LAI increased rapidly from day 20 until a value of 4 (complete light interception) was reached before the start of flowering (day 75 from emergence). As sowing rate was reduced, early development of leaf area was also reduced and the time to reach an LAI of 4 was greater and occurred shortly after the start of flowering at 25 kg/ha and towards the end of flowering at 5 kg/ha (Fig. 3.4). Swards sown at 1 kg/ha did not attain LAI of 4 throughout the season. LAI declined after attaining a maximum value of about 6, slowly in the case of 1 kg/ha sowing rate and rapidly in the 125 to 625 kg/ha sowing rates.

The earlier rapid increase in LAI and the shorter time taken to attain maximum LAI at higher sowing rates was mainly due to higher numbers of plants per m^2 (Fig. 3.2) which in turn improved the amount of solar radiation intercepted (Fig. 3.5) thereby accelerating the rate of growth (Fig. 3.3).

Table 3.4. Summary of ANOVA of DM yields from two cultivars of barrel medic sown on two dates and at five sowing rates.

Source of variation	Harvest 1 (19 Jun)	Harvest 2 (17 Jul)	Harvest 3 (14 Aug)	Harvest 4 (11 Sep)	Harvest 5 (9 Oct)	Harvest 6 (9 Nov)	Harvest 7 (7 Dec)
Sowing date	NA	***	*	NS	NS	NS	NS
Cultivar	*	NS	*	NS	NS	NS	NS
Sowing rate	***	***	***	***	***	***	***
Sowing date x Cultivar	NA	NS	NS	NS	NS	NS	NS
Sowing date x Sowing rate	NA	***	***	***	NS	NS	NS
Cultivar x Sowing rate	NS	NS	NS	NS	*	NS	NS
Sowing date x Cultivar x Sowing rate	NA	NS	NS	*	NS	NS	NS

NA Not applicable NS Not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Harvests 1 and 2. Analysis of variance performed on log-transformed data

Harvest 1, represents only early-sown data

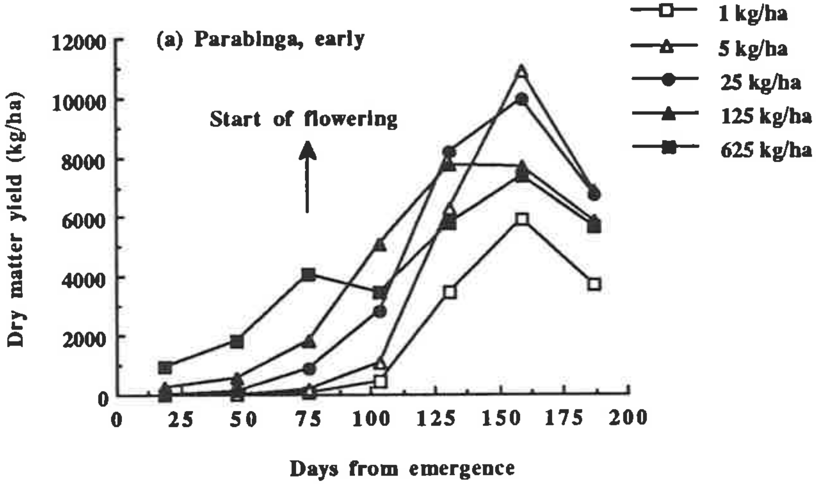
Harvest 7, represents DM at maturity (seed harvest)

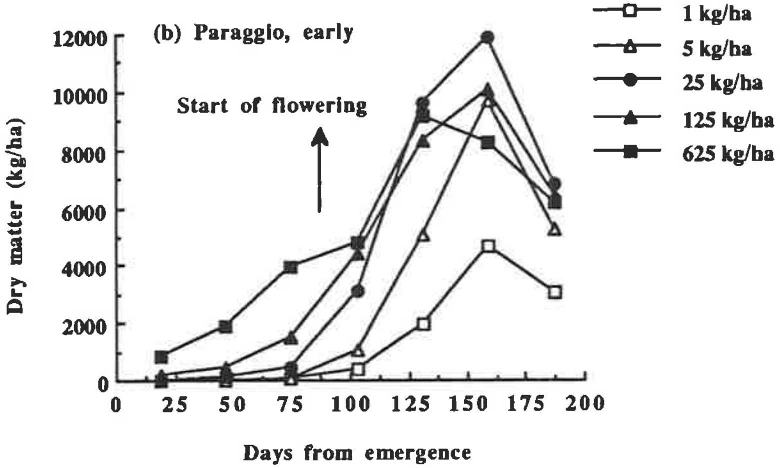
Table 3.5. Summary of ANOVA of LAI data from two cultivars of barrel medic sown on two dates and at five sowing rates.

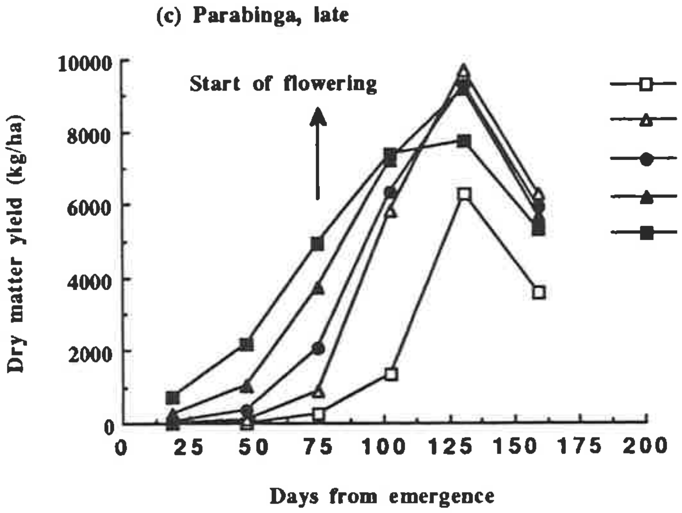
Source of variation	Harvest 1 19 June	Harvest 2 17 Jul	Harvest 3 14 Aug	Harvest 4 11 Sep	Harvest 5 9 Oct	Harvest 6 9 Nov
Sowing date	NA	***	*	NS	NS	NS
Cultivar	NS	NS	***	*	NS	NS
Sowing rate	***	***	***	***	***	***
Sowing date x Cultivar	NA	NS	*	NS	*	NS
Sowing date x Sowing rate	NA	***	***	**	NS	NS
Cultivar x Sowing rate	NS	NS	NS	NS	*	NS
Sowing date x Cultivar x Sowing rate	NA	NS	NS	NS	*	NS

NA Not applicable; NS Not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Fig. 3.3. Effects of sowing rate on dry matter yield of (a) Parabinga, early sown (b) Paraggio, early sown (c) Parabinga, late sown and (d) Paraggio,late sown


(a) Parabinga, early


(b) Paraggio, early


(c) Parabinga, late

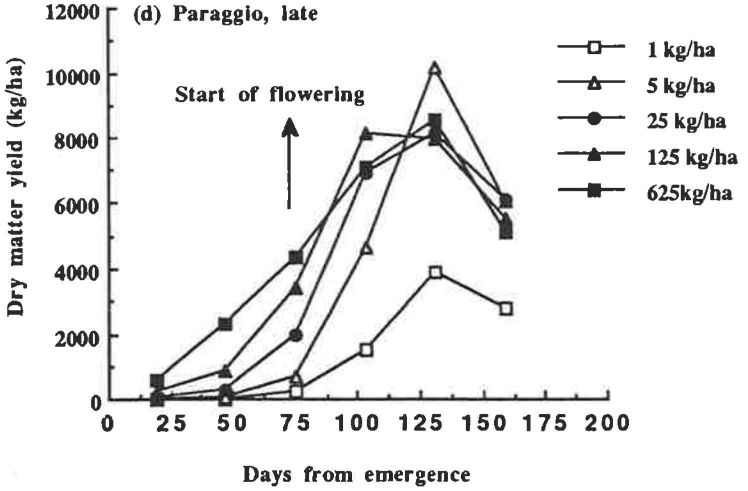
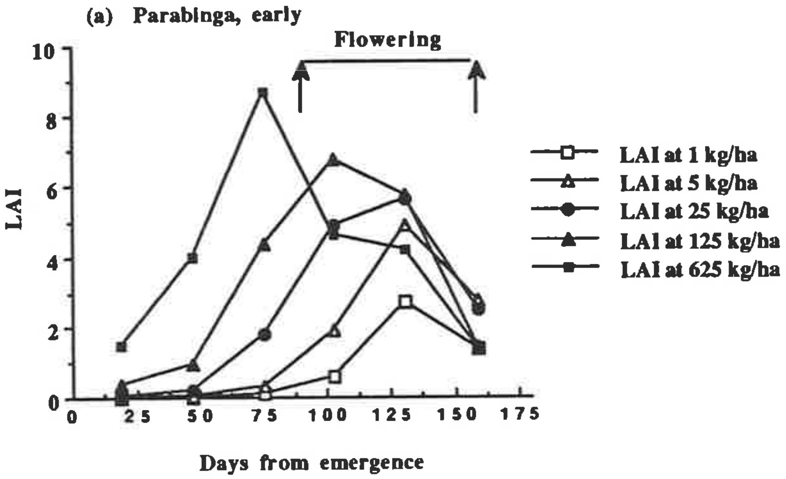
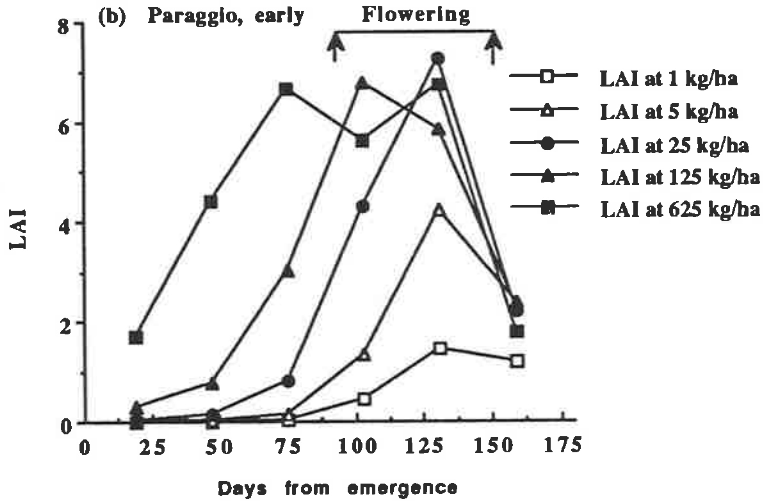
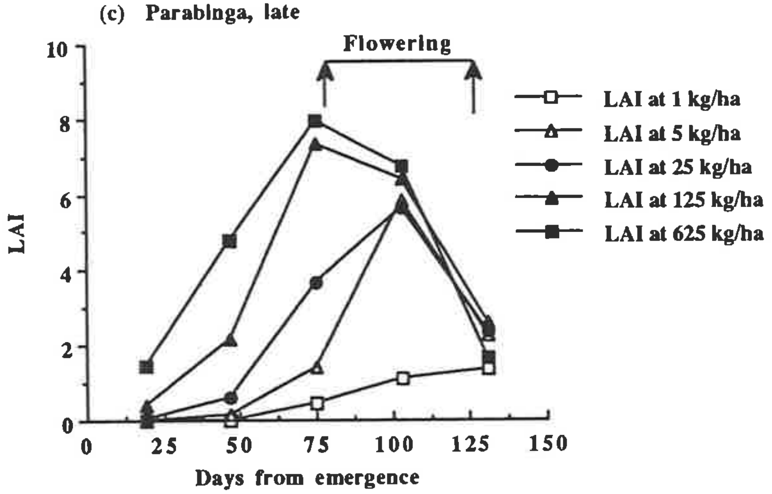

(d) Paraggio, late

Fig. 3.4. Effects of sowing rate on LAI of (a) Parabinga, early sown (b) Paraggio, early sown (c) Parabinga, late sown and (d) Paraggio, late sown


(a) Parabinga, early
Flowering
10
8
6
4
2
0
LAI
0
25
50
75
100
125
150
175
Days from emergence
LAI at 1 kg/ha
LAI at 5 kg/ha
LAI at 25 kg/ha
LAI at 125 kg/ha
LAI at 625 kg/ha


(b) Paraggio, early
Flowering
8
6
4
2
0
LAI
0
25
50
75
100
125
150
175
Days from emergence
LAI at 1 kg/ha
LAI at 5 kg/ha
LAI at 25 kg/ha
LAI at 125 kg/ha
LAI at 625 kg/ha


(c) Parabinga, late
Flowering
10
8
6
4
2
0
LAI
0
25
50
75
100
125
150
Days from emergence
LAI at 1 kg/ha
LAI at 5 kg/ha
LAI at 25 kg/ha
LAI at 125 kg/ha
LAI at 625 kg/ha

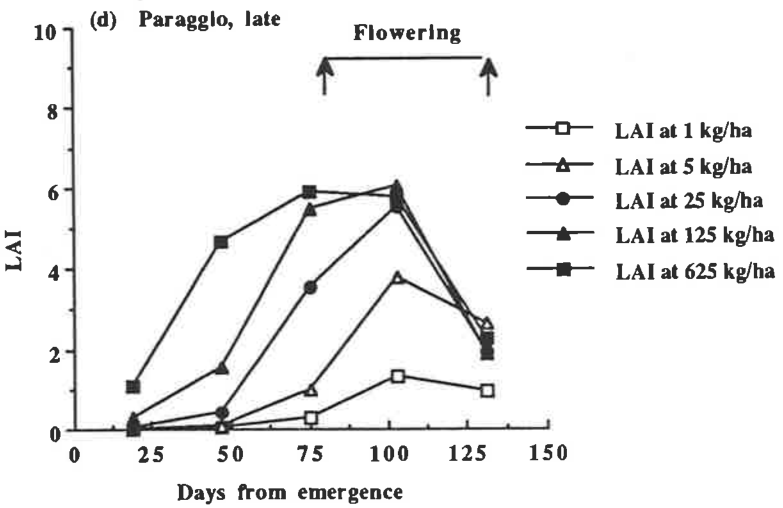
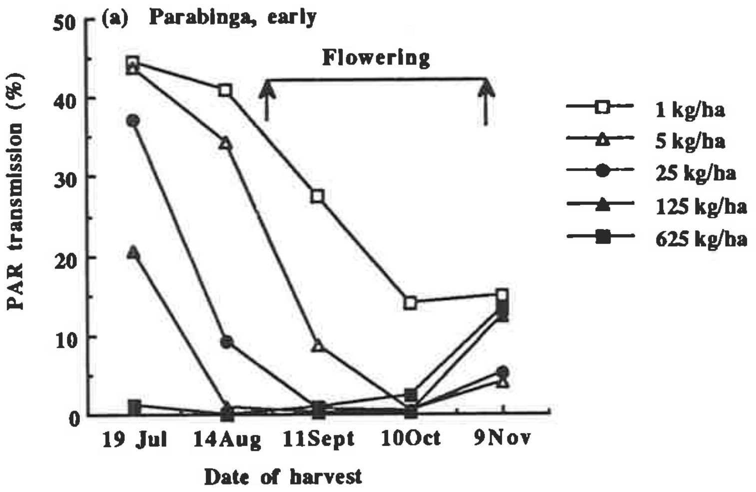
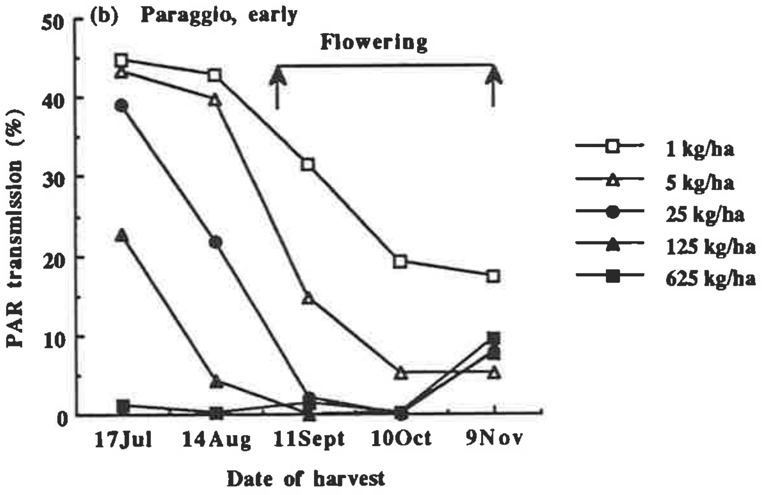
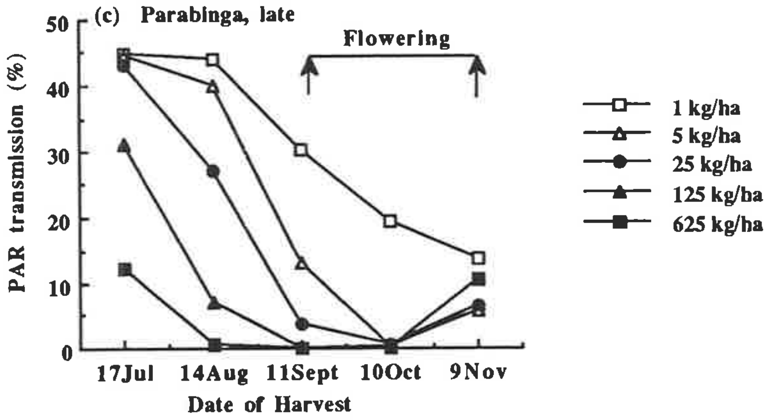
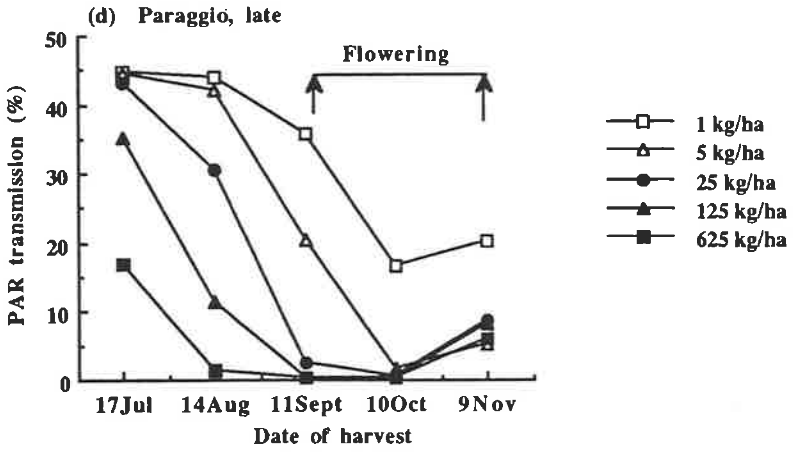

(d) Paraggio, late
Flowering
10
8
6
4
2
0
LAI
0
25
50
75
100
125
150
Days from emergence
LAI at 1 kg/ha
LAI at 5 kg/ha
LAI at 25 kg/ha
LAI at 125 kg/ha
LAI at 625 kg/ha

Fig. 3.5. Effects of sowing rate on PAR transmission (a) Parabinga, early sown (b) Paraggio, early sown (c) Parabinga, late sown and (d) Paraggio, late sown


(a) Parabinga, early
Flowering
PAR transmission (%)
0
10
20
30
40
50
19 Jul
14Aug
11Sept
10Oct
9Nov
Date of harvest
1 kg/ha
5 kg/ha
25 kg/ha
125 kg/ha
625 kg/ha


(b) Paraggio, early
Flowering
PAR transmission (%)
0
10
20
30
40
50
17Jul
14Aug
11Sept
10Oct
9Nov
Date of harvest
1 kg/ha
5 kg/ha
25 kg/ha
125 kg/ha
625 kg/ha


(c) Parabinga, late
Flowering
PAR transmission (%)
0
10
20
30
40
50
17Jul
14Aug
11Sept
10Oct
9Nov
Date of Harvest
1 kg/ha
5 kg/ha
25 kg/ha
125 kg/ha
625 kg/ha


(d) Paraggio, late
Flowering
PAR transmission (%)
0
10
20
30
40
50
17Jul
14Aug
11Sept
10Oct
9Nov
Date of harvest
1 kg/ha
5 kg/ha
25 kg/ha
125 kg/ha
625 kg/ha

3.3.5. PAR transmission.

The time when less than 1% of PAR was transmitted through the swards coincided with an LAI of above 4 (Fig. 3.5) and followed the same trends as those described for LAI. Although the present results do not provide a means of assessing the average level of PAR received from the apex of the sward to the base, they clearly demonstrate that there is a close relationship between sowing rate and the stage of growth at which complete self-shading occurs at ground level. At higher sowing rates, complete self-shading occurred prior to the start of flowering whereas at 5 and 25 kg/ha this shading occurred at various stages after the start of the flowering (Fig. 3.5).

3.3.6. Radiation use efficiency

The total medic dry matter accumulated was strongly correlated with the amount of PAR which the foliage intercepted (Fig. 3.6). The RUE was not significantly different between sowing dates (mean for the two sowing dates 3.10 g/MJ) or between cultivars (mean for the two cultivars 3.15 g/MJ), but was significantly reduced at a sowing rate of 1 kg/ha (Fig. 3.6). As sowing rate increased from 1 kg/ha to 5 kg/ha the RUE almost doubled (1.69 g/MJ to 3.10 g/MJ), but further increases in sowing rate did not increase RUE significantly (Fig. 3.6).

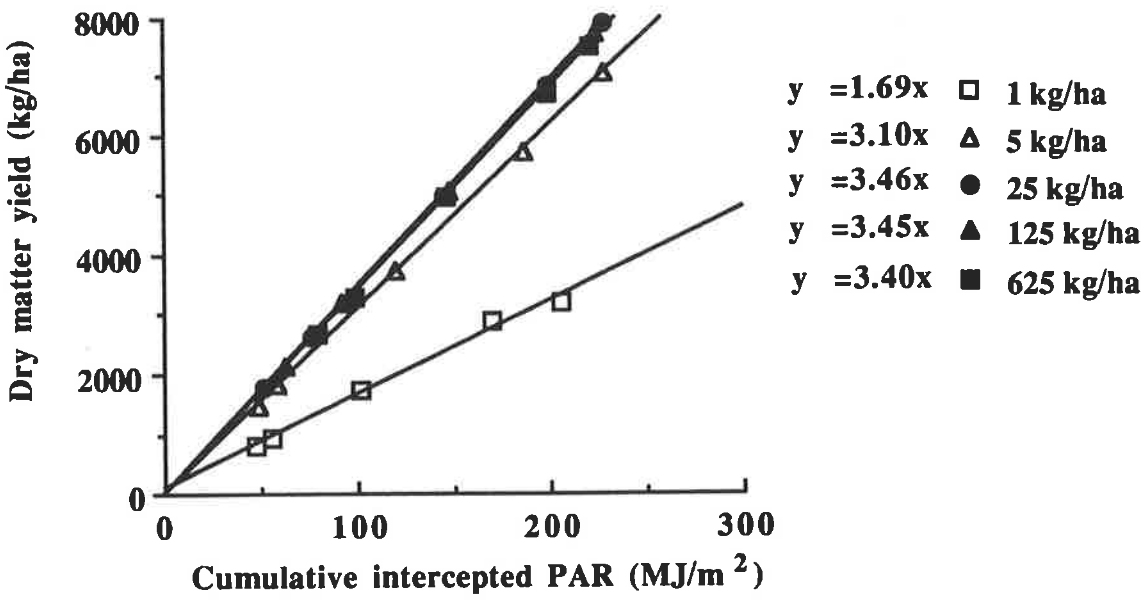


Fig 3.6. Relationship between dry matter production and cumulative intercepted PAR for sowing rates (means of two sowing dates and two cultivars)

3.3.7. Soil moisture content

There was no significant difference in the soil moisture content between the areas sown to the two cultivars. Late-sown swards started flowering when the mean soil moisture content (0-60 cm depth) was lower (13.6%) in comparison to early-sown swards (16.8%). The mean soil moisture content was generally higher under swards sown at 1 kg/ha than those sown at 25 to 625 kg/ha (Table 3.6). The results suggest that differences in soil moisture content above 1 kg/ha sowing rate were small during the reproductive period. The soil moisture content declined during the flowering period, more so on the 1 kg/ha plots, so that at the end of flowering there was no significant difference in the mean soil moisture content between sowing rates and sowing dates (Table 3.6).

Table 3.6. **The effects of different sowing rates on soil moisture content of the area sown to Paraggio barrel medic swards during the 1989 flowering period**

Sowing rate (kg/ha)	Mean soil moisture percentage at 0 - 60 cm		
	Early flowering		End of flowering[c]
	Early sowing[a]	Late sowing[b]	
1	18.4	16.7	11.4
25	16.4	13.4	10.3
125	16.0	12.4	9.3
625	16.6	11.9	10.5
LSD(P<0.05)	1.2	1.8	N.S

[a]Soil sampling - 21 Sep; [b]Soil sampling - 6 Oct;

[c]Sampling for soil moisture content was done on same date and the data represents means of two sowing dates

3.3.8. Number of branches

Sowing rate had a bigger influence on branches per plant and branches per m^2 than did sowing date and cultivar (Table 3.7). The number of branches per plant significantly declined as plant density increased (Table 3.8). The reduction at 25 kg/ha and to some extent at 125 kg/ha sowing rates were attributable to fewer branches initiated or that survived in the lower nodes of insertion, since branching was observed in the upper part of the canopy. Early sowing resulted in significantly more branches per plant (5.0) than late sowing (3.9). Both cultivars produced similar numbers of branches per plant.

The number of branches per m^2 was increased only at 625 kg/ha (Table 3.8). However, branches shorter than 10 cm were not counted, and therefore the number of branches could have been underestimated between the 5 and 125 kg/ha sowing rates. The significant Sowing date x Cultivar interaction was due to low mean number of branches in the early-sown Parabinga (Table 3.9). Severe lodging was observed during early spring (30 August) in the 125 to 625 kg/ha sowing rates when early sown and was greater in the early-maturing cultivar. The interaction observed here could be attributed to the death of some branches as a result of this. In general, the results suggest that a lower sowing rate compensates for the lower number of plants per unit area by vigorous branching, and a longer growing season favours branching per plant in comparison to a shorter growing season.

Table 3.7. Summary of ANOVA of the effects of sowing date, cultivar and sowing rate on the number of branches in barrel medic

Source of variation	Number of branches (#/plant)	(#/m^2)
Sowing date	*	NS
Cultivar	NS	NS
Sowing rate	***	**
Sowing date x Cultivar	NS	*
Sowing date x Sowing rate	NS	NS
Cultivar x Sowing rate	NS	NS
Sowing date x Cultivar x Sowing rate	NS	NS

NS Not significant; * $P<0.05$; **$P<0.01$; ***$P<0.001$

Table 3.8. Effects of sowing rate on the number of branches in barrel medic. (Data represent means of two sowing dates and two cultivars)

Sowing rate (kg/ha)[a]	Number of branches	
	(#/plant)[b]	(#/m^2)
5	11.24 (2.393)	1127
25	3.84 (1.326)	1134
125	1.74 (0.498)	1314
625	1.04 (0.021)	1608
LSD ($P<0.05$)	0.153	326

[a] Data was not collected at 1 kg/ha because of the smaller number of plants per plot

[b] Data in parantheses were transformed to logarithms.

Table 3.9. Effects of sowing date and cultivar on the number of branches per m^2 in barrel medic. (Data represent means of four sowing rates)

Sowing date	Cultivar Parabinga (#/m^2)	 Paraggio (#/m^2)
Early	900	1317
Late	1531	1436
LSD ($P<0.05$)	326	

3.3.9. Flower production and percentage pod set

Flower production. Table 3.10 summarizes ANOVA on the effects of sowing date, cultivar, sowing rate and their interactions on flower production and pod set. As with other yield components, sowing rate had the greatest and most consistent effect on flower production and percentage pod set. Flower production and percentage pod set were assessed at sowing rates of 5 to 625 kg/ha. Generally the maximum number of flowers was recorded on 10 October (Table 3.11). The greatest number of flowers was produced in the early-sown treatments but the differences were only significant during the early part of flowering (Table 3.11). Parabinga produced more flowers (13000/m^2) than Paraggio (9000/m^2) early in the season because of its earlier flowering habit, but as the season progressed the differences became non-significant. During peak flowering (10 October) and towards the end of flowering (18 October), there was a Sowing date x Cultivar interaction due to delayed sowing reducing the number of flowers in the late-flowering cultivar but not in the early-flowering cultivar (Table 3.12). Trends in flower production with sowing rates were similar throughout the flowering period. The highest number of flowers occurred at 625 kg/ha sowing rate and no significant differences were observed between 5 and 125 kg/ha sowing rates (Table 3.13).

Percentage pod set. The highest proportion of flowers that survived to form mature pods occurred at the 5 kg/ha and 25 kg/ha sowing rates, in contrast to flower production which was highest at 625 kg/ha (Table 3.13). Percentage pod set at the 125 kg/ha sowing rate was higher than at 625 kg/ha but the difference was not significant. Sowing date and cultivar did not affect percentage pod set (Table 3.10).

Table 3.10. Summary of ANOVA of the effect of sowing date, cultivar and sowing rate on flower number per m^2 and percentage pod set of barrel medic

Source of variation	Flowers per m^2			Pod set %
	22 Sep	10 Oct	18 Oct	10 Oct
Sowing date	*	NS	NS	NS
Cultivar	***	NS	NS	NS
Sowing rate	***	**	***	***
Sowing date x Cultivar	NS	*	*	NS
Sowing date x Sowing rate	NS	NS	NS	NS
Cultivar x Sowing rate	NS	NS	NS	NS
Sowing date x Cultivar x Sowing rate	NS	NS	NS	NS

NS Not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 3.11. Effects of sowing date on flower production per m^2 by barrel medic. (The values are means of two cultivars and four sowing rates 5 to 625 kg/ha)

Sowing date	Number of flowers per m^2		
	22 Sep	10 Oct	18 Oct
Early	15240	18260	18150
Late	6660	17080	15290
LSD ($P<0.05$)	5970	NS	NS

Table 3.12. Effect of sowing date and cultivar on the number of flowers per m^2 of barrel medic on 10 October and 18 October 1989. (The values are means of 4 sowings rates 5 to 625 kg/ha)

Sowing date	Number of flowers per m^2			
	10 Oct		18 Oct	
	Parabinga	Paraggio	Parabinga	Paraggio
Early	16240	20270	16470	19820
Late	18180	15970	16250	14330
LSD (P<0.05)	3600		3180	

Table 3.13. Effects of sowing rate on the number of flowers per m^2 and percentage pod set of barrel medic. (The values are means of two sowing dates and two cultivars)

Sowing rate (kg/ha)	Number of flowers per m^2			Pod set (%)
	22 Sep	10 Oct	18 Oct	
5	7460	14420	13210	35.7
25	10920	14860	13590	33.8
125	10480	18550	15910	22.3
625	14930	22830	24170	18.2
LSD (P<0.05)	3280	4210	3430	7.9

3.3.10. Partitioning coefficients

Harvest index (HI), defined as the ratio of grain yield to total biomass at maturity (Donald and Hamblin 1976), is frequently used to measure DM partitioning in grain crops. However, since it is measured at maturity, it neglects changes in partitioning between vegetative and reproductive plant parts that may occur in indeterminate crops like annual medics, where vegetative and reproductive growth occur simultaneously. Partitioning coefficients (fruit or pod) weight divided by total above-ground biomass (Egli *et al.* 1985)) were calculated therefore to characterise the distribution of dry matter between vegetative and reproductive plant parts at mid-flowering, end of flowering and at seed maturity.

The partitioning coefficients increased rapidly as the plant progressed from early flower production to end of flowering (Table 3.15). However, the change between the end of flowering and maturity was less despite the fact that the above-ground DM at maturity consisted mainly of stems and pods. The main effects of variety and sowing rate were significant at all three stages, whereas sowing date effects were only significant at peak-flowering (Table 3.14).

The higher partitioning coefficient (15.6%) in the early-sown treatments at early stages of flower production, compared to 8.8% in the late-sown treatments, could be attributed to the differences in the start of flowering which resulted in more pod set in the early-sown treatments. The apparent lack of a significant difference in the partitioning coefficients between sowing dates at the end of flowering and at maturity suggests that the distribution of dry matter between vegetative and reproductive plant parts is insensitive to the duration of the growing season, possibly due to the accelerated rate of pod set and seed development in the late sown-treatments.

The early-flowering cultivar (Parabinga) showed a significantly higher ($P<0.001$) partitioning coefficient than the late-flowering cultivar (Table 3.16) because the development of pods was more advanced.

The differences in partitioning coefficients with sowing rate were similar throughout the reproductive period. The highest partitioning coefficient occurred at sowing rates of 1 and 5 kg/ha whereas the lowest occurred in the three highest sowing rates (Table 3.15). An analysis of variance of each cultivar within a single sowing date gave similar trends, thus verifying the lack of a significant Sowing date x Sowing rate or Cultivar x Sowing rate interaction (Table 3.14) The two highest sowing rates had the highest number of flowers per m^2 (Table 3.13), but this was not reflected in an increase in partitioning to reproductive parts because of decreased percentage pod set (Table 3.13). In contrast, the 5 kg/ha sowing rate had fewer flowers compared to the three higher sowing rates, but the partitioning to reproductive parts was higher because of increased percentage pod set (Table 3.13), mean pod weight and mean seed weight (Figs. 3.9, 3.10). At maturity, the partitioning coefficient at 25 kg/ha was significantly higher than the two higher sowing rates (Table 3.15), possibly because of the difference in mean seed weight (Fig. 3.10). The higher partitioning coefficients with early-maturing cultivars and lower sowing rates suggests that partitioning of assimilates between pod growth and vegetative growth is influenced by cultivar maturity and the ability of a canopy to retain more pods.

Table 3.14. Summary of ANOVA of the effects of sowing date, cultivar and sowing rate on partitioning coefficients of barrel medic

Treatment	Percent partitioning coefficient		
	10 Oct (Peak-flowering)	9 Nov (End of flowering)	7 Dec (Seed harvest)
Sowing date	***	NS	NS
Cultivar	***	***	***
Sowing rate	***	***	***
Sowing date x Cultivar	NS	NS	NS
Sowing date x Sowing rate	NS	NS	NS
Cultivar x Sowing rate	NS	NS	NS
Sowing date x Cultivar x Sowing rate	NS	NS	NS

NS, Not significant; *** P<0.001

Table 3.15. Effects of sowing rate on partitioning coefficients of barrel medic. (The values represent means of two sowing dates and two cultivars)

Sowing rate (kg/ha)	Partitioning coefficient (%)		
	10 Oct (Peak-flowering)	9 Nov (End of flowering)	7 Dec (Seed harvest)
1	16.1	63.9	81.1
5	13.8	62.6	74.6
25	11.5	52.9	62.6
125	8.9	50.8	56.3
625	8.9	52.0	57.8
LSD (P<0.05)	2.8	3.9	2.4

Table 3.16. Effects of cultivar on partitioning coefficients of barrel medic. (The values are means of two sowing dates and five sowing rates)

Date of harvest	Partitioning coefficient (%) Cultivars Parabinga	 Paraggio	LSD (P<0.05)
10 Oct (Mid-flowering)	14.9	8.8	1.7
9 Nov (End of flowering	58.8	54.1	2.5
7 Dec (Seed harvest)	68.5	64.5	1.5

3.3.11. Seed yield

Seed yield was significantly reduced ($P<0.05$) by delayed sowing (Table 3.17, Fig. 3.9). The highest yields occurred at sowing rates of 5 to 25 kg/ha and the lowest at 1 kg/ha (Table 3.17, Fig. 3.7). Although the Cultivar x Sowing rate interaction was not significant, Parabinga (early-flowering cultivar) tended to produce higher seed yields at the 5 kg/ha whereas Paraggio (late-flowering cultivar) produced higher yields at the 25 kg/ha sowing rate (Fig. 3.7).

Relationship between seed yield and seed yield components. The number of pods per m^2 (Fig. 3.8) followed the same trend as seed yield (Fig. 3.7), indicating that seed yield was related to the number of pods/m^2. Mean pod weight declined with increased sowing rate and, except for a sowing rate of 5 kg/ha, Parabinga produced larger pods than Paraggio (Fig. 3.9). The significantly higher mean pod weight for Parabinga could be attributed to more favourable environmental conditions during pod development as a result of early flowering and/or other genetic differences.

The number of seeds per pod was not significantly reduced by delayed sowing and was relatively constant over the range of sowing rates in the experiment, being only significantly reduced at 625 kg/ha (Table 3.18). However, the number of seeds per pod differed significantly between cultivars with Parabinga producing a higher number of seeds per pod (7.1) than Paraggio (6.4).

Mean seed weight was significantly greater in Paraggio (4.4 mg) than in Parabinga (4.0 mg). There was also a significant Sowing date x Sowing rate interaction (Table 3.17). In the early-sown swards there was no response in mean seed weight at the sowing rates of 1 and 5 kg/ha, whereas with late-sowing there was a decline in mean seed weight over all sowing rates (Fig. 3.10).

Table 3.17. Summary of ANOVA of the effects of sowing date, cultivar and sowing rate on seed yield and seed yield components of barrel medic

Source of variation	Seed yield	Pods (#/m^2)	Pod weight (mg)	Seed weight (mg)	Seeds (#/pod)	Harvest Index	Seed:pod ratio
Sowing date	*	*	NS	NS	NS	NS	NS
Cultivar	NS	NS	***	***	***	**	***
Sowing rate	***	***	***	***	*	***	***
Sowing date x Cultivar	NS	NS	NS	NS	NS	NS	NS
Sowing date x Sowing rate	NS	NS	NS	*	NS	NS	NS
Cultivar x Sowing rate	NS	*	*	NS	NS	NS	NS
Sowing date x Cultivar x Sowing rate	NS	NS	NS	NS	NS	NS	NS

NS Not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

The partitioning of the dry matter allocated to the reproductive structure between seed and pod wall development (seed:pod ratio) was significantly ($P<0.001$) affected by the main effects of Cultivar and Sowing rate. The early-maturing cultivar (Parabinga) had a greater seed:pod ratio (32%) than Paraggio (28%) suggesting that Parabinga had a greater ability to partition assimilates to seed development than Paraggio. Each cultivar invested more resources in seed growth than pod wall development when sown at 25 to 125 kg/ha than at lower or higher sowing rates (Table 3.18); the lowest seed:pod ratio occurred at 1 kg/ha sowing rate.

The Harvest Index (HI) was used to characterise the partitioning of dry matter to seed yield at the end of the growing season in contrast to partitioning coefficient which characterised the partitioning of dry matter to pod yield at various stages of reproductive growth. In contrast to the partitioning coefficient and seed:pod ratio which were higher with Parabinga, the HI was significantly higher with Paraggio (21%) than with Parabinga (19%). This could be attributed to the greater mean seed weight of Paraggio (4.4 mg) and slightly more seeds/m^2 as reflected in the number of pods/m^2 (Fig. 3.8) with Paraggio. The highest HI occurred when swards were sown at 5 kg/ha (Table 3.18) and the lowest at 125 and 625 kg/ha. The significant difference between swards sown at 5 and 25 kg/ha was possibly due to greater mean seed weight at 5 kg/ha sowing rate (Fig. 3.10).

Relationship between crop growth rates and pod growth rate. The total dry weight (DM) at the end of flowering, crop growth rates, pod growth rates during the reproductive period and seed yield are shown in Table 3.19. With the exception of the lowest sowing rate where the number of pods was limited by the number of plants per unit area, swards that maintained high crop growth rates during early flowering and higher pod growth rates during the reproductive period resulted in the highest DM and seed yield. The results suggest that the major requirement for seed yield is a high growth rate during the early flowering period.

