THE ECOLOGY AND PRODUCTIVITY OF ANNUAL MEDIC GENOTYPES

by

Mohammad Husein Ababneh, M.Sc.
University of Jordan, Amman

A thesis submitted to the University of Adelaide in fulfilment
of the requirements for the degree of Doctor of Philosophy.

Department of Plant Science
Waite Agricultural Research Institute
The University of Adelaide

July 1991

FOR MY WIFE AND FAMILY WHO

GAVE EVERYTHING FOR NOTHING

TABLE OF CONTENTS

3. COMPARATIVE ECOLOGICAL CONDITIONS IN JORDAN AND SOUTH AUSTRALIA AND THE EXISTING STATUS OF MEDICS IN JORDAN

4. FIELD EXPERIMENT 1: EVALUATION OF MEDIC GENOTYPES UNDER RAINFED CONDITIONS IN JORDAN, 1986-1987

5. FIELD EXPERIMENT 2: COMPARATIVE GROWTH AND SEED PRODUCTION OF FOUR MEDIC GENOTYPES BASED ON EQUAL SOWING RATES AND ON EQUAL SEED NUMBERS PER UNIT AREA IN JORDAN, 1986-87

8. EXPERIMENT 5: EARLY VEGETATIVE GROWTH OF FOUR MEDIC GENOTYPES GROWN IN MICRO-PLOTS AS MONCULTURES, BINARY MIXTURES AND FOUR-WAY MIXTURES

9. GROWTH CABINET STUDIES
EXPERIMENT 6: GROWTH RESPONSE OF FOUR ANNUAL MEDIC GENOTYPES TO TEMPERATURE UNDER CONTROLLED CONDITIONS

EXPERIMENT 7: THE INFLUENCE OF TEMPERATURE AND PLANT DENSITY ON GROWTH AND NITROGEN FIXATION BY TWO ANNUAL MEDIC GENOTYPES

ABSTRACT

The research for this thesis was undertaken in both Jordan and South Australia. Four research priorities were identified and studied, viz.

(i) Surveys of native annual medics in cultivated and uncultivated areas in Jordan;
(ii) Evaluation and adaptation of new annual medics to agro-climatic zones in Jordan;
(iii) Pasture management: effects of defoliation, depth of sowing and role of pure and mixed swards; and
(iv) The effects of temperature and plant density on plant growth and nitrogen fixation by annual medic swards in controlled environmental conditons.

These research priorities were addressed in seven experiments plus field surveys as follows:
Field Surveys: The field surveys in Jordan showed that on cultivated fields the native medics had been eliminated by deep ploughing and bare fallowing but on uncultivated areas there were reasonable medic seed reserves which ranged from 500-1317m^{-2}.

Evaluation of Medic Genotypes : A medic evaluation experiment examined herbage and seed production of nineteen annual medics representative of six *Medicago* species including Australian commercial cultivars sown at the equivalent of 18kg/ha pure germinating seed of Jemalong as standard. This experiment was repeated in the northern, central and southern districts of Jordan. The main conclusions were: dry matter production varied according to the genotype and climatic conditions; *M. scutellata* was the most productive species followed by *M. rotata*, while *M. truncatula* species was the poorest over the three sites. Seed yield reflected the herbage production in both sites and genotypes.

Comparative Growth and Seed Production : This experiment was conducted at Mushagar Research Station in the central district of Jordan in 1986 - 1987. The comparative experiment quantifying the herbage and seed production of four annual medic species, two Australian commercial cultivars namely, *Medicago scutellata* cv. Sava and *Medicago truncatula* cv. Paraggio and two cold-tolerant genotyopes namely, *Medicago rigidula* Sel. 716. and *Medicago rotata* Sel. 1943. All genotypes were sown both at equal sowing rates (30kg/ha pure germinating seed), and equal seed number (825 seeds/m^2). Eight harvests were made through the season.

Defoliation experiment : This experiment at the Waite Institute was designed to identify and quantify the main effects of time and frequency of defoliation on herbage and seed production of the same four annual medic genotypes used in the Jordanian experiment. Four defoliation treatments were applied, viz. (Undefoliated, Defoliated Early, Defoliated Late and Defoliated Early and Late). Defoliation treatments had a marked effect on both herbage production and seed yield.

Depth of sowing experiment : This experiment conducted in a glasshouse using small pots involved three depths of sowing 1, 3 and 5cm using sand and loam. Four medic genotypes (Sava, Para., Rigi., and Rota.) were tested for seedling emergence. The main conclusions were that percentage seedling emergence, cotyledon area index and herbage yield decreased as the depth of sowing increased regardless of genotype or type of soil and the emergence percentage in loam was less than the corresponding depth of sowing in sand. The optimum depth of sowing for medic was 1cm with sandy soil.

Mixture experiment: This experiment was located in raised-beds using microplots (20 x 20cm). Four medic genotypes (Sava, Para., Rigi. and Rota.) were sown in pure stands and in binary mixtures (60kg/ha pure germinating seed). Also all genotypes were sown in 4-way mixtures (60 and 600kg/ha pure germinating seed). Binary mixtures produced an intermediate herbage yield between the most productive genotype, *M. truncatula.* and the other genotypes.

Growth cabinet studies: Four medic genotypes (Sava, Para., Rigi. and Rota.) were compared for growth response to temperature under controlled conditions in two experiments. Conditions common to both Experiments 6 & 7) were 400 μmolquanta/m^2/s 12h day: 12h night and three temperature regimes 10, 15 and 20°C were applied. The main findings in this experiment were that at low temperature (10°C) *M. rigidula.* had the highest shoot growth rate (5.1gDM/m^2/day), but growth declined beyond 15°C.

Temperature and plant density experiment: According to the previous experimental results, two genotypes out of four were chosen to be examined for growth responses and nitrogen fixation as influenced by temperature and plant density. *M. scutellata* which positively responded to temperature and *M. rigidula* which inversely responded to temperature. Three plant densities 888, 2222 and 22,220 plants/m^2 were used. The main conclusions were that growth rate varied according to plant density, temperature regime and genotype; the maximum growth rate was obtained from *M. scutellata* (8.9g/m^2/day) at 15°C with medium density, whilst the lowest growth rate was produced from *M. scutellata* (2.5gDM/m^2/day) at 20°C with high density; at low temperature, growth rate increased as plant density increased for both genotypes. The evidence from these controlled experiments is that *M. rigidula* is a cold-tolerant genotype and has a potential role in southern Australia as well as being suitable for the medic seed export industries to colder-winter countries of the Old World or southern Europe.

Statement

The research presented in this thesis represents original work carried out by myself except where due acknowledgement has been made in the text. This thesis has not been previously submitted in full or part to any other University for any degree or diploma. I consent to the thesis being made available for photocopying and loan if accepted for the award of the degree.

M. H. Ababneh

Acknowledgements

The research for this thesis was planned and carried out under the supervision of Mr. E. D. Carter, Senior Lecturer in the Department of Plant Science, Waite Agricultural Research Institute, The University of Adelaide. I am deeply grateful to him for his patience, guidance, support and criticisms during the planning of experimental work in Jordan and South Australia, and the preparation and checking of this thesis.

Special thanks are due to the late Dr. J.H. Silsbury, who was a co-supervisor for research work in the growth cabinet, for his guidance and help. Many thanks to Dr. P.G. Tow for his co-supervision of my research work in Jordan. I gratefully acknowledge the excellent assistance of Lynne Giles and Trevor Hancock with statistical advice and analyses and Mr. Barry Felberg for all his help with acquisition of equipment and chemicals.

The assistance of Dr. F.L. Stoddard on the computer and Dr. G. McDonald for reviewing drafts of parts of this thesis are acknowledged. Many people helped with field work and with laboratory analyses : Steve Challis, Richard Knowles, Mary Armstrong, Kylie Le Leu, Diona Mobsby and Gayle V. Scott, provided technical assistance during the project which is greatly appreciated.

Deepest gratitude is also due to my wife Enam and children for their endurance, encouragement and sharing the hard life of a postgraduate student.

Best wishes and many thanks go to all who gave assistance in the final preparation of the thesis: Marie and Bill Vince for typing the manuscript, Sue Hughes for some of the correcting, the photographer, Andrew Dunbar, Miss Kylie Le Leu for proof-reading, typing and checking and Lesley Cameron for photocopying.

Last, but not least, deep appreciation and many thanks are extended to the Australian International Development Assistance Bureau and SAGRIC International for providing me with a scholarship for this work, also to the authorities at the Ministry of Agriculture, Amman, Jordan who supported me, encouraged and gave the opportunity for this study.

LIST OF DIAGRAMS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF MAPS

LIST OF APPENDICES

1. GENERAL INTRODUCTION
AND
2. REVIEW OF LITERATURE

1. GENERAL INTRODUCTION

In this thesis the word "medic" applies to an annual species of the legume genus *Medicago*. All medics are winter annuals with herbaceous weak stems, trifoliate leaves and inconspicuous yellow flowers (Whyte *et al.* 1953).

The genus *Medicago* is native to western Asia and the Mediterranean region, though many of its annual species have become naturalized over wide areas in many countries of the world especially those areas with Mediterranean type climate (Heyn 1963). However, annual medics (*Medicago* spp.) also have potential as winter legumes in agricultural areas of subtropical regions, e.g. eastern Australia where the mean winter rainfall (April to September) exceeds 180mm (Clarkson and Russell 1979).

The seasonal distribution of dry matter production is a major feature of the growth of annual pastures in a Mediterranean environment. Yield early in the growing season when feed is normally scarce is an important determinant of year-round carrying capacity of livestock. As the pasture grows, many factors can operate to restrict the rate of increase in plant growth. While some of these restrictions can be removed, others are simply attributed to poor adaptation of the cultivar to the climatic, soil and biological environment of the farm. The solution to these problems is to select a better genotype. The more-important types of restrictions are poor adaptation to the ecological and biological characteristics of the farm, yielding ability of the cultivar, dry conditions also poor nodulation and nitrogen fixation.

Much better knowledge of the factors affecting field behaviour of medics is necessary if they are to be used effectively as components of pastures. Carter (1981b, 1990) has identified 13 factors influencing the persistence and productivity of annual medics and sub clover. In the cereal-livestock zone of southern Australia and its counterparts in West Asia and North Africa, the most important constraints to the productivity and persistence of annual medics are:

* choice of species, cultivars, mixtures and sowing rates

* depth of sowing

- tillage practices affecting regeneration (Carter 1987)
- insect pest control during establishment
- grazing management during the summer-autumn period

It is important that the ecology of cultivars can be examined as well as their potential productivity measured because high herbage production may be on the expenses of seed production. The two may be antagonistic because excessive shading has been shown to reduce seed yield (Collins *et al.* 1978).

These factors all influence seed-seedling dynamics and consequent density, productivity and persistence. This thesis describes field surveys and experiments, a raised-bed experiment, a glasshouse experiment and two growth-cabinet experiments related to the ecology and management of annual medics. Part of the research was conducted in Jordan and the rest at the Waite Agricultural Research Institute, Adelaide, South Australia. Comparative studies on well-known Australian cultivars, *Medicago scutellata* (snail medic) cv. Sava, *M. truncatula* (barrel medic) cv. Paraggio and two selected medic genotypes from the International Centre for Agricultural Research in the Dry Areas (ICARDA), viz. *M. rigidula* Sel. 716 and *M. rotata* Sel. 1943 are an important feature of the research reported in this thesis. This is part of the ongoing pasture research program based at the Waite Institute which concentrates on the ecological and management factors influencing the seed-seedling dynamics and productivity of annual legume-based pastures.

2. REVIEW OF LITERATURE

2.1 The Existing and Potential Role of Annual Medics

In the Mediterranean-type climate of southern Australia, the growth cycle of the self-regenerating annual pasture legumes begins with germination of seed after the opening rains and the establishment of a population of seedlings (Silsbury *et al.* 1984). Cocks (1969) considered a true seasonal opening as receipt of >13mm from over a 7-day period, and since such rainfall may first occur any time between February and June, the processes of germination and emergence may take place in quite contrasting environmental conditions in different years. However, if rains fall too early when temperatures are high the annual legumes rarely survive : severe losses through desiccation of seedlings are normal during February and March in southern Australia.

The role of annual legumes (including medics) in farming systems in Mediterranean-climatic zones is described by Carter (1974, 1975, 1978): annual medics are also being studied as pasture legumes in the 500-800mm annual rainfall zone of subtropical eastern Australia (Clarkson 1970). They grow and persist in this region as far north as Lat. 2.3S, and are very productive in years with adequate cool season rainfall (Russell 1969; Jones and Rees 1972). Unlike southern Australia where a winter-growing season alternates with summer drought, the dry tropic region does not have a well-defined growing seasons, and germination of medics may occur at any time of the year (Clarkson 1970).