Fig 3.7. Effects of sowing rate on seed yield of barrel medic:
(a) sowing rate and sowing date effects on mean seed yield of two cultivars
(b) sowing rate and cultivar effects on mean seed yield of two sowing dates

Fig 3.8. Effects of sowing rate on pods per m^2 of barrel medic:
(a) sowing rate and sowing date effects on mean number of pods per m^2 of two cultivars
(b) sowing rate and cultivar effects on mean number of pods per m^2 of two sowing dates

Fig. 3.7a. Seed yield, sowing date

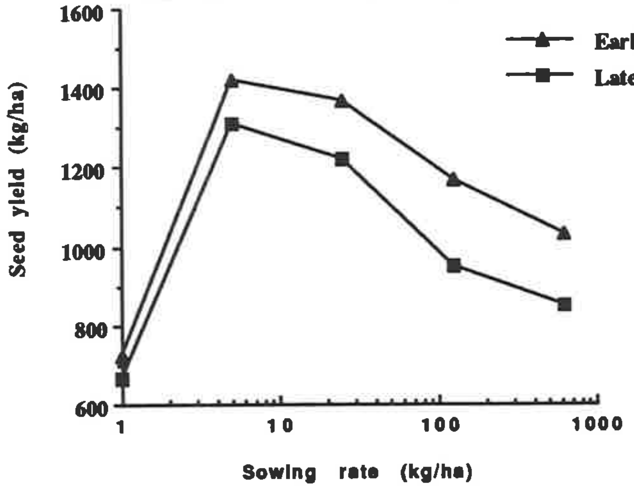


Fig. 3.8a. Pod number, sowing date

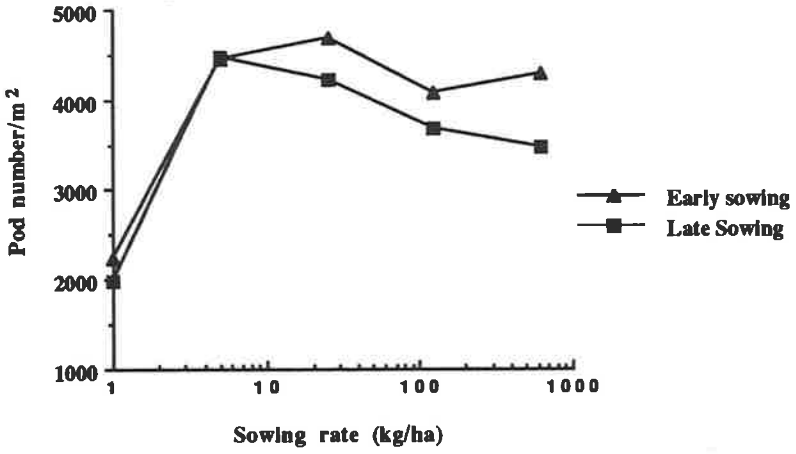


Fig. 3.7b. Seed yield, cultivar

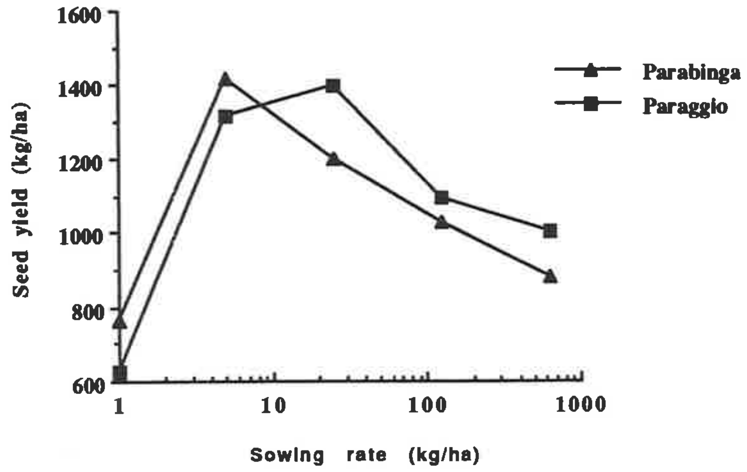
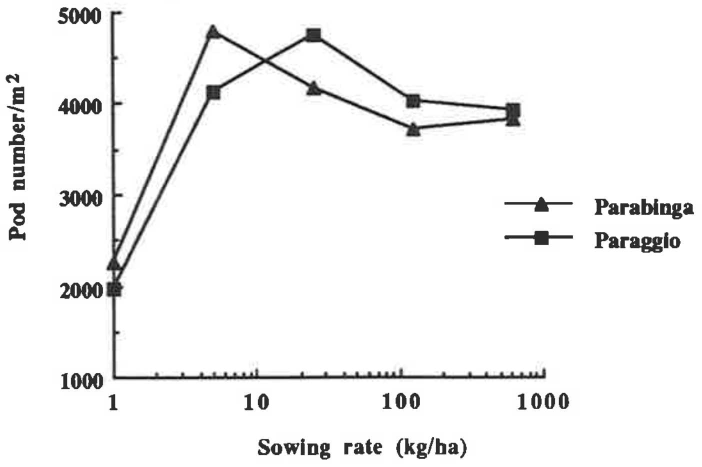


Fig 3.8b. Pod number, cultivar



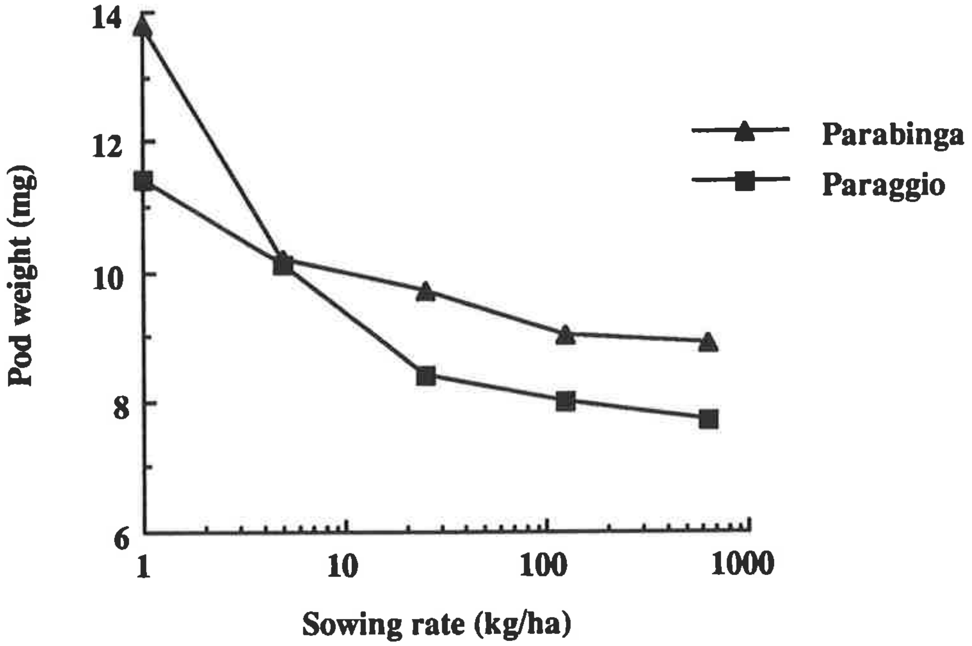


Fig. 3.9. Effects of sowing rate on pod weight of Parabinga and Paraggio barrel medic sown at two sowing dates

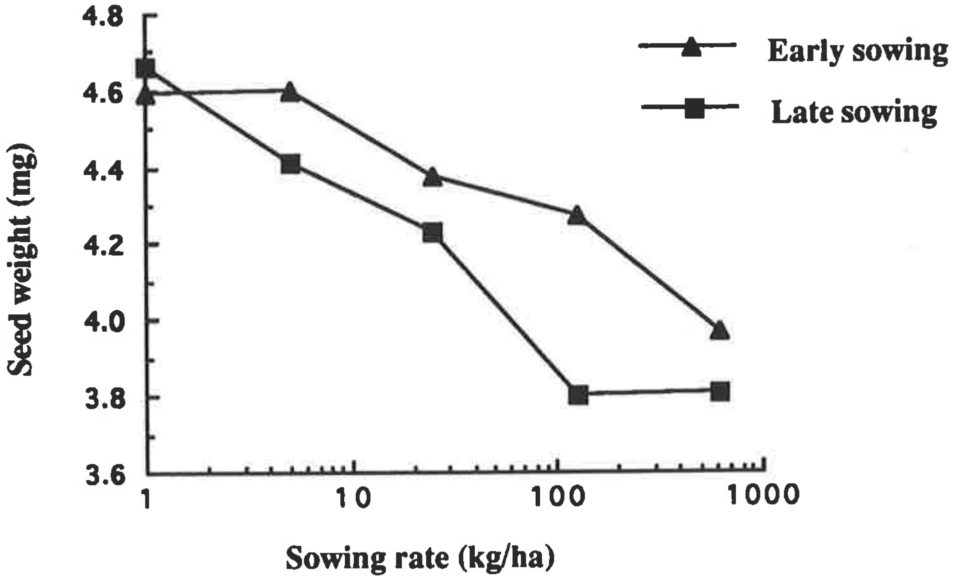


Fig. 3.10. Effects of sowing date and sowing rate on mean seed weight of two cultivars of barrel medic

Table 3.18. **Effects of sowing rate on number of seeds per pod, seed:pod ratio and Harvest Index. (The values are means of two sowing dates and two cultivars)**

Sowing Rate (kg/ha)	Yield components		
	Number of seeds per pod	Seed:pod ratio (%)	Harvest Index (%)
1	7.1	25.9	21.0
5	6.8	30.3	22.6
25	6.8	32.6	20.4
125	6.8	32.4	18.2
625	6.2	29.6	16.8
LSD ($P<0.05$)	0.4	2.1	1.5

Table 3.19. **Comparison of crop growth rates during the reproductive period, pod growth rates and seed yield of barrel medics sown at various rates. (The values are means of two sowing dates and two cultivars)**

Sowing rate	Maximum dry weight (kgDM /ha)	Seed yield (kg/ha)	Crop growth rate ($g/m^2/day$)		Pod growth rates ($g/m^2/day$)	
	End flowering	Maturity	Early flowering	Peak to end of flowering	Early to peak of flowering	Peak to end of flowering
1	5190	695	6.18	10.95	1.06	8.12
5	10100	1366	16.13	16.67	1.98	13.02
25	9790	1296	18.70	7.34	1.52	11.60
125	8720	1060	12.70	3.39	1.35	9.54
625	7960	941	10.61	2.28	1.21	9.53
LSD ($P<0.05$)	1340	137	3.65	5.76	0.30	1.03

3.4. DISCUSSION

3.4.1. Vegetative growth.

The greatest amount of early growth was achieved with sowing an early-flowering cultivar in May at high sowing rates. However, the effects of cultivar and sowing date disappeared by the start of flowering but the influence of sowing rate persisted throughout the season. This is in agreement with earlier experiments (Adem 1977; Silsbury *et al.* 1979) which demonstrated that sowing rate had a greater effect on the rates of dry matter accumulation than either sowing date or cultivar (Table 3.4, Fig. 3.3). High sowing rates resulted in high crop growth rates soon after emergence because of the high density, consequent large leaf area (Figs. 3.2, 3.4) and hence greater interception of solar radiation early in the season (Fig. 3.5). In the absence of low temperature or water stress, pests or diseases, the rate of growth depends on the quantity of radiation intercepted (Blackman and Black 1959; Donald 1963; Brown and Blaser 1968). In the present experiment, water was non-limiting and temperatures were low during the months of June, July and August (Table 3.1) indicating that the early high growth rates at the highest sowing rates were dependent on the amount of solar radiation intercepted.

As the season progressed, herbage production increased and complete self-shading (LAI above 4) occurred before the start of flowering at the two highest sowing rates (125 and 625 kg/ha) and growth rates declined much earlier than at 5 and 25 kg/ha (Table 3.19, Fig. 3.3). Water and temperature were non-limiting by the start of flowering (Table 3.1, 3.6). The decline in growth rates at higher sowing rates is in agreement with the findings of Silsbury and Fukai (1977) and Silsbury *et al.* (1979) and could be attributed to increased respiratory loss and leaf senescence caused by high yields of DM (Fig. 3.3, Fukai 1974; Fukai and Silsbury 1977a,b, c).

There appears to be few published figures on RUE for forage legumes: however, the RUE of about 3.1 to 3.5 g/MJ between the 5 and 625 kg/ha sowing rates is within the range reported for other crops when more than 90% of PAR is intercepted (Monteith 1977; Husain *et al.* 1988; Pilbeam *et al.* 1991; Stützel and Aufhammer 1991). This result emphasises the fact that differences in DM accumulation, except at the 1 kg/ha sowing rate, were largely a consequence of differences in total PAR interception over the growing season, rather than differences in RUE.

Despite the similarity in RUE and LAI at maximum flowering (10 October) in the 5 to 625 kg/ha sowing rates swards, total cumulative dry matter at the end of flowering and at maturity was greatest at the 5 and 25 kg/ha sowing rates. The low final DM at higher sowing rates could be attributed to the early reduced rate of growth (Table 3.19), greater leaf senescence, poorer pod set (Table 3.13, Fig. 3.8), mean pod weight and seed weight (Fig.s. 3.9, 3.10). The study showed that final dry matter production is not related to sowing date, cultivar maturity or to sowing rates in the range of 5 to 25 kg/ha.

3.4.2. Canopy growth and seed yield

The quadrat yield estimate of 1300 kg/ha of seed at the optimum sowing rates (equivalent to a commercial yield of 650 kg/ha) is higher than 440 kg/ha reported by Ragless (1973) and the 500 kg/ha estimated from quadrat yields of Adem (1977) at the Waite Institute. Seed yield in the present experiment was reduced at higher sowing rates, a result that is contrary to earlier work by Adem (1977). Cocks (1988) using the same cultivar as Adem in Syria (annual rainfall 382 mm) found that yields were highest when sowing rates were between 20 and 40 kg/ha in contrast to 5 to 25 kg/ha in the present study. This highlights the importance of seasonal weather, site/soil effects in determining the optimum sowing rate. The similarity in seed yields between sowing rates in Adem's study at the Waite Institute (Adem 1977) was attributed to a favourable, long wet season which resulted in a similar number of pods per m^2 and mean seed weight. In Syria, frost early in the season severely reduced the number of plants per m^2 and, together with the relatively drier growing season, the vegetative growth at lower sowing rates was poor. Low seed yields at lower sowing rates were due to fewer pods per m^2 because of fewer flowers per m^2.

An analysis of the yield components confirms earlier findings (Adem 1977; Cocks 1988, 1990b) that seed yield in annual medics is determined by the number of mature pods per m^2. Mean seed weight in the present experiment contributed to seed yield, but its effects could not compensate for the reduction in the number of pods per m^2 at the lowest sowing rate or later sowing dates (Fig.. 3.8, 3.10). This result suggests that mean seed weight may only increase seed yield if the number of pods per m^2 is not significantly reduced. The stability in the number of seeds per pod within a cultivar across sowing rates (Table 3.18) and sowing dates suggests that this paramater is less important to increases in seed yield within a cultivar.

The total number of flowers per m^2 was greatest at the highest sowing rate because of the high number of branches per m^2 (Table 3.8, 3.13). In contrast, seed yields were greatest at the 5 and 25 kg/ha sowing rate because of high percentage pod set (Table 3.13, Fig. 3.7). The findings that the number of mature pods is determined by percentage pod set is in agreement with the research of Cocks (1988, 1990b). However, where swards do not attain complete light interception as shown by the 1 kg/ha sowing rate in this experiment, seed yield may be low (Fig. 3.4) because of fewer flowers per m^2. Dense swards reduced percentage pod set only when complete self-shading occurred prior to the start of flowering (Fig. 3.5) indicating that better light transmission through the swards during the flowering period was an important factor in determining pod set. The high percentage pod set and seed yield with the occurrence of complete self-shading shortly after flowering or towards the end of flowering (Fig. 3.5, Table 3.13) suggests that seed yield may be more sensitive to poor light penetration during the early flowering period than during the later period of flowering. In Adem's study the spring season was exceptionally wet throughout and as a result even the lowest sowing rate achieved a DM of 700 g/m^2 at the end of flowering. Although LAI and percentage pod set were not recorded in his study, it can be inferred from the results of the present work that seed yield at the lowest sowing rate was high because of high vegetative growth, whereas at the higher sowing rates percentage pod set was increased possibly due to lack of moisture stress. This gives an indication that percentage pod set under dense swards can also be increased by adequate soil moisture supply.

The RUE between 5 and 625 kg/ha sowing rates were not significantly different and remained the same between the vegetative and reproductive periods (Fig. 3.6), suggesting that the differences in seed yield were not due to differences in RUE. The lack of a significant difference in the mean soil moisture content between plots sown at 25 to 625 kg/ha sowing rates also suggests that soil moisture was not responsible for poor pod set at higher sowing rates. The high abscission rate of flowers in the higher sowing rates could therefore be attributed to complete self-shading prior to and throughout the flowering period which may have limited the ability of the canopy to supply sufficient photosynthate to the flowers and immature pods during the pod setting.

The decline in the partitioning coefficients (Table 3.15), mean pod weight (Fig. 3.9), mean seed weight (Fig. 3.10) and HI (Table 3.18) with increases in sowing rate provides further evidence of the importance of the ability of the canopy to supply adequate photosynthate during the pod-setting and pod-filling period to ensure high seed production. The results of this study also demonstrate that under sward conditions the low number of pods per m^2 is not compensated for by increases in mean seed weight. On the contrary, the partitioning of assimilates between the seed and pod wall (seed:pod ratio) was significantly higher at the 25 and 125 kg/ha sowing rates than at other sowing rates (Table 3.18) despite the fact that mean seed weight was not increased in comparison to the 1 and 5 kg/ha sowing rates. This observation suggests that when canopy photosynthesis is limiting and seeds per pod are not reduced, either the seed being a stronger sink attracts more of the assimilates at the expense of pod wall development as suggested by Summerfield *et al.* (1976) or there is remobilisation of assimilates from the pod wall for seed growth.

Comparisons of the crop growth rate during the reproductive period and pod growth rates indicate that in order to achieve higher seed yields, high growth rates should occur during the early flowering period (Table 3.19), which again supports the importance of higher canopy photosynthesis during the early flowering period. It is therefore postulated that environmental or agronomic stresses which decrease herbage dry matter production during this period would be expected to reduce seed yield.

The results of the present experiment show that seed yield is increased with better light penetration. The yield at higher densities was limited by poor light penetration and in these circumstances yields could have been improved by defoliation (Collins 1978; Steiner and Grabe 1986). Commercial seed producers in South Australia use grazing, mechanical defoliation or low rates of herbicides to control vegetative growth before flowering with the aim of increasing seed yield (Carter 1989), but such a strategy will only be beneficial to yield if the amount of vegetative growth after defoliation is large enough to produce a large number of flowers as indicated by the lowest sowing rate in this study. The relationship between light penetration, flower production and seed yield needs further investigation as there are no guidelines available.

3.4.3. Crop duration and seed yield

Seed yield was significantly reduced by late sowing (Fig. 3.7), whereas differences in cultivar maturity showed little effect on yield. The response of seed yield to delayed sowing reported here is similar to previous reports in annual medics (Poole 1970 in Western Australia; Cocks 1988 in Syria; and Thorn and Laslett 1992 in Western Australia). Reductions in seed yield in the present Waite Institute experiment resulted from reduced pods per m^2 and mean seed weight (Fig. 3.7, 3.8, 3.10).

The duration of the vegetative period (sowing to start of flowering) was reduced with late sowing because of the early exposure to warm temperatures and long photoperiods (Clarkson and Russell 1975, 1979; Hochman 1987) in comparison to early-sown swards. Similar reductions occurred in the reproductive period (flowering to maturity) because of low rainfall and high temperatures at the end of the season (Table 3.1). The present data show that a shortened period of vegetative growth had little effect on DM because of the increased initial crop growth rate (Fig. 3.3). This supports the findings of Silsbury and Fukai (1977) and Silsbury *et al.* (1979) who observed that late-sown swards will have a higher initial growth rate leading to similar final dry matter yields, provided sowing is not delayed until very late in the season.

However, reduction in the duration of growth (vegetative and reproductive) reduced the number of flowers, particularly early in the season (Table 3.11). Percentage pod set was not significantly affected by sowing date, suggesting that reductions in the number of pods was largely associated with the reduced number of flowers per m^2 during the early flowering period (Table 3.11).

The lower mean seed weight at the second sowing (Fig. 3.12) was possibly a consequence of reduced soil moisture and high temperatures during seed development. Number of flowers per m^2 at the end of flowering were not significantly different between sowing dates (Table 3.11) but the early-sown swards had a longer period of seed development before the onset of soil moisture stress (Table 3.6) and high temperatures in the later period of seed development. Andrews *et al.* (1977), Wolfe (1985) and Amoabin *et al.* (1987) have demonstrated that water stress during seed development reduces mean seed weight in subterranean clover and annual medic swards.

The mean day/night temperatures during the flowering period were 18/10°C for early sowing and 19/11°C for late sowing and 25/14°C from the end of flowering to maturity for both sowing dates. The 25/14°C mean day/night temperatures are within the range of those that reduced mean seed weight of subterranean clover cv. Daliak (Taylor and Palmer 1979). In their experiment, a temperature of 24/19°C reduced mean seed weight in both unstressed and stressed swards, whereas 18/13°C reduced mean seed weight only in stressed swards, emphasising the fact that in the present Waite Institute study both high temperature and low soil moisture were probably responsible for the reduction in mean seed weight in late-sown swards.

The partitioning coefficient, seed:pod ratio and HI were relatively constant with variation in sowing date. This suggests that variation in pod number and seed yield as a result of delayed sowing was more closely related to the duration of the vegetative growth which reduced the number of flowers early in the season (Table 3.13) and the reproductive period which reduced the mean seed weight (Fig. 3.12), than to the ability of the plant to allocate assimilates to the developing pods and seeds.

Despite differences in maturity, both Parabinga and Paraggio produced similar yields but there were significant differences in the yield components. The early-flowering cultivar (Parabinga) had a larger number of seeds per pod whereas the late-flowering cultivar had a higher mean seed weight. These differences in numbers of seeds per pod and mean seed weight could have compensated for the differences that were to occur in seed yield since no significant differences in the number of pods/m^2 were observed. The partitioning coefficient was higher in the early-flowering cultivar, in contrast to HI which was higher in the late flowering cultivar. The higher HI in the late-flowering cultivar is likely to be due to its heavier seeds (Fig. 3.10) possibly as a result of the higher seed:pod ratio.

3.5. SUMMARY AND CONCLUSION

Winter herbage dry matter yield was highest in early-sown swards and at high plant densities. The end of season total DM production was independent of sowing date and cultivar but was highest at the sowing rates of 5 and 25 kg/ha and significantly reduced at 625 kg/ha. Differences in DM accumulation were due to differences in the amount of light intercepted by the canopy.

In contrast, seed yield was highest from early sowing and at sowing rates of 5 to 25 kg/ha. The major yield component that governed seed yield was the number of pods per m^2 which was determined by the number of flowers produced and the proportion that survived to form mature pods. Delayed sowing reduced seed yield through reductions in the number of flowers during the early part of the flowering season. Sowing rate influenced the number of pods per m^2 through flowers that survived to form mature pods, which appeared to be associated with the growth stage at which complete self-shading (LAI above 4) occurred. The greatest number of flowers occurred at the highest sowing rates but complete self-shading occurred prior to the start of flowering thereby reducing percentage pod set in comparison to lower sowing rates, where complete self-shading occurred later in the flowering period. High crop growth rates during the flowering period appears to be a prerequisite to higher seed yield.

From the results of these studies in Experiment 1, it is postulated that strategies for improving seed yield in dryland (rainfed) annual medics should be based on management that encourages early production of a large number of flowers and ensures adequate light penetration during the flowering period without shortening the reproductive period.

CHAPTER 4

EFFECTS OF LEVEL AND TIMING OF SHADING ON SEED YIELD OF DEFOLIATED AND UNDEFOLIATED SWARDS OF ANNUAL MEDICS

4.1. INTRODUCTION

In annual medics the major determinant of seed yield is the number of pods per unit area (Adem 1977; Cocks 1988, 1990a,b; Ababneh 1991; Chapter 3). Dense swards produce more flowers per m^2 than spaced swards, but percentage pod set is greater in spaced plants because of lower rates of abortion of flowers and young pods (Cocks 1988, 1990b; Chapter 3). Experiment 1(Chapter 3) has shown that complete self-shading (equivalent to a LAI above 4) prior to the start of flowering was associated with low percentage pod set, but at later stages of flowering self-shading did not appear to affect pod set.

This result suggests that seed yield of annual medics may not depend so much on the ability of the medic stand to produce flowers but rather on its ability to produce photosynthate during the flowering period to maximise flower survival and pod set. It also appears that the early period of flowering is more critical for high percentage pod set than the later period. To investigate this further, two shading experiments were conducted in the field at the Waite Agricultural Research Institute in 1989 and 1990. These experiments examined the hypothesis that the inability of the canopy to supply photosynthate to flowers and young pods associated with poor light penetration through the sward is a contributing factor to low seed yields in annual medics.

4.2. EXPERIMENT 2 : EFFECTS OF TIME OF SHADING ON SEED YIELD OF *MEDICAGO SCUTELLATA* cv. SAVA AND *M. TRUNCATULA* cv. PARAGGIO.

The objective of the experiment was to assess the effects of 30% shading at different stages of flowering on pod set, seed yield and seed yield components in *Medicago scutellata* cv. Sava and *M. truncatula* cv. Paraggio.

4.2.1. MATERIALS AND METHODS

Experimental design and sowing details. The experiment was conducted in the same field as Experiment 1 described in Chapter 3 and information about experimental site, methods of sowing and weather conditions are given in Materials and Methods of Chapter 3. A split plot design was used with annual medic species forming the main plots and shading treatments the subplots. The experiment was sown on 1 June 1989 at a rate of 20 kg/ha pure germinating seed. Complete seedling emergence was on 16 June and flowering commenced on 30 August for Sava and 8 September for Paraggio.

When flowering had commenced in each species, a sarlon shade cloth which reduced incoming solar radiation by 30% was installed for the following flowering periods:

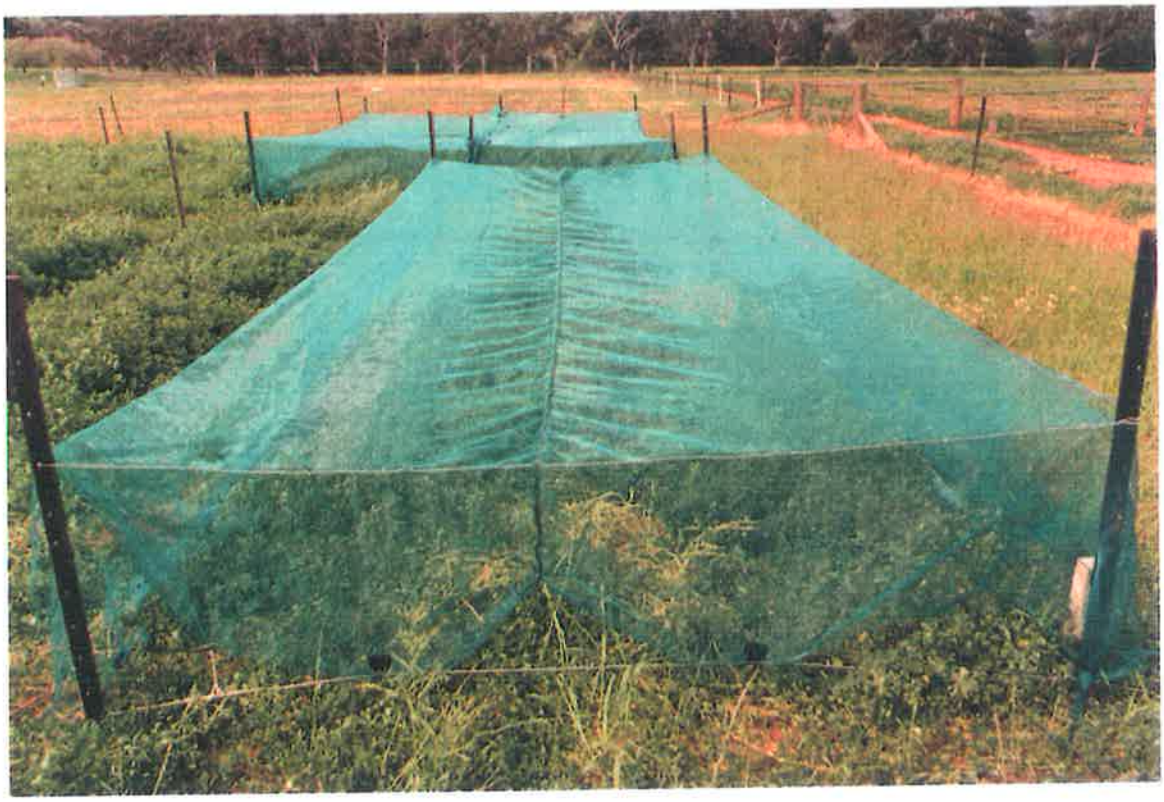
(i) Unshaded control
(ii) 0 - 2 weeks after commencement of flowering
(iii) 2 - 4 weeks after commencement of flowering
(iv) 4 - 6 weeks after commencement of flowering
(v) 0 - 6 weeks after commencement of flowering

The frames for the shades were 2 m wide by 5 m long. The shade cloth covered the top of the frame, forming a skirt 40 cm deep on all sides with a space of 10 cm at the base to allow air circulation (Plate 4.1). The shades were raised from time to time so that the average distance between the top of the sward and the shade cloth was about 10 cm. By the time of cessation of shading the unshaded swards had completed flowering but the shaded treatments completed flowering a week later. When the swards were completely dry and mature, the pods were harvested by vacuuming from three infiltrometer rings (steel cylinders) which formed a total area of 0.2 m^2. Pods were then cleaned as described in Chapter 3. A sub-sample of 75 g of pods was weighed and threshed for the determination of seed yield and seed yield components as described in Chapter 3.

Plate 4.1: Method used for shading medic.

Upper: Experiment 2, 1989.

Lower: Experiment 3, 1990.



4..2.2. RESULTS

There was a trend for shading during 2 - 4 and 0 - 6 weeks of the flowering period to reduce pods per m^2 and seed yield in both species, but the differences were not significant (Table 4.1). Mean seed weight and number of seeds per pod varied little over all shading treatments. The similarity of results from 30% shading and the unshaded control and between the two species suggests that a reduction of normal spring light intensities by 30% has no detrimental effect on annual medic seed yield. However, there were indications, that the early flowering period (0 - 2, 2 - 4 weeks) may be more sensitive than the late flowering period to a reduction in photosynthetic supply as a result of reduced incident light.

Table 4.1. Influence of shading on seed yield and seed yield components from *M. scutellata* cv. Sava and *M. truncatula* cv. Paraggio at the Waite Institute, 1989

	Shading period (weeks)					
	Nil	0 - 2	2 - 4	4 - 6	0 -6	Sig. diff.
(a) Sava						
Seed yield (kg/ha)	1438	1423	1272	1454	1386	NS
Pods (#/m^2)	1455	1435	1355	1548	1512	NS
Seed weight (mg)	17.8	16.4	18.4	17.8	17.8	NS
Seeds (#/pod)	5.6	6.2	5.1	5.3	5.2	NS
(b) Paraggio						
Seed yield (kg/ha)	1656	1510	1492	1636	1479	NS
Pods (#/m^2)	4933	4612	4716	4860	4557	NS
Seed weight (mg)	4.8	4.8	4.7	4.6	4.9	NS
Seeds (#/pod)	7.4	6.8	6.7	7.3	6.6	NS

NS, Not significant

4.3. EXPERIMENT 3 . EFFECTS OF LEVEL AND TIME OF SHADING ON SEED YIELD OF DEFOLIATED AND UNDEFOLIATED SWARDS OF PARAGGIO BARREL MEDIC

The previous experiment (Expt. 2, 1989) showed that medic yield is relatively insensitive to 30% reduction in light during flowering. However, when the canopy is closed, reduction in light intensity of more than 30% at different levels of the canopy from the top are likely to occur. The specific objectives of this experiment were to examine the effects of 30% and 60% shading at different stages of flowering in Paraggio barrel medic on dry matter yield, pod set, seed yield and yield components. Shading by 60% was used to further test if the reduction in yield only occurs with severe reduction in the amount of light penetrating through the sward. Also, by shading before the commencement of flowering the effect of reduction in vegetative growth before flowering on pod set and seed yield could be examined. The potential benefit of improving light penetration into the canopy during flowering in terms of vegetative growth, pod set and seed yield was tested by defoliation at the start of flowering.

4.3.1. MATERIALS AND METHODS

4.3.1.1. Experimental site and sowing details

This experiment was undertaken at the Waite Agricultural Research Institute, South Australia in 1990. The land allocated to the experiment had been under wheat the previous year. The soil type is the same as that described in Chapter 3. Rainfall, temperature and solar radiation were obtained from a nearby meteorological station at the Waite Agricultural Research Institute and are summarised in Table 4.2. The season was marked by the late arrival of opening rains. Winter rainfall was similar to the long term means. Similar trends were observed in September and October but rainfall in November was low.

Field preparation before sowing was similar to that described in Experiment 1 (Chapter 3). Seed of Paraggio barrel medic was weighed out, wet-inoculated with a peat culture of *Rhizobium meliloti* and allowed to dry. Sowing was done with a seed drill which was calibrated to give a sowing rate of 20 kg/ha of seed and 240 kg/ha single superphosphate

(= 27 kgP/ha) at a row spacing of 15 cm. The experiment was sown on 10 July which was very late by normal standards and seedling emergence was complete by 21 July.

As the medic became established, sitona weevil (*Sitona humeralis*) attacked the pasture and the field was sprayed with Dimethoate at a rate of 85 ml/ha. This was effective and no more damage was observed during the rest of the season. Broad-leaf weeds were removed by hand as they appeared whereas grass weeds were eliminated by spraying with Fusilade (Fluazifop-butyl (ai 0.48 kg/L)) at 1.5 litres/ha in late July.

Table 4.2. Rainfall, solar radiation, and temperature data for the Waite Agricultural Research Institute in 1990

(Latitude 34° 58'S, Longitude 138° 38'E, Altitude 122.5 m)

Month	Rainfall (mm)		Solar radiation (MJ/m^2)	Temperature (°C)		
	1990	1925 - 1990		Min.	Max.	Mean
January	22.4	23.4	24.38	16.7	28.3	22.5
February	13.6	24.1	19.11	16.1	26.4	21.2
March	1.2	23.5	18.83	16.8	27.7	22.2
April	17.0	54.3	13.55	13.2	22.1	17.6
May	18.4	79.4	8.45	11.6	19.6	15.6
June	99.2	75.0	6.11	9.0	15.5	12.3
July	110.0	88.2	6.07	8.7	14.5	11.6
August	98.8	75.2	8.38	8.4	14.2	11.3
September	50.0	61.7	15.20	11.1	19.0	15.1
October	46.6	52.5	18.64	12.1	21.9	17.0
November	16.4	36.6	24.06	13.9	25.7	19.8
December	50.4	30.2	22.35	15.0	25.3	20.2
Total	544.0	624.1				

4.3.1.2. Experimental design and shading treatments

The experimental treatments comprised unshaded, 30% and 60% shade conditions at four times of shading: for approximately 3 weeks, from 2 weeks before flowering to 1 week after flower appearance (T1), for 3 weeks in the first half of flowering (T2), for 3 weeks in the second half of flowering (T3), shading throughout the flowering period (T4) and an unshaded control (T0) as shown in Fig. 4.1. The swards were either left undefoliated or defoliated once at a height of 6 cm one week after start of flowering (25 September). The treatments were laid out in a split plot design with shade and time of shading treatment combinations being assigned factorially to the main plots and defoliation treatments in the subplots. The experiment was replicated 4 times.

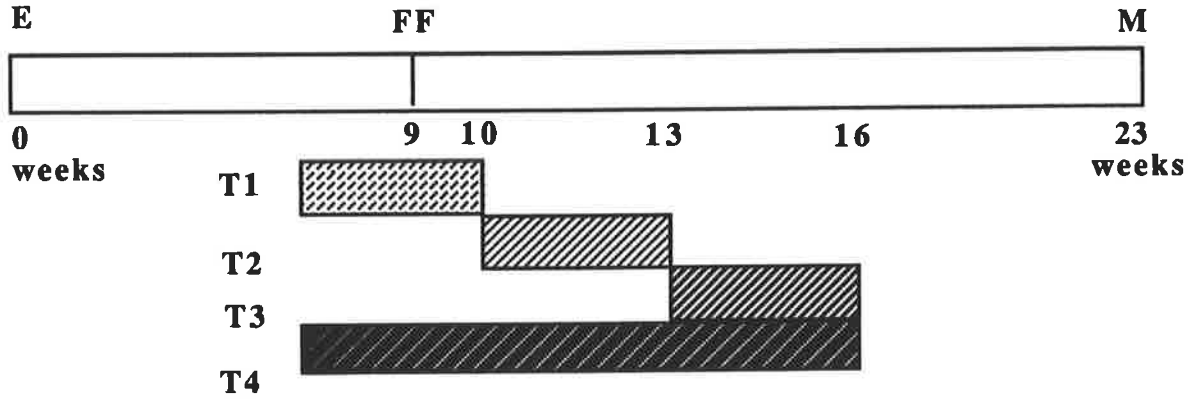


Fig 4.1. Timing and duration of shading treatments, 1990. (E=Emergence, FF=First flower appearance, M=maturity)

The area shaded in each plot was 3 m x 3 m and the method of shading was similar to Experiment 2 (this Chapter). The medic sward was defoliated with a rotary mower at a height of 6 cm. The percentage of light transmitted through each shade cloth was confirmed by continuously recording the amount of light under the shade and above the shade for one week using tube solarimeters.

4.3.1.3. Data collection

Air temperature. During the second half of the flowering period temperatures under the two shade cloths and in the unshaded control were monitored using minimum-maximum thermometers which were suspended on pegs in the sward to avoid contact with the soil surface and to shield from direct sunlight. This was done for one week and the minimum and maximum temperatures were recorded at noon each day.

Irrigation and relative water content determinations. During flowering, rainfall from mid October to November was relatively low and parts of the experiment became visibly stressed. Rainfall was supplemented with spray irrigation at the rate of 13 mm per week for 5 weeks to ensure that the swards were not subjected to severe moisture stress. The final watering was on 22 November when the undefoliated swards were maturing (drying) but the defoliated swards were still in flower. The experiment was located 20 m from a row of *Eucalyptus citriodora* but the replicate nearest to the trees was consistently stressed even shortly after watering. To reduce the variability in yield data this replicate was discarded. There was no obvious effect of the trees on the remaining replicates.

Relative water content (RWC) was determined using the method of Turner (1981) to examine whether there were significant differences in water stress under the various shade and defoliation conditions. Approximately every 2 weeks during the second half of flowering, before commencement of irrigation, 10 leaflets from the third trifoliate leaf from the top of the sward were selected at random and immediately put in a tared vial and sealed. After the fresh weights had been obtained the leaves were floated for 20 hours on distilled water in covered petri dishes at a constant room temperature and a light intensity of 10-12 $\mu Em^{-2}s^{-1}$ until the discs became fully turgid. A preliminary study indicated that there was no difference in RWC between floating the leaflets for 12 and 24 hours. After floating, the leaves were carefully dried with filter paper, ensuring removal of all surface water but care being taken to avoid forcing water out of the leaves. Leaves from each petri dish were immediately returned to the same vial and closed then weighed and oven dried at 85°C for 12 hours for dry weight determination. RWC was calculated from the formula:

$$RWC = \frac{(FW\text{-}DW)}{(TW\text{-}DW)} \times 100\%$$

where FW=Fresh weight of leaves, DW=Dry weight of leaves, TW=Turgid weight of leaves.

Plant numbers. Plant counts were made 30 days after emergence and at the end of the first half of flowering. Two galvanised wire quadrats 25 x 40 cm were placed in each plot perpendicular to the drill rows to sample 3, 25 cm lengths of rows. The mean number of plants at establishment was 350 per m^2 and at the end of the first half of flowering it was 273 per m^2. There was no significant difference in the number of plants per m^2 between plots at establishment and between shading or defoliation treatments at the end of the first half of flowering.

Vegetative growth harvests. To estimate total pasture yield (DM), leaf dry weight, leaf area index (LAI) and specific leaf area (SLA), plant harvests from two quadrats of 25 x 40 cm per plot were made on the following dates: 7 September (47 days from emergence), 3 October (72 days from emergence), 26 October (95 days from emergence) and 20 November (117 days from emergence).

Following defoliation, the residual plant material was harvested to ground level to estimate the remaining pasture yield (DM) and LAI. In the laboratory the harvested material was sub-sampled for leaf dry weight, stem dry weight and leaf area determinations. Leaf area was measured using an electronic planimeter as described in Chapter 3. All plant material was dried in a forced draught dehydrator at 85°C for 24 hours to determine dry weights. In the plots which were shaded throughout, the plots were uncovered for about 10 minutes for harvesting.

Number of flowers and pods. At the end of the first half of flowering (26 October) five plants from the undefoliated swards were carefully removed from each plot ensuring that all the flowers and pods were retained. The number of racemes and pods on each plant as well as flowers per raceme were then counted in the laboratory. The pods present were separated, dried at 85°C for 12 hours and weighed to determine pod weight per plant. The number of flowers per m^2 was estimated by multiplying the number of racemes per plant by the number of flowers per raceme and the number of plants per m^2. Pod weight per m^2 was also estimated from the weight of pods per plant and the number of plants per m^2. Reproductive growth by the end of the second half of shading was not estimated because plants in the undefoliated but unshaded swards were senescing making it difficult to obtain intact plants with pods.

Flower survival. Flower survival in this experiment refers to the percentage of the flowers tagged that survived to form pods by 10 days after tagging. To examine the short-term effects of shading on flower survival, flowers in the T0, T1, T2 and T4 treatments were tagged on two occasions: when treatment T2 began and 10 days later. On each occasion flowers on 10 racemes selected randomly from 10 branches were counted and each raceme tagged. The number of pods arising from tagged flowers was counted 10 days later and expressed as a percentage of the total number of flowers on 10 racemes. The effects of shading followed by exposure to full sunlight, and of exposure followed by shading, were examined by the first tagging of flowers (3 October) in T1 and T2 respectively. Tagging flowers in T4 10 days after the start of T2 shading (12 October) enabled examination of flower survival in swards that had been under shade for a long time in comparison to those that had been under shade for a short time (T2) or under full daylight throughout (T0).

Seed harvest. Pods were harvested on 12 December from three infiltrometer rings which formed a total area of 0.2 m^2. The infiltrometer rings were placed in the north, middle and south position of each plot. Harvesting and pod cleaning was the same as that described in Chapter 3. Before weighing, the cleaned pods were oven dried at 40°C for 12 hours. A sub-sample of 20 g of pods was weighed and threshed to determine seed yield and seed yield components as described in Chapter 3.

Statistical analyses. Statistical analyses was done using GENSTAT V. Two analyses were conducted: to examine the Shading x Defoliation interaction the experiment was analysed as a factorial with nine shading treatments (two levels of shading x four shading times + one unshaded control) and two defoliation treatments. The data were then restricted to two levels of shading x four shading times (i.e. without unshaded control) and two defoliation treatments to test for Shade x Time x Defoliation interaction, whenever it was necessary.

4.3.2. RESULTS

4.3.2.1. Air temperature and relative water content

Air temperature under the shade covers was only 1°C lower than the outside conditions. Temperature reductions of 1 to 3°C under shade treatments of sarlon cloth have been reported in the literature by Fischer (1975) for 55% shade, Collins *et al.* (1978) for 45% and 70% shade and Argel and Humphreys (1983) for 34%, 50% and 70% shade treatments. These authors concluded that changes of such magnitude have little effect on seed yield.

Defoliation significantly increased the RWC from 81.1% to 85.8% on 1 November and from 75.7% to 81.5% on 12 November, but there was no Shade x Defoliation interaction. Shading throughout with 60% shade cloth tended to increase RWC but the differences were not significant (Table 4.3). It should be noted that the swards were also watered with 65 mm of water during October and November which was much more than the average for September or October rainfall. The fact that both unshaded and shaded treatments were not stressed suggests that differences in RWC had little effect on seed yield. Thus the results indicate that the use of the shade covers over field plots enabled a valid comparison to be made between swards grown at different levels of incident light without adverse effects on air temperature and water stress in the plants.