Following settlement, annual medics (and clovers) became naturalised following accidental introduction and there were thousands of hectares of medics (mainly *Medicago truncatula*, *M. polymorpha* and *M. minima*) long before there was any organised medic seed industry. Seed from the annual medics (*Medicago truncatula* and *M. scutellata*) was first harvested at Noarlunga (south of Adelaide) in the mid-1930's (Trumble and Donald 1938; Trumble 1939). Two factors were responsible for rapid spread of naturalised medic species : first, the widespread use of superphosphate and second, the discontinuance of bare-fallowing in the depression period of the mid-1930's. Since then both naturalised species and sown cultivars have played a key role in maintaining and improving soil fertility levels and improving the quantity and quality of livestock feed in the areal belt of southern Australia with predominantly neutral to alkaline soils and mean rainfall of 250-500mm. Thus the ley farming system (annual self-regenerating legume-cereal rotations) started (Day and Michelmore 1952; Donald 1960a; Rossiter 1966; Donald 1970a; 1970b; Geytenbeek 1974; Carter 1974b, 1975). The ley farming system (annual legume-cereal rotations) was developed in the 1940s and became well established in the cereal belt of southern Australia during the 1950s.

In addition to the role of annual medics in the cereal belt annual medics are widespread in the non-cultivated rangeland areas of southern Australia especially *Medicago laciniata* in the 150-200mm rainfall areas also *M. polymorpha* in watercourse areas of these arid areas. In total there are probably 80million ha of medic on cultivated land and adjacent arid rangelands in (mostly) southern Australia.

Webber *et al.* (1977) summarized the specific advantages of the ley farming system that has been adopted over the previous 30 years. The system increased soil fertility, improved soil structure, increased pasture production, increased and stabilized livestock production, increased cereal crop yields and gave better control of soil erosion (Ababneh 1983). The annual medics are important components of the "ley farming system" where they are grown in rotation with cereals (Puckridge and French 1983).

The success of ley farming is closely linked with, on the one hand, the provision of high-quality green feed and dry residues (including pods) in summer when the seeds of medics provide ample digestible protein and, on the other hand, the natural regeneration of large numbers of seedlings following the cropping phase (Carter 1981, 1982; Carter *et al.* 1982; Cocks 1988). Recently, with increased emphasis on developing sustainable farming systems there is renewed interest in the potential role of annual legumes including medics in the United States (e.g. Graves *et al.* 1987) as well as Portugal, North Africa, western Asia and other countries with similar physical and environmental conditions.

In Jordan, where medic species are native, commercial Australian cultivars were introduced in 1980 by a joint Australian-Jordanian Dryland Farming Programme. These medic cultivars showed successful growth in mild-winter areas of the cereal zones . Earlier, Ababneh (1983) reported that the cereal-fallow system was the main feature of field crop production in the rain-fed areas of Jordan; 93% of the total cropped land comprising 529,000 hectares (Agricultural Statistical Yearbook of Jordan 1981).

While progress is being made to replace this cereal-fallow system by a ley farming system, some difficulties need to be solved to achieve the advantages of the new system: some ecological and poor management factors which affect medic emergence, establishment and growth in the first year and regeneration in the following years need to be rectified. As a contribution to solving these problems, a research program started in 1986-1987. An experiment (see Chapter 4) which included 19 cultivars of genotypes *M. scutellata, M. truncatula, M. rigidula, M. rotata* and *M. polymorpha* was conducted at three locations viz. northern, central and southern Jordan. Seed of medics adapted to inland west Asia though not available as commercial cultivars was available for testing along with Australian medic cultivars susceptible to damage by frost which in north-west Syria, can occur on up to 50 days (Cocks and Ehrman 1987). Native species such as *Medicago rigidula* (L.), *M. rotata* and *M. noeana*, have now been selected which combine frost tolerance and adaptation to ley farming (Abd El Moneim and Cocks 1986; Cocks and Ehrman 1987).

From the 19 cultivars and genotypes tested in 1986-1987, the four most-adapted and productive ones were chosen for further study. An experiment (described in detail in Chapter 5) comprised four species of annual medics: two species were Australian commercial cultivars (*M. scutellata* cv.Sava and *M. truncatula* cv. Paraggio) and two species were from cold-tolerant genotypes (*M. rigidula* Sel. 716 and *M. rotata* Sel. 1943) selected in the evaluation program of the International Centre of Agricultural Research in Dry Area (ICARDA) at Aleppo, Syria. These four genotypes formed the basic material for the studies reported in this thesis. A survey of the surviving native medic species in cultivated and uncultivated areas in Jordan formed part of this research program.

Further study of the growth responses of annual medics to ecological and management factors is justified on both practical and theoretical grounds. In a practical sense, it is important to know if there are major differences between species or cultivars of annual medics in response to: (i) climatic factors such as rainfall and temperature and (ii) Management factors such as plant density sowing method, depth of sowing, soil texture and mechanical defoliation. In contrast to the ample research data for subterranean clover (*Trifolium subterraneum* L.) which shows the time course of dry matter growth to be strongly influenced by sowing rate and by temperature, few data appear to be available for the annual medics. Although some workers have examined change in dry matter during the growing season (Amor 1966; Poole 1970; Adem 1977), few figures for crop growth rate of medic swards are available in the literature. There thus appears to be a need to describe and quantify the growth of annual medics which are of considerable importance on alkaline soils in the regions of Mediterranean climate; to compare growth rates of medic swards with those recorded for subterranean clover.

Annual species of *Medicago* are the key to successful cereal-pasture rotations in the integrated crop-livestock farming systems on the neutral to alkaline soils of southern Australia (Carter 1974, 1975, 1981). However many medic stands have deteriorated in recent years due to deep ploughing or poor management. This deterioration has promoted research on the adaptability and productivity of local and introduced annual *Medicago* species. Indeed Leeuwrick (1974) suggested that the species used in Australia are, in west Asia, only adapted to a small area near the Mediterranean Sea. However other species, including *M. rigidula* (L.) All., *M. rotata* Boliss. and *M. minima* (L.) Bart, occur in inland areas where there is a risk of frost. It is therefore of great practical importance to study the frost tolerance of these inland species in comparison with the Australian cultivars. Therefore, current research presented in this thesis aims to identify and quantify the effects of ecology and management on the adaptability and productivity of some new *Medicago* cultivars grown in Jordan and southern Australia and compare these with existing Australian medic cultivars.

2.2 Ecology and Distribution of Annual Medics

2.2.1 Geographic Origin of Annual Medics

The semi-arid areas of west Asia have a Mediterranean climate with an annual rainfall of 250-500mm occurring during the months of October to May. In the drier areas the predominant land use is cereal production in rotation with cultivated bare fallow but, as rainfall increases, lentils (*Lens culinaris* Med), Chickpeas (*Cicer arietinum* L.) and vegetable crops replace the bare fallow. Livestock production (mainly sheep and goats) is based on feeding the grain, straw and stubble of cereals and grain legumes, and grazing of native pasture (Cocks 1985). In Jordan, a few farmers grow common vetch (*Vicia sativa* L.), bitter vetch (*V. ervilia* L.) and chickling vetch (*Lathyrus* spp.) all three of which are either grazed or harvested as hay or grain and straw.

It is important to increase livestock production in these areas and one promising way of doing so is to use the otherwise unproductive fallow for self-regenerating pastures based on annual legumes. This ley farming system (Carter 1974, 1975, 1977, 1978, 1980, 1981, 1982; Puckridge and French 1983) is used widely in southern Australia where pastures comprise subterranean clover (*Trifolium subterranean* L.) and several species of annual medics (*Medicago truncatula* Gaertn., *M. littoralis* Rhods ex Lois., *M. rugosa* Desr., *M. scutellata* L.) Miller, *M. tornata* (L.) Miller, and *M. polymorpha* L.).

As a result of hard-seededness these annual legume species are able to survive the cereal phase and regenerate a volunteer pasture phase which can be grazed by livestock. Attempts have been made to introduce ley farming based on annual medics, which unlike subterranean clover, are adapted to the alkaline soils (Robson 1969) which are widespread in west Asia. These attempts have often failed because the commercially-available Australian medics appear to lack frost tolerance (Bailey 1967; Van der Veen 1967; Tamimi 1976; Kernick 1978). Variation in frost tolerance occurs among European populations of several perennial grasses (Lorenzetti *et al.* 1971), and ecotypic differentiation in other characters has been found among Mediterranean annual legumes, especially in Australia where they have been present for about 100 years, (Woodward and Morley 1974; Donald and Neal-Smith 1937). Indeed, substantial genetic change has occurred in subterranean clover in only 19 years (Cocks *et al.* 1982) which is consistent with the remarkable adaptation of *Agrostis tenuis* and *Anthoxanthum odoratum* to soils contaminated with heavy metals (McNeilly 1968; Antonovics 1972) or improved with lime (Snaydon and Davies 1976). It is thus very likely that variation in frost tolerance occurs both within and between medic species.

Cocks and Ehrman (1987) reported the variation in the frost tolerance (frost survival percentage) and the origin of seven species and cultivars of annual medics as shown in Table 2.1.

Table 2.1 Frost tolerance of annual medic species

Species	Cultivar Name or Accession number	Origin	Frost Survival (%)	Some Agronomic Characters
M. polymorpha	Circle Valley	Coolgardie Australia *	21	Early flowering; spineless pods
M. scutellata	Robinson	Noarlunga Australia *	5	Upright growth; large spineless pods
M. truncatula	Cyprus	Cyprus	7	Early flowering; short spiny pods
M. truncatula	Jemalong	Forbes Australia #	14 14	Most popular Australian cultivar
M. rigidula	Selection 716	Jisr Al-shougr Syria	95	High herbage yield
M. rigidula	Selection 1919	Terbol Lebanon	98	Very high seed yield
M. rotata	Selection 2123	Azaz Syria	90	Upright growth; large spineless pods

* Mackay (1982) # Barnard (1972)

The first four are Australian cultivars and the final three are ICARDA selections. The frost tolerance was expressed as the percentage (at 35 days after establishment-count) of the original population surviving until 12 March 1985 and was related to the environment of origin.

2.2.2 The Frequency and Distribution of Annual Medics

The genus *Medicago* is native to western Asia and the Mediterranean region though many of its annual species have become naturalized over wide areas of the world (Heyn 1963). Medics are the most widespread annual pasture legumes in southern Australia. The Australian cultivars of annual medic are adapted to a Mediterranean climate with wet winters and dry summers. Most cultivars grow best in alkaline soils receiving from 300-500mm of rainfall each year. The distribution of the annual medics is influenced by the degree of spininess of pods and by a multitude of edaphic and climatic factors (Robson 1969). Species with pods which adhere firmly to wool or hair of animals generally have a wider distribution than those with smooth pods (Andrew and Hely 1960; Heyn 1963; Crawford 1973). The natural distribution of *M. arabica* is probably restricted by its requirements for deep, well-drained and very fertile soils. Also, within a zone favourable to medics, distribution of species is affected more by soil variation than by variation in climate (Andrew and Hely 1960). Medic species like *M. constricta* appear to be prevalent only in areas having deep brown soils. These soils have an alkaline surface reaction and a silt fraction of 55-60 (Buringh 1960). Such species have now spread to other parts of the world and most of them have become well established in the zones with Mediterranean-like climate.

In Australia, Ewing (1983) reported that a high proportion of most commercial medic cultivars were selected from direct introductions of genetic material from overseas or by breeding from introduced material. Relatively few of the successful cultivars are Australian ecotypes, or bred from Australian ecotypes. This contrasts with the situation for subterranean clovers where most varieties are locally-collected ecotypes or have been bred from local ecotypes. Important exceptions among medics are Jemalong, Hannaford and, more recently, Circle Valley. The imported material which has been used directly as varieties such as Cyprus and Harbinger, or as parent material for crosses such as Tornafield and Serena, comes from geographically-diverse sources (Table 2.2).