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Table 4.3. Effects of shading on relative water content (RWC) of Paraggio barrel medic during the second half of flowering.

(Data represent means of the undefoliated and defoliated swards)

Shading treatments		RWC (%)	
Level of shading	Time of shading	1 Nov	12 Nov
Control	Unshaded	75.7	78.4
30%	Second half of shading	74.0	76.1
60%	Second half of shading	79.4	78.7
30%	Shading throughout	81.1	81.8
60%	Shading throughout	81.5	83.9
	Sig. diff.	NS	NS

4.3.2.2. Herbage production

Tables 4.4, 4.5 and 4.6 summarise the ANOVA for total pasture yield (DM), LAI and SLA for shading treatments, defoliation and their interactions. There were no significant Shading x Defoliation interactions for vegetative growth and so the effects of shading (averaged over undefoliated and defoliated swards) and the average effects of defoliation (averaged over all shading treatments) are discussed.

Defoliation reduced DM yield from 9649 kg/ha to 5759 kg/ha (Appendix Table 4A) at end of the shading treatments (day 116). The maximum LAI at this time was also reduced from 5.8 to 3.2. Shading during the vegetative stage of growth (T1) did not significantly reduce total DM at the start of flowering (Table 4.4, Fig. 4.2). Shading during flowering tended to reduce the growth rate of the sward, but often not enough to reduce DM significantly at the end of the shading treatments (day 116, Fig 4.2). Shading during the first half of flowering (T2) with 30% or 60% shade cloth, or 60% shading throughout, reduced the growth rate so that DM yields by the end of the first half of shading (Tables 4.5, 4.7, Fig. 4.2) were reduced significantly. By the end of T3 shading, DM in the 60% shading during the first half of flowering (T2) was similar to the unshaded control because of accelerated growth rate after shade removal (Fig 4.2b). In the 60% shading throughout (T4), DM was much lower than the unshaded control but the differences were not significant. The lack of a significant difference at the end of the second half of flowering (T3) with 60% shade cloth could be attributed to the high variability in data (Coefficient of variation = 22%).

LAI rose to a peak by the end of the first half of flowering in all treatments (Fig. 4.3). Shading appeared to have had little detrimental effect on LAI due to the increased SLA at reduced light intensity (Fig. 4.4). The consistently-high LAI with 30% shading throughout is attributable to the high DM (Fig. 4.2a) and high SLA (Fig. 4.4a). The decline in LAI during the second half of flowering for most treatments could be attributed to the senescencing of older larger leaves as indicated by the decline in SLA.

Table 4.4. **Summary of ANOVA of total pasture yield (DM), LAI and SLA at the end of the vegetative stage shading of Paraggio barrel medic**

Source of variation	DM vegetative stage	LAI vegetative stage	SLA vegetative stage
Shading treatment	NS	NS	**
Defoliation	***	***	NS
Shading treatment x Defoliation	NS	NS	NS

NS, Not significant ** P<0.01 *** P<0.001

Table 4.5. **Summary of ANOVA of total pasture yield (DM), LAI and SLA at the end of the first half of flowering of Paraggio barrel medic**

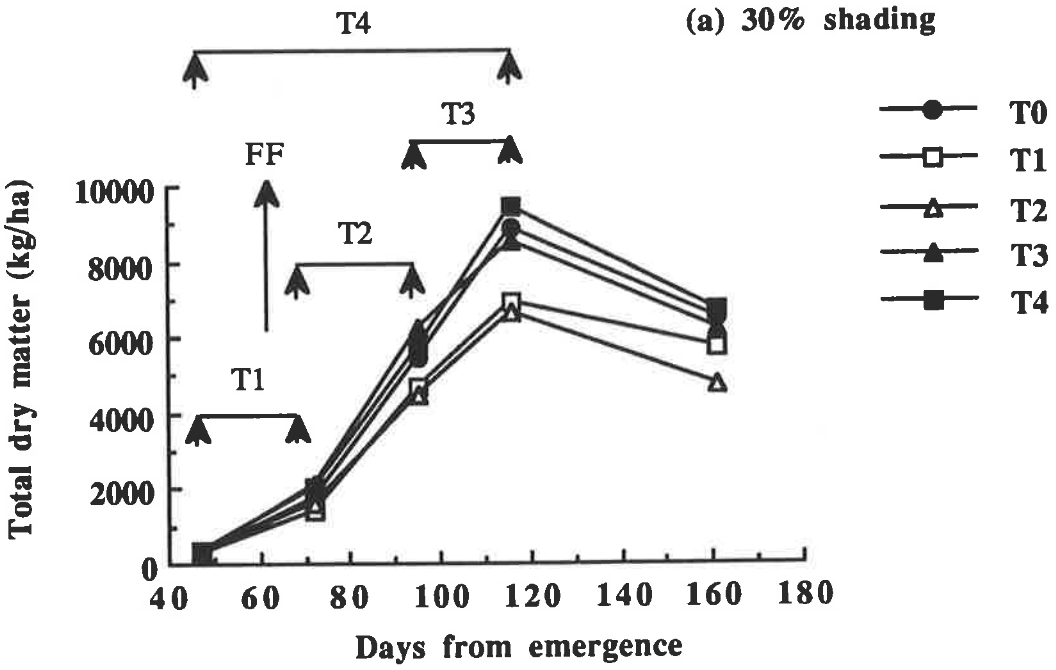
Source of variation	DM first half of flowering	LAI first half of flowering	SLA first half of flowering
Shading treatment	*	NS	***
Defoliation	***	***	NS
Shading treatment x Defoliation	NS	NS	NS

NS, Not significant * P<0.05 *** P<0.001

Table 4.6. **Summary of ANOVA of total pasture yield (DM), LAI and SLA at the end of the second half of flowering of Paraggio barrel medic**

Source of variation	DM second half of flowering	LAI second half of flowering	SLA second half of flowering
Shading treatment	NS	NS	***
Defoliation	***	**	NS
Shading treatment x Defoliation	NS	NS	NS

NS, Not significant ** P<0.01 *** P<0.001



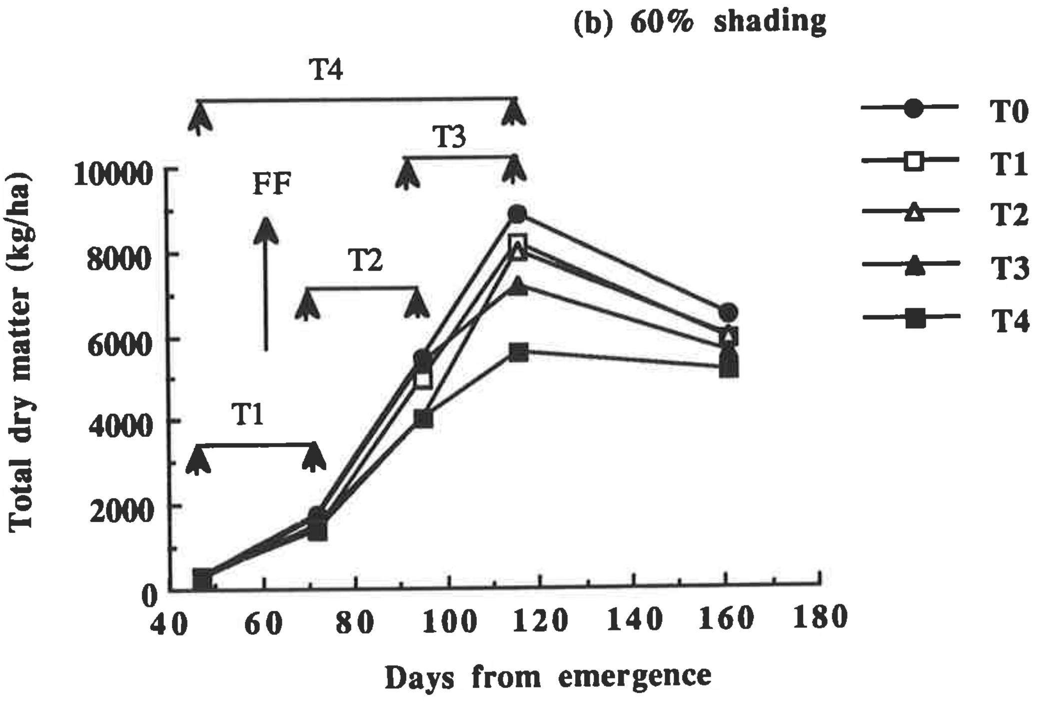
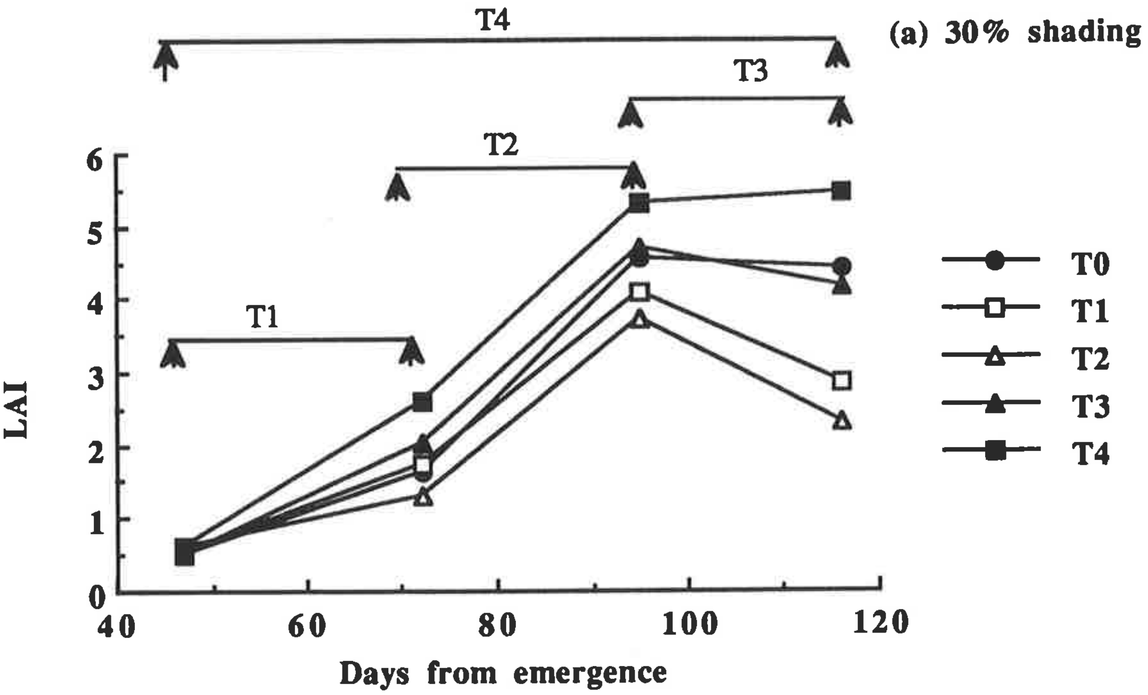


Fig. 4.2. **Effects of 30% and 60% shading on total herbage yield (DM) of Paraggio barrel medic.**

(Values are means of undefoliated and defoliated swards. FF indicates the day of first flower appearance)



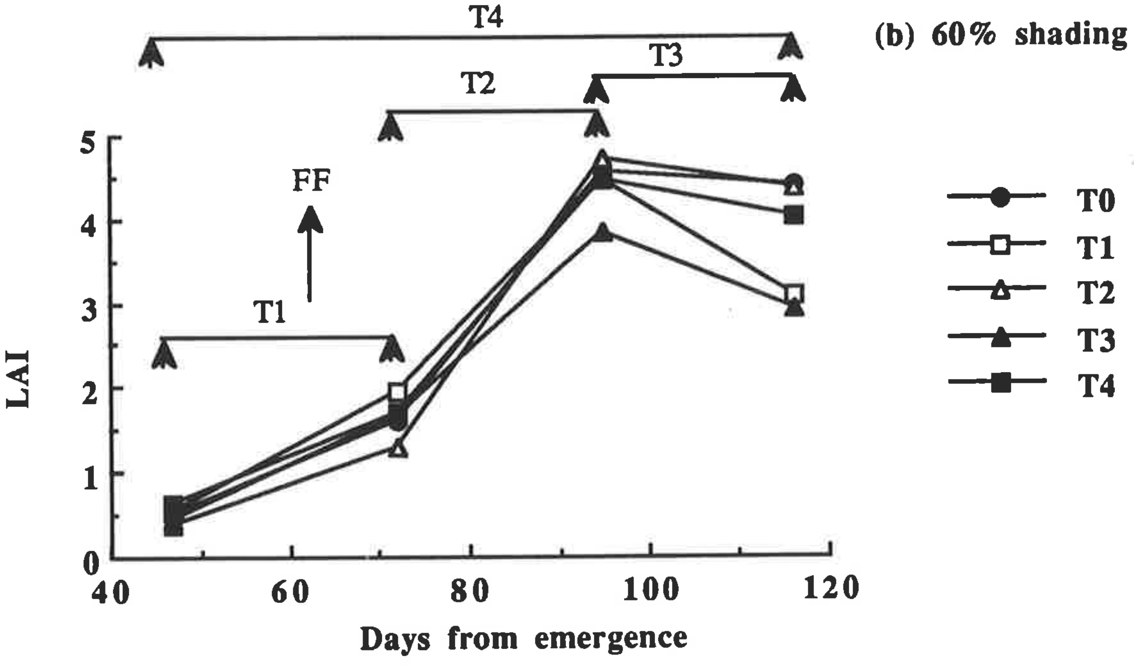
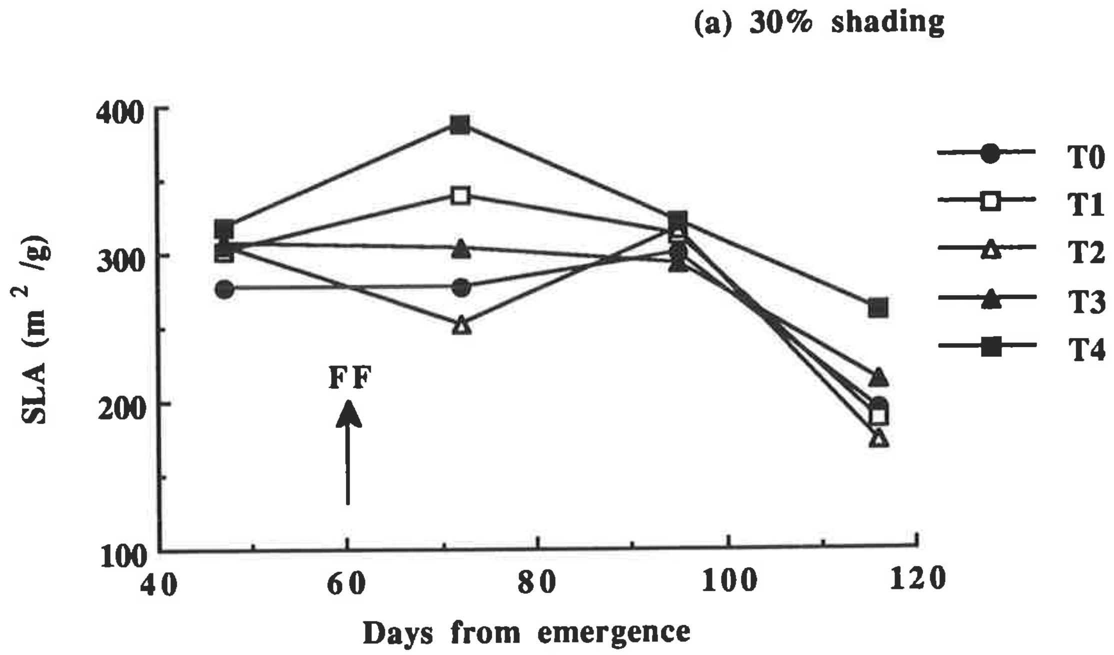


Fig. 4.3. Effects of 30% and 60% shading on LAI of Paraggio barrel medic.

(Values are means of undefoliated and defoliated swards. FF indicates the day of first flower appearance).



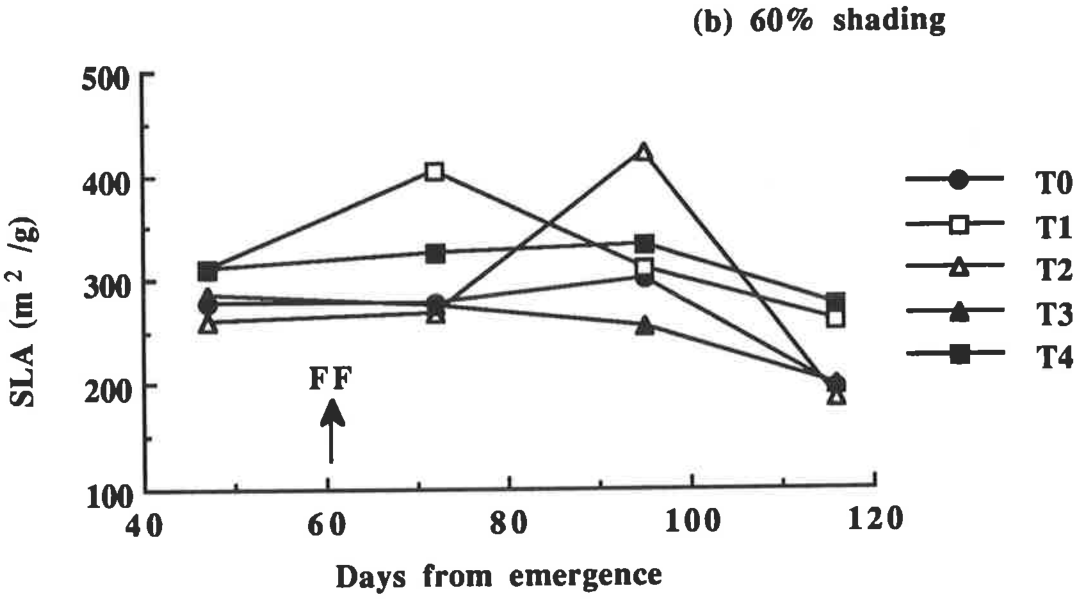


Fig. 4.4. **Effects of 30% and 60% shading on SLA of Paraggio barrel medic.**

(Values are means of undefoliated and defoliated swards. FF indicates the day of first flower appearance).

4.3.2.3. Reproductive growth

Visual observations indicated that shading during the vegetative period delayed flower appearance by one week and that the delay under 60% shade was greater than under the 30% shade. As in the previous experiment, the flowering period in treatments T3 and T4 was extended by about 1 week after removal of shades. Defoliation delayed flower re-appearance by about a week and extended the flowering period by about one and a half weeks. The average number of flowers per fertile raceme remained constant (1.7) irrespective of defoliation or shading treatments.

Shading during the first half of flowering (T2) significantly reduced crop growth rates of undefoliated swards (Table 4.7). There was a tendency also for 60% shading to reduce the number of flowers per m^2 and pods per m^2 during this T2 shading period, but the differences were not significant (Table 4.7). The lack of a significant difference in the number of flowers and pods per m^2 could be partly attributed to the variability in the data (Coefficient of variation = 23.4%) as a result of variability in individual plant growth. Data on the number of flowers per m^2 and pods per m^2 in the defoliated swards were not collected.

Table 4.7. Effects of shading on crop growth rate and reproductive growth during the first half of flowering of undefoliated Paraggio barrel medic, Waite Institute, 1990

Shade level	Shade time	Crop growth rate and reproductive growth at end of first half of flowering		
		Crop Growth Rate (g/m^2/day)	Flowers (#/m^2)	Pods (#/m^2)
Unshaded	Control	23.6	18100	7810
30%	Vegetative stage	19.5	15660	7970
30%	First half of flowering	15.8	14640	6430
30%	Second half of flowering	23.3	NA	NA
30%	Shading throughout	24.1	16000	7770
60%	Vegetative stage	22.7	15600	6790
60%	First half of flowering	12.4	13330	4390
60%	Second half of flowering	21.3	NA	NA
60%	Shading throughout	15.0	10810	4360
	LSD (P<0.05)	8.4	NS	NS

NA, Data not collected NS, Not significant

There was no Shade x Defoliation interaction involving flower survival. Defoliated swards had a higher mean flower survival across shading treatments (54%) compared with the undefoliated swards (49%) but the differences were not significant.

Reducing incident light by 30% had no significant effect on the survival of flowers tagged at either time. Under 60% shade cloth, flower survival was reduced if the flowers continued to develop under reduced light intensities (T2 and T4). However, if the flowers were exposed to full sunlight after shading (T1), flower survival was equivalent to that of the control treatment (Table 4.8). Flowers in swards that had been under 60% shade for only a short time (T2 tagged on 12 October) had an equal chance of reduced flower survival as swards that had been shaded for a long time (T4 tagged on 12 October). The results show that reductions in incident light intensity by 60% reduces flower survival. The results also show that the light environment after tagging was more important than that prior to tagging or the length of period under which the sward had been under shade. The higher flower survival when flowers were tagged at the start of T2 shading than 10 days later, suggests that first-produced flowers have a greater chance of survival than the later flowers.

Table 4.8. **Effects of shading on the survival of flowers produced during the first half of flowering.** (Flowers were tagged at the start of T2 and ten days later and the number of pods counted ten days after tagging)

Shade level	Time of shading	Survival of flowers tagged at the beginning of T2 (3 October) (%)	Survival of flowers tagged 10 days after beginning of T2 (12 October) (%)	
		Undefoliated	Undefoliated	Defoliated
Unshaded	Control (T0)	72.2	50.5	66.8
30%	Vegetative stage (T1)	86.8	59.0	54.5
30%	First half of flowering (T2)	69.0	42.6	51.0
30%	Shading throughout (T4)	77.0	55.8	49.8
60%	Vegetative stage (T1)	77.5	56.2	63.2
60%	First half of flowering (T2)	52.1	36.8	50.1
60%	Shading throughout (T4)	52.3	33.1	40.8
	LSD (P<0.05)	14.6	11.8	NS

NS, Not significant

Comparison of crop growth rates of the undefoliated swards (Fig 4.5, Table 4.7) show that flowers per m^2, flower survival, pods per m^2 were positively correlated with high crop growth rates. These results emphasise the importance of maintaining high growth rates to promote flower survival and pod production. The lack of a significant increase in flower survival with defoliation suggests that there is considerable loss of yield potential through flower and immature pod abortion even when light penetration is improved through the swards by defoliation.

4.3.2.4. Seed yield and seed yield components

Table 4.9 summarises the ANOVA for seed yield and seed yield components. Defoliation significantly reduced seed yield from 987 kg/ha to 668 kg/ha (Appendix Table 4B). There was no Shading treatment x Defoliation interaction suggesting that shading had similar effects on seed yield and seed yield components in both the undefoliated and defoliated swards.

Table 4.10 shows the effect of shading on seed yield and seed yield components, averaged over the undefoliated and defoliated swards. Seed yields of swards that were under 30% shade did not differ significantly from the unshaded control. However, as in Experiment 2 of this Chapter, seed yield tended to be more sensitive to shading during the first half of flowering than to shading at other stages. Shading throughout the flowering period with 60% shade significantly reduced seed yield by 52%, whereas shading during the first half of flowering significantly reduced yields by 25% (Table 4.10). Shading during the vegetative stage (T1) resulted in seed yields similar to those from swards grown entirely in full daylight. Similarly, shading during the second half of flowering caused no reduction in seed yield. Comparison of the shading treatments without the control revealed a significant ($P<0.001$) Shade x Time of shading interaction, with shading during the first half of flowering and 60% shading throughout the flowering period resulting in significantly lower seed yields (Table 4.10). This shows that the early flowering period was more sensitive to reduced light than any of the other stages of growth.

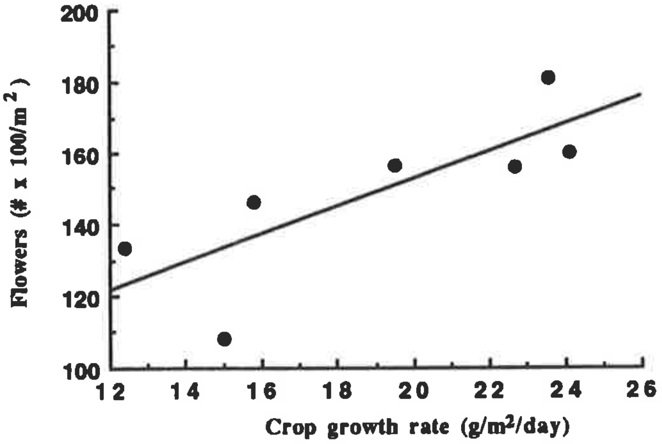
The number of pods per m^2 was significantly reduced from 3535 to 2691 by defoliation (Appendix Table 4B). The effects of shading on the number of pods followed the same trend as seed yield. Comparatively, the number of pods produced in this experiment were lower than those for the same cultivar (Paraggio) in Experiment 1 (Chapter 3) and in Experiment 2 of this Chapter even though the numbers of flowers per m^2, estimated at the end of the first half of flowering in the unshaded treatments (Table 4.8), were higher than those obtained at the optimum sowing rate in Experiment 1. Although the percentage survival of flowers to form mature pods was not determined in the present experiment, the fact that the number of flowers per m^2 were higher than those in Experiment 1 suggest that pods per m^2 at maturity were reduced by low percentage pod set.

The number of seeds per pod was significantly reduced from 6.1 to 5.5 by defoliation. Shading did not reduce the number of seeds per pod significantly, suggesting that seed number per pod is insensitive to light intensity incident on the sward. Defoliation did not reduce mean seed weight significantly. Shading during the second half of flowering or throughout the flowering period with 60% shade cloth significantly reduced mean pod weight and mean seed weight (Table 4.10). When the 60% shade cloth was removed at the end of the vegetative stage shading (T1) or at the end of the first half of flowering (T2), mean seed weight was similar to that of unshaded control, indicating that compensation occurred in seed growth after shade removal.

The seed:pod ratio was significantly increased by 60% shading during the second half of flowering period but not by 60% shading throughout (Table 4.10). In both 60% shading throughout and shading during the second half of flowering, mean seed weight was significantly reduced but the number of pods per m^2 was high in the 60% shading during the second half of flowering. This result suggests that the high seed:pod ratio was related to the large number of seeds per m^2 in the 60% shading during the second half of shading which could have imposed a severe demand on the amount of assimilates allocated to pod wall development.

The harvest index (HI) was generally low, indicating that only a small proportion of the available dry matter was used for seed production. Defoliation significantly reduced the HI from 16% to 12% but with shading, only 60% shading throughout the flowering period significantly reduced HI (Tables 4.9, 4.10). The reduction in HI with defoliation is attributable to fewer seeds per pod, whereas 60% shading throughout reduced HI through reduced mean seed weight.

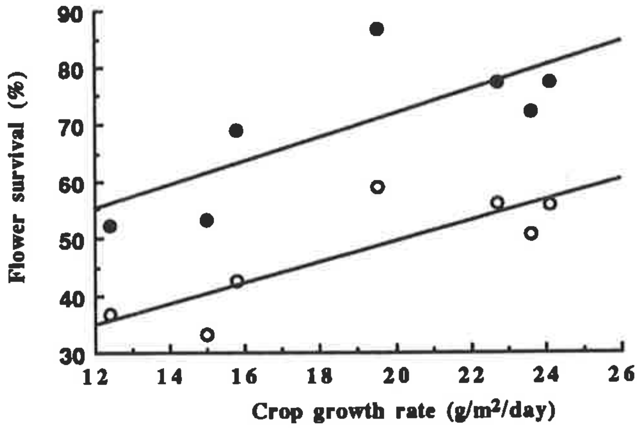
(a) **Flowers** y = 7490 + 388x (r = 0.79*)



(b) **Flower survival**

● Flowers tagged on 3 October, y = 30.17 + 2.08x (r = 0.78*)

○ Flowers tagged on 12 October, y = 13.15 + 1.82x (r = 0.84*)



(c) **Pod number,** y = 1126 + 283x (r = 0.85*)

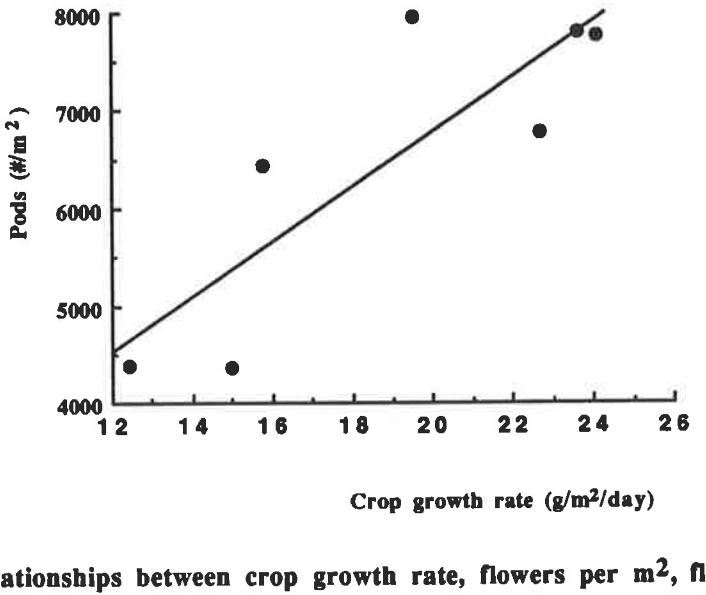


Fig. 4.5. **Relationships between crop growth rate, flowers per m^2, flower survival and pods per m^2 during the first half of flowering of undefoliated swards of Paraggio barrel medic subjected to different shading treatments, Waite Institute, 1990.**

Table 4.9. Summary of ANOVA of the effects of shading treatment and defoliation on seed yield and seed yield components, Waite Institute, 1990

Source of variation	Seed yield (kg/ha)	Pods (#/m^2)	Pod weight (mg)	Seed weight (mg)	Seeds (#/pod)	Seed:pod ratio (%)	Harvest Index (%)
Shading treatment	**	**	**	**	NS	***	**
Defoliation	***	***	NS	NS	***	***	***
Shading treatment x Defoliation	NS	NS	NS	NS	NS	NS	NS

NS, Not significant ** P<0.01 ** P<0.001

Table 4.10. Influence of shading on seed yield and seed yield components of Paraggio barrel medic, Waite Institute, 1990. (Data represents means of the undefoliated and defoliated swards)

Shade level	Time of shading	Seed yield (kg/ha)	Pod (#/m^2)	Pod weight (mg)	Seeds (#/pod)	Seed weight (mg)	Seed:pod ratio (%)	Harvest Index (%)
Unshaded	Control	963	3518	90	5.9	4.64	30.4	15.0
30%	Vegetative stage	866	3222	87	5.8	4.51	30.4	14.9
30%	First half of flowering	788	2950	83	5.9	4.51	32.2	17.0
30%	Second half of flowering	915	3382	80	6.0	4.44	33.5	14.6
30%	Shading throughout	847	3016	87	6.0	4.62	31.6	13.3
60%	Vegetative stage	890	3243	96	5.7	4.70	28.1	14.7
60%	First half of flowering	722	2869	91	5.4	4.73	27.4	12.2
60%	Second half of flowering	1006	3833	74	6.3	4.20	36.0	18.0
60%	Shading throughout	455	1998	78	5.3	4.25	29.2	9.5
	Treatment LSD (P<0.05)	220	696	9	NS	0.28	3.0	4.7
	Shade x Time[a] LSD (P<0.05)	148	433	4	NS	0.30	3.2	4.2

[a] Comparison of shaded treatments without the control

NS, Not significant

4.4. DISCUSSION

The highest seed yield obtained in Experiment 3 of this Chapter was lower than that obtained in Experiment 1 (Chapter 3) and Experiment 2 of this Chapter which could be attributed partly to the late sowing. Although, the experiment was irrigated, sowing on 10 July delayed the start of flowering until 25 September and the end of flowering was delayed so that the second half of flowering occurred during November when temperatures were high (Table 4.2). This result highlights the importance of early sowing in maximising seed production in annual medics. Seed yield, as in previous studies (Adem 1977; Cocks 1988, 1990a,b; Chapter 3) was closely related to the number of pods per m^2.

Defoliation in 1990 reduced medic DM at the end of flowering from 9649 kg/ha to 5759 kg/ha (Appendix Table 4A) and seed yield from 987 kg/ha (Appendix Table 4B) to 668 kg/ha (Appendix Table 4B) despite an increase in flower survival during the first half of flowering (Table 4.8). However, defoliation caused a delay in flower re-appearance after defoliation and flowering continued into December. Irrigation was stopped on the 22 November. The temperatures and levels of moisture stress during this time were probably high enough to affect yield. Temperatures during the month of November were 26/20°C (day/night), and Downes and Gladstones (1984a) have demonstrated in *Lupinus angustifolius* L. that temperatures higher than 21/16°C day/night reduce seed yield through increased flower abortion. Severe moisture stress during the flowering period has been shown to reduce seed yield in subterranean clover and annual medics, with the reduction being mainly through fewer burrs/pods per m^2 (Andrews *et al.* 1977; Collins 1981; Wolfe 1985). The reduction in seed yield with defoliation in this experiment was through a reduction in the number of pods per m^2 suggesting that the adverse effect of defoliation was through the failure of the late-produced flowers to form mature pods. These results suggest that an improvement in light penetration through the sward by a single defoliation at the start of flowering may only increase seed yield if a large number of flowers are produced during early spring. However, the effect of shading on seed yield and seed yield components was similar for both defoliated and undefoliated swards.

In 1989, the effect of 30% shade on seed yield of Sava and Paraggio was similar (Table 4.1) suggesting that different species of annual medics may have a similar response to shade environment. In both 1989 and 1990, 30% shading did not significantly reduce seed yield (Tables 4.1 and 4.10) or vegetative growth in 1990 (Fig 4.2a). The lack of a significant reduction in seed yield with 30% shading is consistent with the results of McGowan and Williams (1973) who demonstrated that seed production in undersown subterranean clover was only significantly reduced when light transmission through the barley crop during spring fell below 60% of incident light. In grain legumes, Hedley and Ambrose (1979) also reported no significant reduction in seed yield of leafless pea genotypes when they were shaded by 30% shade cloth during the vegetative period or throughout the flowering period. It therefore follows that light saturation for seed production in annual medics and grain legumes occurs at light intensities c. 70% of full daylight and this is of practical importance in terms of mixed pasture or in undersowing cereal crops with annual medics.

Shading throughout the flowering period with 60% shade cloth reduced seed yield by 52%, mainly through a reduction in the number of pods per m^2 and, to a lesser extent, in mean seed weight (Table 4.10). The reduction in the number of pods per m^2 with 60% shading throughout the flowering period could be attributed to poor flower survival (Table 4.8) and to a lesser degree to fewer flowers per m^2 (Table 4.7). The results are in agreement with the findings in Chapter 3 where complete self-shading throughout the flowering period reduced seed yield mainly through poor percentage pod set. Collins *et al.* (1978), working with subterranean clover, found similar effects of shading but attributed the reduction in the number of burrs mainly to the reduced number of inflorescences rather than poorer flower survival. In the present study, the interpretation of data on numbers of flowers per m^2 is affected by high variability, but flowers per m^2 were much lower in the 60% shading throughout than in the unshaded control (Table 4.7). The extension of the flowering period after shade removal could have caused some compensation in flowers per m^2 but because of the high temperatures during the month of November (Table 4.2) and the fact that late-produced flowers are more likely to abort than early-produced ones (Cocks 1988, 1990a,b; Table 4.8), it is unlikely that these flowers contributed much to final pod number.

Shading during the vegetative stage (T1) was included to examine whether the reduction in crop growth in undefoliated swards at higher sowing rates observed before flowering in Experiment 1 could cause a reduction in seed yield. This treatment did not reduce crop growth, but the LAI values of the swards at the start of shading were low because of late sowing and not all the incident light was being intercepted (Fig 4.3a,b). This suggests that when the LAI is low, a reduction in the amount of solar radiation received by the medic sward does not result in reduced crop growth rate. The result is in agreement with the reviews of Blackman and Black (1959); Donald (1963); Brown and Blaser (1968) which show that at low light intensities less leaf area is required to intercept the available light for accelerated growth. Seed yields in (T1) were similar to the unshaded control because of the lack of a reduction in flower survival and crop growth rates during the flowering period (Tables 4.7, 4.8, 4.10). Meadley and Milbourn (1971) reported similar results in vining peas, that is, removal of 50% shade at the start of flowering, increased flower production and percentage pod set so that seed yields were similar to the unshaded control.

When 60% shading was imposed during the first half of flowering, medic DM and flower survival were significantly reduced during the shading period (Fig 4.2b, Table 4.8). The number of flowers and pods per m^2 were also much lower than the unshaded control (Table 4.7). However, compensation occurred after shade cloth removal so that the DM was similar to the unshaded control by the end of the second half of shading and seed yield was significantly reduced but by 25% only (Fig 4.2B, Table 4.10). Reduction in seed yield was due to fewer pods per m^2. Data on flower survival were not collected during the second half of flowering: however, results on short-term effects of shading on flower survival during the first half of shading showed that an improvement in light intensity following shading increased flower survival (Table 4.8). Shading during the second half of flowering with 60% shade cloth did not reduce pods per m^2, indicating that the largest loss of yield in this experiment occurred during the first half of flowering. These results support the findings of Experiment 1 which showed that early production of a large number of flowers and better light penetration during early flowering is more important in terms of pod set and seed yield than better light penetration later in the flowering period.

The lack of a significant reduction in seed yield with 60% shading during the vegetative stage (T1) and the more than 25% compensation in yield after shade removal at the end of the first half of flowering (T2) contrasts with the results in determinate cereals. In wheat and maize, for example, shading before flowering or at anthesis reduces seed yield with reductions being proportional to the intensity of shading (Fischer 1975; Fisher and Palmer 1983) and there is very little compensation following shade removal. This result illustrates the added flexibility of an indeterminate plant to reduced light intensity at some stages of the reproductive period.

The number of mature pods is limited by both the abscission of flowers and young pods (Cocks 1988). In the present study, apart from flower abortion, it was also observed that young pod abscission was also higher under shade conditions than under full daylight. Studies in grain legumes show that once freshly-pollinated and fertilised pods have passed the stage of abortion, they become stronger sinks, thereby importing assimilates from leaves at other flowering nodes for their growth instead of relying on the source leaf alone (Jeuffroy and Warembourg 1991; Pigeaire *et al.* 1992). In *Lupinus angustifolius*, Pigeaire *et al.* (1992) have defined this stage as when pods are more than 10 mm in length. No such studies have been reported in forage legumes and the lack of a reduction in pod numbers with 60% shading during the second half of flowering in this experiment suggests that most of the pods produced in full daylight had passed the abscission stage and they contributed most to final pod numbers, rather than the pods produced during the second half of flowering.

High temperature influences seed set in most pasture seed crops by preventing the formation of viable pollen and causing flower abscission (Nitsch 1965). Although the influence of temperature on pod set has not been studied in annual medics, the mean day/night temperature of 20/11°C during the first half of flowering is within the range suitable for vegetative growth (Ababneh 1991). Downes and Gladstones (1984a) have shown a similar range to be most suitable for optimum pod set in *Lupinus angustifolius* L. During the second half of flowering the mean day/night temperatures were 26/20°C (Table 4.2) and half of the period had day temperatures over 30°C, which were possibly too high for effective pod set. This supports the contention that the first half of flowering contributed more to the number of mature pods in comparison to the second half of flowering.

There have been a number of possible mechanisms suggested for flower/pod abscission in legumes. Increased flower abscission by the 60% shading throughout the flowering period is in agreement with the results of Experiment 1 (Chapter 3) where complete self-shading throughout flowering at the 125 and 625 kg/ha sowing rates reduced crop growth rates and percentage pod set in comparison to where complete self-shading occurred later during the reproductive period (e.g. at the 25 kg/ha sowing rate). The finding that high crop growth rates increased flower survival (Fig. 4.5) supports the prevalent hypothesis in grain legumes that pod set is partly reduced by the supply of photoassimilates to developing flowers and young pods (e.g. Schou *et al.* 1978; Brun and Betts 1984).

However, some studies indicate that light may affect flower and pod development through mechanisms other than photosynthesis and assimilate supply. Heindl and Brun (1983) found that shading flowers and young pods of soybean, without shading the photosynthetic leaves increased abscission. In addition, through the use of ^{14}C-labelling of source leaves, they showed that shading of pods reduced the strength and intensity of young developing sinks. Heindl and Brun (1983) concluded that light received by soybean flowers and young pods has a role in regulating both their abscission and their capacity to accumulate photoassimilates (sink strength).

Further evidence for the ability to attract assimilates (sink strength) to regulate abscission is provided by studies of Pate and Farrington (1981) for *Lupinus angustifolius*, and Brun and Betts (1984) and Spollen *et al.* (1986a,b) for soybean. In these studies flowers that eventually abscissed accumulated substantially less ^{14}C-labelled assimilates than those that successfully set pods. Since this difference was observable within a few days after anthesis, when reproductive structures have an extremely low demand for assimilates, Pate and Farrington (1981) concluded that pod set is unlikely to be limited by contemporary assimilate supply to and within a specific inflorescence. In addition, it appeared that phloem transport was inhibited in abortive flowers several days before abscission (Pate and Farrington 1981).

There are also many studies reported in the literature which indicate a role of growth regulators in reproductive development of legumes (Carlson *et al.* 1987; Dyer *et al.* 1988;

García-Martínez *et al.* 1991). However, the nature of interaction in determining abscission is not known. Reports on the use of exogenous application of cytokinins to reduce flower abscission in several grain legumes (Crosby *et al.* 1981; Dyer *et al.* 1988; Rylott and Smith 1990) appear to implicate their ability to increase the sink strength and delay senescence of leaf tissue as a feature of their mode of action in pod development. Cytokinins are produced by the root system and transported to the inflorescence in the channels of xylem or phloem (Sitton *et al.* 1967; Wareing *et al.* 1968; Heindl *et al.* 1982). Factors which reduce translocation from the root to the shoot, such as low light, are thus likely to reduce the supply of cytokinin to reproductive organs thereby increasing abortion (Davey and Van Staden 1978a,b,c; Heindl *et al.* 1982).