Table 2.2 The origin of Australian cultivars of annual medics

Species	Cultivar	Source
M. truncatula	Hannaford	Naturalized, South Australia
	Jemalong	Naturalized, New South Wales
	Cyprus	Cyprus
	Cyfield	Cyprus x two other genotypes
	Borung	Tunisia
	Ghor	Jordan
	Akbar	Israel
	Ascot	Cross of two South Australian lines
M. littoralis	Harbinger	Iran via California
M. rugosa	Paragosa	Portugal
	Paraponto	Italy
	Sapo	Portugal
M. tornata	Tornafield	United States of America x Israel
	Murrayland	Naturalized
	Swani	Libya
M. polymorpha	Serena	Naturalized x Chilean
	Circle Valley	Naturalized Western Australia
M. scutellata	Robinson	Naturalized South Australia
	Sair	Selected from commercial snail South Australia.
	Sava	Introduced via German Democratic Republic via Russia
M. rigidula	ICARDA selection	
	Sel. 716	Syria
	Sel. 1919	Lebanon
M. rotata	Sel. 2123	Syria
	Sel. 1943	Turkey

\# Source: Cocks and Ehrman (1987)

Several medic species were accidently introduced into Australia by early settlers in the 1800s and these have spread widely by natural means, often in wool. The common naturalized medics in Queensland are burr medic (*Medicago polymorpha*) and woolly burr medic (*M.*

minima). These are often seen on roadsides. Other species which occur less frequently in southern Queensland are cutleaf medic (*M. laciniata*), button medic (*M. orbicularis*) and black medic (*M. lupulina*). Additional species are found in southern states. Subsequent to naturalization medics have been developed as commercial cultivars of pasture plants in southern Australia.

In Jordan and most areas of West Asia and North Africa drought conditions over the past 30 years and poor management (heavy grazing pressure, deep sowing and deep tillage) have all caused abnormal reduction of medic seed-reserves and consequent seedling density and had far more influence on yield and botanical composition than did the initial medic populations. However, where zero or shallow cultivation was used and grazing was less severe there were significant correlations between medic-emergence-survival (February-March) and September seed reserves (Carter 1974, 1975, 1978, 1981; Carter *et al.* 1989) reported that grazing sheep can seriously deplete potential medic seed reserves and that this may result in grossly inadequate seedling density. Medic seed reserves in the top 5cm of soil are a reliable indicator of potential density and productivity of medic pastures (Carter 1982). For this reason core-sampling techniques have been developed to enable farmers to assess their needs for sowing additional medic seed before the autumn rains (Carter 1988; Carter *et al.* 1989).

On the neutral and alkaline soils of New South Wales, naturalized annual medics (*Medicago polymorpha; M. minima*), and the sown barrel medic cultivars Jemalong and Cyprus (*M. truncatula*) are important pasture legumes (Moore 1970). In northern New South Wales the development of native pastures containing annual medics by the application of fertilizer has been proposed (Hilder and Spencer 1954; Sheridan 1973), and in the southern and central western wheat-sheep belt, medics have been included in ley pastures in crop rotations to increase soil organic matter and nitrogen (Brownlee and Scott 1977).

2.2.3 Development of Native Medic Cultivars More Suited to Jordanian Conditions than those Introduced from Australia

The commercial Australian cultivars of medic are susceptible to damage by frost, which in north-west Syria, can occur on up to 50 days (Cocks and Ehrman 1987). Native species such as *Medicago rigidula* (L.), *M. rotata*, and *M. noeana* have now been selected which combine frost tolerance and adaptation to ley farming (ABD El Moneim and Cocks 1986; Cocks and Ehrman 1987). Therefore, the Australian cultivars are not particularly suited to Jordanian conditions. The small size of seeds from *M. littoralis* and *M. truncatula* often leads to poor emergence and establishment of first year pastures. Various aspects of the Australian cultivars have been encouraging, for example, *M. scutellata*, cv. Robinson has established well, producing moderate levels of forage and seed when sown at heavier rates e.g. 40kg/ha to simulate a regenerating pasture and the regeneration of annual medics has been good when sufficient seed had been set and not over-grazed during summer and autumn (Carter 1981).

Initially medics can be grown productively in the marginal areas of the cereal zone. The annual medics have shown some potential in terms of producing a good pasture. However, lines which are better-adapted and more-productive are needed to exploit this potential. Farmers will only become interested if highly-productive pastures are reliably produced and the Australian cultivars are not capable of doing this. Some more cultivated *Medicago* species have been showing this potential production, particularly *M. rigidula* and *M. rotata* (Bull 1984).

2.3 Evaluation of Annual Medicago Species

2.3.1 Historical Background of Annual Medics in Australia

Annual medics originated in the Mediterranean region (Heyn 1963). The spiny burrs of many species of annual medic have helped disperse them widely from their centres of origin. The pastures of the agricultural areas in South Australia contain both native and exotic herbage plants. Twelve species of annual medic were recorded in South Australia and twenty new species were introduced (Trumble 1939). Up to the late 1930s South Australia's cereal zone had been exploited by extensive cropping on fallow. Under the fallow-wheat system, much of the natural soil fertility was exhausted, soil erosion was acute in many areas, soils were difficult to work because their structure had been broken down and there was insufficient forage to feed the increasing numbers of livestock (Webber and Williams 1977). Annual medics are used as the key to successful cereal-pasture rotations in the integrated crop-livestock farming system (Carter 1981). During recent years some 46 million hectares have been used annually for crops and sown pastures (15m.ha. crops, 3m.ha. fallow and 28m.ha sown pastures Carter (1975). Annual medics generally appear more sensitive to soil acidity and more tolerant of soil alkalinity than subterranean clover (Trumble and Donald 1938).

Western Australia is one of the many parts of the world where a number of accidentally introduced medic species have become naturalised. It is likely that these arrived early in the agricultural development of the state. They most likely came here from western Europe and the western Mediterranean. Though subterranean clovers led to the way in Western Australia's improved pasture boom of the 1950s and 1960s, farmers and scientists soon realised that some soil types and situations did not suit sub clover at all. The forest soils of the wheat belt were typical of these. They were the well-favoured clay loams which usually were alkaline. But volunteer medics seemed to grow well there, particularly burr medic and Goldfield medic. Unfortunately, these plants had very spiny burrs which contaminated wool. Then in the late 1950s, some commercial barrel medic (*Medicago truncatula*) was introduced from South Australia, it had a prolific growth habit and its burrs were not as spiny as the volunteer species, but it matured too late for most of the short growing season wheatbelt districts.

It was not long before better-suited, earlier-maturing lines were being sought to take advantage of the situation. Like the sub clover's, pasture medics have suffered considerable decline, resulting largely from the poorer returns from sheep and wool relative to wheat in the wheatbelt, a series of droughts, and the continuous cropping system now developing. Nevertheless some farmers are looking again to legume-based pastures as part of a longer term rotation.