In the present study, flowers produced under 60% shade conditions and exposed to full daylight later had an equal chance of survival as those produced under full daylight conditions throughout (Table 4.8). Although the experiment was not designed specifically to test the roles of source supply and sink strength in regulating flower survival, the data appear to be in favour of source supply or factors inherent in the reproductive structures themselves or hormonal hypotheses rather than direct influence of light on sink strength. If sink strength was the factor most limiting flower survival, it would be expected that flowers produced under full daylight would have had a better chance of survival when put under shade conditions than those produced and raised under shade conditions throughout, but clearly this was not the case.

Shading with 60% shade cloth throughout flowering and during the second half of flowering reduced mean pod weight and mean seed weight (Table 4.10). This may be a mechanism to ensure that the actively-developing pods present, when assimilate supply was limited by shading, reach maturity. The increase in seed:pod ratio when the swards were shaded during the second half of flowering also suggests that when the assimilate supply to a large number of developing pods is reduced by shading, the seed, being a more powerful sink, leaves little carbohydrate for extra dry weight accumulation in the pod wall. Alternatively it could be that the pod wall acts as a temporary storage organ such that under stressed conditions the DM in the pod wall can be utilized to maintain seed growth. This observation is in agreement with the results of Experiment 1 (Chapter 3) and of Summerfield *et al.* (1976) with cowpeas where 50% shading during the grain-filling stage reduced the seed:pod ratio.

The low values of HI in Chapter 3 and Experiment 3 of this Chapter show that there is considerable loss of yield potential in annual medics even under adequate source supply. The similarity of DM yield and seed yield between the unshaded and the 30% shade treatments suggests that annual medics are capable of producing substantial amounts of seed under mixed pastures or when undersown into cereal crops when the level of shading is not too great. However, the present study was irrigated during the spring season and because severe moisture stress is a common occurrence during spring in South Australia (French and Schultz 1984) more investigations on the interrelationships between the level of shading and moisture stress on seed production are required. The similarity in seed yield between the unshaded and 60% shading during the second half of flowering suggests that seed yield in annual medics under dryland farming conditions can be improved by maximising the yield potential during the early flowering period by improving the light incident on the flowers and pods. In the present study, defoliation increased flower survival but seed yield was limited by the number of flowers per m^2. The conflict between reducing the number of flowers when swards are defoliated (Experiment 3 of this Chapter) and inadequate photosynthetic supply when swards are not defoliated as observed in Chapter 3 and Experiment 3 of this Chapter could possibly be resolved by the proper timing of defoliation/grazing and this strategy is investigated in later Chapters. In situations where cereals are undersown with annual medics, seed yields can be improved by delayed sowing of the cereal crop, sowing cereals at low rates or defoliating the cereal crop in late winter to allow better light penetration to the medic sward during the early flowering period.

SUMMARY AND CONCLUSIONS

Seed yield in defoliated swards was constrained by fewer flowers per m^2 during early spring as a result of delayed flower re-appearance after defoliation so that improvement in flower survival did not increase seed yield. In undefoliated swards the major constraint to seed yield was the survival of flowers to form mature pods. Reductions of normal spring light intensities by 30% showed no source limitation to dry matter yield, flower survival and seed yield. Reducing irradiance by 60% throughout the flowering period significantly reduced seed yield but had little effect on the final dry matter production. The early flowering period was more sensitive to a reduction in solar radiation than the late flowering period. Improvement in seed yield may therefore come from improving the proportion of potential yield realised during the early-flowering period, by greater retention of pods through better light penetration at this time. The importance of canopy manipulation through defoliation to maximise flower production and flower survival during the early flowering period is investigated in later Chapters.

CHAPTER 5

EFFECTS OF DEFOLIATION INTENSITY, FREQUENCY AND TIME OF FINAL DEFOLIATION ON SEED YIELD OF PARAGGIO BARREL MEDIC

5.1. INTRODUCTION

The varieties of annual medics currently used by farmers, like other forage crops, have been selected mainly for high herbage production because of the desire to improve greenfeed production and nitrogen fixation (Crawford *et al.* 1989). Seed production is also one of the selection criteria, but it is often secondary to herbage production. In dense pasture swards with LAI values above 4 at the start of flowering, seed yield may be limited because a high proportion of the flowers and young pods abort (Chapters 3, 4). The two experiments (i.e. Expt. 2 and Expt. 3) described in Chapter 4 suggest that these losses could be due to an inadequate supply of photosynthate, which can result from poor light penetration through the sward to the source leaves of flowers and young pods. In contrast, towards the end of flowering, pod production is less sensitive to low light (Chapters 3, 4). These results suggest that under dryland conditions, where cessation of flowering due to high temperature and declining availability of soil moisture is beyond the farmer's control, increases in seed yield may depend largely on identifying suitable management practices to optimize pod set during the early part of the flowering period.

Annual medic seed producers and graziers in South Australia try to increase seed yield by reducing excessive vegetative growth prior to flowering by grazing, mowing or using low rates of herbicides (Carter 1988). Tow and Al Alkailah (1981) and Carter (1989) showed that a single, lenient defoliation (at a height of 5 - 8 cm) of *M. truncatula* cvv. Jemalong and Paraggio at the start of flowering had little effect on seed yield, whereas severe defoliations (at a height of 1 and 2 cm) significantly reduced seed yield (Tow and Al Alkailah 1981). In contrast, Collins (1978) found in subterranean clover that defoliation at the start of flowering increased seed yield. In commercial situations, the grazing management of many pastures is such that pastures are subjected to frequent and often severe defoliation, especially during autumn and winter, which may affect seed yield adversely. These experimental results suggest that the severity of defoliation is important for the management of annual medic seed crops and that grazing or mechanical defoliation strategies may be different from those of subterranean clover. The timing of the final defoliation in relation to the cultivar and environment is also important to subterranean clover seed yield (Rossiter 1961; Collins 1978; Steiner and Grabe 1986): however, in annual medics there is apparently little information on the influence of variation in timing of final defoliation or grazing on commercial seed production.

Two field experiments were therefore carried out to examine the influence of severity, frequency and time of final defoliation on the canopy structure, reproductive growth and final seed yield of annual medic. One experiment was conducted in a lower-rainfall area (360 mm per annum, at Korunye, South Australia) and the other in a higher-rainfall area (583 mm per annum, at the Waite Institute, South Australia) so that the influence of defoliation in relation to the environment in which the pasture is grown could be assessed. Climatic data for both these sites is summarised in Table 5.1.

Table 5.1. **Rainfall data for Korunye S.A. and rainfall, temperature and solar radiation data for Waite Agricultural Research Institute , S.A..**

Month	Korunye S.A		Waite Agricultural Research Institute S.A					
	Rainfall (mm)		Rainfall (mm)		Temperature (°C)			Solar rad. (MJ/m^2/day)
	1883 - 1990	1990	1925 - 1991	1991	1991			1991
					Max.	Min.	Mean	
January	8.5	6.4	23.8	54.4	28.7	17.7	23.2	24.1
February	9.9	10.4	23.8	0.0	29.8	16.2	23.0	26.3
March	10.7	0.0	23.2	5.0	25.2	14.8	20.0	18.3
April	19.3	2.2	54.2	42.6	22.5	13.7	18.1	12.3
May	41.3	11.8	78.4	12.8	18.7	10.6	14.6	8.0
June	51.8	65.6	76.0	141.8	17.0	11.4	14.2	5.2
July	57.3	63.4	88.5	103.0	14.7	8.6	11.7	6.1
August	49.4	60.4	75.4	88.0	14.9	8.8	11.8	8.8
September	31.9	32.0	62.1	90.0	18.4	10.0	14.2	13.1
October	28.7	19.6	51.8	7.6	22.2	12.1	17.1	19.7
November	31.0	2.2	36.6	35.0	23.9	13.6	18.8	23.4
December	29.1	26.4	29.8	5.6	25.2	14.3	19.7	24.8
Total	360.1	274.0	623.5	585.8				

5.2. EXPERIMENT 4 (KORUNYE)

5.2.1. MATERIAL AND METHODS

Site and experimental design. The experiment was conducted in a commercial seed crop of Paraggio barrel medic sown in May 1990 at Korunye, 60 km north of Adelaide. Korunye lies within the transition zone between solonised brown soils and red brown earths (Carter *pers comm.*). The seed crop was grown by the farmer under normal district practices and the plant density at the start of flowering was 580 plants per m^2. The swards were heavily grazed by sheep at a stocking density of c. 20 sheep/ha to a height of 3 cm during July. The long-term rainfall and monthly rainfall for 1990 are shown in Table 5.1. The swards were rainfed throughout the growing season. The start of flowering was defined as the stage when 10% of the plants in the sward had began to flower. After the start of flowering (6 September) the following treatments were applied to the sward: control (undefoliated); defoliated to 3 cm at start of flowering; defoliated to 3 cm, 10 days after start of flowering; defoliated to 3 cm, 20 days after start of flowering; defoliated to 6 cm at start of flowering; defoliated to 6 cm, 10 days after start of flowering and defoliated to 6 cm, 20 days after start of flowering. Thus the experiment comprised 6 defoliation treatments and an uncut control forming a total of 7 treatments which were laid out as a randomised block experiment with 4 replicates. Defoliations were carried out using a hand-operated rotary mower.

Vegetative harvests. Samples to estimate total dry matter production (DM) in each plot were cut at ground level from two quadrats each measuring 25 cm x 40 cm. Pasture cuts were taken at approximately 10-day intervals until the end of flowering. At each sampling, the harvested material was sub-sampled to measure leaf dry weights and leaf area. LAI was measured using an electronic planimeter as described in Chapter 3. The dissected parts were then dried in a forced-draught dehydrator at 85°C for 12 hours to determine the dry weight. The amount of photosynthetic active radiation (PAR) transmitted through the canopy was estimated from LAI as described in Chapter 3.

Flower production and percentage pod set. The number of flowers was estimated at the start of flowering and at the end of flowering. Ten plants were carefully removed from each plot ensuring that all the racemes were retained. The number of flowers per raceme was estimated from 20 randomly selected racemes and was found to be 2. The number of racemes from the 10 plants were counted. The total number of flowers per m^2 and percentage pod set was calculated as in Chapter 3.

Seed harvest. Pods were harvested by vacuuming an area of 0.2 m^2, cleaned and a sample of 16 g threshed to determine seed and seed yield components as described in Chapter 3.

5.2.2. RESULTS

The herbage yield at the start of flowering was 1420 kgDM/ha. Highest herbage yields and LAI at the end of flowering (Table 5.2) and highest seed yield (Table 5.3) occurred in the undefoliated control but these were not significantly different from lenient defoliations at the start of flowering. Delays in time of defoliation beyond the start of flowering and/or severe defoliation significantly reduced DM, LAI and seed yield.

The total number of flowers per m^2 at the end of flowering was half those in Experiment 1 (Chapter 3). Defoliation at the start of flowering or 10 days after the start of flowering did not reduce flowers per m^2 or percentage pod set significantly (Table 5.2). Seed yield was significantly reduced by severe defoliation and/or defoliations delayed beyond the start of flowering and was correlated with total DM at the end of flowering ($r = +0.99$; $n=5$), pods per m^2 ($r = + 0.99$; $n=5$) and seeds per m^2 ($r = +1.00$; $n=5$) at maturity. Seed size was only significantly reduced by severe defoliation whereas the number of seeds per pod was stable except with defoliation 20 days after start of flowering (Table 5.3). There was a strong negative relationship between the amount PAR transmitted through the canopy and seed yield, but LAI was generally low even in the control (Table 5.2) indicating that vegetative growth was reduced by the amount of light intercepted. The poor vegetative growth is attributable to the low rainfall in spring (Table 5.1). The seed:pod ratio and HI were highest in the undefoliated control also defoliations at the start of flowering and were lowest following severe defoliation at 20 days after start of flowering (Table 5.3).

Table 5.2. **Effects of cutting height and time of defoliation on dry matter yield, LAI and total number of flowers at end of flowering and percentage pod set of Paraggio barrel medic at Korunye in 1990**

Height of defoliation	Time of defoliation	Herbage (kgDM/ha)	LAI	Trans. of PAR (%)	Flowers (#/m^2)	Pod set (%)
Control	Undefoliated	4840	1.15	16.6	8790	42.6
3 cm	Start of flowering	3671	0.87	21.1	9200	30.2
3 cm	10 days after flowering	2340	0.62	25.7	7553	26.1
3 cm	20 days after flowering	1441	0.21	37.6	NA	NA
6 cm	Start of flowering	4426	1.03	18.1	10138	39.1
6 cm	10 days after flowering	3249	0.68	24.5	756	27.3
6 cm	20 days after flowering	1666	0.25	35.9	NA	NA
	LSD (P<0.05)	1134	0.30	5.83	NS	NS

NA, Data not collected; NS, Not significant

Table 5.3. **Effects of cutting height and time of defoliation on seed yield and seed yield components of Paraggio barrel medic at Korunye in 1990**

Height of defoliation	Time of defoliation	Seed yield (kg/ha)	Pods (#/m^2)	Seeds (#/m^2)	Seed weight (mg)	Seeds (#/pod)	Seed:pod ratio (%)	Harvest Index (%)
Control	Undefoliated	936	3590	22830	4.12	6.35	30.3	16.6
3 cm	Start of flowering	663	2728	17080	3.87	6.27	28.7	17.9
3 cm	10 days after flowering	358	1726	9670	3.68	5.60	26.5	13.5
3 cm	20 days after flowering	107	952	2840	3.75	2.98	22.7	6.1
6 cm	Start of flowering	855	3464	21500	3.98	6.22	29.8	17.6
6 cm	10 days after flowering	529	2109	13140	4.02	6.28	27.4	14.7
6 cm	20 days after flowering	195	1201	4920	3.93	4.02	24.9	8.8
	LSD (P<0.05)	115	543	3279	0.26	0.70	1.8	2.3

5.3. EXPERIMENT 5 (WAITE INSTITUTE)

5.3.1. MATERIALS AND METHODS

Sowing details and experimental design. The experiment was conducted at the Waite Agricultural Research Institute, near Adelaide, in 1991. The field was previously under oats for two years and details of the soil are given in Chapter 3. The long-term rainfall as well as the monthly rainfall, temperature and solar radiation for 1991 are shown in Table 5.1. The area was irrigated with 17 mm of water per day for 2 days using spray irrigation before sowing. Paraggio barrel medic was sown at 20 kg/ha, representing the sowing rate that gave optimum seed yield in Experiment 1 (Chapter 3) and 200 kg/ha, representing plant densities that significantly reduced seed yield in Experiment 1. Seeds were weighed, inoculated and sown with a cone-seeder-fitted seed drill in plots 10 rows wide at a row spacing of 15 cm and 10 m long. The experiment was sown on 9 May 1991. Phosphorus at a rate of 9 kg P/ha was applied as single superphosphate at the time of sowing. Thirteen millimetres of water was applied using overhead sprays whenever necessary to give satisfactory germination and emergence because of dry conditions soon after sowing. Irrigation was stopped as soon as the rains became reliable and the medic was then rainfed throughout the season. Seedling emergence was complete by 1 June. First flower appearance (26 August) was defined as the start of flowering in this experiment.

Defoliation treatments commenced on 23 July (53 days after emergence). A hand-operated rotary mower was used to give the following defoliation treatments:

D0 - undefoliated control;

D1 - a single early defoliation (23 July) to 3 cm height;

D2 - as for D1 plus a 3 cm (severe) defoliation at flower appearance (infrequent);

D3 - as for D1 plus a 6 cm (lenient) defoliation at flower appearance (infrequent);

D4 - as for D1 plus a 3 cm (severe) defoliation on 8 August and at flower appearance (frequent);

D5 - as for D1 plus a 6 cm (lenient) defoliation on 8 August and at flower appearance (frequent);

D6 - as for D1 plus a 3 cm (severe) defoliation at two and a half weeks after flower appearance (infrequent); and

D7 - as for D1 plus a 6 cm (lenient) defoliation at two and a half weeks after flower appearance (infrequent).

There were 16 treatment combinations (Sowing rates (2) x Defoliations (8)) arranged in a randomised complete block design with 4 replicates (Plate 5.1).

Plant numbers and vegetative harvests. Samples for determination of plant numbers and DM yield per plot were cut at ground level in three quadrats of 30 cm x 33 cm each at 30 and 60 days from the first flower appearance. The undefoliated control and D1 treatments at first flower appearance (26 August 1991) were sampled at monthly intervals until the end of flowering but because of hail damage on 23 August, which disturbed crop growth, yields before flowering will not be discussed. As both treatments which were defoliated at two and a half weeks after first flower appearance did not recover from defoliation they were not sampled subsequently.

At each harvest, plants at 20 kg/ha sowing rate were counted whereas at the 200 kg/ha sowing rate, a sample of 50 plants was counted and dried at 85°C for 24 hours. The total number of plants was then calculated from the total dry weight per quadrat. After counting, the herbage in the first two replicates was sub-sampled for determination of leaf area as described in Chapter 3 and LAI was calculated from herbage yields for all the replicates.

Plate 5.1: **Experiment 5:** **Effects of defoliation and density on growth of Paraggio barrel medic.**

Upper: **Medic growth on plots sown at 20 kg/ha and 200 kg/ha, 45 days after emergence.**

Lower: **The impact of defoliation at 3 cm and 6 cm on 26 August on growth at the start of flowering.**

The remainder of the sample was dried at 85°C for 24 hours before weighing. PAR transmission was estimated from LAI as described in Chapter 3.

Leaf water potential. Leaf water potential was measured on 12 October and 18 October (134 and 140 days after plant emergence) using a Scholander pressure chamber (Waring and Cleary 1967). A fully-expanded leaf, usually the third from the top, was taken randomly and placed immediately into a polythene bag. The leaf was then transferred to the pressure chamber within one minute of detachment from the plant and the pressure adjusted until water was seen at the cut surface of the petiole. Each measurement was repeated on 3 leaves per plot on each date. All measurements were made between 10.30 a.m and 2.00 p.m, which coincided with the time when there was little change in leaf water potential (Fig 5.1).

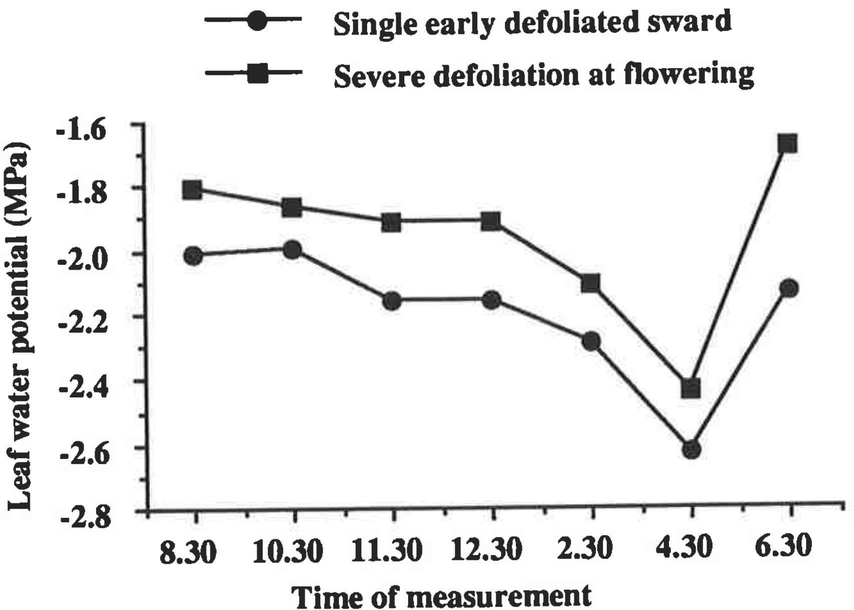


Fig. 5.1. Effects of time of the day on leaf water potential on 11 October 1991

Flower production and percentage pod set. Dates of commencement of flowering and flower re-appearance after each defoliation were recorded. The number of flowers per raceme was estimated in the field by counting the number of flowers from 20 randomly selected racemes in each plot on 20 September and 15 October. Each raceme consisted of 2 flowers irrespective of the experimental treatment. The results were in close agreement with those of Chapter 3 and expectations for Paraggio barrel medic (Oram 1990).

The number of racemes from 5 randomly uprooted plants from each treatment was counted on 27 September and 29 October. The branches from each plant were carefully recovered even though they were entangled in the sward. The total number of flowers per m^2 and percent pod set were calculated as described in Chapter 3. The number of branches was counted at the end of the flowering period (29 October). Only branches that were more than 10 cm long were counted.

Seed harvest. Harvesting of pods was done by vacuuming an area of 0.2 m^2. Threshing to determine seed yield and yield components was the same as in Chapter 3.

5.3.2. RESULTS

5.3.2.1. Plant density

The mean plant density 40 days after establishment was 583 plants/m^2 for the 20 kg/ha sowing rate and 1617 plants/m^2 for the 200 kg/ha sowing rate (Plate 5.1). In all treatments density fell with time. At 200 kg/ha, severe defoliation at first flower appearance (D2) reduced plant numbers by about 50%, whereas lenient (but frequent) defoliation (D5) reduced plant numbers by 25% (Table 5.4). Lenient, but infrequent, defoliation (D3) and single early defoliation (D1) did not significantly reduce plant numbers by the 27 October (end of flowering) at both sowing rates (Table 5.4). At the lower sowing rate (20 kg/ha) only severe, but infrequent, defoliation (D2) reduced the plant numbers significantly, whereas at 200 kg/ha sowing rate, severe defoliation at the start of flowering (D2, D4) significantly reduced the number of plants per m^2.

The reduced number of plants per m^2 was compensated by increases in the number of branches per plant in each sowing rate (Table 5.4) so that by the end of the flowering period (60 days from flower appearance) the number of branches per m^2 was not significantly different between treatments (Table 5.4). The greatest compensation occurred where the plant numbers were severely reduced by defoliation (Table 5.4). The results show that severe defoliation of dense swards can reduce the number of plants per m^2 but the number of branches at the end of flowering may not be affected because of better branching in sparse swards.

5.3.2.2. Herbage yield and canopy structure

A hail storm on the 23 August severely damaged plots. The mean DM yields at first flower appearance (26 August) was 1416 kg/ha and there was no difference between sowing rates or undefoliated swards and those with a single, early defoliation, possibly because of the hail damage. Table 5.5 shows the summary of ANOVA for herbage production, LAI and PAR transmission through the canopy at 30 days and 60 days after flowering. Herbage production and LAI increased with time after defoliation and the amount of PAR transmitted through the canopy consequently fell. The yield of DM on undefoliated treatments was higher in the swards sown at 20 kg/ha than in swards sown at 200 kg/ha (Table 5.6) possibly because of quicker recovery after the hail storm. Swards sown at 200 kg/ha were dense and erect and as a result the hail storm knocked off most of the growing points which slowed down the recovery as compared to the more prostrate swards in the 20 kg/ha sowing rates.

Sowing rate x Defoliation interactions were significant at mid-flowering but at the end of flowering only the main effect of defoliation was significant. In general, a single early defoliation of swards sown at 20 kg/ha and no defoliation at both sowing rates gave the highest herbage yields (Table 5.6). Severe defoliation of swards sown at 200 kg/ha resulted in four times less DM than the undefoliated control, whereas severe defoliation (D2, D4) of swards sown at 20 kg/ha yielded two times less than the undefoliated control (Table 5.6). The lower herbage yields in swards sown at 200 kg/ha is attributed to poor recovery after defoliation.

The single early-defoliated and undefoliated swards at both sowing rates reached LAI above 4 at mid-flowering (30 days after flower appearance) and were completely self-shaded for most of the flowering period (Table 5.6). Severe but infrequent defoliation (D2) of swards sown at 20 kg/ha resulted in a LAI of 2 at mid-flowering and hence only complete self-shading during the second half of flowering. In contrast, severe defoliation of swards sown at 200 kg/ha resulted in an LAI of less than 0.5 at mid-flowering (Table 5.6) and hence DM yields were limited by poor light interception.

Treatments defoliated at two and a half weeks after flower appearance did not recover well from defoliation and therefore were not further sampled. The poorest recovery occurred in the swards sown at 20 kg/ha which is rather surprising: however, these swards had rapidly regrown after the 23 July defoliation, so that by two and a half weeks after flower appearance the 20 kg/ha swards were more-dense and taller than those sown at 200 kg/ha . Regrowth of the swards sown at 200 kg/ha was poorer because the defoliation on 23 July reduced plant numbers and removed most of the leaves. As a result of this difference in recovery of the swards, defoliation two and a half weeks after first flower appearance removed most of the growing points in swards sown at 20 kg/ha resulting in death of most plants compared to the 200 kg/ha sowing rate swards.

Table 5.4. Effects of defoliation height , frequency and time of final defoliation on the number of plants per m^2,branches per plant and per m^2 of Paraggio barrel medic at Waite Institute, 1991

Sowing Rate & defoliation height	Frequency of defoliation	Time of final defoliation	Plants /m^2 29 Oct.	Branches/plant 29 Oct.	Branches/m^2 29 Oct.
20 kg /ha					
	Undefoliated	Control	300	2.3	667
3 cm	Single	Early	256	2.8	694
3 cm	Infrequent	Flower appearance	137	7.3	954
6 cm	Infrequent	Flower appearance	276	4.3	1110
3 cm	Frequent	Flower appearnce	245	4.5	1103
6 cm	Frequent	Flower appearance	256	4.0	975
200 kg/ha					
	Undefoliated	Control	323	2.8	916
3 cm	Single	Early	429	1.8	723
3 cm	Infrequent	Flower appearance	139	6.0	772
6 cm	Infrequent	Flower appearance	349	3.0	1046
3 cm	Frequent	Flower appearance	166	4.3	671
6 cm	Frequent	Flower appearance	240	4.0	923
	Sowing rate x Defoliation	LSD (P<0.05)	90	NS	NS

NS, Not significant

Table 5.6. Effects of defoliation height, frequency and time of final defoliation on herbage yield, LAI and light transmission of Paraggio barrel medic at Waite Institute, 1991[a]

Height of defoliation	Frequency of defoliation	Time of final defoliation	Herbage yield (kgDM/ha)		LAI		Light transmission (PAR) (%)	
			30 days after flowering	60 days after flowering	30 days after flowering	60 days after flowering	30 days after flowering	60 days after flowering
20 kg/ha Sowing rate								
	Undefoliated	Control	5987	13370	8.3	12.6	0.7	0.0
3 cm	Single	Early	4916	13320	7.1	14.8	0.7	0.0
3 cm	Infrequent	Flower appearance	1386	5770	2.0	5.2	12.9	1.0
6 cm	Infrequent	Flower appearance	2493	7550	3.2	8.5	2.6	0.1
3 cm	Frequent	Flower appearance	2664	6840	3.3	7.5	2.5	0.1
6 cm	Frequent	Flower appearance	3188	8150	3.4	8.8	2.3	0.0
200 kg/ha sowing rate								
	Undefoliated	Control	4355	11340	5.8	10.6	0.5	0.0
3 cm	Single	Early	3692	8270	5.6	8.5	0.4	0.1
3 cm	Infrequent	Flower appearance	609	3510	0.3	2.1	33.2	9.9
6 cm	Infrequent	Flower appearance	1500	5100	1.3	4.5	14.9	0.7
3 cm	Frequent	Flower appearance	674	3560	0.4	2.6	32.1	4.7
6 cm	Frequent	Flower appearance	1398	4520	1.3	3.7	14.6	2.7
	(Mean defoliation	LSD (P<0.05)	432	1430	0.7	1.9	3.7	2.9)[b]
	Sowing rate x Defoliation	LSD (P<0.05)	611	NS	NS	NS	5.2	4.0

NS, Not significant

[a] Data from defoliation treatments at two and a half weeks after flower appearance are not included

[b] Defoliation LSD for the means of 20 and 200 kg/ha sowing rates

Table 5.5. **Summary of ANOVA on the effects of defoliation height, frequency and time of final defoliation on herbage yield, LAI and PAR transmission of Paraggio barrel medic at Waite Institute, 1991**[a]

Source of variation	30 days after flowering			60 days after flowering		
	Yield (kgDM/ha)	LAI	Trans. of PAR %	Yield (kgDM/ha)	LAI	Trans. of PAR %
Density	***	***	***	***	***	***
Defoliation	***	***	***	***	***	***
Density x Defoliation	*	NS	***	NS	NS	*

NS, Not significant; * P<0.05; ***P<0.001

[a] Statistical analyses excludes data from treatments defoliated at two and one half weeks after flower appearance.

5.3.2.3. **Leaf water potential**

The main effects of Sowing rate and Defoliation on mean leaf water potential were highly significant (P<0.001) but the Sowing Rate x Defoliation interactions were non significant. There was little difference between the undefoliated swards and single early defoliated swards but further defoliations up to or at the start of flowering significantly increased the leaf water potential (Table 5.7).

Table 5.7. Effects of defoliation height, frequency and time of final defoliation on leaf water potential of Paraggio barrel medic at Waite Institute, 1991

Height of defoliation	Frequency of defoliation	Time of final defoliation	Leaf water potential (MPa)[a]	
			12 October	18 October
	Undefoliated	Control	-1.69	-2.00
3 cm	Single	Early	-1.72	-2.00
3 cm	Infrequent	Flower appearance	-1.50	-1.69
6 cm	Infrequent	Flower appearance	-1.54	-1.76
3 cm	Frequent	Flower appearance	-1.48	-1.79
6 cm	Frequent	Flower appearance	-1.41	-1.77
	Defoliation	LSD (P<0.05)	-0.12	-0.10

[a]Mean leaf water potential for 20 and 200 kg/ha sowing rates

5.3.2.4. Reproductive growth

Time of flowering. The first flower appeared on 26 August (86 days after emergence). A single, early (23 July) defoliation did not delay the time of first flower appearance, whereas defoliation at first flower appearance delayed the time for the re-appearance of flowers by 1.5 to 3 weeks. Severe defoliation (D2, D4), lenient but frequent defoliation (D5) of swards sown at 20 kg/ha and lenient defoliations of swards sown at 200 kg/ha (D3, D5) delayed re-appearance of flowers by about 1.5 weeks whereas severe defoliation (D2, D4) of swards sown at 200 kg/ha and lenient but infrequent defoliation (D3) of swards sown at 20 kg/ha delayed re-appearance of flowers by about 3 weeks. The delay in flower re-appearance was related to the rate of leaf production after defoliation. Infrequently-defoliated swards at the 20 kg/ha sowing rate were more erect by the time of final defoliation and this resulted in more leaf removal. In the 200 kg/ha sowing rate all swards were erect and leaf removal was more severe in the severely-defoliated swards than in the leniently-defoliated swards.

Flower production and percentage pod set. The total number of flowers per m^2 in undefoliated swards was similar between the two sowing rates, but across defoliation treatments 20 kg/ha sowing rate produced significantly ($P<0.001$) more flowers (16,739 flowers per m^2) than 200 kg/ha (12,120 flowers per m^2). The overall defoliation effects were highly significant ($P<0.001$) but Sowing rate x Defoliation interactions were not significant for flowers per m^2 and percentage pod set (Table 5.8). The greatest mean number of flowers across sowing rates was produced in the undefoliated swards (D0) and the lowest in the severe but infrequent defoliation (D2). The mean percentage pod set across sowing rates was significantly increased by severe defoliation (D2, D4) and lenient but frequent defoliation (D5) (Table 5.8). Trends of flower production and percentage pod set between sowing rates and defoliation treatments are shown in Appendix Table 5A.

Table 5.8. Effects of defoliation height, frequency and time of final defoliation on the number of flowers per m^2 and percent pod set of Paraggio barrel medic at the Waite Institute, 1991[a]

Height of defoliation	Frequency of defoliation	Time of final defoliation	Flowers during first half of flowering (26 Aug to 27 Sep) (#/m^2)	Flowers during second half of flowering (28 Sept to 29 Oct) (# /m^2)	Total flowers at end of flowering (26 Aug to 29 Oct) (# /m^2)	Pod set (%)
	Undefoliated	Control	11430	9120	19530	12.7
3 cm	Single	Early	11910	3880	16010	15.2
3 cm	Infrequent	Flower appearance	4230	6710	10930	24.5
6 cm	Infrequent	Flower appearance	6470	8070	14540	15.6
3 cm	Frequent	Flower appearance	6390	5620	12010	21.4
6 cm	Frequent	Flower appearance	7970	5590	13550	22.2
	Defoliation	LSD ($P<0.05$)	4730	NS	2980	5.0

[a] Data represents means for 20 and 200 kg/ha sowing rate

NS, Not significant

5.3.2.5. Seed yield

The amount of herbage DM at the end of flowering in the undefoliated swards of this experiment were higher than those achieved in Experiment 1 (Chapter 3) but pods per m^2 and seed yields were lower. Table 5.9 shows a summary of the ANOVA of the effects of Sowing rate, Defoliation and Sowing rate x Defoliation interactions on seed yield and seed yield components in this experiment. The main effects of sowing rate were not significant but Sowing rate x Defoliation interaction effects were highly significant ($P<0.001$). The lack of a significant difference between sowing rates in the undefoliated swards in this Experiment is contrary to the findings in Chapter 3 where sowing at a rate of 25 kg/ha resulted in significantly higher seed yields than at 125 kg/ha. In the present study hail storms on the 23 August severely defoliated swards so that the DM yields, and hence light penetration, the number of flowers per m^2 and percentage pod set were similar between the 20 kg/ha and 200 kg/ha undefoliated swards (Appendix Table 5A), in contrast to Chapter 3 where complete self-shading occurred before the commencement of flowering at 125 kg/ha and after the start of flowering at 25 kg/ha sowing rate. This difference between experiments is further evidence that seed yield is greatly affected by light penetration through the swards during flowering.

Table 5.9. Summary of ANOVA on the effects of defoliation height, frequency and time of final defoliation on seed yield and seed yield components of Paraggio barrel medic at the Waite Institute, 1991[a]

Source of variation	Seed yield (kg/ha)	Pods (#/m^2)	Seeds (#/m^2)	Seed weight (mg)	Seeds (#/pod)	Seed:pod ratio (%)	Harvest Index (%)
Both sowing rates							
Density	NS	NS	NS	*	NS	NS†	**
Defoliation	NS	NS	NS	NS	NS†	***	***
Density x Defoliation	**	*	*	NS†	NS	**	*

[a]Summary of ANOVA excludes data from defoliation at two and a half weeks after flowering

NS, Not significant; † $P<0.10$; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Severe, but frequent, defoliation at first flower appearance (D4) significantly increased seed yield in swards sown at 20 kg/ha, whereas lenient, but frequent, defoliation up to first flower appearance (D5) increased seed yield in swards sown at 200 kg/ha (Table 5.10). Severe, but infrequent, defoliation at first flower appearance (D2) increased seed yield in swards sown at 20 kg/ha but the differences were only significant at $P<0.10$. When lenient or severe defoliations were performed at two and a half weeks after first flower appearance (D6 or D7), seed yields were significantly reduced with the greatest reduction occurring in swards sown at 20 kg/ha (Table 5.10). The number of pods per m^2 was not significantly increased by defoliation treatments. However, significant reductions in pods per m^2 were observed in lenient, but infrequent, defoliation at first flower appearance (D3) of the swards sown at 20 kg/ha and in lenient or severe defoliations at both sowing rates when performed at two and a half weeks after first flower appearance (D6, D7; Table 5.10).

The number of seeds per m^2 was not significantly increased by defoliation treatments but followed the same trends as seed yield (Table 5.10). Mean seed weight was increased by severe and frequent defoliation at first flower appearance (D4) in swards sown at 20 kg/ha but the differences were only significant at $P<0.10$ (Table 5.10). There were trends of an increase in the number of seeds per pod with defoliation but the differences were generally not significant (Table 5.10). The results show that increases in seed yield with severe but frequent defoliation at first flower appearance (D4) in the swards sown at 20 kg/ha or with lenient but frequent defoliation (D5) in the swards sown at 200 kg/ha were due to small but non-significant increases in the various individual yield components.

Seed:pod ratio was not significantly increased by defoliation treatments at the start of flowering but was significantly reduced by severe defoliation (D2, D4) in swards sown at 200 kg/ha and severe and frequent defoliation (D2) in swards sown at 20 kg/ha. The harvest indices (HI) were less than a half of those achieved in Experiment 1 (Chapter 3) suggesting that only a very small proportion of the DM produced was used for seed yield in this experiment (Table 5.10). Swards defoliated at the start of flowering had generally higher values of HI than the single, early defoliation or undefoliated swards.

Table 5.10. Effects of defoliation height, frequency and time of final defoliation on seed yield and seed yield components of Paraggio barrel medic at the Waite Institute, 1991.

Height of defoliation	Frequency	Time of final defoliation	Seed yield (kg/ha)^a	Pods (#/m^2)^a	Seeds (#/m^2)	Seed weight (mg)	Seeds (#/pod)	Seed:pod ratio (%)	Harvest Index (%)
20 kg/ha Sowing rate									
D_0	Undefoliated	Control	632	2737	13880	4.65	5.0	31.6	7.2
D_1 3 cm	Single	Early	659	2374	14240	4.63	6.0	31.3	7.6
D_2 3 cm	Infrequent	Flower appearance	793	3025	16760	4.89	5.5	29.9	10.0
D_3 6 cm	Infrequent	Flower appea rance	549	2055	11270	4.75	5.5	30.0	7.8
D_4 3 cm	Frequent	Flower appearance	822	2673	15680	5.25	5.9	28.5	8.4
D_5 6 cm	Frequent	Flower appearance	679	2621	14700	4.61	5.6	29.2	7.8
D_6 3 cm	Infrequent	Flowering	3	3	NA	NA	NA	NA	NA
D_7 6 cm	Infrequent	Flowering	54	151	NA	NA	NA	NA	NA
200 kg/ha sowing rate									
D_0	Undefoliated	Control	662	2730	14790	4.49	5.3	31.8	7.4
D_1 3 cm	Single	Early	685	2608	14570	4.77	5.7	31.5	7.8
D_2 3 cm	Infrequent	Flower appearance	500	2137	10890	4.61	5.8	24.4	9.4
D_3 6 cm	Infrequent	Flower appearance	664	2615	15140	4.40	5.2	30.9	9.8
D_4 3 cm	Frequent	Flower appearance	596	2418	12690	4.66	5.6	24.9	9.6
D_5 6 cm	Frequent	Flower appearance	849	3189	17990	4.91	5.4	30.2	10.5
D_6 3 cm	Infrequent	Flowering	207	922	NA	NA	NA	NA	NA
D_7 6 cm	Infrequent	Flowering	401	1781	NA	NA	NA	NA	NA
	Sowing rate x Defoliation	LSD ($P<0.05$)	169	640	4060	NS	NS	2.9	1.4
		LSD ($P<0.10$)	141	533	3370	0.34	NS	2.4	1.1

[a] LSD includes data from the swards defoliated at two and a half weeks after flowering
NA data not collected hence LSD excludes data from the two and a half weeks after flowering
NS, Not significant

5.4. DISCUSSION

The end-of-season dry matter yields at the Waite Institute were 2-3 times greater than at Korunye (Tables 5.2 and 5.6), but the highest seed yields at each site were similar (Tables 5.3 and 5.10). The higher dry matter yields at the Waite Institute were due to high rainfall (133 mm) during the reproductive period (September to November) in comparison to 54 mm at Korunye. Seed yields at the Waite Institute were limited by the relatively low rainfall (7.6 mm) during the middle of the reproductive period (October) in comparison to Korunye where there was 32 mm of rainfall during September and 20 mm during October. This result is in agreement with the findings of Andrews *et al.* (1977) and Wolfe (1985) that severe moisture stress during the flowering and active pod-setting period reduces seed yield in annual medic and subterranean clover cultivars. Swards grown at the Waite Institute produced twice the number of flowers (Table 5.8) as those at Korunye (Table 5.2), but percentage pod set, in contrast, was 3 times greater at Korunye and HI was 2 times higher. Data on leaf water potential were not collected at Korunye, but because of higher rainfall in October (19.6 mm), and the fact that lower vegetative growth reduced the level of water stress at the Waite Institute (Table 5.7), it could be speculated that swards at Korunye were under less moisture stress during the pod setting period than those at the Waite Institute. This reduced moisture stress together with the better light transmission through the canopy throughout the flowering period could have been responsible for the increase in percentage pod set (Table 5.2). Additionally, although seeds matured under a better moisture supply at the Waite Institute (November rainfall 35 mm) than at Korunye (November rainfall 2.2 mm) the best seed yields at the Waite Institute were not greater than those at Korunye. This result is in agreement with the results of Andrews *et al.* (1977) in subterranean clover where severe moisture stress towards the end of flowering had little effect on seed yield in the late-flowering cultivar Northam A, suggesting that adequate moisture supply during the pod-setting and early seed-filling period is more important than that during the period of seed maturity.

The highest quadrat seed yield estimates of 936 kg/ha at Korunye and the 850 kg/ha at the Waite Institute are comparable to reasonable commercial yields expected in South Australia.

The 440 kg/ha quoted by Ragless (1973) is, assuming a harvest efficiency of 50%, equivalent to a plot yield of 880 kg/ha. However, these were generally lower than yields reported for the Waite Institute in other seasons, which exceeded 1000 kg/ha (Adem 1977; Carter 1988; Ababneh 1991; Chapters 3 and 4 of this thesis). The high seed yields generally achieved at the Waite Institute in other seasons were due to the longer and wetter seasons whereas in the 1991 season, seed yield was limited by severe moisture stress during flowering and early pod development in October. The number of flowers per m^2 in the 1991 season in the undefoliated swards sown at 20 kg/ha was higher (20,500 flowers per m^2) than in 1989 (14,900 flowers per m^2) in swards sown at 25 kg/ha. However, percentage pod set was 3 times greater in 1989 than in 1991 (Tables 3.13, 5.8) suggesting that the reductions in seed yield in 1991, as a result of moisture stress, was mainly due to the failure of flowers to form mature pods. The lower seed yields achieved at Korunye (1990) in comparison to those at the Waite Institute in other seasons is attributable to the lower rainfall and shorter reproductive period which reduces DM yield and hence the number of flowers per m^2. These studies show that the amount and distribution of rainfall during the reproductive period was the major factor influencing seed yield between sites and seasons.