The most common naturalised species in Australia are burr medic (*Medicago polymorpha*), Goldfields medic (*M. minima*) and cut leaf medic (*M. laciniata*). Other species that have been recorded but are not widespread are *M. praecos*, *M. arabica*, *M. intertexta* and *M. orbicularis*. In their natural Mediterranean environment annual medics grow over a wide range of soils, temperature regimes and growing seasons. They are found most commonly on alkaline soils but some species are found on mildly acid soils. In the Mediterranean region, light alkaline soils are common, and medics are widespread on these soils. Some medic species such as *M. truncatula* occur more commonly on the more fertile soils while others are common on less fertile soils. An example is *M. littoralis* which is common on sandy sea shore areas. Other species, particularly *M. polymorpha* are widespread, growing in association with *M. truncatula* on heavy alkaline soils and with species such as *M. arabica*, *M. truncatula* and *M. murex* on infertile and acid soils (Francis and Gillespie 1977).

The range within species is also great. Flowering times for Mediterranean ecotypes of *M. truncatula* range from 66 to 136 days after sowing, and there is a strong relationship between time from germination to flowering and length of growing season at the sites from which the material was collected (Cocks, Mathison and Crawford 1980). Whereas sub clovers are rarely found in their natural environment in areas with less than 450mm annual average rainfall, medics are common in areas with rainfall as low as 100mm annual average. One species, (*M. laciniata*), grows in North Africa on sandy soils with rainfall down to 50mm annual average.

2.3.2 Importance of Annual Medics in Farming Systems

Pasture legumes, mainly the annual self-regenerating medics (*Medicago* spp.) and clovers (*Trifolioum spp.*) are worth at least $US2,500 million each year to the crop and livestock industries (Carter 1981). Although these pasture and forage crop legumes are normally renewable resources, in recent years many legume stands have deteriorated from poor grazing management, new pasture pests and other causes (Carter *et al.* 1982). Annual medics are of considerable importance in arid and semi-arid regions, because most of them are drought resistant and can survive under low rainfall. They provide valuable forage and pasture for the livestock sector and, like other pasture legumes, medic owes its importance in agriculture to its ability to fix nitrogen which increases soil fertility and replaces the need for mineral nitrogen fertilizer application to cereal crops. Medics are ideal legumes for inclusion in ley farming systems because they are self-regenerating and can produce seed under limited moisture conditions (Downes 1969). In Australia, medic leys have been acknowledged for restoring declining soil fertility, improving quantity and quality of wheat yield and providing livestock feed during non-cropping years of the rotation (Webber and Bicknell 1973).

Generally, Australian soils are very low in soil nitrogen but we rely on well adapted introduced pasture, forage crop, and grain legumes to maintain and/or increase levels of soil nitrogen by way of symbiotic nitrogen fixation. These pasture and forage crop legumes, notably subterranean clover (*Trifolium subterraneum*), the annual medics mainly (*Medicago truncatula*) and the perennial lucerne (*Medicago sativa*) in southern Australia. The net increment of soil nitrogen resulting from symbiotic nitrogen fixation varies with productivity of the leguminous sward being generally in the range 50-150 kgN/ha/year under rainfed conditions. This nitrogen accumulated under grazed pasture provides the major nitrogen requirements of our cereal crop production as well as maintaining the ongoing productivity of the permanent pastures in our higher rainfall areas. The annual increment of soil nitrogen from grazed leguminous pastures in Australia was estimated at US$2500 (Carter 1981).

The importance of legume-based pastures for maintaining the fertility and structure of soils in the wheat-sheep producing regions of Australia is well recognized (Donald 1965; Greenland 1971: Leigh and Noble 1972). In the ley farming system of southern Australia barrel medic (*Medicago truncatula* Gaertn.) plays a major role, particularly in drier areas and on alkaline soils (Amor 1965; Webber 1975). Most of the annual medics found in Australia have been introduced fortuitously. These are of considerable economic importance to the wheat, wool and meat-producing industries in the semi-arid regions of the continent, because they are the only pasture legumes of any consequence which occur there (Beadle 1948).

In southern inland Queensland (Lat. 24-29°S, mean annual rainfall 500-800mm), native pastures are the major source of feed for sheep and beef cattle (Keating 1967; Weston *et al.* 1975). Although these pastures are of adequate quality from late spring to early autumn, animal production in the cooler months is poor (Lee and Rothwell 1966; Alexander and Beattie 1968; Russell 1985) owing to protein shortages in the feed (Milford 1964; Addison *et al.* 1984a). Nitrogen deficiency also limits pasture growth (Graham *et al.* 1981; Lloyd and Hilder 1985). As hand feeding of protein-rich supplements is expensive and not readily accepted by graziers, other approaches are to use stand-over summer-growing legumes such as the shrub Leucaena (Addison *et al.* 1984b) or to graze more winter-active legumes such as lucerne. Summer-growing herbaceous legumes have so far been unsuccessful because they cannot withstand dry summers and cold winters. However, winter annual legumes can grow and persist on many soils, the most adapted species being the annual medics (Russell 1969; Clarkson 1970; Jones and Rees 1972).

2.3.3 Current Interest in Annual Medics

Today there is strong interest in medics in several areas in response to increased intensity of cropping. In the wheat belt, especially the drier parts, medics have survived and are regenerating after crops, even following the series of dry seasons. Under the same circumstances, subterranean clovers have almost disappeared from most low rainfall wheatbelt pastures on light acid soils. A number of factors contribute to the better performance of medics compared to sub clover in farming systems: the first factor is hard-seededness. Persistence of annual plants in the Mediterranean environment is dependent both on the level of seed production and the efficiency of its subsequent germinations. Both medics and sub clovers produce a proportion of seeds that do not germinate in the year following their production. These seeds are known as hard seeds, and become capable of germinating over time as a result of being subject to widely fluctuating temperatures on or in the soil during summer (Quinlivan 1961). Although within-and-between species variation occurs, the rate of softening of hard seeds among medics is generally much slower than of sub clovers, so that after three summers a substantial reserve of hard seed of medics remains (Quinlivan, unpublished data).

The second factor is the drought tolerance: Medics have been shown to be deeper rooted than subterranean clover on sandy soils (Ozanne, Asher and Kirton 1965). This may be an explanation for the ability of medics to set seed under adverse moisture conditions so common in spring in low-rainfall areas. It also has been demonstrated that time from flowering to pod maturity is reduced by moisture stress in medics (Clarkson and Russell 1976).