The present experiments show that the effects of defoliation on annual medic seed yield varies with site, sowing rate, timing and severity of final defoliation. Defoliation at the Waite Institute increased seed yield but only when the treatments were severe but frequent at flower appearance (D4) in swards sown at 20 kg/ha or lenient but frequent at the flower appearance (D5) on swards sown at 200 kg/ha (Table 5.10). The number of pods per m^2 was not significantly increased by defoliation but increases in seed yield occurred because of small increases in the number of seeds per pod and mean seed weight (Table 5.10). These results suggest that under severe moisture stress during the pod-setting period, defoliation strategies that enhance a high seed set per pod and mean seed weight can increase seed yield if the number of pods per m^2 is not significantly reduced.

Lenient defoliation at the start of flowering on swards sown at 20 kg/ha had no effect on seed yield at both sites (Tables 5.3, 5.10), whereas severe defoliation at start of flowering significantly reduced seed yield at Korunye (Tables 5.3). The lack of an increase in seed yield with lenient defoliation at the start of flowering is in agreement with the results of Tow and Al Alkailah (1981), Carter (1989) and Ababneh (1991) who found that lenient defoliation at early flowering did not increase seed yield in *M. truncatula* cvv. Jemalong and Paraggio. In the experiments reported here, it seems that the lack of a clear positive response to lenient defoliation was mainly a result of the failure to increase the number of mature pods per m^2 at Korunye or pods per m^2 and/or mean seed weight at the Waite Institute (Tables 5.3, 5.10). The lack of increase in the number of pods per m^2 with lenient defoliation at both sites or severe defoliation at the Waite Institute could be attributed to the removal of early-formed flowers or flowering nodes with defoliation. Although the number of flowers per m^2 was not significantly reduced (Table 5.2, Appendix Table 5A), flowering was delayed with defoliation and the late-produced flowers set fewer pods per m^2 because of drier and hotter conditions (Table 5.1). The significant decrease in seed yield with severe defoliation at Korunye was due to both fewer pods per m^2 and lower mean seed weight. This could be attributed to poorer recovery in vegetative growth than in the leniently-defoliated swards (Table 5.2) such that a large proportion of flowers were produced late in the season when the environmental conditions were unsuitable for both pod set and seed development (Table 5.1).

The increases in seed yield following defoliation (D4 at 20 kg/ha; and D5 at 200 kg/ha) at the Waite Institute were associated with reductions in DM yield at the end of flowering to below 7000 kg/ha (Fig 5.2, Tables 5.6, Table 5.10). This reduction in DM did not generally improve light penetration (Table 5.6) but did improve leaf water potential (Table 5.7) which may have contributed to the increase in mean seed weight. However, the fact that leaf water potential was not reduced by the other defoliation treatments made up to first flower appearance (Table 5.7) suggests that the trends in leaf water potential may not account fully for the observed yield increases. Other factors could have affected the relationship between DM production and seed yield e.g. increased respiration in swards with DM above 7000 kg/ha or late production of flowers in swards with DM less than 4000 kg/ha at the end of flowering.

Defoliations made after the start of flowering reduced seed yields at both sites (Tables 5.3, 5.10). The reductions were mainly due to the death of plants as a result of removal of both photosynthetic surfaces and bud sites and/or production of flowers during the unfavourable weather conditions. The effects were more severe in the 20 kg/ha sowing rate at the Waite Institute than at Korunye and in the 200 kg/ha sowing rate. Plants in the 20 kg/ha sowing rate treatments at the Waite Institute were fewer and more vigorous than those at Korunye or in the 200 kg/ha sowing rate and defoliation resulted in the death of most of them. This poor recovery of swards sown at 20 kg/ha from late defoliation at the Waite Institute is in agreement with the findings of Loch *et al.* (1976) who reported that vigorously-growing swards of *Stylosanthes guianensis* were more disadvantaged by late defoliations than less vigorously growing swards. Similar findings with subterranean clover have been reported by de Koning and Carter (1987).

The results of the present experiments show that the beneficial effects of defoliation depends on the weather conditions during the growing season. In general, it appears that defoliation at the start of flowering has little effect on seed yield but may increase seed yield if plant water stress is high (e.g. during dry spring weather). The importance of different levels of water stress and defoliation on seed production in annual medics is the subject of further investigation in Chapter 6.

Mechanical defoliation is usually more severe than grazing because of the unselective removal of leaf and other plant parts. Published studies on grazing show that severe grazing up to the start of flowering or beyond the start of flowering reduces seed yield. For example in seven *Medicago* species consisting of seventeen cultivars at Katanning in Western Australia, Thorn and Revell (1987) found that severe grazing at 16 sheep/ha from 33 days after sowing to the start of flowering reduced dry matter yield to less than 4000 kg/ha in all the cultivars and seed yield was significantly reduced. At Esperance in Western Australia (average rainfall 500 mm with 130 mm during the reproductive period) Bolland (1987) found reductions in seed yield of about 30% in cultivars of *M. truncatula* and *M. littoralis* when the swards were continuously grazed at 4 sheep/ha up to approximately three weeks after flowering. Thorn (1989), while reviewing management aspects in annual legume pastures, pointed out that much of the reduction in seed yield with grazing up to the start of flowering is associated with reduced vegetative growth during the reproductive period. The findings that grazing reduces seed yield because of reduced herbage DM is in agreement with the defoliation studies in this Chapter which show that increased seed yield after defoliation depends on the amount of herbage DM residue after defoliation (Fig. 5.2) and suggests that timing and severity of grazing or defoliation will depend on the spring rainfall of a particular site. Further studies, under a wide range of environmental conditions, are required in order to predict the importance of mechanical defoliation or grazing as a strategy to increase commercial seed yield. The question of whether the findings that mechanical defoliations up to the start of flowering does not reduce seed yields significantly is applicable to a wide range of annual medic species and cultivars is examined in Chapter 7.

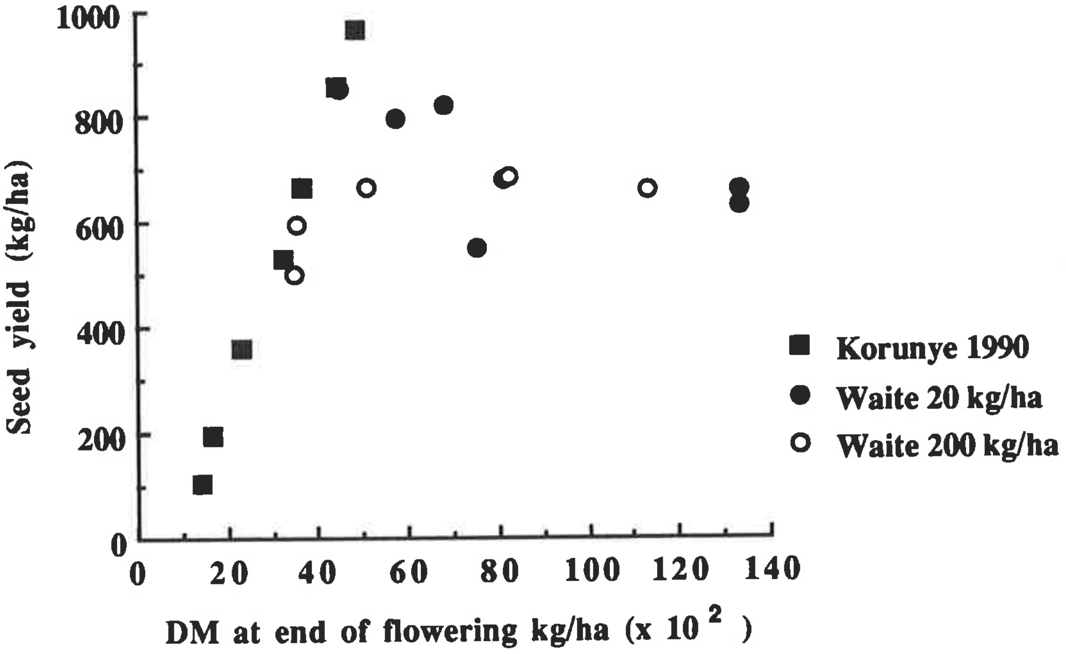


Fig. 5.2. **The relationship between DM at the end of flowering and seed yield of Paraggio barrel medic in 1990 and 1991**

Strategies to increase seed yield in many crops requires the identification of the most important and stable components of yield. The results of the experiment at Korunye and those of Chapters 3 and 4 show that increase in seed yield was determined by increases in pods per m^2, but the Waite Institute Experiment in this Chapter showed that significant increases in seed yield are not always associated with significant increases in the number of pods per m^2. This result suggests that defoliation management strategies and environmental conditions during the flowering and early seed-filling period can alter the importance of a particular yield component to seed yield in annual medics. Studies to further test the hypothesis that seed yield is not always associated with a large number of pods per m^2 is investigated in Chapter 7 of this thesis with a wide range of cultivars.

The hypothesis that better light penetration through the swards during early flowering increases seed yield through improved pod set, which was examined in Chapters 3 and 4 appears to be only applicable under conditions of adequate moisture supply during the reproductive period. Under severe soil moisture stress during the active pod-setting and seed-filling period, as experienced in 1991 at the Waite Institute, efficiency in the use of the available soil moisture appears to be more important than light penetration and increased seed yield through mean seed weight rather than through pod set. The experiments in this chapter demonstrate that when severe moisture stress occurs during the flowering period, swards with high light penetration throughout the flowering period can have better percentage pod set but the number of pods per m^2 will be low because of the fewer flowers produced during the early-flowering period (Table 5.2, Appendix Table 5A). The results of this chapter and those of Chapter 3 and 4 show that any management strategy that reduces the early production of a large number of flowers per m^2 in Paraggio barrel medic is unlikely to increase seed yield in dryland farming systems through increases in the number of pods per m^2. Therefore, in seasons and at sites where vegetative growth during the reproductive period is likely to be limited, as experienced at Korunye in 1990, management strategies that enhance vegetative growth and increase flowers per m^2 during the early flowering period are more important in increasing seed yield and increases are most likely through setting more pods.

5.5. SUMMARY AND CONCLUSIONS

Seed yields in the two seasons were relatively low because of low rainfall during the reproductive period. At Korunye (1990) yields were limited by the low number of flowers because of the low rainfall which reduced the vegetative growth and duration of flowering. Seed yields at the Waite Institute were limited by low percentage pod set because of moisture stress during the active pod-setting and seed-filling period.

Defoliations at the start of flowering increased seed yield at the Waite Institute but had little effect on yield at Korunye. The increase in yield was mainly through reductions in plant water stress which increased mean seed weight and number of seeds per pod. The results suggest that defoliation at the start of flowering is unlikely to decrease seed yield significantly. In areas or seasons with low rainfall during the active pod-setting and seed-filling period, defoliation can increase seed yield if canopy growth is sufficient to increase plant water stress. In areas or seasons where canopy growth is likely to be limited by low rainfall during the reproductive period defoliation before the start of flowering may be more beneficial.

CHAPTER 6

EXPERIMENT 6: EFFECTS OF WATER STRESS AND DEFOLIATION ON SEED YIELD OF PARAGGIO BARREL MEDIC

6.1. INTRODUCTION

Seed production of annual medics in South Australia relies on natural rainfall (Potts and Ison 1987). Rainfall in the winter months (June-August) is usually adequate for plant growth but moisture stress of unpredictable severity, timing and duration can occur anytime from mid-September (French and Schultz 1984). Much of the variation in seed yield between the experiments described in this thesis has been associated with the variability in rainfall during September and October which coincides with flower production and pod set.

The detrimental effects of dry periods or drought under rainfed conditions can be modified to some extent through selection of cultivars that flower early or by sowing early so that a large proportion of pods are set before the onset of severe moisture deficit. It may, however, be difficult to always attain the maximum seed yields in annual medics and subterranean clover by early sowing of early-flowering cultivars because the rate of flower production will be limited by low temperature during the winter period (Taylor and Palmer 1979). With early sowing of late-flowering cultivars, the commencement of flowering and the rate of flowering will also be limited by unfavourable photoperiod and low temperature during the winter period (Clarkson and Russell 1975, 1979; Hochman 1987). Furthermore, such strategies may result in large amounts of vegetative growth especially if high sowing rates are used and the sward is not grazed, which may increase self-shading during the early period of flower production thereby reducing pod set (see Chapter 3). Alternatively if moisture stress occurs early, the high vegetative growth may result in increased plant water stress thereby reducing pod set (Experiment 5, Chapter 5). Selecting for early-maturing cultivars, on the other hand, has the disadvantage of reducing herbage production and poor utilization of late spring rainfall if it occurs (Dear and Loveland 1984).

A common management strategy used by producers of annual medic seed is to graze the swards during the winter season. Studies on the effects of defoliation up to the start of flowering on seed yield have produced inconsistent results ranging from no significant reduction (Tow and Al Alkailah 1981; also Chapter 5 of this thesis) to a significant reduction (Ewing 1984; Thorn and Revell 1987; Ewing and Howieson 1989). From the data of Ewing (1984), Ewing and Howieson (1989) and Chapter 5 of this thesis it appears that where reduction in seed yield has occurred it has been associated with reduction in herbage yields to below 4000 kgDM/ha at the end of flowering and is mainly caused by the delayed flower production and/or reduction of flowers per m^2. Experiment 5 (Chapter 5) showed small increases in seed yield with some defoliation treatments at the start of flowering and this was associated with reductions in plant water stress which enhanced seed development. Similar increases due to reduced plant water stress as a result of grazing have been reported by Steiner and Grabe (1986) in subterranean clover.

Most of the studies on water stress during the reproductive phase of annual medics have been conducted on either undefoliated swards (Clarkson and Russell 1976) or on swards that have been defoliated up to the start of flowering (Wolfe 1985; Amoabin *et al.* 1987). No attempts have been made to examine the interactions between defoliation and water stress during the reproductive phase. Furthermore, few studies have been conducted to examine the effects of low soil moisture on herbage production and the interrelationships between herbage production, and low soil moisture throughout flowering, seed yield and seed yield components. However, such studies are important because the levels of water stress vary considerably between seasons and sites (e.g. Experiment 4 (Chapter 5) at Korunye in 1990 and Experiment 1 (Chapter 3) at Waite Institute in 1989).

The following experiment (Experiment 6) was conducted to test the hypothesis that defoliation of medic reduces plant water stress which in turn increases pod set, mean seed weight and seeds per pod as reported in Experiment 5 (Chapter 5) and by Steiner and Grabe (1986) for subterranean clover.

6.2. MATERIALS AND METHODS

Experiment 6 was carried out at the Waite Agricultural Research Institute in a glasshouse under natural daylight from May to October 1991. Temperature was regulated and measurements with two minimum and maximum thermometers showed the mean maximum temperature to be 23°C and the mean minimum temperature 10°C.

6.2.1. Experimental details

Plastic trays, 40 cm length x 28 cm wide x 15 cm deep which had small drainage holes in the bottom were used. The bottom of each tray was lined with a sheet of paper with holes to allow drainage and 12 kg of sterilized UC soil was then placed in each tray.

A soil water retention characteristic of the potting mix was determined at potentials of 0.003 MPa, 0.01 MPa, 0.03 MPa, 0.1 MPa and 1.5 MPa on duplicate samples drained from saturation on "porosity A" sintered glass funnels (Klute 1986). The gravimetric water content was determined from duplicate samples of the same soil by weighing before and after drying in an oven for 24 hours at 105°C. Soil moisture content was then plotted against the soil moisture potential as shown in Appendix Fig. 6.1.

Seed of Paraggio barrel medic, at a rate equivalent to 20 kg/ha of pure germinating seed, was sown in rows spaced at 6 cm across in each tray on 6 May. At the appearance of the first monofoliate leaf the emerged plants were thinned to 60 plants per tray (536 plants/m^2). The plants were then watered with a solution containing *Rhizobium meliloti* (group A medic inoculant). Plants were watered every day to field capacity until 3 weeks after the start of flowering when the water stress treatments were imposed.

The experiment comprised the following treatments:

Water treatments:

W0: Nonstressed - Watering to 10.8% moisture content (0.06 MPa)

W1: Stressed - Watering to 6.5% soil moisture content (0.04 MPa)

Defoliation treatments:

D0: Uncut throughout the growing period

D1: Cut twice to a height of 5 cm with the first cut at first flower appearance and a second cut at 24 days after start of flowering

The higher level of moisture content corresponded to the weight of 12.5 kg of soil plus tray and the lower level corresponded to a weight of 11.3 kg of soil plus tray. A correction was not applied to account for the weight of the plants as the experiment progressed. A split plot design comprising two blocks and 5 replicates of the 4 combinations of defoliation and water stress in each block was used. The water stress treatments formed the subplots while the defoliations formed the main plots (Fig. 6.1).

Block I				**Block II**				
D1		**D0**		**D1**		**D0**		**REPS**
W0	W1	W0	W1	W0	W1	W0	W1	**I**
W0	W1	W1	W0	W0	W1	W0	W1	**II**
W0	W1	W1	W0	W0	W1	W1	W0	**III**
W1	W0	W1	W0	W0	W1	W1	W0	**IV**
W1	W0	W0	W1	W1	W0	W0	W1	**V**

D0=Undefoliated, D1=Defoliated

W0=No moisture stress, W1=Moisture stress

Distance between defoliation treatments was 50 cm

Fig. 6.1. Showing layout of the glasshouse experiment on the effects of moisture stress and defoliation on seed yields of Paraggio barrel medic.

Plants commenced flowering on 20 July and the final defoliation in the defoliated treatments was made on 14 August. Water stress treatments were then imposed. Each tray was weighed every day and when necessary, water was added until tray weight corresponded to 12.5 kg/ha (non-stressed) or to 11.3 kg/ha (stressed) treatment. Trays were re-randomised every two weeks within the glasshouse to reduce any effects of variation within the glasshouse.

To avoid prostrate growth of the sward in each tray, a black fly-wire screen that allowed 66% of the glasshouse radiation to pass through was placed around the sides of each tray to ensure that the swards grew upwards (Plate 6.1). To prevent the undefoliated swards shading the defoliated swards, the trays of defoliated swards were raised on bricks and lowered subsequently to ensure that the tops of the undefoliated and defoliated swards were at the same height.

6.2.2. Measurements

Leaf water potential and relative water content. Leaf water potential (LWP) was measured on three occasions using a Scholander pressure chamber (Waring and Cleary 1967). On each occasion, measurements were taken immediately before commencing watering and the next morning after watering. A fully-expanded leaf, usually the third from the top, was taken randomly and immediately placed in the pressure chamber and the pressure adjusted until water was seen at the surface of the petiole. Each measurement took one minute from the detachment of the leaf from the plant to the measurement of leaf water potential by the pressure chamber. Each measurement was repeated three times. All measurements were made in the morning between 8.30 a.m and 9.30 a.m and only treatments from one block were measured.

Relative water content (RWC) was also determined on the same day as LWP using the method of Turner (1981). Between 10.00 a.m and 10.30 a.m, 10 fully expanded leaves from the third trifoliate leaf from the top of the sward, were selected at random and immediately put in a tared vial and sealed. The procedure used to determine the RWC was the same as that described in Experiment 3 (Chapter 4).

Number of flowers per raceme. The number of flowers on 20 racemes selected at random from all treatments was counted on 4 September and 15 September. The number of flowers per raceme was similar for both dates so the mean data from the two dates was taken to represent the number of flowers per raceme.

Herbage and seed harvest. Watering according to treatments was terminated on 24 September (140 days after sowing). The undefoliated swards appeared to have completed flowering whereas the defoliated swards were still producing flowers but at a much slower rate. Visual observations also indicated that all plants were still green and most of the late flowers were not setting pods. All plants were then watered with half the amount of water that was given to the stressed plants until 1 October to enable the developing pods to reach physiological maturity. On 3 October the experiment was terminated and all plants in each tray were harvested by cutting them at soil level. No attempt was made to measure the root weight.

In the laboratory the number of plants for each treatment was counted. Ten plants were then selected at random and the number of racemes per plant counted. The total number of flowers per m^2 was obtained by multiplying the number of flowers per raceme by the number of racemes per plant by the number of plants per m^2. Percentage pod set was calculated as detailed in Chapter 3.

Total herbage production (DM) was determined after drying all the material, including the pods, at 85°C for 24 hours. Pods were then separated from the herbage material and cleaned for weighing. A sample of 16 to 20 g of pods was taken for seed threshing. Threshing and determination of other seed yield components followed the same procedure as described in Chapter 3.

6.3. RESULTS

6.3.1. Leaf water potential

Table 6.1 gives the mean leaf water potential for the different watering treatments during the flowering and pod-filling period. The stressed treatments had significantly lower LWP both before and after watering relative to non-stressed treatments. Defoliation treatments did not increase leaf water potential significantly and there was no Defoliation x Water stress interactions. Results of RWC measurements (Appendix Table 6A) confirmed the trends in leaf water potential.

Table 6.1. Mean levels of leaf water potential (MPa) of non-stressed and stressed swards of undefoliated and defoliated Paraggio barrel medic. (Measurements were made between 8.30 a.m and 9.30 a.m)

Dates of measurement	Before watering			After watering		
	Non-stressed	Stressed	LSD (P<0.05)	Non-stressed	Stressed	LSD (P<0.05)
5 - 6 September	− 1.90	−2.37	0.14	− 1.34	−1.55	0.11
10 - 11 September	− 1.66	− 2.23	0.26	− 1.50	−1.96	0.09
15 - 16 September	− 1.67	− 2.39	0.28	− 1.48	−1.78	0.13

6.3.2. Vegetative and reproductive growth

The main effects of defoliation and water stress on herbage production at the end of the experiment, the number of flowers per raceme, the number of flowers per m^2 and percentage pod set were all significant (Table 6.2).

Water-stressed swards produced significantly lower herbage yields, fewer flowers per raceme, fewer flowers per m^2 and had a lower percentage pod set than the non-stressed swards (Table 6.3). Greater flower production in the non-stressed swards was due to more flowers per raceme and increased herbage yields (Table 6.3).

Defoliation significantly reduced herbage yields and the number of flowers per m^2 but increased percentage pod set (Table 6.3). The number of flowers per raceme, as in Chapter 5, was not reduced significantly by defoliation. The reduction in the number of flowers per m^2 with defoliation could be partly attributed to the removal of flowers with cutting, since defoliation was done 3 weeks after start of flowering.


PCH
PCH
A
B

6.3.3. Seed yield and yield components

Seed yield was significantly reduced by defoliation and water stress (Tables 6.2, 6.3). There were no significant Defoliation x Water stress interactions for seed yield and yield components indicating that the defoliated and undefoliated swards responded to watering treatments in a similar manner.

Water stress significantly reduced the number of pods per m^2, whereas mean seed weight, the number of seeds per pod and seed:pod ratio were not significantly reduced by water stress (Table 6.3). Defoliation did not significantly reduce the number of pods per m^2 and the number of seeds per pod but, in contrast to the effect of water stress, mean seed weight was significantly reduced by defoliation.

There was a significant ($P<0.05$) Defoliation x Water stress interaction in HI. The lowest HI was obtained when the undefoliated swards were stressed but there was no significant difference between the defoliated but stressed swards and the non-stressed swards (Table 6.4). The high HI in the defoliated but stressed swards is attributed to the high seed yield (405 kg/ha) relative to total herbage yield (3368 kgDM/ha) whereas the low HI in undefoliated but stressed swards is due to higher total herbage yield (5369 kgDM/ha) but relatively low seed yield (530 kg/ha) (see Appendix Table 6B).

Plate 6.1: **Experiment 6: Glasshouse experiment on the effects of defoliation and plant water stress on the growth of Paraggio barrel medic.**

Upper: **Early growth of medic in plastic trays.**

Lower: **Growth at a later stage showing the method of restricting growth to the area of the trays using black, plasticised flywire.**

Table 6.2. **Summary of ANOVA on the effects of water stress and defoliation on vegetative growth, reproductive growth, seed yield and yield components of Paraggio barrel medic in a glasshouse at the Waite Institute**

Source of variation	Yield (kgDM/ha)	Flowers (#/raceme)	Flowers (#/m^2)	Pod set (%)	Seed yield (kg/ha)	Pods (#/m^2)	Seeds (#/pod)	Seed weight (mg)	Seed:pod ratio (%)	Harvest Index (%)
Water stress	***	***	***	**	***	***	NS	NS	NS	***
Defoliation	***	NS	*	*	**	NS	NS	**	*	NS
Defoliation x Water stress	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

NS, Not significant; * P<0.05; ** P<0.01; *** P<0.001

Table 6.3. **Effects of water stress and defoliation on dry matter yield, flower production, percentage pod set, seed yield and yield components.**

Yield component	Water stress treatments			Defoliation treatments		
	Non-stressed	Stressed	LSD (P<0.05)	Undefoliated	Defoliated	LSD (P<0.05)
Dry matter yield (kgDM/ha)	7292	4369	470	6844	4817	403
Flowers per raceme	1.6	1.4	0.1	1.5	1.5	NS
Flowers per m^2	14610	9000	790	12730	10580	1700
Pod set (%)	27.3	23.4	2.5	23.7	27.1	2.9
Seed yield (kg/ha)	941	467	79	804	605	119
Pods (#/m^2)	3929	2003	217	3050	2882	NS
Seeds (#/pod)	6.3	6.0	NS	6.0	6.3	NS
Seed weight (mg)	3.80	3.90	NS	4.39	3.31	0.32
Seed:pod ratio (%)	28.2	27.2	NS	29.2	26.1	2.7

NS, Not significant

Table 6.4. Effects of water stress and defoliation on harvest index of Paraggio barrel medic grown in a glasshouse at the Waite Institute

Water stress	Harvest index (%)	
	Undefoliated sward	Defoliated sward
Non-stressed	12.9	12.1
Stressed	9.8	12.1
LSD (P=0.05)	1.7	

6.4. DISCUSSION

In the present study (Experiment 6) water stress reduced seed yields by 50% whereas defoliation reduced yields by 25% only. This experiment, like other studies in this thesis, showed that pods per m^2 were more important than mean seed weight or seeds per pod in determining the seed yield of annual medics. Reductions in the number of pods due to water stress were caused by the production of fewer flowers because of decreased herbage accumulation and fewer flowers per raceme as well as fewer flowers surviving to form mature pods (Table 6.3). Both moisture stress and defoliation reduced herbage yield to 4,800 kgDM/ha or less at the end of the experiment and also reduced seed yield. This result is consistent with the results from Chapter 5 which showed that DM yields of less than 4,000 kg/ha at the end of the flowering season significantly reduced seed yield (Fig 5.2).

The smaller effect of defoliation on seed yield is attributable to the lack of a significant difference in the number of pods per m^2. Following defoliation, there was a significant increase in percentage pod set which compensated for the fewer flowers per m^2 (Table 6.3). These results support the findings of Experiment 5 (Chapter 5) which showed that when vegetative growth and flower production was low there was an increase in percentage pod set, with the result that the number of pods per m^2 was not significantly reduced by defoliation (Table 5.6). Mean seed weight in Experiment 5 was not significantly reduced by defoliation (Table 5.10) because of reduced plant water stress (Table 5.7) and better light transmission (Table 5.6) as a result of defoliation at the start of flowering. In contrast, Experiment 6 shows that reductions in seed yield were partly due to reduced mean seed weight. However, this reduction in mean seed with defoliation was mainly due to the presence of immature seeds because the experiment was terminated when most seeds of the undefoliated swards were in a more advanced stage of growth than those of defoliated swards.

Defoliation significantly reduced herbage yields but in contrast to the findings of Experiment 5 did not increase RWC and LWP of the plants, or the number of seeds per pod and mean seed weight. The lack of a significant increase in RWC or LWP with defoliation in Experiment 6 study is possibly due to the relatively small differences in herbage yield between the defoliated and undefoliated swards (Table 6.3).

The reasons for the increase in percentage pod set with defoliation, despite the lack of a significant difference in leaf water potential are less obvious. In Experiment 5 increases in percentage pod set with defoliation were associated with better light transmission throughout flowering (Table 5.6) and reduced plant water stress (Table 5.7). In the present study, although Defoliation x Water stress interactions were not significant, the results show that percentage pod set in the non-stressed swards were relatively similar (26%) between the undefoliated and defoliated swards, but in the stressed sward percentage pod set was higher (26%) in the defoliated than in the undefoliated swards (21%). Visual observations showed that the undefoliated swards showed more signs of wilting than the defoliated swards. It could therefore be speculated that the reduction in LWP was more gradual in the defoliated than in the undefoliated swards and hence increased percentage pod set. Defoliation significantly reduced mean seed weight (Table 6.3) but the HI was significantly higher in the defoliated and stressed sward than in the undefoliated but stressed swards. The high HI in the defoliated but stressed swards was due to an increase in seed yield resulting from an increased pod set with defoliation. This result suggests that partitioning of assimilates for pod set is higher with lower herbage yield than with higher herbage yield under drought conditions (Table 6.4).

Mean seed weight in Experiment 6 was not significantly reduced by water stress. Similar trends were observed with reduction in incident light in Chapter 4 where 60% shading throughout the reproductive period did not reduce mean seed weight significantly. Both studies show that mean seed weight is only slightly affected by environmental stress. One explanation might be that storage reserves from stems are remobilised for seed development when photosynthesis is inhibited by light stress or by water stress. Studies in cereals have shown that under drought conditions the contribution of stem-stored assimilates to kernel filling and grain growth is greater (Gallagher *et al.* 1976; Bidinger *et al* 1977) than under well-watered conditions. A further explanation might be that the reduced number of pods after water stress or light stress leaves sufficient assimilate within the plant to maintain a normal seed weight. Evidence for the latter argument has been presented by Frederick *et al.* (1989) for soybean cultivars under drought stress.

The stability in the number of seeds per pod with water stress and defoliation in Experiment 6 is in agreement with the other studies reported in this thesis (Chapters 3, 4, 5). The results confirm that the number of seeds per pod in annual medics is relatively stable to stresses imposed by water deficit or reduced light transmission through the swards.

It is concluded that water stress reduces seed yield mainly through production of fewer pods per m^2 and this is caused by fewer flowers per m^2 as a result of reduced vegetative growth and by poor percentage pod set. Defoliation increased percentage pod set and this compensated for fewer flowers per m^2 so that seed yield was only reduced by 25% in comparison to water stress which reduced seed yield by 50%. However, defoliation failed to support the findings that defoliation minimises moisture stress thereby increasing mean seed weight and seeds per pod as reported in Chapter 5. The failure of defoliation to reduce moisture stress was possibly due to the low DM achieved in the undefoliated swards. Further investigations that can give higher DM yield like those observed in the field Experiments at the Waite Institute are required.

CHAPTER 7

EXPERIMENT 7: INFLUENCE OF MEDIC CULTIVARS AND DEFOLIATION ON FLOWER SURVIVAL AND SEED YIELD

7.1. INTRODUCTION

Seed production in annual medic cultivars varies considerably even when the end-of-season dry matter yields are similar (Thorn and Revell 1987; Cocks 1988, 1990b; Carter 1989; Ewing and Howieson 1989; Ababneh 1991). In most of these studies variation in seed yield has been shown to relate principally to differences in the number of mature pods produced, rather than to variation in seeds per pod or mean seed weight (e.g. Cocks 1988, 1990a,b). This positive relationship between the number of pods per m^2 and seed yield implies that events occurring before and during flowering are paramount in determining whether one cultivar will perform better than another in terms of final yield. Some studies have implicated differences in cultivar maturity alone to be responsible for the variability in the number of pods per m^2 under dryland farming conditions (Poole 1970; Crawford 1983; Crawford *et al.* 1989, Thorn and Laslett 1992) while recent studies in Syria (Cocks 1988, 1990) implicate percentage pod set in addition to cultivar maturity.

Cocks (1988, 1990a,b) found that there was variability in flower retention in a range of medic species and cultivars under both spaced and sward conditions in Syria. In some cultivars up to 95% of the fully-opened flowers failed to form mature pods. The greatest retention was associated with cultivars with the lowest potential sink size (defined as the number of flowers x individual pod weight) at each flowering node (Cocks 1990a,b) and those species or cultivars that were early flowering (Cocks 1988, 1990a,b). Percentage pod set was also greatest in cultivars from drier areas or poor soils because these had a lower potential sink size due to smaller pods and smaller seeds than species from more favourable areas.

South Australia is a major producer of annual medic seed (Carter *pers. comm.*) and seed yields vary between cultivars (Australian Bureau of Statistics 1979-1989), but the reproductive components that cause this variation have not been well documented. An experiment was conducted at the Waite Agricultural Research Insitute in 1991 which examined some of these traits in a range of cultivars. The specific aim of this experiment was to compare the herbage yields (DM) of medic cultivars and to determine the extent to which seed yield is limited by DM, flowers per m^2 or percentage pod set. The experiment also examined the effects of cultivar maturity on flower production, percentage pod set and seed yield because in other crops early flowering has often been shown to be beneficial to yield in dryland farming.

Studies with Paraggio barrel medic in Chapter 5 have shown that defoliation at the start of flowering is unlikely to decrease yield if the leaf area prior to flowering is great enough to intercept more than 95% of incoming light (equivalent to LAI 4) or if there is a significant level of plant water stress during seed development. An aim of this experiment was also to examine the ability of annual medic cultivars to recover and produce high herbage yields following defoliation at the start of flowering and to find out if the potential benefit of defoliation to seed yield is applicable to a wide range of medic species and cultivars.

Finally, by growing medic cultivars with different mean seed weight, number of seeds per pod and number of flowers per raceme the hypothesis that the potential size of the sink at each flowering node limits percentage pod set was tested. The extent to which limitations imposed by the potential sink size is improved by early flowering or defoliation was also examined.

7.2. MATERIALS AND METHODS

7.2.1. Sowing details and experimental design

The experiment was conducted at the Waite Agricultural Research Institute, near Adelaide, in 1991. The field used was the same as that used for Experiment 5 of Chapter 5. The long-term rainfall also monthly rainfall, temperature and solar radiation for 1991 are shown in Table 5.1. The area was irrigated before sowing with 17 mm of water per day for 2 days using spray irrigation. Six species of annual medic consisting of eleven cultivars were sown at 16 kg/ha pure germinating seed. This sowing rate was within the range that gave maximum seed yield in Chapter 3. The cultivars (including unnamed genotypes) that were used covered a range of maturity (days to first flower appearance), number of flowers per raceme, number of seeds per pod and mean seed weight (Table 7.1).

Before sowing, seeds were inoculated with *Rhizobium meliloti*. The seed was sown in plots 10 rows wide (row spacing of 15 cm) by 10 m long, using a cone seeder on 9 May 1991. A randomised complete block design with 4 replications was used. Single superphosphate at a rate of 160 kg/ha (= 18 kgP/ha) was applied at the time of sowing. Thirteen millimetres of water was applied using overhead sprays whenever necessary to give satisfactory germination because of dry conditions soon after sowing. Irrigation was stopped as soon as rains became reliable and the crop was then rainfed throughout the season. Seedling emergence was complete by 1 June.

Defoliation treatments commenced on 19 July, one week after the first appearance of flowers in the earliest-flowering cultivar Serena (Table 7.2). Each of the 10 metre plots was split into three: undefoliated control, defoliation at 6 cm (lenient) or defoliation at 3 cm (severe). This resulted in 33 treatment combinations (11 cultivars x 3 defoliations). A plot area of 1.5 x 2.5 m was allocated for data collection in each defoliation treatment. Apart from Serena and Ghor the rest of the cultivars were defoliated two or three times, depending on the time of first flower appearance (Table 7.2). A hand-operated rotary blade mower was used for the defoliation treatments.

7.2.2. Plant density at establishment and number of nodules

Plant numbers at establishment were estimated from two quadrats of 30 cm x 33 cm 30 days after emergence. The number of nodules per plant was counted on 10 plants per plot which were carefully dug up on the 15 July.

7.2.3. Plant numbers and vegetative harvests

Samples to determine plant numbers and herbage yield were cut at ground level in two quadrats, each of 30 cm x 33 cm on 5 August, 24 September and 21 October. The date 21 October can be considered to be the end of flowering in all cultivars because Paraponto had completed flowering by 21 October, and severe stress in the other cultivars, indicated by severe wilting of the swards during the day, curtailed flowering and few flowers appeared after 21 October. The number of plants per m^2 at the end of flowering was also recorded. At each time of sampling herbage from two replicates was sub-sampled for determination of leaf area as described in Chapter 3. The leaf area from the two replicates was then used to estimate LAI from herbage yields in all replicates. DM determinations were made after the samples had been dried at 85°C for 24 hours. PAR transmission was estimated from the LAI as described in Chapter 3, with the assumption that every variety has the same extinction coefficient.

7.2.4. Flower production and percentage pod set

Dates of commencement of flowering, flower re-appearance after defoliation and end of flowering were recorded. A hail storm on the 23 August knocked off a large percentage of the flowers in the early-flowering cultivars (Ghor, Serena, Sava and Paraponto) mainly by breaking the branches, and consequently yield data could have been adversely affected. The number of flowers per raceme was estimated in the field by counting the number of flowers from 20 randomly selected racemes in each treatment on 24 September and 17 October except in the cultivar Ghor, which was severely attacked by a fungal disease after the hail storm.

The number of branches and racemes were counted from 5 randomly selected plants from each treatment on 20 October. Branches that were less than 10 cm long were not counted. The total number of flowers per m^2 and percent pod set was calculated as in Chapter 3.

7.2.5. Seed harvest

Harvesting of pods was as described in Chapter 5 and the method of threshing to determine seed yield and seed yield components was similar to Chapter 3.

Table 7.1. Annual medic species, cultivars and genotypes recommended for various rainfall and soil zones, also reproductive data[a b]

Species	Cultivar or Genotype	Rainfall range (mm)	Soil type	Days to first flower	Flowers (#/raceme)	Seeds (#/pod)	Seed weight (mg)
M. littoralis	Harbinger	250 - 400	Soils suitable for barrel medic and in addition, on more sandy alkaline and slightly acid soils where barrel medic will not grow	99	5.0	4.0	2.6
M. polymorpha	Serena	200 - 350	Acid soils (pH 6.0 to 7.0) and fairly wide array of soil types	75	5.0	4.5	3.0
	SC01011	NA	NA	NA	NA	NA	NA
	SC01012	NA	NA	NA	NA	NA	NA
M. rugosa	Paragosa	>350	Heavy alkaline soils	111	4.0	1.5	7.0
	Paraponto	>300		101	5.0	1.3	11.0
M. scutellata	Sava	>250	Neutral to alkaline soils of both heavy and light texture	83	2.0	5.0	17.0
M. tornata	Murrayland	>250	Sandy soils, pH from mildly acid to strongly alkaline	119	6.0	4.8	2.4
	Tornafield	400	Sandy soils, particularly on solodized solonetz soils, not suited to barrel medics	115	10.6	5.0	3.0
M. truncatula	Ghor	NA	NA	77	3.0	6.0	4.0
	Paraggio	350 - 500	Neutral to alkaline sand and sandy loams to red brown earth and clay soils	114	3.0	7.0	4.2

Source of data

[a] Flowering dates, flowers per raceme, seeds per pod and mean seed weight (mg/seed) were obtained from Jeff Auricht of Parafield Plant Introduction Research Centre. All the data is based on single spaced plants sown in April.

[b] Rainfall and soil type data was obtained from Oram (1990) and Lake (1990).

NA, Cold tolerant line data not available

Table 7.2. **Dates of first flower appearance, days from emergence, dates of defoliation and frequency of defoliation of annual medic cultivars and genotypes sown at the Waite Institute, 1991**

Species	Cultivar or Genotype	Date of first flower appearance	Days from emergence	Dates of defoliation		
				First defoliation	Second defoliation	Third defoliation
M. littoralis	Harbinger	12 August	79	19 July	5 August	-
M. polymorpha	Serena	11 July	42	19 July	-	-
	SC01011	3 September	95	19 July	5 August	30 August
	SC01012	30 August	90	19 July	5 August	30 August
M. rugosa	Paragosa	23 August	84	19 July	5 August	30 August
	Paraponto	2 August	62	19 July	5 August	-
M. scutellata	Sava	5 August	65	19 July	5 August	-
M. tornata	Murrayland	25 August	85	19 July	5 August	30 August
	Tornafield	3 September	95	19 July	5 August	30 August
M. truncatula	Ghor	19 July	50	19 July	-	-
	Paraggio	26 August	87	19 July	5 August	30 August

7.3. RESULTS

7.3.1. Plant density and number of branches

Cultivar differences in plant density were highly significant ($P<0.001$) throughout the growing season. Establishment on 1 July ranged from 51% to 93%, but the highest number of plants per m^2 was not necessarily associated with the highest emergence (Table 7.3). As expected, the highest plant density was associated with smaller-seeded cultivars and the lowest with larger-seeded cultivars (Tables 7.1, 7.3).

The numbers of plants at the end of flowering, as in previous experiments (Chapter 3, 4, Experiment 5 Chapter 5), were lower but followed the same trend as those at establishment (Table 7.3). Defoliation did not affect plant density significantly. This is in agreement with most defoliation treatments on swards sown at 20 kg/ha in Chapter 5 where defoliations that ceased before or at the start of flowering did not reduce the number of plants per m^2 significantly. Visual observations indicated that swards sown at 16 kg/ha were more prostrate at the time of defoliation than those sown at 20 or 200 kg/ha in the neighbouring experiment (Chapter 5). The results suggest that when swards are sown at lower sowing rates the number of plants per m^2 are unlikely to be reduced by defoliation.

The effects of cultivar on the number of branches per plant and per m^2 at the end of flowering were significant ($P<0.05$ and $P<0.01$ respectively). Paragosa produced the highest number of branches per plant and per m^2 (Table 7.3). Serena produced the lowest number of branches per plant but because of the high number of plants per m^2, the number of branches per m^2 was not significantly different from Paragosa (Table 7.3). Although Sava and SC01011 did not produce the lowest number of branches per plant, the number of branches per m^2 were the lowest because of the fewer number of plants per m^2. Data for Ghor was not collected because of the fungal attack. The number of branches for Paraponto was not collected also because the plants were senescing at the time of sampling and it was difficult to recover accurately all the branches entangled in the sward, whereas for Murrayland, data was deliberatetly not collected because of its poor vegetative growth.

Table 7.3. Effects of cultivar or genotype on plant density and branches at the end of the flowering period in undefoliated swards of annual medics sown at the Waite Institute in 1991

Species	Cultivar or Genotype	Expected plant density (#/m^2)	Observed plant density by 1 July (#/m^2)	Percent establishment (%)	Plant density at end-flowering (#/m^2)	Number of branches at the end of flowering in undefoliated swards (#/plant)	(#/m^2)
M. littoralis	Harbinger	692	350	50.6	151	4.05	612
M. polymorpha	Serena	468	304	65.0	172	3.05	525
	SC01011	388	351	90.5	86	3.65	314
	SC01012	394	305	77.4	123	3.85	449
M. rugosa	Paragosa	295	222	75.2	118	6.47	761
	Paraponto	179	109	60.9	78	NA	NA
M. scutellata	Sava	138	102	73.9	80	3.65	290
M. tornata	Murrayland	873	619	70.9	186	NA	NA
	Tornafield	370	266	71.9	122	4.65	567
M. truncatula	Ghor	359	335	93.3	NA	NA	NA
	Paraggio	386	312	80.8	134	4.05	543
Cultivar	LSD ($P<0.05$)		117		53	1.92	257

NA, Data not collected.

There was no Cultivar x Defoliation interaction for the number of branches per plant and per m^2. Defoliation significantly ($P<0.001$) increased the number of branches per plant and per m^2. The highest mean number of branches across cultivars occurred with severe defoliation (8.1 branches per plant and 982 per m^2), whereas the lowest occurred in the undefoliated swards (4.2 branches per plant and 508 per m^2). Leniently-defoliated swards produced an intermediate number of branches.

7.3.2. Nodulation and early crop growth

Nodulation was evaluated 45 days after emergence. Serena, Ghor and Sava had the highest number of nodules but these were not significantly different from Paraggio and the cold-tolerant cultivars of *M. polymorpha* (SC01011 and SC01012). Murrayland and Harbinger were the poorest in early nodulation (Fig. 7.1, Appendix Table 7A) and were visually paler than the rest.

Winter herbage yields (DM) were highest with Ghor and the *M. polymorpha* cultivars (Serena, SC01011 and SC01012) but lowest with Harbinger and Tornafield (Fig 7.1, Appendix Table 7A).

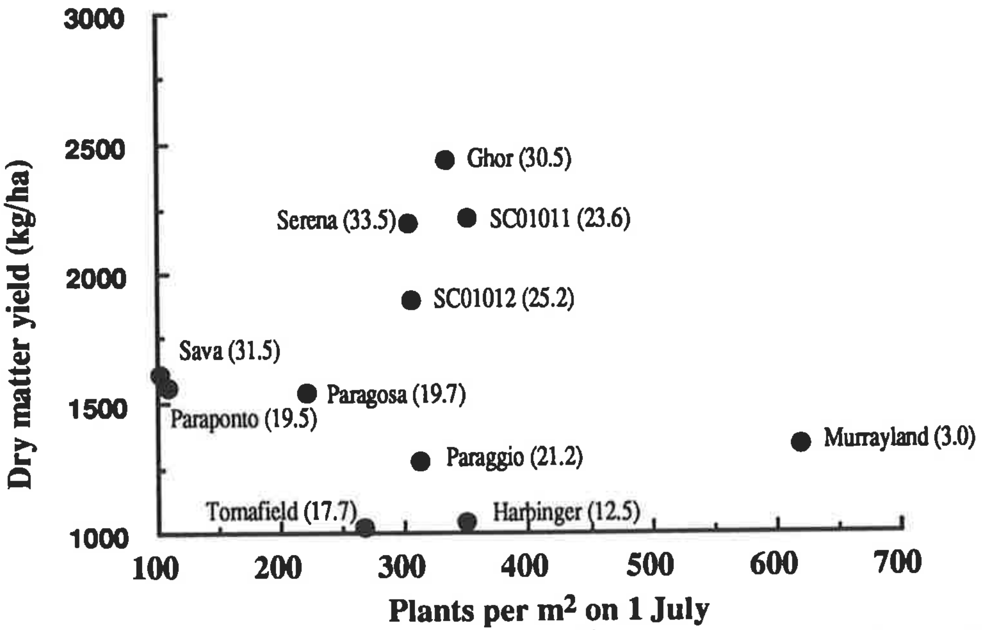


Fig. 7.1. Relationship between plants per m^2 and early winter dry matter yields of undefoliated swards of annual medics sown at the Waite Institute in 1991. Data in parenthesis shows the number of nodules per plant (Appendix Table 7A).

The early winter herbage production was related to the number of plants per m^2 except in the cultivars Harbinger, Murrayland and Tornafield where yields were low because of poor nodulation (Fig. 7.1, Appendix Table 7A). The low yields with the cultivar Paraggio when the number of nodules and plants per m^2 is high is an unexpected result.

7.3.3. Herbage yield during the reproductive period

Table 7.4 shows the ANOVA summary for DM on 24 September (early part of flowering), 21 October (end of flowering), and LAI and PAR transmission on the 24 September.

The effects of Cultivar and Defoliation on dry matter production were statistically significant at both harvests; however, there was no Cultivar x Defoliation interaction, indicating that the effect of defoliation was similar for all cultivars (Table 7.4). The undefoliated swards had the highest mean DM yields across cultivars; 8370 kg/ha by 24 September and 9810 kg/ha by 21 October. Lenient defoliations resulted in significantly more DM (5150 kg/ha) than severe defoliations (3670 kg/ha) by the 24 September, but by the 21 October both leniently- and severely-defoliated swards had similar DM yields of about 8000 kg/ha. Despite a lack of a significant Cultivar x Defoliation interaction, defoliated swards of some cultivars, such as Serena, Sava, Paraggio, Paragosa and SC01012, achieved almost similar final DM yields as the undefoliated swards whereas others had lower DM (Appendix Table 7B). A comparison of growth rates of the severely-defoliated swards (Appendix Table 7C) shows that these cultivars had the highest growth rates during the spring period, whereas the low-yielding Tornafield and Murrayland had the lowest growth rates.

At the 24 September sampling, the mean cultivar DM yield across defoliation treatments was highest in Serena but lowest in Murrayland (Table 7.5). Other cultivars produced DM yields that were not significantly different from each other. By the end of flowering (21 October), DM yields were highest in Paraggio, Serena and Sava and lowest in Murrayland (Table 7.5). There was a significant correlation between early winter DM and DM on the 24 September ($r=0.71$, $P<0.05$, $n=8$) but not on the 21 October ($r=0.53$, $n=8$). Herbage production (DM) at both sampling dates was not related to the day to first flower. The lack of a significant correlation between the day to first flower or early high winter DM and DM on the 21 October is due to some cultivars having a higher growth rate in spring than others (Table 7.5). For example, Paraggio (a late flowering cultivar) and Sava (an early flowering cultivar) were poor winter producers but had the highest DM by the 21 October because of high growth rates in spring. Murrayland and Tornafied (both late-flowering cultivars) had the lowest winter and spring DM because of low growth rates in spring. Serena had lower growth rates during the later part of spring but had high DM because of its ability to grow faster during the winter and early spring season (Table 7.5).

Table 7.4. Summary of ANOVA on the effects of cultivar and defoliation on herbage yield, LAI and PAR transmission on 24 September, herbage yield at the end of flowering (21 October) and growth rate[a]

Source of variation	24 Sep			21 Oct	Growth rate ($g/m^2/day$)
	Herbage yield (kgDM/ha)	LAI	PAR	Herbage yield (kgDM/ha)	24 Sep to 21 Oct
Cultivar	***	***	***	***	*
Defoliation	***	***	***	*	***
Cultivar x Defoliation	NS	*	***	NS	NS

[a] Excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

NS, Not significant; * $P<0.05$; *** $P<0.001$

Table 7.5. Effects of cultivar on herbage yield of annual medics sown at the Waite Institute, 1991[a]. (Data represents means of all the defoliation treatments)

Species	Cultivar or Genotype	Herbage yield (kgDM/ha) on		Growth rate ($g/m^2/day$)
		24 Sep	21 Oct	24 Sep to 21 Oct
M. littoralis	Harbinger	4100	7080	11.0
M. polymorpha	Serena	9330	10460	10.3
	SC01011	5590	8610	4.2
	SC01012	5690	8460	11.2
M. rugosa	Paragosa	5140	8970	14.2
	Paraponto	6540	8430	7.0
M. scutellata	Sava	6430	10640	15.0
M. tornata	Murrayland	3110	5240	7.9
	Tornafield	5110	7340	8.3
M. truncatula	Paraggio	6260	10540	15.8
Cultivar	LSD ($P<0.05$)	1440	1980	7.0

[a] LSD excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

7.3.4. LAI and PAR transmission

There were significant Cultivar x Defoliation interactions for LAI and the amount of PAR transmitted through the canopy to the ground on 24 September (Tables 7.6, 7.7). The highest LAI occurred in undefoliated swards of SC01011 and Serena, despite their differences in maturity, while the lowest occurred with Murrayland (Tables 7.2, 7.6). Serena produced LAI above 7 after defoliation. The cultivar Murrayland in all treatments, and Harbinger in defoliated swards, produced the lowest LAI (less than 3) whereas the other cultivars responded similarly to defoliation with LAI values of about 3 when severely defoliated and 5 when leniently defoliated (Table 7.6).

The amount of PAR transmitted to the ground followed the same trends as LAI and was greatest in Murrayland, suggesting that the low final DM with Murrayland was partly due to low light interception (Tables 7.5, 7.7). The LAI at which complete self-shading occurs for efficient utilization of light for canopy net photosynthesis is 3 and 4 (Chapter 3, Fukai and Silsbury 1977) or a PAR transmission of 4.5% (Ludlow and Wilson 1971). Based on these assumptions, most of the cultivars even in the severely-defoliated swards, attained complete self-shading (LAI 4) by 24 September (Table 7.7) and this was because of high growth rates during the spring period (Appendix Table 7A).

Table 7.6. Effects of cultivar and defoliation on LAI on 24 September in swards sown at the Waite Institute in 1991[a]

Species	Cultivar or Genotype	LAI		
		Undefoliated sward	Leniently defoliated sward	Severely defoliated sward
M. littoralis	Harbinger	8.3	2.7	1.8
M. polymorpha	Serena	13.4	11.0	7.0
	SC01011	13.7	5.5	3.1
	SC01012	8.2	5.3	3.8
M. rugosa	Paragosa	10.5	4.8	3.0
	Paraponto	7.4	4.8	3.5
M. scutellata	Sava	10.8	5.5	3.1
M. tornata	Murrayland	2.8	0.8	1.2
	Tornafield	6.8	4.5	2.9
M. truncatula	Paraggio	7.6	5.6	3.2
Cultivar x Defoliation	LSD ($P<0.05$)		2.9	

[a] LSD excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

Table 7.7. **Number of days from start of flowering to 24 September and the effects of cultivar and defoliation on PAR transmission by 24 September of annual medic swards sown at the Waite Institute, 1991**[a]

Species	Cultivar	Days from start of flowering to 24 Sept.[b]	PAR transmission (%) on 24 September		
			Undefoliated sward	Leniently-defoliated sward	Severely-defoliated sward
M. littoralis	Harbinger	43	0.05	5.34	8.85
M. polymorpha	Serena	75	0.00	0.01	0.15
	SC01011	21	0.02	0.39	3.43
	SC01012	25	0.05	0.91	1.59
M. rugosa	Paragosa	32	0.03	0.73	4.26
	Paraponto	53	0.82	0.95	1.96
M. scutellata	Sava	50	0.00	0.95	2.94
M. tornata	Murrayland	30	5.60	22.72	17.82
	Tornafield	21	0.17	1.35	4.23
M. truncatula	Paraggio	29	0.32	0.95	3.26
Cultivar x Defoliation	LSD ($P<0.05$)			4.01	

[a] LSD excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

[b] Days from first flower appearance to 24 September. There was a delay of about 10 days for flower re-appearance after defoliation

7.3.5. Reproductive growth

7.3.5.1. Flower production

The number of days from first flower appearance to 24 September varied greatly with cultivars (Table 7.7). Flower re-appearance after defoliation did not vary with cultivars, if defoliation occurred on the same date. In general, there was a delay in flower re-appearance of about 10 days following severe defoliation.

The time from emergence to flower appearance was shorter than data presented in Table 7.1, which was from a very early sowing (April). Cultivars differed significantly ($P<0.001$) in the number of racemes per m^2 and flowers per m^2 at the end of the flowering period. Data on *M. rugosa* cv. Paraponto and *M. tornata* cv. Murrayland and *M. truncatula* cv. Ghor were not collected. In Paraponto, stems were drying due to early maturity and so it was difficult to accurately recover all the branches so that the number of racemes could be counted. Ghor was attacked by a fungal disease, *Ascochyta imperfecta* (black stem) in August/September and hence the yields could not have been a reflection of the normal sward. Murrayland was deliberatetly not sampled because of its poor vegetative growth. The highest number of racemes per m^2 in the other cultivars occurred with Paragosa and Serena, whereas the highest number of flowers per m^2 occurred with Tornafield (Table 7.8). The lowest number of racemes per m^2 occurred with SC01011 and Tornafield but the lowest number of flowers was with Sava followed by Paraggio (Table 7.8).

The highest number of racemes or flowers per m^2 was not always associated with the highest DM (Tables 7.5, 7.8). The large number of flowers per m^2 in Tornafield was due to the high number of flowers per raceme (Table 7.8). In Paragosa, which was the second highest in terms of flower production, the large number of flowers per m^2 was mainly due to the high number of racemes per m^2 possibly as a result of the high number of branches per m^2 (Tables 7.3, 7.8). The significantly-lower number of racemes and flowers per m^2 with Sava was a result of fewer branches per m^2 and fewer flowers per raceme (Tables 7.3, 7.8), whereas with Paraggio, the small number of flowers per m^2 could be attributed to fewer flowers per raceme (Table 7.8).

The duration of flowering was shorter in the later-flowering cultivars, mainly because of the prolonged period of moisture stress during October. By 21 October the swards were visibly water stressed and had stopped flowering. Paraponto was the only cultivar to have fully completed flowering by this time and had the highest seed yield (Table 7.10). However, the early-flowering cultivars in general did not produce the highest number of flowers per m^2 in this study because of fewer flowers per raceme (Table 7.8). The results suggest that selecting or breeding for early flowering without increasing the number of flowers per raceme may not necessarily result in higher flower production and seed yield.

There was a general decline in the number of flowers with defoliation (35,700 in undefoliated swards, 33,700 in leniently-defoliated swards and 31,200 in the severely-defoliated swards) but the differences were small and non-significant. Cultivar x Defoliation interaction effects were non-significant for the number of racemes per m^2 and flowers per m^2. The lack of a significant reduction in the number of flowers with defoliation was due to increased branching and is in agreement with the results of Chapter 5, where defoliation at the start of flowering did not significantly reduce the number of flowers per m^2 in the swards sown at 20 kg/ha because of increased branching. This result suggests that flower production is unlikely to be limited by defoliation at the start of flowering in most annual medic cultivars.

Table 7.8. Effects of cultivar on flower production, percentage pod set and seed yield of medic swards sown at the Waite Institute in 1991[a]. (The data represent means of all the defoliation treatments)

Species	Cultivar or Genotype	Days to first flower	Racemes (#/m^2)	Flowers (#/m^2)	Mean pod weight (mg/pod)	Flowers (#/raceme)	Potential sink size (mg/node)	Pod set (%)	Seed yield (kg/ha)
M. littoralis	Harbinger	79	8917	38740	29.4	4.4	127.9	25.9	848
M. polymorpha	Serena	42	11550	28360	24.6	2.4	59.5	33.1	1017
	SC01011	95	4617	21680	41.5	4.7	193.0	25.5	770
	SC01012	90	7784	40200	23.6	5.2	122.0	24.8	938
M. rugosa	Paragosa	84	12610	44230	19.7	3.5	69.0	21.6	797
	Paraponto	62	NA	NA	25.3	4.2	105.0	NA	1268
M. scutellata	Sava	65	7086	9823	195.8	1.4	268.2	13.3	755
M. tornata	Murrayland	85	NA	NA	31.6	4.9	153.9	NA	409
	Tornafield	95	5289	62870	23.0	11.9	273.2	12.7	780
M. truncatula	Paraggio	87	8758	19970	82.9	2.3	189.0	16.9	626
Cultivar	LSD (P<0.05)		3211	12270	12.0			9.2	190

[a] LSD excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

NA, Data not collected

7.3.5.2. Percentage pod set

The number of flowers that survived to form mature pods differed significantly ($P<0.001$) between species and cultivars including unnamed genotypes. The *M. polymorpha, M. rugosa* and *M. littoralis* cultivars used in this study had higher percentage pod set than *M. tornata, M. scutellata* and *M. truncatula* cultivars (Table 7.8). Among the cultivars, the highest percentage pod set occurred in Serena and the lowest in Tornafield and Sava followed by Paraggio (Table 7.8).

Percentage pod set was significantly and negatively correlated with the potential sink size ($r= -0.56$, $P<0.001$, $n=30$ for undefoliated swards, $r= -0.60$, $P<0.001$, $n=30$ for leniently- and $r= -0.41$, $P<0.05$, $n=30$ for severely-defoliated swards). Percentage pod set was significantly and negatively correlated with the day to first flower appearance in the undefoliated swards ($r= -0.48$, $P<0.01$, $n=30$) but not in the defoliated swards ($r= -0.27$, $n=30$ for leniently-defoliated and $r= -0.02$, $n=30$ for severely-defoliated swards). The correlations between percentage pod set and the number of flowers per raceme, number of seeds per pod and mean seed weight were not significant. Even the correlation between percentage pod set and potential sink size or percentage pod set and the day to first flower appearance were not very strong, suggesting that no single attribute had an overriding influence on percentage pod set over all the cultivars. For example, with Serena the high number of flowers that survived to form mature pods was due to both early flowering and a small potential sink size but in Paragosa percentage pod set was reduced by the late flowering despite a small potential sink size (Table 7.8). Sava, in contrast, was early flowering but pod set was limited by the larger potential sink size. In Tornafield, pod set was limited by both late flowering and a larger potential sink size (Table 7.8).

7.3.6. Seed yield and yield components

Table 7.9 shows the ANOVA summary for seed yield and seed yield components. The effects of cultivars were highly significant ($P<0.001$) in all yield components but defoliation had no significant effect except for the harvest index (HI) where severe defoliation increased the HI from 10.8% in undefoliated swards to 12.3% in severely defoliated swards. Significant Cultivar x Defoliation interactions only occurred with the number of pods per m^2 (Table 7.9). Seed yield varied with cultivars rather than with species. The highest yield for example was with the *M. rugosa* cultivar Paraponto (Table 7.10) whereas the other cultivar of this species, Paragosa, was one of the lowest yielding. In *M. tornata*, the cultivar Tornafield produced significantly higher mean seed yield across all defoliations than Murrayland (Table 7.10).

Seed yield across the cultivars and defoliation was correlated with percentage pod set, pods per m^2, seed per m^2, HI and seed:pod ratio but not with DM on the 24 September in the undefoliated swards or at the end of flowering (21 October) for both defoliation treatments (Table 7.11). Seed yield was also not related to winter DM production (Fig 7.1, Appendix Table 7D). The result suggests that the ability of a cultivar to partition more assimilates to pod set and seed growth rather than vegetative growth or pod wall development is important in determining seed yield among the cultivars tested. However, the correlations, even between pods per m^2 and seed yield were low, suggesting that there is considerable variation and compensation between components and that selecting for one component will not necessarily increase yield. For example Paraponto achieved the highest yields mainly because of the high number of pods per m^2 and its relatively heavier mean seed weight in comparison to the other cultivars (Tables 7.10, 7.12). *M. scutellata* had the heaviest mean seed weight but its seed yields were limited by the low number of pods per m^2 (Tables 7.10, 7.12). The significantly-higher seed yield with Serena than with Harbinger, despite similar number of pods per m^2, is attributable to the higher mean seed weight and seed:pod ratio (Tables 7.10, 7.12).

The number of pods per m^2 was correlated with the number of flowers per m^2 ($r= 0.63$, $P<0.01$, $n=30$) and percentage pod set ($r= 0.54$, $P<0.01$, $n=30$). There was a Cultivar x Defoliation interaction in the number of pods per m^2 (Table7.10) and this was mainly due to SC01012 having higher percentage pod set in the undefoliated than defoliated swards, whereas Tornafield had a higher percentage pod set in the defoliated than in the undefoliated swards (Appendix Table 7E). These results suggest that even selection for the number of pods per m^2 involves more than one attribute and some cultivars may be more sensitive to defoliation in terms of percentage pod set than others.

Table 7.9. Summary of ANOVA on the effects of cultivar and defoliation on seed yield and seed yield components of annual medics sown at the Waite Institute in 1991[a]

Source of variation	Seed yield (kg/ha)	Pods (# /m^2)	Seeds (#/m^2)	Seeds (#/pod)	Seed weight (mg)	Seed:pod ratio (%)	Harvest Index (%)
Cultivar	***	***	***	***	***	***	***
Defoliation	NS	NS	NS	NS	NS	NS	**
Cultivar x Defoliation	NS	**	NS	NS	NS	NS	NS

[a] Summary excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

NS, Not significant; ** P<0.01; *** P<0.001

Table 7.10. Effects of cultivars and genotypes on seed yield and seed yield components of annual medics sown at the Waite Institute in 1991.

(The data represents means of all defoliation treatments)

Species	Cultivar or Genotype	Seed yield (kg/ha)	Seeds (#/m^2)	Seeds (#/pod)	Seed weight (mg)	Harvest Index (%)	Seed:pod ratio (%)
M. littoralis	Harbinger	848	31920	3.37	2.64	10.4	30.4
M. polymorpha	Serena	1017	30760	3.46	3.29	12.8	46.3
	SC01011	770	18970	3.97	4.05	10.0	38.8
	SC01012	938	26400	3.21	3.53	13.0	48.0
M. rugosa	Paragosa	797	12140	1.40	6.56	12.9	46.6
	Paraponto	1268	14280	1.30	9.40	15.9	45.9
M. scutellata	Sava	755	5034	4.41	15.04	9.5	33.9
M. tornata	Murrayland	409	16690	3.50	2.99	9.4	28.3
	Tornafield	780	18170	2.54	4.30	14.8	47.4
M. truncatula	(Ghor[a]	631	14520	5.93	4.37	7.4	-)
	Paraggio	625	13540	5.41	4.65	7.5	30.6
Cultivar	LSD ($P<0.05$)	190	4390	0.49	0.89	1.9	4.9

[a] LSD excludes data for Ghor because the cultivar was attacked by a fungal disease in early spring and the yields may not be representative of a normal sward.

Table 7.11. **Correlation coefficients for seed yield and components of seed yield in undefoliated and defoliated swards of annual medic cultivars sown at the Waite Institute in 1991**

Component of seed yield	Correlation coefficient values		
	Undefoliated	Leniently defoliated	Severely defoliated
DM at 24 September[a]	0.29	0.40*	0.37*
DM at end of flowering (21 October)[a]	0.02	0.13	0.16
Flowers (#/raceme)[b]	-0.20	0.22	0.13
Racemes (#/m^2)[b]	0.15	0.18	0.01
Flowers (#/m^2)[b]	0.01	0.33	0.13
Potential sink size per raceme[b]	-0.25	-0.21	0.06
Flower survival (%)[b]	0.45***	0.42**	0.35*
Day of first flower[a]	-0.10	-0.34	-0.21
Pod number (#/m^2)[a]	0.63***	0.71***	0.64***
Seed number (#/m^2)[a]	0.37*	0.48**	0.46**
Seeds per pod (#/pod)[a]	-0.33*	-0.30	-0.19
Mean seed weight (mg/seed)[a]	0.28	0.11	0.22
Mean pod weight (g/100 pods)[a]	0.12	-0.20	-0.10
Seed:Pod ratio[a]	0.66***	0.64***	0.57***
Harvest index (%)[a]	0.82***	0.72***	0.68***
Seed index (Seed # ÷ biological yield)[a]	0.04	0.08	0.08

* $P<0.05$ ** $P<0.01$ *** $P<0.001$

[a] Correlation coefficients exclude data for Ghor. The number of data points for each defoliation treatment =40

[b] Correlation coefficients exclude data for Ghor, Paraponto and Murrayland. The number of data points for each defoliation treatment =32

Table 7.12. Effects of cultivars , genotypes and defoliation on pod number per m^2 of annual medics sown at the Waite Institute, 1991

Species	Cultivars or Genotype	Pods (# /m^2)		
		Undefoliated	Leniently defoliated	Severely defoliated
M littoralis	Harbinger	9518	8471	10519
M polymorpha	Serena	9617	8646	8867
	SC01011	5308	4412	4562
	SC01012	10088	7271	7290
M rugosa	Paragosa	9892	8085	7948
	Paraponto	11057	9738	12203
M scutellata	Sava	1367	1124	1055
M tornata	Murrayland	5522	4223	4273
	Tornafield	4988	8704	7781
M truncatula	(Ghor[a]	2554	2446	2310)
	Paraggio	2278	4041	2313
Cultivar x Defoliation	LSD ($P<0.05$)		2168	

[a] LSD excludes data for Ghor because the cultivar was attacked by a fungal disease and the yields may not be representative of a normal sward.

7.4. DISCUSSION

In this Experiment seed yield ranged from 400 to 1268 kg/ha. The lowest yield was associated with the lowest spring herbage DM yield. However, seed yield was significantly correlated with DM in the defoliated swards on the 24 September (where DM was reduced, Table 7.11) but not at end of flowering (21 October) or in the undefoliated swards at both dates of DM harvests (Table 7.11). This result is in agreement with the data from Chapter 5 (Fig. 5.2) where low DM was associated with low seed yield and there was no relationship between seed yield and DM above c. 7000 kg/ha, a value achieved by most cultivars at the end of flowering (21 October) in the present experiment.

Most cultivars produced seed yields that were similar to the commercial yields of 440 kg/ha (880 kg/ha assuming a harvest efficiency of 50% Cocks (1988)) that are typical of South Australian conditions (Ragless 1973). The exceptions were Paraponto and Serena which produced high yields and Murrayland and Paraggio which produced low yields. The yields of Paraggio in the present experiment were similar to those of Paraggio in the neighbouring experiment (Experiment 5 of Chapter 5) but were lower than those reported for the same site in other seasons, despite the similarity in the end of season dry matter yields (Adem 1977; Ababneh 1991; Chapter 3 and 4 of this thesis). The lower yields are attributable to moisture stress during the month of October (Table 5.1). Flowers per m^2 in the 1991 season were higher than that at the optimum sowing rate in 1989 (Chapter 3), but percentage pod set was 2 to 3 times lower (Tables 3.12, 5.8, 7.8). The results suggest that the apparently-greater moisture stress in 1991 (evidenced from severe wilting that occurred during flowering) reduced seed yield through a large loss of flowers. The lower yields for both Paraggio and Sava in 1991 compared to other seasons (Ababaneh 1991;Chapters 3 and 4 of this thesis) suggests that the cultivars used in the present experiment produced lower yields than would be expected in a normal season.

The cultivars used in this study differed significantly in DM production (Tables 7.4, 7.6). Early winter production was associated with high plant density except in those cultivars that had poor early nodulation (Fig. 7.1). Early flowering was not always associated with high early winter DM production because of differences in early nodulation and plants per m^2 (Tables 7.3, Fig. 7.1). There was also no relationship between early flowering or early winter DM production and DM at the end of flowering (21 October) because of accelerated growth rates in some cultivars once they attained full light interception (Table 7.5). As with DM, days to first flower was also not significantly correlated with seed yield. These results show that selecting for early flowering does not necessarily result in reduced DM at end of flowering or high seed yields at maturity. This finding is in contrast to the reports of Crawford (1983) and Crawford *et al.* (1989) which suggested that early-flowering cultivars produce higher seed yields.

Seed yield did not differ significantly between defoliation treatments (Table 7.9). The lack of a significant increase in seed yield was mainly due to the failure of defoliation to increase the number of pods per m^2, except in the cultivar Tornafield (Table 7.12). The number of flowers at the end of flowering was not significantly reduced by defoliation, suggesting that defoliation did not increase pods per m^2 because it didn't significantly increase percentage pod set (Appendix Table 7E). As in Experiment 5 of Chapter 5 this could be attributed to the delay in flower re-appearance such that most of the flowers were produced under severe moisture stress following defoliation. This result is consistent with the findings of Chapter 5, Tow and Al Alkailah (1981), Carter (1989), Ababneh (1992) where defoliation did not increase seed yield because of its failure to increase the number of pods per m^2. The finding in Experiment 5 of Chapter 5 that severe defoliation at the start of flowering of swards sown at 20 kg/ha increased seed yield through increases in mean seed weight under rainfed conditions was not observed with severe defoliations in this study. This result suggests that increases in seed yield following defoliation through increased mean seed weight may not be common under rainfed conditions even with the same cultivar and same site.

The lack of a significant decrease in seed yield with defoliation at the start of flowering in Experiment 7 is in disagreement with the sheep grazing studies on a range of annual medic cultivars in Western Australia (Ewing 1984; Thorn and Revell 1987) and with the results of severe defoliation on Paraggio barrel medic at Korunye in Chapter 5. However, in Experiment 7 the lowest DM at the end of flowering was at least 4500 kg/ha which was greater than the 4000 kg/ha achieved in the Western Australia and Korunye experiments. From Fig. 5.2 of Chapter 5 and the result of Experiment 7, it is suggested that defoliation at the start of flowering is unlikely to reduce seed yield in a range of cultivars if the DM yield at the end of flowering is above 4000 kg/ha.

The differences in seed yields from cultivars used in Experiment 7 were significant. The superiority in seed yield of *M. polymorpha* and *M. rugosa* cultivars in comparison to *M. tornata* cv. Tornafield, *M. littoralis* cv. Harbinger and *M. truncatula* cultivars has been reported in Western Australia (Thorn and Revell 1987; Ewing and Howieson 1989) on a moderately acid (pH 4.6 - 5.9), light textured soil of the 250 - 400 mm rainfall cereal-livestock zone. Cocks (1988,1990) has also reported the superiority of *M. polymorpha* cultivars to *M. truncatula* cv. Jemalong in Syria on a reddish brown clay with an annual rainfall of 340 mm. In the present study, cultivar differences in seed yield were mainly attributable to the number of pods per m^2 (Table 7.10, 7.11, 7.12), a result that is consistent with the earlier findings on annual medics (Cocks 1988, 1990 and Chapters 3, 4 and 5 of this thesis) that seed yield is determined by the number of pods per m^2. In some cultivars, however, high seed yields were the result of the combined effects of the large number of pods per m^2 and seeds per pod and/or high mean seed weight (Tables 7.10, 7.12). The results suggest that, although the maximisation of pods per m^2 should be an aim of agronomists working with a single cultivar, this does not justify the use of pods per m^2 in isolation as a selection criterion by breeders.

The cultivars (and unnamed genotypes) used in this study resulted in a 6-fold range of flowers per m^2 (Table 7.8) but the highest number of pods per m^2 was not always associated with the highest number of flowers per m^2 because high percentage pod set compensated for fewer flowers in some cultivars (Table 7.8). This result is in agreement with those of Cocks (1988, 1990) and of Chapter 3 and 5 of this thesis, which showed that the number of flowers per m^2 is not a major determinant of seed yield in annual medics if canopy closure (LAI 4) occurs at some stage during the reproductive period. In the present study, increases in seed yield due to high numbers of flowers per m^2 only occurred if a large number of flowers were produced before the onset of severe moisture stress.

The 4-fold range in percentage pod set between the cultivars used in Experiment 7 and the fact that seed yield was positively correlated ($r = 0.45$, $P<0.05$) with percentage pod set demonstrates that the differences in seed yield in the cultivars currently grown by South Australian farmers is partly due to differences in percentage pod set. The superiority of *M. polymorpha* cultivars in percentage pod set in this study is consistent with the findings of Cocks (1990) where *M. polymorpha* Sel. cv. Tah had higher percentage pod set than the other cultivars tested under both low and high density swards in Syria. The magnitude of percentage pod set reported for *M. polymorpha* cv. Serena and *M. truncatula* cv. Paraggio are in close agreement to those reported for the same species by Cocks (1990) in Syria.

Comparative studies on a range of medic cultivars in Australia are not available in the literature: however, the 34-36% pod set recorded in Chapter 3 from sowing rates of 5 to 25 kg/ha in undefoliated swards of *M. truncatula* cv. Paraggio, in comparison to 13% recorded in Experiment 7 and 12% in Experiment 5 of Chapter 5, suggests that the cultivars used in Experiment 7, especially the late flowering cultivars, were capable of higher percentage pod set than those recorded here. The poor pod set in this study and Experiment 5 of Chapter 5 is attributable to moisture stress during the month of October (Table 5.1, 5.6).

An analysis of the various components that determine percentage pod set show that percentage pod set is increased by a smaller sink size at each flowering node and by early flowering. The magnitude by which each parameter influenced percentage pod set varied with cultivars (Table 7.8). As with seed yield, or the number of pods per m^2, the correlations were generally weak indicating that none of the parameters had an overriding influence on percentage pod set on its own.

The finding that a smaller sink size at each flowering node results in an increase in percentage pod set agrees with the studies of Cocks (1990), which indicated that intra-plant competition for assimilates may be one of the causes of the variation in seed yield in annual medic cultivars. Studies in *Vicia faba* have implicated competition between flowers within a raceme for assimilates as being responsible for the excessive flower abortion (Gates *et al.* 1981, 1983). Gates *et al.* (1983) have argued that the competition occurs because all the flowers within a raceme have a common vascular supply. Flinn and Pate (1970) and Jeuffroy and Warembourg (1991) have also demonstrated in grain legumes that the major source of assimilates for flowers and freshly-pollinated fruits is the subtending leaf at each flowering node and that developing pods receive assimilates from leaves at other nodes only when these are beyond the final stage of abortion. In a developing medic sward, the flowers are usually in sunlight, but the young pods may be partly shaded because the sward canopy grows over them. This suggests that if the abortion of flowers and very young pods is related to photosynthate supply, then it should be as a result of competition from pods deep in the canopy that have already passed the stage of abortion and/or from the shoot apices, both of which are stronger sinks than flowers and young pods.

The potential sink size hypothesis implies that even under optimum conditions cultivars with the same days to first flower may differ in percentage pod set because of the competition for assimilates at each flowering node. Also, under dryland farming conditions, moisture stress can occur any time during the flowering period and this may reduce the effectiveness of increasing seed yield by selecting for lower potential sink size in late flowering cultivars because pod set may still be reduced by a late production of flowers e.g. Paraggio and Paragosa (Table 7.8). This study suggests that a greater understanding of the physiological interaction between the potential sink size at each flowering node, the number of flowering nodes per plant, the assimilate supply at each flowering node and within the whole plant, and their relationship with the flowering period, is required if the physiological constraints to yield are to be better defined.

It is obvious from the results of Chapter 3 of this thesis, as well as those of Poole (1970); and Cocks (1988); Thorn and Laslett (1992) that management strategies that encourage a large production of flowers early in the season are important for maximising seed yield in annual medics. The results of this Chapter and those of Chapter 3 show that the greatest increase in seed yield only occurs when production of a large number of flowers is accompanied by a large percentage pod set (Tables 3.13, 7.8). The results of the present study also show that early flowering can increase percentage pod set between cultivars but only if the potential sink size is small e.g. Serena compared to Sava in Table 7.8. These results confirm the findings of Cocks (1990) that seed yield in annual medics is determined by early flowering and a high percentage pod set, and they indicate also, that no single criterion can be used to select for high seed yield. If percentage pod set was to be used as a selection criterion for high seed yielding cultivars, then it will involve selecting cultivars that are early flowering with more flowers per raceme, fewer seeds per pod or smaller seeds. However the ecological significance of smaller seeds in the ley farming system is a controversial subject, because of the poor establishment of smaller-seeded cultivars, as they cannot emerge from greater depths and usually produce weaker and less vigorous seedlings during the autumn/winter season when feed supply is in great demand (Carter 1987; Squella 1992). On the other hand, small-seeded legumes are clearly the most successful under heavy grazing (Carter 1967, 1987).

A fundamental objective in pasture and forage crop seed production is to increase seed yield without reducing herbage production. The present study shows that high herbage production does not necessarily reduce seed yield. This result is consistent with the reviews of Davies (1981) and Lorenzetti (1981) for temperate perennial forage legumes and the studies by Samaroo (1988) with annual temperate forage legumes which show that seed yield and DM are independent of each other and that it may be possible to select for high herbage production as well as high seed yield together. The lack of a significant Cultivar x Defoliation interactions in herbage and seed yield in the present study suggests that annual medic cultivars can be evaluated for persistence to grazing and high seed production simultaneously, provided that the time of final defoliation is based on the same phenological stage for each cultivar. Achieving high seed yields without jeopardising herbage production requires identification of the most important components of yield on which selection or breeding can be based, but the present study shows that selection for yield using a single component may be difficult since yield is determined by various parameters at various stages of reproductive growth (Tables 7.8, 7.11). The interpretation of the best selection criterion in this study is limited by information from a single experiment and a lack of information in the literature. However, it could be proposed that selecting for yield over a wide range of environments may be an easier way of identifying cultivars that are high yielding across seasons than selection based on an individual character. There is a strong case for continuing the evaluation of annual medics by widespread testing over a range of climatic and edaphic environments. However, improved seed production by management strategies is possible.

High yield also depends on reducing the incidence of pests and diseases. Although the effects of biotic factors on seed yield was not a component of this study, the low yields of Ghor which were largely caused by the fungal disease black stem, emphasizes the need to have cultivars with adequate levels of resistance to common pests and diseases.

7.5. SUMMARY AND CONCLUSIONS

The study shows that there is variation in seed yield between the annual medic cultivars even when the dry matter production at the end of the flowering period is similar. The number of pods per m^2 accounted for most of the differences in yield, although in some cultivars seed increases were due to the number of pods and the number of seeds per pod or mean seed weight. There was variation in percentage pod set among the annual medic cultivars tested in this study and this appeared to have a relatively bigger effect on seed yield than the number of flowers per m^2 or early flowering *per se*. Cultivars with a lower potential sink size had a better percentage pod set than those with a greater sink size. Early flowering was important to achieve high percentage pod set if the potential sink size was small but was not significantly correlated with overall seed yield because of the cultivar influence on the number of flowers produced, number of seeds per pod and mean seed weight.

The study suggests that a combination of early flowering and a greater percentage pod set are suitable criteria for identifying high seed yielding cultivars, but not early flowering alone. Defoliation management strategies to optimise seed yield appears to be similar in all annual medic cultivars. It appears that significant decreases in seed yield following defoliation at the start of flowering when DM at the end of flowering is greater than 4500 kg/ha is not a common feature in annual medics. However, further experimentation in a wide range of environments and seasons is required in order to ascertain the importance of this strategy in increasing seed yields. In dryland farming, where severe moisture stress is likely to occur any time during the flowering period, the results of this study suggest that for a range of cultivars strategies that encourage a greater production of flowers and higher pod set before the onset of moisture stress are likely to increase seed yield. This is consistent with results of more detailed studies on a single cultivar reported in earlier Chapters.

CHAPTER 8

8. GENERAL DISCUSSION AND CONCLUSIONS

The results of each experiment, and some of their interrelationships have already been partly reviewed in separate discussions of each experiment; this discussion seeks to interpret the main findings and identify gaps in knowledge for future research. The seed yields of medics in the studies described in this thesis varied between seasons and cultivars. The greatest variability within a cultivar was due to rainfall during the reproductive period. In a season with good rainfall during the months of September and October, or when rainfall was supplemented by irrigation (Chapters 3, 4), the best yields were above 1000 kg/ha, whereas in a season with poor rainfall between September and November (Experiment 4 in Chapter 5) or during the month of October (Experiment 5 in Chapter 5 and Experiment 7 in Chapter 7) the best yields for most cultivars were below 1000 kg/ha. This is consistent with results from a survey of commercial seed crops of annual medics in the Lower North region of South Australia (Fig 8.1 and Appendix Table 8A) which showed a significant correlation between rainfall during August to October and seed yield. In contrast to seed yield, total herbage mass (kgDM/ha) at the end of flowering was greatest in seasons with the highest rainfall during the growing season (Experiment 1 in Chapter 3, Experiment 5 in Chapter 5). These results demonstrate that a major constraint to seed yield is the amount and distribution of rainfall during the spring period.