Another contrasting situation between sub clovers and medics is the site of seed production. Medics produce their seed above the ground, while sub clovers, as their name implies, tend to bury their seed for efficient seed protection. If seed burial is not possible or is impaired by a hard soil surface layer, then seed yield and quality can be reduced drastically (Collins, Frances and Quinlivan 1976). Many wheatbelt soils form a hard surface layer as they dry out, and conditions which will impair seed burial occur often in these environments. This increases the percentage of surface burrs of sub clover and greatly increases the loss of clover seeds or medic seeds through grazing (Carter 1981; de Koning and Carter 1989; Carter *et al.* 1989).

Medics and clovers are the main pasture legume used in ley farming systems and successfully used in Australia and some other countries with a Mediterranean climate. In general, we can increase livestock production on sown pastures by expanding the grazing areas, increasing pasture and forage crop production per unit area (yield), increasing stockrate (utilization) and increasing production per head (efficiency). There is no merit in increasing the production of pasture unless there are sufficient grazing animals to efficiently convert that extra pasture into livestock products. This involves a consideration of the optimal level of utilization of the pasture and the choice of appropriate stocking rates (Carter 1988).

In Australia some 40 million hectares of crop and sown pasture land is dependent on legumes to provide soil nitrogen through fixation and to guarantee quantity and quality of livestock feed (Carter 1981). Annual legumes are used extensively in temperate Australia as a means of increasing soil fertility, pasture productivity and pasture quality. Annual medic species are better adapted than other annual legumes to the extensive calcareous soils of southern Australia

(Crawford 1968). Attempts to establish and maintain legume pastures are not uniformly successful throughout the cereal areas, but on alkaline soils, barrel-medic (*Medicago truncatula*) and burr medic (*M. polymorpha*) establish readily (Webber and Williams 1977).

The most widely sown species is barrel medic, *Medicago truncatula* Gaertn., which has fulfilled the predictions that were made when attention was first drawn to its value (Trumble 1939). Heyn (1963) described three varieties of *M. truncatula*, viz. v. *Truncatula*, v. *Longeoculeala*, and v. *Tricycla*. The collection studied is predominantly *M. truncatula* v. *Truncatula*. A few accessions of v. *Longeoculeata*, found occurring throughout the range of the species, are included. *M. truncatula* v. *Tricycla* is rare: Negre (1956) regarded it as restricted to the margins of the arid zones.

The wide variety of soils and climatic conditions in the cereal zones influence the choice of medic species, cultivars and mixtures best suited to the particular locality. In recent years the development of new medic cultivars has extended the area over which highly productive medic stands can be grown. In the past, naturalized burr medic has predominated in some areas, but problems of burrs in wool and the availability of newer medics with more desirable features have brought about its replacement. The main medics grown in South Australia are:

1. Barrel medic *(Medicago truncatula)* cv. Jemalong, Hannaford, Cyprus and Borung.
2. Strand medic *(Medicago littoralis)* cv. Harbinger and Harbinger A.R.
3. Gama medic *(Medicago rugosa)* cv. Paragosa.
4. Snail medic *(Medicago scutellata)* cv. Sava and Robinson.
5. Disc medic *(Medicago tornata)* cv. Tornafield

2.3.4 Yielding Ability of Annual Medics

The increase in herbage yield of a plant community is consequent on the operation of a system composed of many interacting sub systems or growth processes, such as photosynthesis, respiration, transpiration, water uptake, nutrient uptake and the partitioning of assimilate between plant parts. Herbage yield and plant morphology change with time, with surrounding environment and with the operation of plant competition. The daily net uptake of carbon dioxide by a plant canopy provides and example of the way in which the rate of a process, e.g. leaf photosynthesis, is modified in the community by change in environmental conditions since the photosynthetic response of a leaf to irradiance depends on the conditions under which the leaf was grown (Kumura 1969). Likewise, response in respiration to immediate change in temperature depends on the temperature at which the plants were grown (Pearson and Hunt 1972b).

As the ability to predict development is an important requirement in modelling plant growth in field situations (Russell 1977) it appears worthwhile to study the growth and development of medics under controlled conditions, thereby establishing the values of parameters to use in a function describing their field behaviour. An early assessment of the role of dark respiration as a factor in plant production, as distinct from a plant physiological phenomenon, was made by Monsi and Saeki (1953) who considered the rate of respiration per unit ground area to be proportional to the amount of herbage present. Subsequently de Wit (1965), in his model of canopy photosynthesis, assumed the loss to be proportional to the daily photosynthetic gain.

The growth process in pasture legumes is the most important factor in measuring the productivity and yielding ability of any crop. Our major pasture legumes (annual medics, subterranean clover, lucerne, strawberry clover and white clover) are well adapted to growing while being grazed because the plants have large numbers of growing points near ground level. These growing points tend to escape grazing and therefore provide numerous "take off" points for regrowth. What are these growing points? Plants are composed of multitudes of cells of different kinds. For the plant to grow, the number of cells has to increase. Growing points are centres of activity where new cells are continually being produced and grouped into the tissues of new leaves, stems and roots, and eventually flowers and seeds.

The growing points of our pasture legumes are at the tips of main stems and branches and of roots. They leave the new cells behind them as they push ahead. If a growing point is nipped off, no more new cells are produced on that branch and it stops growing. On a well-developed plant there are normally multitudes of growing points. The more there are left after grazing, the more quickly will new leaves appear. In the annual medics, barrel medic and some other species develop a system of prostrate branches like that of the sub clovers, especially under close grazing, with more upright types like the snail and gama medics, grazing may need to be more carefully controlled to avoid destroying too many growing points.

In all legumes, the growth of leaves, stems and roots is accompanied by the development of a system of root nodules housing *Rhizobium* bacteria. Rhizobia fix nitrogen from the soil atmosphere and pass it on for use by the plant. Signs that nitrogen fixation is proceeding satisfactorily are the presence of large nodules with pink coloured flesh and large, healthy green leaves.