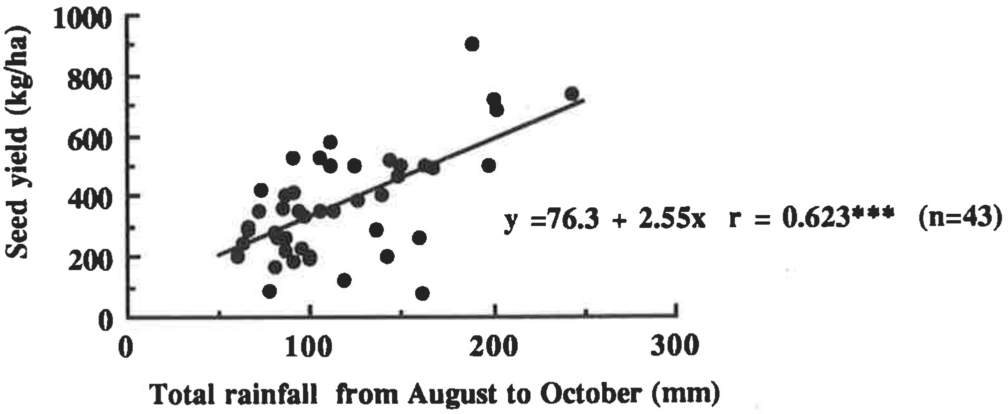


Fig 8.1. **The relationship between rainfall during August to October and seed yield in commercial seed crops of Paraggio barrel medic. The data were obtained from a survey of medic seed growers in the Lower North region of South Australia**

Across experiments, seed yield of Paraggio barrel medic was significantly and positively correlated with the number of pods per m^2 (Fig 8.2). Between cultivars, high seed yield was also associated with a high number of pods per m^2, but the correlation was weak (Table 7.11, Fig 8.3) because of the compensation that occurred between different yield components. For example, in Chapter 7 Sava produced fewer pods per m^2 but because of a larger mean seed weight, seed yield was higher than in the small-seeded cultivar Murrayland (Tables 7.10,7.12). This emphasises the fact that seed yield within a cultivar can be increased by maximising production of pods per m^2 but this cannot be used as a criterion for selecting high-yielding cultivars. Mean seed weight or number of seeds per pod contributed relatively little to increases in seed yield within a cultivar; and only when the number of pods per m^2 was not significantly affected by treatment (Experiment 5 in Chapter 5) was yield associated with this trait.

The potential number of pods per m^2 is set by the number of flowers per m^2 but the number of pods at maturity is determined by the proportion of these flowers that survive to form mature pods. Flower density is dependent on the number of flowers per raceme and branches per m^2. The results from the various experiments in this thesis indicate that as long as medic swards can grow so that they are intercepting all the light before flowering ends, flowers per m^2 will be high enough not to limit yield (Chapters 3, 5, 7). The major limitation appears to be the proportion of flowers that form mature pods, a result consistent with the findings of Cocks (1988, 1990a,b).

An important finding of the studies reported in this thesis is that the number of pods per m^2, and hence seed yields, will be high only when a canopy produces a large number of flowers per m^2 before the onset of complete self-shading (Chapters 3, 4) and/or severe moisture stress (Chapters 5, 6, 7). Early production of a large number of flowers by a medic cultivar is promoted by early sowing or by early emergence in a self-regenerating pasture, which depends on the timing of the opening rains (Chapters 3, 4). Seed yield will be reduced when the opening to the season is late, especially in late-maturing cultivars (Cocks 1988; Thorn and Laslet 1992). However, early sowing or regeneration often produces large amounts of herbage but, under rainfed conditions, there is a balance between DM production and seed yield. Depending on season, early sowing at the optimum sowing rate can produce swards with large amounts of vegetative growth at the start of flowering if they are not grazed (Chapters 5, 7 and E. D. Carter *pers. comm.*). If soil moisture is not limiting, such swards will give reduced seed yields through poor percentage pod set as a result of complete self-shading during the early flowering period (Chapters 3, 4). However, if available soil moisture is low, yields will be reduced through poor pod set and reduced mean seed weight as a result of increases in the level of plant water stress (Experiment 5 in Chapter 5). Between medic species and cultivars, early production of a large number of flowers may be achieved by using early-flowering cultivars which have a large number of flowers per raceme. The disadvantage is that cultivars with a large number of flowers may also result in a higher potential sink size which reduces seed yield through poor percentage pod set (Chapter 7).

From the point of view of providing livestock feed, it is desirable to maximise herbage production by the pasture: however, the relationship between seed yield and herbage production is not a simple one but is influenced greatly by seasonal conditions. Fig 8.4 shows the relationship between seed yield and herbage production from three experiments. When water availability was high (Waite Institute 1989) high seed yields were associated with high herbage production. However, high herbage production at the beginning of flowering can result in self shading which will reduce pod set and seed yield. In a year with low rainfall during October, when the swards became obviously stressed (Waite Institute 1991), high vegetative growth reduced yields because the greater levels of water stress resulted in lower pod set (Chapter 5). When rainfall is low throughout the season and the sward does not intercept all the available light (Korunye 1990), yield is limited by the number of pods per m^2, even though percentage pod set is high. In this case, high herbage production is beneficial to seed yield. In these experiments herbage production below 4000-5000 kgDM/ha reduced seed yields; the response to herbage production above this level varied between years. As a consequence of these relationships, management strategies to improve seed yield, such as defoliation, will vary according to the expected seasonal conditions.

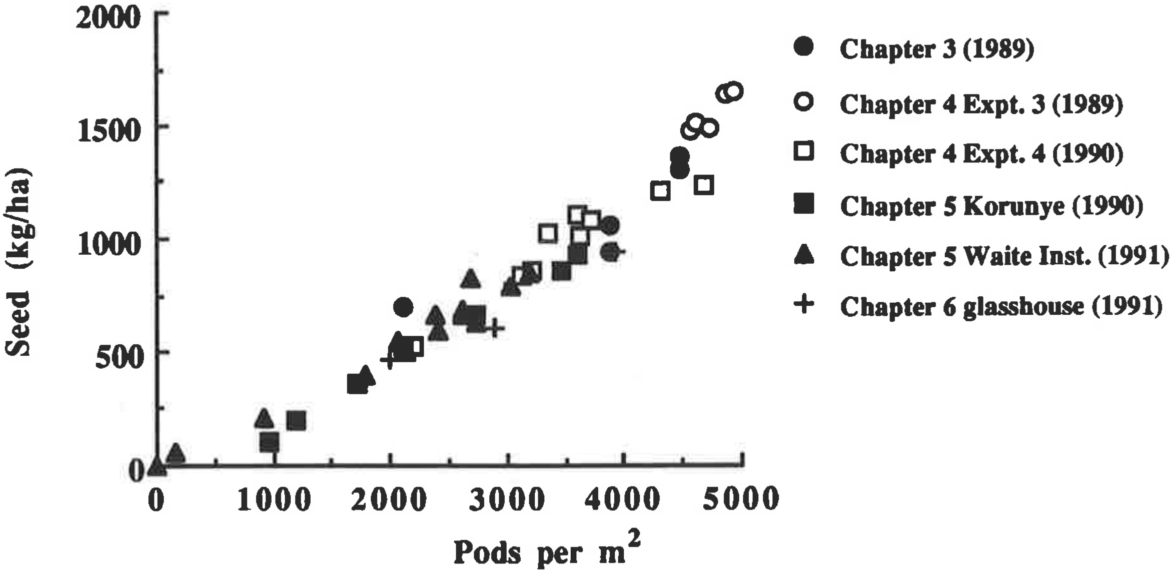


Fig. 8.2. Relationship between pods per m^2 and seed yield of Paraggio barrel medic

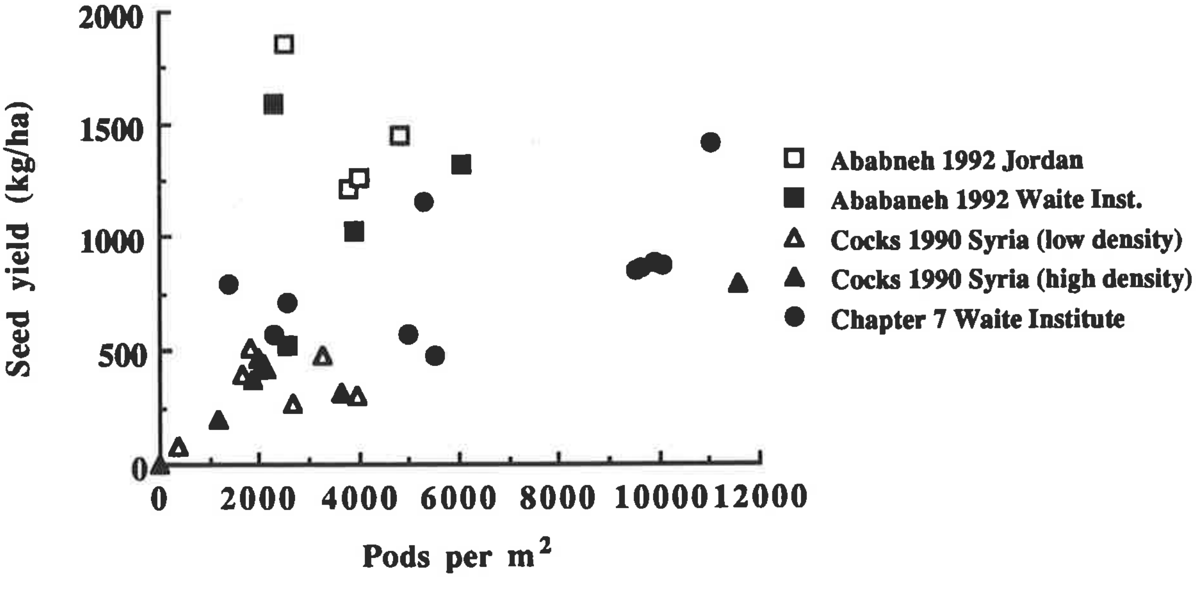


Fig. 8.3. Relationship between pods per m^2 and seed yield across medic cultivars in undefoliated swards. Cultivars used were: *M. rigidula* Sel. 716, *M. rotata* Sel. 1943, *M. scutellata* cv. Sava, *M. truncatula* cv. Paraggio (Ababneh 1992); *M.noeana* Sel. 1938, *M. noeana* Acc. SA 15845, *M. polymorpha* Sel. Tah, *M. rigidula* Sel. 1900, *M. rigidula* Sel. 7116, *M rotata* Sel. 2123, *M. truncatula* cv. Jemalong (Cocks 1990b); for Chapter 7 see text.

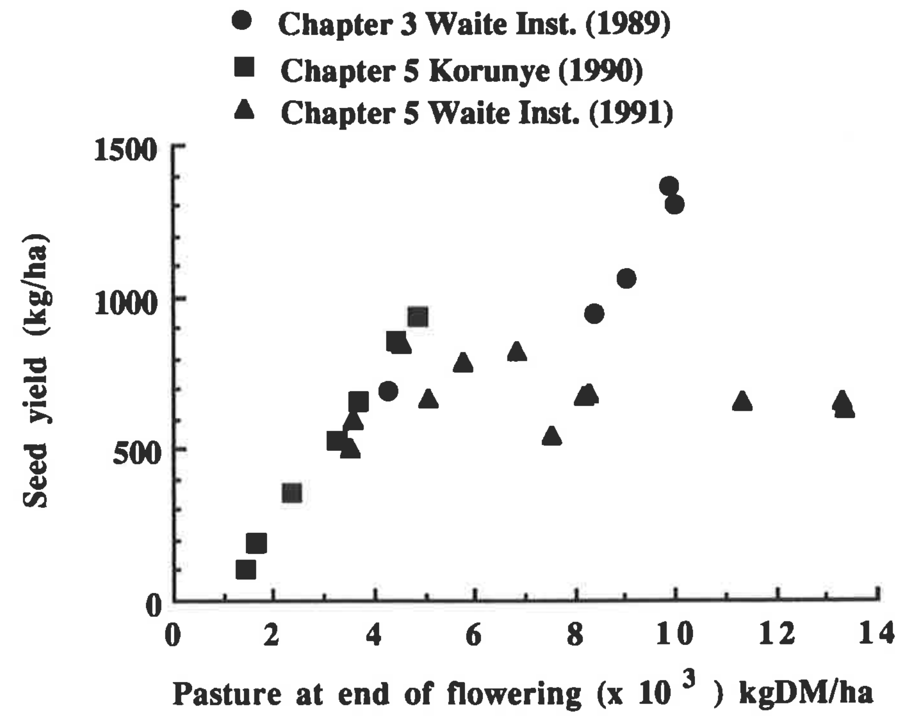


Fig. 8.4. Relationship between herbage DM at end of flowering and seed yield of Paraggio barrel medic

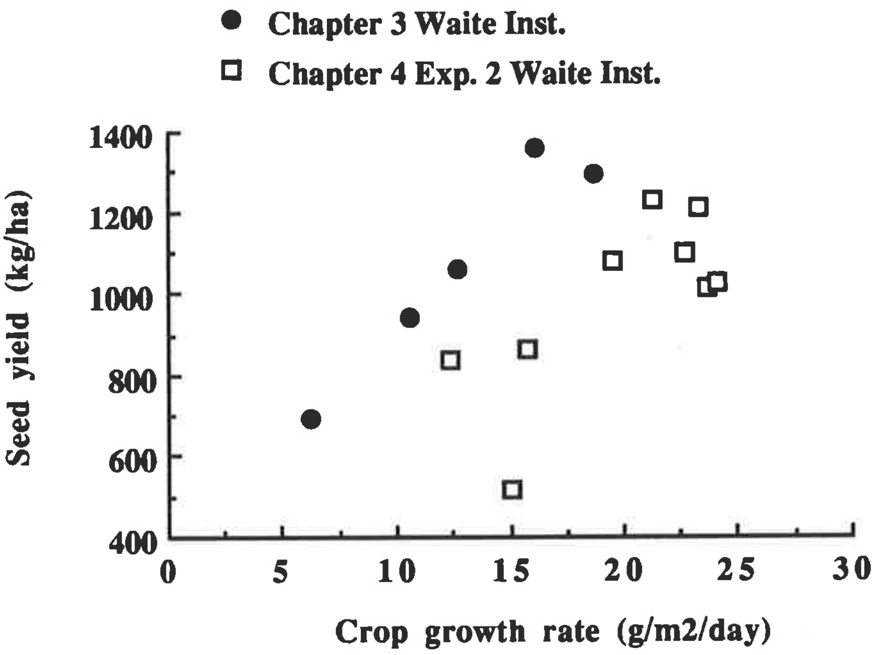


Fig. 8.5. Relationship between crop growth rate during early flowering and seed yield of Paraggio barrel medic

Studies on the effects of defoliation at the start of flowering on seed yield show inconsistent results, ranging from an increase to a significant decrease in seed yield (Chapters 5, 6, 7).

Where significant increases in seed yield occurred, these were due to increases in the number of seeds per pod and mean seed weight and not due to an increase in pods per m^2. Visual observations in these experiments showed that defoliation delayed flower re-appearance by between 1 and 3 weeks. This was a result of slow recovery after defoliation due to reduced leaf area, which in turn delayed the timing of peak flower production. Although the density of flowers per m^2 at the end of the flowering period was not significantly reduced by defoliation (see Experiments 4, swards sown at 20 kg/ha in Experiment 5, and Experiment 7), peak production of flowers occurred later in the season when temperatures were high and/or soil moisture availability was low, conditions that are unsuitable for high pod set (Downes and Gladstones 1984a; Wolfe 1985; Amoabin *et al.* 1987; Chapter 6). This delay in the production of flowers does not reduce the total number of flowers per m^2, but it does reduce the proportion of young pods that mature, which may be a reason why defoliation studies conducted in the higher rainfall areas of the State do not show an increase in seed yield (Carter 1989; Ababneh 1991; Chapter 7). However, in lower rainfall areas severe defoliation may reduce herbage production to levels that will limit seed yield (e.g. Korunye 1990). A seed yield of about 1000 kg/ha requires about 5000 kgDM/ha at the end of flowering (Fig 8.4). Under rainfed conditions, grazing or defoliation strategies should aim to achieve this amount of herbage production but clearly the management of the sward will vary depending on site and season.

The studies reported in Chapter 5 indicate that time of final defoliation and the severity of defoliation should be matched to the expected growing conditions, such that the risk of moisture stress, which can reduce the number of flowers per m^2 or pod set, can be minimised. This requires local experience, but from the studies reported in this thesis it can be postulated that: (i) where adequate rainfall is likely to occur during the flowering period, seed yield can be increased by severe defoliation prior to the start of flowering, which increases percentage pod set as a result of better light penetration through the sward during the flowering period, (ii) where moisture stress is likely to occur during the active pod-setting and seed-filling period, defoliation up to the start of flowering can increase seed yield by increasing mean seed weight and number of seeds per pod as a result of reduced plant water stress and (iii) where pre-flowering growth is limited by low rainfall, defoliation should cease before flowering.

Commercial seed producers in South Australia spray their medics with low rates of herbicides prior to the start of flowering to control broadleaved weeds and grasses (E. D. Carter *pers. comm.* and farm survey). The broadleaf herbicides retard vegetative growth for some time and often reduce the size of the leaves thereby modifying the canopy prior to the start of flowering. Unlike defoliation, which completely eliminates the flowering nodes, herbicides do not remove the flowering nodes and this may result in a larger production of flowers earlier in the season than that achieved by defoliation. This early flower production together with the better light penetration and reduced water stress as a result of modified canopy at the start of flowering may result in high pod set and seed yield. However, no data are available in the literature on the effects of low rates of broadleaf herbicides on seed yield of annual self-regenerating legumes. Studies in temperate perennial forage legumes show that growth regulators increase seed yield by increasing the number of florets per m^2. Puri and Laidlaw (1983) and Jakesova and Svetlik (1984), cited by Hampton (1988), showed that application of daminozide (Alar) increased seed yield of *Trifolium pratense* by increasing inflorescence number, while Belonogor *et al.* (1983) also cited by Hampton (1988) increased seed yield by applying gibberellic acid at flowering. There is a need to exploit the use of low rates of herbicides, particularly if these control broadleaved weeds as well as modify the medic canopy to allow better light penetration through the sward for increased pod set. However, the use of growth regulators will increase costs of production and should only be used if the increases in seed yield are high enough to justify the added cost.

Even with the best management practices, there is still considerable loss of yield potential in annual medics because of the low percentage pod set. Over 60% of flowers fail to form mature pods under sward conditions (Chapters 3, 5, 6, 7) a result consistent with the experiments of Cocks (1988, 1990b) in Syria. The studies of Cocks (1988, 1990b) and visual observations in the experiments described in this thesis indicate that the loss of yield potential involves not only abortion of flowers but also young pods. Lack of pollination is universally believed to be a major constraint to herbage legume seed production (Lorenzetti 1981). Recent studies with

Lotus spp. (Tabora and Hill 1991; Hill and Supanjani 1992) and with *Trifolium repens* (Pasumarty and Thomas 1990) identify ovule degeneration after pollination in addition to a lack of pollination as the major causes of seed loss. In annual medics, except for a single preliminary study by Cocks (1987) involving mechanical tripping of flowers, which showed that pod set was not constrained by pollination, detailed research into pollination and pod set is lacking. A better understanding of pollination, fertilization and seed set may be a prerequisite to any substantial progress in improving seed yield through better agronomic practices or breeding.

Poor light penetration through the swards and plant stress through inadequate soil moisture have been identified in this thesis as major causes of poor percentage pod set. The observation that high growth rates during the early-flowering period were associated with a high partitioning coefficient (Chapter 3) and high seed yield (Fig 8.5) suggests that inadequate photosynthate supply to flowers and the very young pods may be responsible for the poor percentage pod set. In annual medics, flowers and young pods are produced in the upper canopy where the subtending leaves are exposed to large amounts of light. The question as to whether poor pod set occurs because of competition for assimilates from stronger sinks (vegetative apices, developing leaves and pods) and how it takes place could not be answered by the data of this thesis. Studies on competition for assimilates within a plant are required to provide an understanding of the assimilate requirements for high pod set.

When herbage production at the end of flowering and seed yield were examined over a range of cultivars it was found that these were independent of each other (Chapter 7). This is consistent with the reviews of Davies (1981) and Lorenzetti (1981) in temperate perennial legumes and the study of Samaroo (1988) with annual forage legumes, which reported that herbage and seed yield behave, to a large extent, as independent variables. Therefore, it may be possible to select varieties that produce large quantities of herbage as well as produce high seed yields. The lack of a correlation between seed yield and DM between cultivars is partly attributed to the indeterminate growth habit which allows potential number of pods (flowers per m^2) to be proportional to the size of the sward (branches per m^2 and/or DM). Furthermore, changes in weather conditions or agronomic practices can mask the differences between cultivars in DM and seed yield by changing the ability of the sward to set seed (Davies 1981; Lorenzetti 1981).

The research described in this thesis suggests that it may be difficult to select for high seed yield by selecting for a single yield component because seed yield is determined at various stages of the reproductive period and there is compensation between yield components. Selection for high herbage production and seed yield in a wider range of environments is suggested as a viable option for selection of cultivars that can produce high seed yields in a wide range of seasons. The effects of defoliation at a similar stage of growth on seed yield were similar for the medic cultivars used in this study (Chapter 7). The lack of a significant Defoliation x Cultivar interaction suggests that selection for high seed yield can be done together with evaluation for persistence to defoliation.

The practical implications and suggested future research as a result of the studies reported in this thesis are summarised as follows:

1. Management strategies to increase seed yield should aim at high early flower production and a larger percentage pod set. Early sowing at low to medium sowing rates (5-25 kg/ha; Chapter 3) or using early-flowering cultivars with a large number of flowers per raceme but with lower mean seed weight or fewer seeds per pod (lower potential sink size; Chapter 7) are suggested as strategies that can increase seed yield in annual medics.

2. Defoliation is unlikely to decrease seed yield in a wide range of cultivars if the final defoliation is completed before the start of flowering (Chapters 5, 7). Increases in seed yield with defoliation may occur if the herbage yield is large enough to increase plant water stress during dry spring weather (Chapter 5) or limit light transmission through the canopy during the flowering period. However, the success of this strategy in increasing seed yield requires local experience and studies on the severity and timing of final defoliation in a wide range of environments are required. The studies described in this thesis suggest that a herbage mass of less than approximately 5000 kgDM/ha is likely to result in a decrease in seed yield.

3. Seed yields over a wide range of cultivars were not simply related to cultivar maturity or to herbage dry matter at the end of flowering (Chapter 7), therefore it may be possible to select for both high herbage production and high seed yield concurrently.

4. Genetic variation exists for characters that would be amenable to selection for high seed yield in annual medics without reducing herbage production e.g. early flowering, flowers per m^2 and percentage pod. However, seed yield is determined at various stages of growth and no single yield component accounts for all the variation in seed yield between cultivars. Therefore, it is suggested that selection for high herbage yield and high seed yield should be based on final seed yield in a wide range of environments.

5. A large proportion of the flowers formed in annual medics do not set pods that develop to maturity. The studies indicate that poor light penetration through the sward, plant stress through inadequate soil moisture and high temperature may be responsible for this flower and young pod abortion. However, the developmental and physiological factors causing poor pod set are not well understood and further studies are required if rapid progress in designing agronomic strategies that can increase seed yield, or for selecting high-yielding cultivars, is to be made.

6. The results of experiments described in Chapters 3 and 4 demonstrated that poor light penetration during the later stages of flowering was no disadvantage to seed yield. This shows that when annual medics are sown under a cereal crop, increased seed production is possible by manipulating sowing date or defoliating the companion crop so that competition for light occurs during the later part of flowering. However, this assumes that there is no soil moisture deficit in spring (which is common in cereal districts) and that there are no complications with the use of herbicides to control weeds in the cereal crop. Further research at different sites and in different seasons is required.

In conclusion, this thesis research has identified the importance of the early period of flowering and pod production to seed yield in annual medics. Poor growth during this time due to incomplete light interception, self-shading or water stress will limit seed yield. The two most important medic cultivar characteristics for high seed yield are high early production of flowers and a high percentage pod set and it is also possible to select cultivars that have high herbage production as well as high seed yields. This research has provided an understanding of the limitations to seed yield in annual medics and suggested management strategies for a limited range of environments. Further work over a more extensive set of environments is needed to extend these principles.

Appendix Table 4A. **Effects of shading and defoliation on dry matter yield at the end of second half of flowering (116 days from emergence) of Paraggio barrel medic, Waite Institute, 1990**

Shade level	Shade time	Dry matter yield (kg/ha)		
		Undefoliated swards	Defoliated swards	Means
Unshaded	Control	10404	7314	8859
30%	Vegetative stage	8760	5139	6949
30%	First half of flowering	7397	5923	6660
30%	Second half of flowering	10801	6237	8519
30%	Shading throughout	11961	6923	9442
60%	Vegetative stage	10911	5488	8200
60%	First half of flowering	9448	6484	7966
60%	Second half of flowering	9553	4733	7143
60%	Shading throughout	7608	3590	5599
	Defoliation mean	9649	5759	

Appendix Table 4B. **Effects of shading and defoliation on seed yield and pods per m^2 at maturity of Paraggio barrel medic, Waite Institute, 1990**

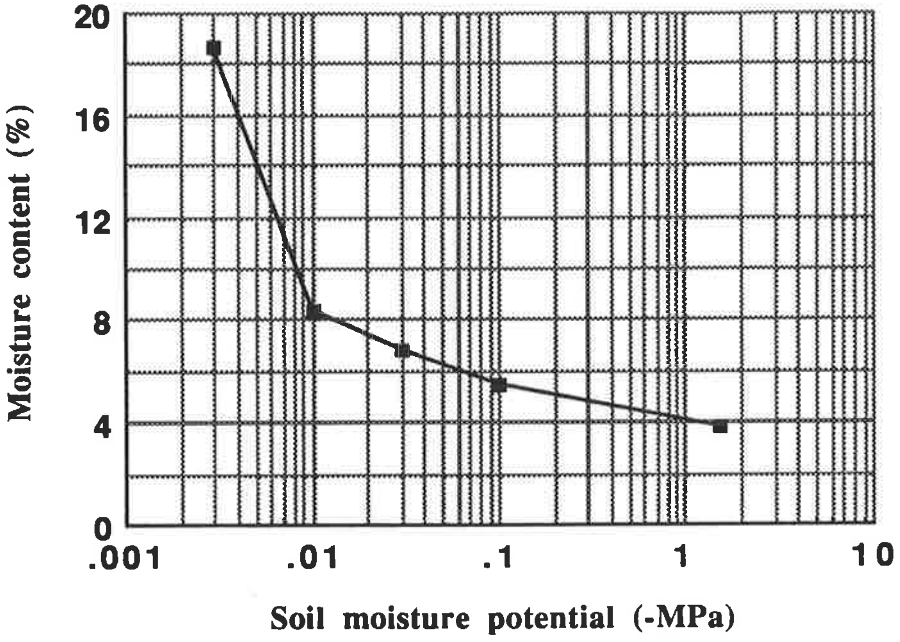
Shade level	Shade time	Seed yield (kg/ha)			Pods (#/m^2)		
		Undefoliated swards	Defoliated swards	Means	Undefoliated swards	Defoliated swards	Mean
Unshaded	Control	1013	912	963	3625	3410	3518
30%	Vegetative stage	1080	652	866	3714	2731	3222
30%	First half of flowering	865	710	788	3209	2691	2950
30%	Second half of flowering	1210	619	915	4312	2453	3382
30%	Shading throughout	1028	666	847	3353	2679	3016
60%	Vegetative stage	1102	678	890	3606	2881	3243
60%	First half of flowering	838	606	722	3129	2608	2869
60%	Second half of flowering	1228	782	1006	4678	2967	3833
60%	Shading throughout	520	389	455	2194	1801	1998
	Defoliation mean	987	668		3535	2691	

Appendix Table 5A. Effects of sowing rate, defoliation height, frequency and time of final defoliation on the number of flowers per m^2 and percentange pod set of Paraggio barrel medic at Waite Institute 1991

Height of defoliation	Frequency of defoliation	Time of final defoliation	Flowers during first half of flowering (26 Aug to 27 Sep) (# x 10^2/m^2)	Flowers during second half of flowering (28 Sep to 29 Oct) (# x 10^2/m^2)	Total flowers at end of flowering 26 Aug to 29 Oct) (# x 10^2/m^2)	Pod set (%)	Seed yield (kg/ha)
20 kg /ha sowing rate							
	Undefoliated	Control	128.66	88.53	205.48	12.4	632
3 cm	Single	Early	138.74	32.35	175.38	13.7	659
3 cm	Infrequent	Flower appearance	62.82	77.07	139.89	20.1	793
6 cm	Infrequent	Flower appearance	55.04	102.75	157.79	12.3	549
3 cm	Frequent	Flower appearnce	103.74	56.85	160.59	15.2	822
6 cm	Frequent	Flower appearance	105.44	59.75	165.19	15.4	679
	Defoliation[a]	LSD (P<0.05)	N.S	NS	NS	NS	174
200 kg/ha sowingrate							
	Undefoliated	Control	99.85	93.79	185.10	13.5	622
3 cm	Single	Early	99.46	45.29	144.76	16.8	685
3 cm	Infrequent	Flower appearance	21.70	57.06	78.68	29.0	500
6 cm	Infrequent	Flower appearance	74.42	58.58	133.00	18.8	664
3 cm	Frequent	Flower appearance	24.08	55.61	79.70	27.5	596
6 cm	Frequent	Flower appearance	53.90	51.96	105.86	27.0	849
	Defoliation[a]	LSD (P<0.05)	39.62	NS	32.47	8.0	NS
	Sowing rate x Defol	LSD (P<0.05)	NS	NS	NS	NS	187

[a] LSD for defoliation treatments analysed separately for each sowing rate

Appendix Fig 6A. Moisture characteristics of the potting mix



Appendix Table 6A. Mean levels of RWC (%) of non-stressed and stressed swards of the undefoliated and defoliated swards of Paraggio barrel medic. Measurements were made between 10.00 and 10.30 a.m

Dates of measurement	Before watering			After watering		
	Non-stressed	Stressed	LSD (P<0.05)	Non-stressed	Stressed	LSD (P<0.05)
5 - 6 September	68.5	58.1	4.5	81.6	78.2	2.2
10 - 11 September	78.3	71.1	2.7	80.3	76.9	1.4
15 - 16 September	78.6	73.8	2.1	82.3	77.9	1.7

Appendix Table 6B. Effects of water stress on production of herbage and seed by defoliation by defoliated and undefoliated swards of Paraggio barrel medic in the glasshouse experiment

Defoliation treatment	Herbage yield (kgDM/ha)		Seed yield (kg/ha)	
	Non-stressed	Stressed	Non-stressed	Stressed
Undefoliated	8318	5369	1078	530
Defoliated	6268	3368	805	405

Appendix Table 7A. Effects of cultivar and genotype on nodulation and winter dry matter yields of undefoliated swards of annual medics sown at Waite Institute in 1991

Species	Cultivar & genotype	Nodule number per plant (15 July)	Dry matter yield (kg/ha) (5 August)
M. littoralis	Harbinger	12.5	1043
M. polymorpha	Serena	33.5	2193
	SC01011	23.6	2210
	SC01012	25.2	1901
M. rugosa	Paragosa	19.7	1538
	Paraponto	19.5	1566
M. scutellata	Sava	31.2	1615
M. tornata	Murrayland	3.0	1341
	Tornafield	17.7	1020
M. truncatula	Ghor	30.5	2441
	Paraggio	21.2	1273
Cultivar	LSD (P<0.05)	10.2	646

Appendix Table 7B. Effects of cultivar and defoliation on dry matter yield of annual medics sown at the Waite Insitute in 1991[a]

Species	Cultivar & genotype	Dry matter yield (kg/ha) on 24 September			Dry matter yield (kg/ha) on 21 October		
		Undefoliated	Leniently defoliated	Severely defoliated	Undefoliated	Leniently defoliated	Severely defoliated
M. littoralis	Harbinger	7060	2880	2360	8480	6300	6440
M. polymorpha	Serena	12350	9510	6110	11160	9290	10920
	SC01011	9530	4180	3050	11840	6760	7240
	SC01012	7630	5320	4110	7460	9440	8500
M. rugosa	Paragosa	7850	4530	3050	9030	8960	8920
	Paraponto	8930	6390	4300	12080	5270	7940
M. scutellata	Sava	9330	6410	3550	10330	10300	11280
M. tornata	Murrayland	4680	1940	2710	6910	4370	4450
	Tornafield	6990	4500	3830	8120	7720	6190
M. truncatula	Paraggio	9310	5850	3630	12640	8730	10250
Cultivar	LSD ($P<0.05$)[a]	3160	2300	1090	5440	3630	2900

[a]Data analysed separately for each defoliation treatment

Appendix Table 7C. Effects of cultivar, genotype and defoliation on crop growth rate of annual medics sown at the Waite Institute in 1991[a]

Species	Cultivar & genotype	Growth rates 24 September to 21 October (g/m^2/day)		
		Undefoliated	Leniently defoliated	Severely defoliated
M. littoralis	Harbinger	5.3	12.7	15.1
M. polymorpha	Serena	-4.4[b]	-0.8[b]	17.8
	SC01011	8.5	9.5	15.5
	SC01012	-0.7[b]	15.3	16.3
M. rugosa	Paragosa	4.4	16.4	21.8
	Paraponto	-4.1[b]	11.7	13.5
M. scutellata	Sava	3.7	14.4	28.6
M. tornata	Murrayland	8.3	9.0	6.4
	Tornafield	4.2	11.9	8.7
M. truncatula	Paraggio	12.3	10.6	24.5
Cultivar	LSD (P<0.05)	NS	NS	10.4

[a]Data analysed separately for each defoliation treatment

[b]Negative growth rates because the swards were senescing by the 21 October

NS, Not significant

Appendix Table 7D. Effects of cultivar, genotype and defoliation on annual medic seed yield sown at the Waite Institute in 1991

Species	Cultivar & genotype	Seed yield (kg/ha) Undefoliated	Leniently defoliated	Severely defoliated	Mean
M littoralis	Harbinger	853	885	807	848
M polymorpha	Serena	866	1077	1108	1017
	SC01012	1161	792	860	938
	SC01011	877	704	729	770
M rugosa	Paragosa	887	725	780	797
	Paraponto	1413	1258	1133	1268
M scutellata	Sava	792	775	698	755
M tornata	Murrayland	474	379	373	409
	Tornafield	570	836	935	780
M truncatula	Ghor	710	616	567	631
	Paraggio	576	630	668	625
Cultivar	LSD (P<0.05)[a]	326	365	273	180

[a]Data analysed separately for each defoliation treatment and excludes data for Ghor

Appendix Table 7E. Effects of cultivar and defoliation on percentage pod set of annual medics sown at the Waite Institute 1991

Species	Cultivar & genotype	Percentage pod set (%) Undefoliated	Leniently defoliated	Severely defoliated
M littoralis	Harbinger	24.7	30.4	22.7
M polymorpha	Serena	39.0	29.9	30.5
	SC01011	20.9	32.7	22.8
	SC01012	36.3	19.2	18.8
M rugosa	Paragosa	20.4	23.7	20.8
	Paraponto	NA	NA	NA
M scutellata	Sava	14.6	14.4	10.8
M tornata	Murrayland	NA	NA	NA
	Tornafield	9.4	13.8	14.8
M truncatula	Paraggio	13.2	12.1	25.4
Cultivar	LSD (P<0.05)[a]	18.7	13.4	13.7

[a]Data analysed separately for each defoliation treatment

Appendix 8. Questionnaire to medic seed producers.

8 October 1992

QUESTIONNAIRE TO MEDIC SEED PRODUCERS

Francis Muyekho, a PhD student based at the Waite Institute, is researching the factors which may influence seed production of annual medics. In particular, he has been assessing the impact of medic plant density, defoliation and water stress on flowering, flower abortion, pod development and seed yield.

Reza Chaichi, another PhD student based at the Waite Institute but working at Korunye and Roseworthy, has been looking at the impact of sheep grazing (stocking density and grazing duration during spring) on medic growth and seed production.

To verify that our research results are relevant to the needs of seed producers we would be very grateful if you could complete the attached questionnaire as far as you are able to assist our research on this important topic. We can ensure confidentiality of this information but if you are concerned then omit your name and telephone number but complete the other details.

Please return the questionnare in the stamped, addressed envelope by November 6, 1992.

Yours sincerely,

E.D. Carter
Senior Lecturer in Agronomy

Enquiries: E.D Carter (08) 372 2213
F. Muyekho (08) 372 2414

Name: -- Telephone Number -------------------------
Address of farm or locality--
Soil type -- Soil pH ---

		Rainfall (mm)			Medic seed yield
Year	Species/Cultivar	Aug	Sept	Oct	(kg/ha)
1982					
1983					
1984					
1985					
1986					
1987					
1988					
1989					
1990					
1991					

Comments on your management of medic stands

1. Usual grazing practice for medic seed-producing stands

2. Usual herbicide practice for medic seed-producing stands

Appendix 9. List of papers published from this thesis

Carter E. D., Porter R. G., Ababneh M. H., Squella F., Muyekho F. N. and Valizadeh R. (1992). The production and management of annual pasture legumes in ley farming systems of south Australia. Proc. 6th Aust. Agron. Conf., Armidale, N.S.W. pp. 418-421.

Muyekho F. N., Carter E. D and McDonald G. K. (1992). Influence of defoliation intensity and time of final defoliation on seed yield of Paraggio barrel medic. Proc. 6th Aust. Agron. Conf. Armidale, N.S.W. p. 539.

Muyekho F. N., McDonald G. K. and Carter E. D. (1992). Effects of level and timing of shading on seed yield of defoliated and undefoliated swards of annual medics. Review and Contributed papers. 4th Aust. Seeds Res. Conf. Broadenbeach, Queensland. pp. 151-156.

Muyekho F. N., Carter E. D. and McDonald G. K. (1993). Effects of defoliation intensity, frequency, and time of defoliation on seed yield of barrel medic. XVII Intern. Grassld. Congr. Lincoln, New Zealand. Feb 1993. (In press)

Muyekho F. N., Carter E. D. and McDonald G. K. (1993). Effects of sowing date and sowing rate on seed yield of barrel medic. Proc. 7th Aust. Agron. Conf. Four-page paper. (In press)

Muyekho F. N., Carter E. D. and McDonald G. K. (1993). Effects of defoliation on pod set and seed yield in a range of medic cultivars. One page paper/poster. (In press)

REFERENCES

Ababneh, M. H. (1991). The ecology and productivity of annual medic genotypes. PhD Thesis, The University of Adelaide, Australia. 265p.

Ababneh, M. H., Silsbury, J. H. and Carter, E. D. (1989). Growth responses of annual medics to temperature. Proc. 5th Aust. Agron. Conf., Perth, WA. p. 428.

Adem. L. (1977). Studies on the ecology and agronomy of annual *Medicago* species. MAg.Sc. Thesis, The University of Adelaide, Australia. 171p.

Aitken, Y. (1955). Flower initiation in pasture legumes. III. Flower initiation in *Medicago tribuloides* Desr. and other annual medics. Aust. J. Agric. Res. 6: 259-264.

Amen, R. D. (1963). The concept of seed dormancy. American Scientist. 51: 740-823.

Amoabin, S., Stern, W. R. and Turner, N. C. (1987). Seed yield of three annual pasture legumes in response to water deficits during flowering and seed development. Proc. 4th Aust. Agron. Conf., Melbourne, Victoria. p. 165.

Amor, R. L. (1966). Herbage and seed production of three barrel medic cultivars and Harbinger medic in the Victorian Mallee. Aust. J. Exp. Agric. Animal Husb. 31: 361-364.

Andrews, P., Collins, W. J. and Stern, W. R. (1977). The effect of withholding water during flowering on seed production in *Trifolium subterraneum* L. Aust. J. Agric. Res. 28: 301-307.

Argel, P. J. and Humphreys, L. R. (1983). Environmental effects on seed development and hardseededness in *Sylosanthes hamata* cv. Verano. II. Moisture supply and illuminance. Aust. J. Agric. Res. 34: 271-277.

Aufhammer, W. and Götz-Lee, I. (1991). Effects of inflorescence removal on interactions between reproductive storage sites of field beans (*Vicia faba*) under different shading treatments. J. Agric. Sci. Camb. 116: 409-415.

Australian Bureau of Statistics, Adelaide. Agriculture South Australia 1979-1980.

Bean, E. W. (1964). The influence of light intensity upon the growth of an S.37 cocksfoot (*Dactylis glomerata*) sward. Ann. Bot. 28: 427-443.

Bean, E. W. (1971). Temperature effects upon inflorescence and seed development in tall fescue (*Festuca arundinacea.* Schreb.). Ann. Bot. 35 : 891-897.

Bean, E. W. (1972). Seed quality: its variation, control, and importance in breeding and varietal assessment. Welsh Plant Breeding Station, Annual Report, 1972, pp.194-208.

Begg, J. E. and Turner, N. C. (1976). Crop water deficitts. Advances in Agronomy. 28: 161-217.

Belikov, I. F. and Kosteskii, E. (1958). Distribution of the products of photosynthesis in soybean at early stages of its development. Dokl. Akad. Nauk. SSSR, Bot. Sci. Sect. 119: 112-115. (Cited by Shibles *et al.*, 1975).

Belikov, I. F. (1955). Migration and distribution of photosynthates in soybean during the period of vegetation. Fiziologiya Rastenii., 2: 354 (cited by Shibles *et al.* 1975)

Belikov, I. F. and Pirskii, L. I. (1966). Violation of the local distribution of assimilates in soyabean. Soviet Plant Physiology. 13: 361-364.

Belonogov, V. E., Kalininskava, T. A. and Likholat, T. V. (1983). Effect of gibberellin and 6-benylaminopurine on dry matter and seed yield in red clover. Fiziologiya Rastenii. 30: 724-730 (cited by Hampton 1988)

Biddiscombe, E. F. (1975). Effect of moisture stress on flower drop and seed yield of Narrow leafed Lupin.(*Lupinus angastifolius* L. cv. Unicrop). J. Aust. Inst. Agric. Sci. 41: 70-72.

Bidinger, F., Musgrave, R. B. and Fischer, R. A. (1977). Contribution of stored pre-anthesis assimilate to grain yield in wheat and barley. Nature. 270: 431-433.

Blackman, G. E. and Black, J. N. (1959). Physiological and ecological studies in the analysis of plant environment. 12. The role of light factor in limiting growth. Ann. Bot. 23: 131-145.

Blomquist, R. V. and Kust, C. A. (1971). Translocation pattern of soyabeans as affected by growth substance and maturity. Crop Sci. 11: 390-393.

Bolland, M. D. A. (1987). The effect of grazing and soil type on the seed production of several *Trifolium* spp. compared with subterranean clover and annual medics. J. Aust. Inst. Agric. Sci. 53: 293-295.

Brougham, R. W. (1958). Leaf development in swards of white clover (*Trifolium repens*). N.Z.J. Agric. Res. 1: 707-718.

Brown, R. H. and Blaser, R. E. (1968). Leaf area index in pasture growth. Herb. Abstr. 38: 1-9.

Brun, W. A and Betts, K. J. (1984). Source/sink relations of abscising and nonabscising soybean flowers. Plant Physiol. 75: 187-191.

Burton, G. W. and De Vane, E. H. (1953). Estimating heritability in Tall fescue (*Festuca arundinacea*) from replicated clonal material. Agron. J. 45: 478-481.

Callaghan, A. R. and Millington, A. J. (1956). The wheat industry in Australia. Angus and Robertson, Sydney. 486 p.

Carlson, D. R., Dyer, D. J., Cotterman, C. D. and Durley, R. C. (1987). The physiological basis for cytokinin increases in pod set in IX93-100 soyabeans. Plant Physiol. 84: 233-239.

Carter, E. D. (1967). Pasture management and utilization. Biennial Report 1966-67, Waite Agricultural Research Institute, The University of Adelaide pp. 43-3.

Carter, E. D. (1968a). Changes in seed supply of annual pasture grazed continuously by sheep at five stocking rates. Proc. Aust. Grasslands Conf., Perth, 1968. Vol. 1, Sect. 1b, pp. 7-10.

Carter, E. D. (1968b). The effect of stocking rate on the production and utilization of annual pasture and on wool production. Proc. Aust. Grasslands Conf., Perth, 1968. Vol. 1, Sect. 1a, pp. 9-11.

Carter, E. D. (1975). The potential role of integrated cereal-livestock systems from southern Australia in increasing food production in the Near East and North African Region. UNDP/UNDP Regional Project on Improvement and Production of Field and Food Crops: Regional Meeting-Lahore-Peshawar-Karachi, Pakistan. 35p. + Appendices.

Carter, E. D. (1977). Stocking rate and the ecosystem: some soil-plant-animal interrelationships on annual pastures in South Australia. Proc. XIII Intern. Grassland Congr., Leipzig, G.D.R. Section 6, pp. 348-354.

Carter, E. D. (1978). A review of the existing and potential role of legumes in farming systems of the Near East and North African Region. A report to ICARDA). Waite Agricultural Research Institute. 120p.

Carter, E. D. (1981). Seed and seedling dynamics of annual pastures in South Australia. Proc. XIV Int. Grassland Cong. Lexington, Ky., USA. pp. 447-450.

Carter, E. D. (1982). The need for change in making the best use of medics in the cereal-livestock farming systems of South Australia. Proc. 2nd. Aust. Agron. Conf., Wagga Wagga, NSW. p. 180.

Carter, E. D. (1987). Establishment and natural regeneration of annual pastures. In Temperate Pastures: Their Production, Use and Management. (Eds. J. L. Wheeler, C.J. Pearson and G.E. Robards). Australian Wool Corporation CSIRO, pp. 35-51.

Carter, E. D. (1988). Strategies to optimise herbage and seed production, and seed survival of subterranean clover grazed sheep. Research proposal to Wool Research and Development Fund. 8p.

Carter, E. D. (1989). The production and management of pastures based on annual medics and clovers. Pasture Symposium. The University of Adelaide, Waite Agricultural Research Institute. Charles Hawker Conference Centre. Feb. 15, 1989. pp. 1-12.

Carter, E. D. (1990a). Better pastures-more profitable crops. Paper presented to the agricultural bureau of South Australia: Lower Eyre Peninsula Conference, Ungarra. March 1990. 11p.

Carter, E. D. (1990b). The role of grazing animals in weed control. Proc. 9th Australian Weeds Conference, Adelaide, S. Aust. August 1990. pp. 239-242.

Carter, E. D., Armstrong, M. and Sommer, K. J. (1988). Effects of tillage and hay-making practices on survival and productivity of annual pasture legumes. Workshop on Tillage Systems, Rotation, Nitrogen and Cereal Root Diseases. Adelaide, South Australia. pp. N4, N5.

Carter, E. D. and Challis, S. (1987) Effects of depth of sowing medic seeds on emergence of seedlings. Proc. 4th Aust. Agron. Conf., Melbourne, Vict, p.192

Carter, E. D.; Challis, S. and Ridgway, I. G. (1977). The use of heavy solvents for separating seed from soil. Proc. XIII Intern. Grassland Congress, Leipzig, G.D.R. Section 6, pp. 735.

Carter, E. D., Le Leu, Kylie, M. and Baldwin, G. B. (1989). Predicting the emergence of annual pasture legumes: commercialisation of a soil-coring technique. Proc. 5th Aust. Agron. Conf., Perth, W. Aust. p. 438.

Carter, E. D. and Sivalingam, T. (1977). Some effects of treading by sheep on pastures of the Mediterranean climatic zone of South Australia. Proc. XIII Intern. Grassland Congr., Leipzig, G.D.R. Section 5, pp. 307-12.

Carter, E. D., Wolfe, E. C. and Francis, C. M. (1982). The problems of maintaining pastures in the cereal-livestock areas of southern Australia. Proc. 2nd Aust. Agron. Cof., Wagga Wagga, N.S.W. pp. 68-82

Clarkson, N. M. (1970). Pasture research in the granite and traprock areas of South-east Queensland. Tropical Grasslands. 4: 171-174.

Clarkson, N. M. and Russell, J. S. (1975). Flowering responses to vernalization and photoperiod in annual medics (*Medicago* spp.). Aust. J. Agric. Res. 26: 831-838.

Clarkson, N. M. and Russell, J. S. (1976). Effect of water stress on the phasic development of annual *Medicago* species. Aust. J. Agric. Res. 27: 227-234.

Clarkson, N. M. and Russell, J. S. (1979). Effect of temperature on the development of two annual medics. Aust. J. Agric. Res. 30: 909-16.

Clements, H. F. (1964). Interaction of factors affecting yield. Ann. Rev. Plant. Physiol. 15: 409-442.

Cocks, P. S. (1973). The influence of temperature and density on the growth of communities of subterranean clover (*Trifolium subterraneum* L. cv. Mt. Barker). Aust. J. Agric. Res. 24: 479-495.

Cocks, P. S. (1987). Effectiveness of self-fertilization. Preschedule (m28). In Annual Report of Pasture and Forage Livestock programme. ICARDA, Syria. pp. 124-125.

Cocks, P. S. (1988). Seed production and seed survival under grazing of annual medics (*Medicago* spp.) in north Syria. J. Agric. Sci., Camb. 110: 455-463.

Cocks, P. S. (1990a). Dynamics of flower and pod production in annual medics (*Medicago* spp.). I. In spaced plants. Aust. J. Agric. Res. 41: 911-921.

Cocks, P. S. (1990b). Dynamics of flower and pod production in annual medics (*Medicago* spp). II. In swards at low and high density. Aust. J. Agric. Res. 41: 923-931.

Collins, W. J. (1978). The effect of defoliation on inflorescence production, seed yield and hard-seededness in swards of subterranean clover. Aust. J. Agric. Res. 29: 789-807.

Collins, W. J. (1981). The effects of length of growing season, with or without defoliation, on seed yield and hard-seededness in swards of subterranean clover. Aust. J. Agric. Res. 32: 783-792.

Collins, W. J. and Aitken, Y. (1970). The effect of leaf removal on flowering time in subterranean clover. Aust. J. Agric. Res. 21: 893-903.

Collins, W. J. and Quinlivan, B. J. (1980). The effects of continued water supply during and beyond seed development on seed production and losses in subterranean clover swards. Aust. J. Agric. Res. 31: 287-295.

Collins, W. J., Rhodes, I., Rossiter, R. C. and Palmer, M. J. (1983). The effect of defoliation on seed yield of two strains of subterranean clover grown in monocultures and in binary mixtures. Aust. J. Agric. Res. 34: 671-679.

Collins, W. J., Rossiter, R. C. and Ramos, M. A. (1978). The influence of shading on seed yield in subterranean clover. Aust. J. Agric. Res. 29: 1167-1175.

Cornish, P. S. (1985). Adaptation of annual *Medicago* to a non-Mediterranean climate. II. Relationships between maturity grading and forage production, seed pod production and pasture regeneration. In : The ecology and agronomy of annual medics. (Ed. Z. Hochman) NSW. Dept. Agric. Tech. Bull. 32. pp. 17-22.

Crawford, E. J. (1983). Selecting cultivars from naturally occurring genotypes: evaluating annual *Medicago Species*. In: Genetic resources of forage plants. (Eds. J.G. McIvor and R. A. Bray). pp. 203-15. (CSIRO Aust., Melbourne.)

Crawford, E. J. (1985). Variability in six major characteristics of 12 annual medic species. Proc. 3rd. Aust. Agron. Conf., Hobart, Tasmania. p. 25.

Crawford, E. J., Lake, A. W. H. and Boyce, K. G. (1989). Breeding annual *Medicago* species for semi-arid conditions in southern Australia. Advances in Agronomy. 42: 399-437.

Crosby, K. E., Aung, L. H., Buss, G. R. (1981). Influence of 6-benzlaminopurine on fruit-set and seed development in two soybean, *Glycine max* (L.) Merr. genotypes. Plant Physiol. 68: 985-988.

Davey, J. E. and Van Staden, J. (1978a). Cytokinin activity in *Lupinus albus*. I. Distribution in vegetative and flowering plants. Physiologia Plantarium. 43: 77-81.

Davey, J. E. and Van Staden, J. (1978b). Cytokinin activity in *Lupinus albus*. II. Distribution in fruiting plants.. Physiologia Plantarium. 43: 82-86.

Davey, J. E. and Van Staden, J. (1978c). Cytokinin activity in *Lupinus albus*. III. Distribution in fruits. Physiologia. Plantarium. 43: 87-93.

Davidson, J. L and Donald, C. M. (1958). The growth of swards of subterranean clover with particular reference to leaf area. Aust. J. Agric. Res. 9: 53-73.

Davidson, J. L. and Birch, J. W. (1972). Effects of defoliation on growth and carbon dioxide exchange of subterranean clover swards. Aust. J. Agric. Res. 23: 981-993.

Davidson, J. L. and Milthorpe, F. L. (1966a). Leaf growth in *Dactylis glomerata* following defoliation. Ann. Bot. 30: 173-184.

Davidson, J. L. and Milthorpe, F. L. (1966b). The effect of defoliation on the carbon balance in *Dactylis glomerata*. Ann. Bot. 30:185-198.

Davidson, J. L. and Phillip, J. R. (1958). Light and pasture growth. Symposium of Climatology and Microclimatology, Canberra, A.C.T. Austr. 1956. pp. 181-187. (UNESCO: Paris).

Davidson, J. L., Gibson, A. H. and Birch, J. W. (1970). Effects of temperature and defoliation on growth and nitrogen fixation in subterranean clover. Proc. XI Int. Grassland Congr.,Surfers Paradise, Queensland, Australia. pp. 542-545.

Davies, W. E. (1981). Selection for high seed production in leguminous forage plants-a review. In : Breeding high yielding forage varieties combined with high seed yield (Ed. G. Van Bogaert), pp. 139-151, Eucarpaia, Merelbeke, Belgium.

de Koning, C. T. (1990). The ecology and productivity of new cultivars of subterranean clover (*Trifolium subterraneum* L.). Ph.D. Thesis, The University of Adelaide, Australia, 270p.

de Koning, C. T. and Carter, E. D. (1987). Impact of grazing by sheep on subterranean clover cultivars. Proc. 4th. Aust. Agron. Conf., Melbourne, Victoria,. p. 169.

de Koning, C. T. and Carter, E. D. (1989). The survival of seeds of subterranean clover following ingestion by sheep. Proc. XVI Intern. Grassland Congr., Nice, France, pp. 1031-1032.

de Wit, C. T. (1965). Photosynthesis of leaf canopies. Agric. Res. Rept, (Wageningen). 663: 1-57.

Dear, B. S. and Loveland, B. (1984). Herbage production and seed yield of defoliated subterranean clover swards in a cool temperate environment. Aust. J. Exp. Agric. Anim. Husb. 24: 543-549.

Denmead, O. T. and Shaw, R. H. (1960). The effect of soil moisture at different stages of growth on the development and yield of corn. Agron. J. 52: 357-361.

Devitt, A. C., Quinlivan, B. J. and Francis, C. M. (1978). The flowering of annual legume pasture species and cultivars in Western Australia. Aust. J. Exp. Agric. Animal Husb. 18: 75-80.

Donald, C. M. (1951). Competion among pasture plants. I. Intra-specific competition among annual pasture plants. Aust. J. Agric. Res. 2: 355-376.

Donald, C. M. (1954). Competition among pasture plants. II. The influence of density on flowering and seed production in annual pasture plants. Aust. J. Agric. Res. 5: 585-397.

Donald, C. M. (1963). Competition among pasture plants. Advances in Agronomy. 15: 1-118.

Donald, C. M. and Hamblin, J. (1976). The biological yield and harvesting index of cereals as agronomic and plant breeding criteria. Advances in Agronomy. 28: 361-405.

Downes, R. W. and Gladstones, J .S. (1984a). Physiology of growth and seed production in *Lupinus angustifolius* L. II. Effects of temperature before and after flowering. Aust. J. Agric. Res. 35: 493-509.

Downes, R. W. and Gladstones, J .S. (1984b). Physiology of growth and seed production in *Lupinus angustifolius* L. III. Effects of defoliation and lateral branch excission on dry matter and seed production at different growth temperatures. Aust. J. Agric. Res. 35: 511-520.

Dyer D., Cotterman, J. C., Cotterman, C. D., Kerr, P. S. and Carlson, D. R. (1988). Cytokinins as metabolic stimulants which induced pod set. In: Plant growth substances 1988. Spring-Verlag. (Eds. R. P. Pharis, S. B. Road). pp. 457-467.

Egli,.D. B., Guff, R. D. and Leggett, J. E. (1985). Partitioning of assimilate between vegetative and reproductive growth in soybean. Agron. J. 77: 917-922.

Ewing, M. A. (1984). Low rainfall pasture project. Summary of experimental results. Dept. Agric. W. Aust. Dryland Res. Inst., Merredin. 25p.

Ewing, M. A. and Howieson, J. G. (1989). The development of *Medicago polymorpha* L. as an important pasture species for southern Australia. Proc. XVI Intern. Grassland. Congr., Nice, France, pp. 197-198.

Farrington, P. and Pate, J. S. (1981). Fruit set in *Lupinus angustifolius* cv. Unicrop. I. Phenology and growth during flowering and early fruiting. Aust. J. Plant Physiol. 8: 293-305.

Fitzpatrick, E. C. and Nix, H. A. (1970). The climatic factor in Australian grassland ecology. In: Australian Grasslands. (Ed. R. M. Moore) A.N.U. Press, Canberra. pp. 3-27.

Fischer, R. A. (1975). Yield potential in a dwarf spring wheat and the effect of shading. Crop Sci. 15: 607-613.

Fischer, R. A. and Wood, J. T. (1979). Drought resistence in spring wheat cultivars. III. Yield association with morpho-physiological traits. Aust. J. Agric. Res. 30: 1001-1020.

Fisher, K. S. and Palmer, A. F. E. (1983). Maize. In: Symposium on potential productivity of field crops under different environments. International Rice Research Institute. pp. 155-180.

Flinn, A. M. and Pate, J. S. (1970). A quantitative study of carbon transfer from pod and subtending leaf to the ripening seeds of the field pea (*Pisum arvense* L.). J. Exp. Bot. 21: 71-82.

Frederick, J. R., Alm,. D.A. and Hesketh, J. D. (1989). Leaf photosythetic rates, stomatal resistance and internal CO_2 concentrations of soybean cultivars under drought stress. Photosynthetica. 23: 575-584.

French, R. J. and Schultz, J. E. (1984). Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. Aust. J. Agric. Res. 35: 743-764.

Fukai, S. (1974). Effects of light energy and temperature on growth of subterranean clover communities. PhD. Thesis, The University of Adelaide, Australia. 215p.

Fukai, S. and Silsbury, J. H. (1976). Response of subterranean communities to temperature. I. Dry matter production and plant morphogenesis. Aust. J. Plant Physiol. 3: 527-543.

Fukai, S. and Silsbury, J. H. (1977a). Response of subterranean communities to temperature. II. Effects of temperature on dark respiration. Aust. J. Plant Physiol. 4: 159-167.

Fukai, S. and Silsbury, J. H. (1977b). Responses of subterranean clover communities to temperature. III. Effects of temperature on canopy photosynthesis. Aust. J. Plant Physiol. 4: 273-282.

Fukai, S. and Silsbury, J. H. (1977c). Effect of irradiance and solar radiation on dry matter growth and net CO2 exchange of *Trifolium subterraneum* L. swards at a constant temperature. Aust. J. Plant Physiol. 4: 485-497.

Gallagher, J. N., Biscoe, P. V. and Hunter, B. (1976). Effects of drought on grain growth. Nature (London). 264: 541-542.

García-Martínez J. L., Martí M., Sabater, T., Maldonada, A. and Vercher, Y. (1991). Development of fertilized ovules and their role in the growth of pea pod. Physiologia Plantarium. 83: 411-416.

Gates, C. T. (1964). The effect of water stress on plant growth. J. Aust. Inst. Agric Sci. 30: 3-22.

Gates, P., Smith, M. L. and Boulter, D. (1983). Reproductive physiology of *Vicia faba* L. In 'The Faba bean (*Vicia faba* L.): a basis for improvement'. (Ed., P. D. Hebblethwaite) pp. 133-42. (Butterworths: London.).

Gates, P., Yarwood, J. N., Harris, N., Smith, M. L. and Boutler, E. (1981). Cellular changes in pedicel and penduncle during flower abscission in *Vicia faba* L. In: *Vicia faba*, physiology and breeding. World Crops: Production, Utilization, Description, Vol. 4 (Ed. R. Thompson). pp. 299-316. The Haque, Martnus Nijhoff.

Gentilli, J. (1972). Australian climate patterns. Thomas Nelson, Australia, 285p.

Gentilli, J. (Editor). (1971). Climates of Australia and New Zealand. World Survey of climatology. Vol.13. Elsevier, Amsterdam, 405p.

Gifford, R. M. and Evans, L. T. (1981). Photosynthesis, carbon partitioning, and yield. Ann. Rev. Plant Physiol. 32: 485-509.

Greenwood, E. A. N., Carbon, B. A., Rossiter, R. C. and Beresford, J. D. (1976). The response of defoliated swards of subterranean clover to temperature. Aust. J. Agric. Res. 27: 593-610.

Griffiths, D. J., Lewis, J. and Bean, E. W. (1966). The problem of breeding for improved seed yields in grassses. Proc. X Intern. Grassland Congr., Helsinki. pp. 749-754.

Hagon, M. W. (1973). The effect of defoliation on flowering and seed yield in subterranean clover. Aust. J. Agric. Res. 24: 211-217.

Hampton, J. G. (1988). Herbage seed production. Advances in research and technology of seeds. Pudoc Wageningen. pp. 1-28.

Hay, R. K. M., Walker, A. J. (1989). An introduction to the physiology of crop yield. Longman Scientific and Technical. Chapt. 2. pp. 7-30.

Hebblethwaite, P. D., Wright, D.and Noble, A. (1980). Some physiological aspects of seed yield in *Lolium perenne*. L. (Perennial ryegrass). In: Seed production. (Ed. P.D. Hebblethwaite). Butterworths, London-Boston. pp. 71-88.

Hedley, C. L. and Ambrose, M. J. (1979). The effects of shading on the yield components of six "leafless" pea genotypes. Ann. Bot. 44: 469-478.

Heindl, J. C. and Brun, W. A. (1983). Light and shade effects on abscission and ^{14}C-photoassimilate partitioning among reproductive structures in Soyabean. Plant physiol. 73: 434-439.

Heindl, J. C., Carlson, D. R., Brun, W. A. and Brenner, M. L. (1982). Ontogenetic variation of four cytokinins in Soybean root pressure exudate. Plant Physiol. 70: 1619-1625.

Henckel, P. A. (1964). Physiology of plants under drought. Ann. Rev. Plant Physiol. 15: 363-386.

Heyn, C. C. (1963). "The annual species of *Medicago*" Scripta Hierosoly-mitana. (XII Magness press. The Hebrew University, Jerusalem). 154p.

Hill, M. J. (1980). Temperate pasture grass seed crops. Formative factors. In: Seed Production. (Ed. P. D. Hebblethwaite). Butterworths London-Boston. pp. 137-149.

Hill, M. J. and Supanjani. (1992). Reproductive abortion in birdfoot trefoil (*Lotus corniculatus* L.). Review and Contributed papers. 4th Aust. Seeds Res. Conf. Broadbeach, Queensland. pp. 143-149.

Hochman, Z. (1985). Early assessment of aphid tolerant accessions of annual medics for Central Western New South Wales. In: The Ecology and Agronomy of Annual Medics. Tech. Bull. No32, Dept. Agric., NSW. pp. 29-33.

Hochman, Z. (1987). Quantifying vernalization and temperature promotion effects on time of flowering of three cultivars of *Medicago truncatula* Gaertn. Aust. J. Agric. Res. 38: 279-286.

Holliday, R. (1960). Plant population and crop yield: Part I. Field Crop Abstr., 13: 159-167.

Howell, T. A., Meek, D. W. and Hatfield J. L. (1983). Relationship of photosynthetically active radiation in San Joaquin Valley. Agric. Meteorol. 28: 157-175.

Howieson, J. G. and Ewing, M. A. (1989). The development of *Medicago polymorpha* L. as an important pasture species for southern Australia. Proc. XIV. Intern. Grassland Congr., Nice, France. pp. 197-198.

Hsiao, T. C. (1973). Plant responses to water stress. Ann. Rev. Plant Pysiol. 24: 519-570.

Hsiao, T. C., Fereres, E., Acevedo, E. and Henderson, D. W. (1976). Water stress and dynamics of growth and yield of crop plants. In 'Water and Plant Life'. (Eds. O. L. Lange, L. Kappen and E. D. Schulze). Ecological studies 19. Springer- Verlag: Berlin, Heidelberg, N.York. pp. 282-305.

Huff, A. and Dybing, C. D. (1980). Factors affecting shedding of flowers in soyabean (*Glycine max* (L.) Merrill). J. Exp. Bot. 31: 751-762.

Humphreys, L. R. (1979). Tropical pasture seed production. FAO. Plant production and protection paper No. 8. Rome, Italy.

Humphreys, L. R. and Riveros, F. (1986). Tropical pasture seed production. FAO Plant Production and Protection Paper No. 8. revised, Rome, Italy.

Humphreys, L. R. and Robinson, A. R. (1966). Relationship between carbohydrate accumulation and leaf area in growth. Queensland J. Agric. Animal. Sci. 23: 221-259.

Husain, M. M., Hill, G. D. and Gallagher, J. N. (1988). The response of field beans (*Vicia faba* L) to irrigation and sowing date. 2. Growth and development in relation to yield. J. Agric. Sci. Camb. 11: 233-254.

Jakesova, J. and Svetlik, V. (1984). Influence of sowing, trace elements and growth regulators on yield and quality of seed of tetraploid red clover. Wissenchftliche Beitrage, martin-Luther-Universitat Halle-Wittenberg. 54: 378-389.

Jeuffroy, M. H. and Warembourg, F. R. (1991). Carbon transfer and partitioning between vegetative and reproductive organs in *Pisum sativum* L. Plant Physiol. 97: 440-448.

Jones, R. M. and Rees, M. C. (1972). Persistence and productivity of pasture species at three localities in subcoastal South-East Queensland. Tropical Grasslands. 6: 119-134

Kaufmann, N. R. (1972). Water deficits and reproductive growth. In 'Water deficit and plant growth'. (Ed. T. T. Kozlowski), Vol.II. pp. 93-24. Acad. Press. N.Y., London.

Klute, A. (1986). Water retention: Laboratory methods. In 'Methods of soil analysis'. Part 1. 2nd Edition. American society of Agronomy, Madison, Wisconsin, USA.

Lake, A. W. H. (1990). Medic cultivars for South Australia. In better legume pastures for more cereal-livestock profits. The University of Adelaide. Pasture Symposium No. 2, Feb 1990, pp. 19-21.

Lambert, R. G. and Link, A. J. (1958). Effects of high temperature on yield of peas. Plant physiol. 33: 347-350.

Leaf, E. L. (1972). In: Crop processes in controlled environment. Eds. A. R. Rees, K. B. Cocksheull, D. W. Hand and R. G. Hurd. pp. 175-184. Academic Press -London and New York.

Leeper, G. W. (Editor). 1970. The Australian Environment. CSIRO/MUP, Melbourne, 4th Edition., 163p.

Loch, D. S., Hopkinson, J. M. and English, B. H. (1976). Seed production of *Stylosanthes guyanensis*. 2. The consequences of defoliation. Aust. J. Exp. Agric. Anim. Husb. 16: 226-230.

Lorenzetti, F. (1981). Relationship between dry matter and seed yield in leguminous forage plants. In: Breeding high yielding forage (Ed. G. Van Bogaert), pp. 57-74. Eucarpia, Merelberke, Belgium.

Ludlow, M. M. (1978). Light relations of pasture plants. In 'Plant relations in pasture'. (Ed. J. R. Wilson). CSIRO. pp. 35-49.

Ludlow , M. M. and Charles-Edwards, D. A. (1980). Analysis of regrowth of a tropical grass/legume sward subjected to different frequencies and intensities of defoliation. Aust. J. Agric. Res. 31: 673-692.

Ludlow, M. M. and Ng, T. T. (1976). Effect of water deficit on carbon dioxide exchange and leaf elongation rate of *Panicum maximum* var. trichoglume. Aust. J. Plant Physiol. 3: 401-413.

Ludlow, M. M. and Wilson, G. L. (1971). Photosynythesis of tropical pasture plants. I. Illuminance, carbon dioxide concentration, leaf temperature, and leaf-air vapour pressure difference. Aust. J. Biol. Sci. 24: 449-470.

McCree, K. J. (1974). Changes in stomatal response characteristics of grain sorgum produced by water stress during growth. Crop. Sci. 14: 273-278.

McCree, K. J. and Troughton, J. H. (1966). Non-existence of an optimum leaf area index for the production rate of white clover grown under constant conditions. Plant Physiol. 41: 1615-1622.

McGowan, A. A and Williams, W. A. (1973). Factors affecting competition between subterranean clover and a barley cover crop. Aust. J. Exp. Agric. Anim. Husb. 13: 56-62

McWilliams, J. R. (1978). Response of pasture plants to temperature. In plant relations in pastures. pp. 17-33. Ed. J.R. Wilson, CSIRO. 425p.

Meadley, J. T. and Milbourn, G. M. (1971). The growth of vining peas. III. The effect of shading on abscission of flowers and pods. J. Agric. Sci. Camb. 77: 103-108.

Millar, B. D. and Denmead, O. T. (1976). Water relations of wheat leaves in the field. Agron. J. 68: 303-307.

Milthorpe, F. L. and Moorby, J. (1974). Fruit and flowering. In: An introduction to crop physiology. Chapter 8. pp. 71-109. Cambridge Univ. Press, London.

Mitchell, K. J. (1956). Growth of pasture species. IV. White clover (*Trifolium repens*) subterranean clover (*Trifolium subterraneum* L) and lotus major (*L.uliginosus*). New Zealand J. Sci. and Tech. A37: 395-413.

Monteith, J. L. (1977). Climate and the efficiency of crop production in Britain. Philos. Trans. R. Soc. London, B. 281: 277- 294.

Nitsch, E. I. (1965). The physiology of flower and fruit development. In: Encyclopedia of plant physiology. (Ed W. Ruhland). Vol. 15, Part I . pp. 1537-1647. Spring-Verlag: Berlin, New York.

Nix, H. A. (1975). The Australian climate and its effects on grain yield and quality. In: Australian Field crops, Vol. 1. Wheat and other temperate cereals. A. Lazenby and E. M. Matheson (Eds.), pp. 183-226.

Oram, R. N. (1990). Register of Australian herbage plant cultivars. CSIRO Australia. 304 p.

Pasumarty, S. V. and Thomas, R. G. (1990). Effect of canopy structure and light intensity on seed production in white clover. Proc. New Zealand Grassland Association. 52: 1107-110.

Pate, J. S. and Farrington, P. (1981). Fruit set in *Lupinus angustifolius* cv. Unicrop. II. Assimilate flow during flowering and early fruiting. Aust. J. Plant Physiol. 8: 307-318.

Pigeaire, A., Delane, R., Seymour, M. and Atkins, A. (1992). Predominance of flowers and newly formed pods in reproductive abscission in *Lupinus angustifolius* L. Aust. J. Agric. Res. 43: 1117-1129.

Pilbeam, C. J., Hebblethwaite, T. E., Nyongesa, T. E,. and Ricketts. H. E. (1991). Effects of plant population density on determinate and inderterminate forms of winter field beans (*Vicia faba*). II. Growth and development. J. Agric. Sci. Camb. 116: 385-393.

Poole, M. L. (1970). An agronomic evaluation of *Medicago tornata* cv. Tornafield, a new medic cultivar. Aust. J. Exp. Agric. Anim. Husb. 10: 405-409.

Porter, N. G. (1980). Attempts to control the growth pattern of Lupin plants. Proc. 1st. Intern. Lupin Workshop. Lima, Peru 1980.

Porter, N. G. (1982). Interaction between lateral branch growth and pod set in primary inflorescences of lupin. Aust. J. Agric. Res. 33: 957-965.

Potts, W. H. C. and Ison, R. L. (1987). Australian seed industry. Occasional Paper No 1. Grains Council of Australia. 161p.

Puckridge, D. W. and French, R. J. (1983). The annual legume pasture in cereal-ley farming system of Southern Australia. Agriculture, Ecosystems and Environment. 9: 229-267.

Puri, K. P. and Laidlaw, A. S. (1983). The effect of cutting in spring and application of Alar on red clover (*Trifolium pratense* l.) seed production. J. Appl. Seed prod. 1: 12-18.

Quinlivan, B. J., Devitt, A. C. and Francis, C. M. (1973). Seed rate, time of sowing and fertilizers for subterranean clover seed production. Aust. J. Exp. Agric. Anim. Husb. 13: 681-684.

Quinlivan, B. J., Francis, C. M. and Devitt, A. C. (1974). The determinants of yield in subterranean clover seed crops. Proc. 12th. Intern. Grassland Congr. Moscow. USSR. pp. 942-949.

Ragless, D. C. (1973). Medic seed production as an adjunct to mixed farming. *Agronomy Branch Report* 51, Adelaide: South Australian Department of Agriculture.

Reed, K. F. M. and Cocks, P. S. (1982). Some limitations of pasture species in southern Australia. Proc. 2nd. Aust. Agron. Conf., Wagga Wagga, NSW, pp. 142-160.

Robson, M. J. (1972). The effect of temperature on the growth of S.170 tall fescue (*Festuca arundinacea*). I. Constant temperature. J. Appl. Ecol. 9: 643-53.

Rossiter, R. C. (1961). The influence of defoliation on the components of seed yield in swards of subterranean clover (*Trifolium subterraneum*). Aust. J. Agric. Res. 12: 821-833.

Russell, J. S. (1969). Evaluation of temperate legumes on a solodic soil and a gilgaied clay soil in the southern brigalow region. Tropical Grasslands. 3: 123-135.

Rylott, P. D. and Smith, M. L. (1990). Effects of applied plant growth substances on pod set in broad beans (*Vicia faba* Var. *major*). J. Agric. Sci. Camb. 114: 41-47.

Saeki, T. (1960). Interrelationships between leaf amount, light distribution and total photosynthesis in a plant community. Bot. Mag. (Tokyo). 73: 155-163.

Salter, P. J. and Goode, J. E. (1967). Crop response to water at different stages of growth. Res. Rev. No. 2. pp. 46-60. (Comm. Agri. Bur. : Farnham Royal, Bucks, England).

Samaroo, B. H. (1988). Relationship between dry matter yield, seed yield and flowering time in annual forage legumes under dry conditions. J. Appl. Seed prod. 6: 31-35.

Schou, J. B., Jeffers, D. L., and Streest, J. G. (1978). Effect of reflectors, black boards, or shades applied at different developmental stages on growth and yield components of soybeans. Crop Sci. 18: 29-34.

Scott, W. R. (1971). An agronomic evaluation of subterranean clover cultivars. Proc. NZ. Grassland Ass. 33: 134-40.

Shibles, R. M. and Weber, R. C. (1966). Interception of solar radiation and dry matter production by various soyabean planting patterns. Crop Sci. 6: 55-59.

Shibles, R. M., Anderson, I. C. and Gibson, A. H. (1975). Soybean. In: Crop physiology. Some case histories. (Ed. L. T Evans), Cambridge University Press. pp. 151-189.

Silsbury, J. H. and Fukai, S. (1977). Effect of sowing time and sowing density on the growth of subterranean clover at Adelaide. Aust. J. Agric. Res. 28: 427-440.

Silsbury, J. H., Adem, L., Baghurst, P. and Carter, E. D. (1979). A quantitative examination of the growth of swards of *Medicago truncatula* cv. Jemalong. Aust. J. Agric. Res. 30: 53-63.

Sinha, N. C. and Singh, R. P. (1986). Physiological basis of irrigation scheduling for seed production in Egyptian clover Syn. Berseem (*Trifolium alexandrinum* L.). J. Agron. Crop Sci. 156: 246-252.

Sitton D., Itai, C. and Kende, H. (1967). Decreased cytokinin production in roots as a factor in shoot senescence. Planta, 73: 296-300.

Slatyer, R. O. (1967). Plant-water relations. Chapter 9, pp 275-86. Acad. Press London, NY.

Slatyer, R. O. (1973). In: Plant response to climate factors. (Ed. R. O. Slatyer.) p. 177. UNESCO: Paris.

Slatyer, R. O. (1974). Effects of water stress on plant morphogenesis. In: Plant morphogenesis as the basis for scientific management of range resource. pp. 3-13. U.S. Dept Agric Miscel. Pub. No. 1271.

Spollen, W. G, Wiebold, W. J. and Glenn, D. S. (1986a). Intraraceme competition in field-grown soybean. Agron J. 78: 280-283.

Spollen, W. G., Wiebold, W. J. and Glenn, D. S. (1986b). Effect of altered intraraceme competition on carbon-14-labelled assimilate and abscisic acid in soybean. Crop Sci. 26: 1216-1219.

Squella, F. (1992). The ecological significance of seed size in Mediterranean annual pasture legumes. PhD. Thesis. The University of Adelaide, Australia. 466p.

Squire, G. R. (1990). The physiology of tropical crop production. C.A.B. International. pp. 71-102.

Steiner, J. J. and Grabe, D. F. (1986). Sheep grazing effects on subterranean clover development and seed production in Western Oregon. Crop Science. 26: 367-372.

Stern, W. R. (1960). The light factor in grass and clover swards. PhD. Thesis. The University of Adelaide, Australia. 356p.

Stern, W. R. (1965). The effects of density on the performance of individual plants in subterranean clover swards. Aust. J. Agric. Res. 16: 541-555.

Stützel, H. and Aufhammer, W. (1991). Light interception and utilization in determinate and indeterminate cultivars of *Vicia faba* under contrasting plant distributions and population densities. J. Agric. Sci. Camb. 116: 395-407.

Summerfield, R. J., Huxley, P. A., Dart, P. J. and Hughes, A. P. (1976). Some effects of environmental stress on seed yield of cowpea (*Vigna unguiculata* (L.) Walp.) cv. Prima. Plant and Soil. 44:527-546.

Tabora, R. S. and Hill, M. J. (1991). An examination of vegetative and reproductive growth and their contribution to seed yield in 'Grasslands Maku' lotus (*Lotus uliginosus* Schk.). Applied Seed Production. 9 (supplement):7-15

Taylor, G. B. (1965). Studies on three annual species of *Trifolium* with particular reference to seed develpoment. MSc. Thesis. The University of Western Australia, Perth, Australia.

Taylor, G. B. and Palmer, M. J. (1979). The effect of some enviromental conditions on seed development and hardseededness in subterranean clover (*Trifolium subterranum* L.). Aust. J. Agric. Res. 30: 65-76.

Taylor, G. B. and Rossiter, R. C. (1974). Persistence of several annual legumes in mixtures under continuous grazing in south-west of western Australia. Aust. J. Exp. Agric. Anim. Husb. 14: 632-639.

Thaine, R., Ovenden, S. L. and Turner, J. S. (1959). Translocation of labelled assimilates in soybean. Aust. J. Biol. Sci. 12: 349-272.

Thorn, C. W. (1989). Aspects of management of annual regenerating legumes. Proc. 5th. Aust. Agron. Conf., Perth.WA., pp. 123-140.

Thorn, C. W. and Laslett, G. (1992). Time of planting effects on seed prodction of burr medic. Proc. 6th. Aust. Agron. Conf. Armidale, NSW. pp. 535.

Thorn, C. W. and Revell, C. K. (1987). The effect of grazing on seed production of a range of annual medic species. Proc. 4th. Aust. Agron. Conf., Melbourne, Victoria. p. 170.

Thrower, S. L. (1962). Translocation of labelled assimilates in the soybean. Aust. J. Biol. Sci. 15: 629-649.

Tow, P. G. (1989). Monitoring annual medicago ley pastures for management decisions. Proc. XVI. Intern. Grassland. Congr. Nice, France. pp. 601-602.

Tow, P. G., Al. Alkailah, (1981). Factors affecting seed production in Jemalong Barrel medic. Aust. Seed Science Newsletter. No 7. pp. 74-89.

Turner, N. C. (1981). Techniques and experimental approaches for the measurement of plant water status. Chapter 3. Plant and Soil. 58: 339-366.

Turner, N. C. (1974). Stomatal behaviour and water status of maize sorghum and tobacco under field conditions. II. At low soil water potential. Plant. Physiol. 53:360-365.

Turner, N. C. and Begg, J. E. (1973). Stomatal behaviour and water status of maize, sorghum, and tobacco under field conditions. I. At high soil water potential. Plant Physiol. 51: 31-36.

Turner, N. C. and Begg, J. E. (1974). Adaptation to stress in crops of sorghum and sunflower. Physiological mechanisms. CSIRO.Aust. Div. Plant Ind. Annual Report, 1974. p.102.

Turner, N. C. and Begg, J. E. (1978). Response of pasture plants to water deficits. In 'Plant relations in pastures'. pp 51-65. (Ed. J. R. Wilson). CSIRO. 425p.

Walton, G. H. (1975). Response of burr burial in subterranean clover (*Trifolium subterraneum*) to defoliation. Aust. J. Exp. Agric. Anim. Husb. 15: 69-73.

Ward, C. Y. and Blaser, R. E. (1961). Carbohydrate food reserves and leaf regrowth of orchard grass. Crop Sci. 1: 366-370.

Wardlaw, I. F. (1967). The effect of water stress on translocation in relation to photosynthesis and growth. I. Effect during grain development in wheat. Aust. J. Biol. Sci. 20: 25-39.

Wardlaw, I. F. (1968). The control and pattern of movement of carbohydrates in plants. Bot. Rev. 34: 79-105.

Wardlaw, I. F. (1969). The effect of water stress on translocation in relation to photosynthesis and growth. II. Effect during leaf development in *Lolium temulantum* L. Aust. J. Biol. Sci. 22: 1-16.

Wareing, P. F., Khalif, M. M. and Treharne, K. J. (1968). Rate-limiting processes in photosynthesis at saturating light intensities. Nature. 220: 453-457.

Waring, R. H. and Cleary, B. D. (1967). Plant moisture stress: evaluation by pressure bomb. Science. 155: 1248-1254.

Watts, W. R. (1974). Leaf extension in *Zea mays*. III. Field measurements of leave extension in response to temperature and leaf water potential. J. Exp. Bot. 25: 1085-1096.

Whyte, R. O., Nilsson-Leissner, G. and Trumble, H. C. (1953). Legumes in Agriculture. FAO Agricultural Studies. No 21.

Wiley, R. W. and Heath, S. B. (1969). The quantitative relationships between plant population and crop yield. Advances in agronomy. 21: 281-321.

Williams, C. H. (1981). Chemical properties. In: Red-brown earths of Australia. (Eds. J. M. Oades, D. G. Lewis and K. Norrish). pp. 47-62.

Williams, C. M. J. and Vallace, N. A. (1982). New medic pasture systems to increase production in pasture/cereal rotations in the Victorian Mallee. Proc. 2nd. Aust. Agron. Conf., Wagga Wagga, NSW. p. 317.

Woledge, J. (1972). The effect of shading on the photosynthetic rate and longevity of grass leaves. Ann. Bot. 36: 551-561.

Woledge, J. and Jewiss, O. R. (1969). The effect of temperature during growth on the subsequent rate of photosynthesis in leaves of tall fescue (*Festuca arundinacea* Schreb.). Ann. Bot. 33: 897-913.

Wolf, D. D., and Blaser, R. E. (1972). Growth rate and physiology of alfalfa as influenced by canopy and light. Crop Sci. 12: 23-36.

Wolfe, E. C. (1985). Subterranean clover and annual medics boundaries and common ground. In the Proceedings 'The Ecology and Agronomy of Annual Medics'. (Ed. Z. Hochman), NSW. Dept. Agric. Tech. Bull. 32. Condobolin, NSW (1981).

Yates, J. J. (1961). Seed-setting in subterranean clover (*Trifolium subterraneum* L.). III. The effect of plant density. Aust. J. Agric. Res. 12: 10-26.

Yoda, K., Kira, T. and Hozumi, K. (1957). Intra-specific competition among higher plants. IX. Further analysis of the competitive interaction between adjacent individuals. J. Inst. Polytech. Osaka City Uni. 8: 161-178.