While the presence of many centres of cell production is important for recovery from grazing, a source of energy to drive the growth process is equally essential. That source is solar radiation. Plant leaves trap certain parts of the sun's energy and use it in the manufacture of material needed for growth. The process of using the energy of the sun to manufacture carbohydrates from carbon dioxide and water is called photosynthesis. Increase in total plant production can be obtained as the difference between net photosynthetic gain during the day and dark respiration loss at night. The ratio of dark respiration loss at night to net photosynthetic gain during the day indicates the contribution of dark respiration to dry matter production (Fukai and Silsbury 1977). The ratio changes from day to day with environmental conditions (Agata *et al.* 1971).

Although the contribution of medics in mixed farming areas of temperate Australia is well known (Amor 1965), there are many strains of several medic species available for testing in Australia (Cocks *et al.* 1980). Barrel medic (*Medicago truncatula* Gaertn.)† is widely sown in much of the drier portions of the wheatbelt. The earliest sowing were made from a strain found at Noarlunga in South Australia (Trumble 1939). Although there was much variations in this commercial species, Amor (1966) reported that Harbinger medic produced more herbage than commercial barrel medic. Barrel medic 173 was also better than commercial barrel medic, but not as good as Harbinger medic. Cyprus barrel medic was little different from commercial barrel medic. There were no consistent differences between the cultivars in spring production, on the other hand Harbinger medic had greater early production. Also, Harbinger medic consistently produced a greater weight of pods than commercial barrel medic (later named cv. Hannaford) and barrel medic 173 (later named cv. Jemalong), and the weight of Cyprus barrel medic pods was greater than that of commercial barrel medic and barrel medic 173. These differences were more pronounced when the number of pods and seeds per square link†† were compared, the smaller-seeded Harbinger medic and to a lesser extent Cyprus barrel medic, being more prolific than the other cultivars. Later-maturing cultivars produced as much herbage in spring as Harbinger medic, and may be more useful in finishing off late lambs by extending the period of green feed until late October. Both Harbinger medic and Cyprus barrel medic flowered about 14 days earlier than commercial barrel medic and barrel medic 173 (Amor 1966).

Seed production is another criterion that can be used to compare the value of annual medics. It has a twofold role. High seed production coupled with hard-seededness enables a cultivar to persist in areas where dry years are common or where the land is cropped frequently. It also provides a valuable high-protein supplement to dry paddock feed during the summer. Commonly the whole pods comprise c.20% protein (E.D. Carter - *Pers. comm.*)

---

† Formerly known as *Medicago tribuloides* Desr.

†† $1m^2$ = c.25 square links

Winter production of annual pastures is important and differences do exist between annual medics (Amor 1966). Poole (1970) reported that the most common annual medic pastures sown in Western Australia are the barrel medics, Cyprus and Jemalong and Harbinger medic. Quite large differences are found between species for pod and seed production. Tornafield had a much higher seed weight to pod weight ratio than the other medics and, although Harbinger had the highest pod yield, Tornafield produced more seed.

Quinlivan (1965) found that Cyprus barrel medic had a high potential for hard seed production resulting in poor regeneration in some years. Amor (1966) reported that Harbinger medic produced more winter herbage and more seed than the two late-maturing barrel medics (commercial barrel medic i.e. cv. Hannaford and barrel medic 173 i.e. cv. Jemalong, and is well suited to the drier parts of the wheat belt. Crawford (1962a) reported an 85 to 102 percent increase over commercial barrel medic in winter growth. Cyprus barrel medic is also early maturing and has a high level of seed production. Both Argyle (1962) and Crawford (1963) reported better winter growth from Cyprus barrel medic than from commercial barrel medic. Barrel medic 173 matures at the same time as commercial barrel medic, but makes a higher production of its growth in winter. This has also been reported by Andrew and Hudson (1954), Buckley (1960), Crawford (1962b) and Anon, (1963), although it has not performed well in Western Australia (Argyle 1962). Under wet conditions, it may suffer from chlorosis and retarded winter growth (Anon. 1963).

Annual *Medicago* species have been shown to be productive and have the advantage of quicker forage production than other temperate legumes (Bowdler and Lowe 1980). Success of annual medic species in cereal/pasture rotations in South Australia has depended on high seed yields and adequate proportions of hard seed. In recent years, Sitona weevil (*Sitona discoidens*), spotted alfalfa aphid (SAA) (*Treioaphis trifolil*) and blue green aphid (BGA) (*Acyrthosiphon kondoi*) have greatly reduced medic productivity (Tow and Hodgkins, 1982).

2.3.5 Leaf Photosynthesis and its Correlation with Leaf Area

The influence of Leaf Area (LA) on gas exchange traits and other leaf characteristics may be important in assessing the relationship of CO_2 exchange rate (CER) to yield. Many attempts have been made to relate CER to yield of crop plants and to select plants for high CER in order to improve yield. In most comparisons of crop genotypes, the relationship of leaf CER to yield was found to be poor (Dornhoff and Shibles 1970; Berdahl *et al.* 1972; Bhagsari 1981), probably because CER measurements inadequately represented the total seasonal photosynthesis of the plant canopies (Zelitch 1982). In some cases, close correlations have been observed and in others there were no correlation.

Specific leaf weight (SLW) is one leaf characteristic most often correlated (positively) with CER (Dornhoff and Shibles 1970); Delaney and Dobrenz 1974; Dornhoff and Shibles 1976; and Hesketh *et al.* 1981), but in some studies the two were not related (Heichel and Musgrave 1969). Leaf thickness, a major component of SLW , was positively correlated with CER in Soybean *Glycine max* (L.) Merr (Dornhoff and Shibles 1970) and alfalfa (*Medicago sativa* L.) (Delaney and Dobrenz 1974). Significant negative correlations have been observed between CER and leaf area in genotype comparison of alfalfa (lucerne), also leaf area showed significant correlations with dark respiration for alfalfa (Delaney and Dobrenz 1974).

Maximum photosynthetic rate and Leaf Area Index (LAI) decreased as plants aged (Jeffers and Shibles 1969). Shibles and Weber (1965) found that soybean communities exhibited a critical type of LAI response (rate of dry matter production increases with increasing leaf area, attains a maximum, and does not change with further increase in leaf area). Saeki (1960) hypothesized that the optimum leaf area index increases as light level increases. Jeffers and Shibles (1969) reported there was no detectable interaction of temperature with solar radiation or of temperature with LAI on photosynthesis. A critical LAI of 3.6 - 4.2 occurs, evidently, because respiration of shaded leaves is minimal.

Forrester, Krotkov and Nelson (1966) have demonstrated a light-induced respiration in soybeans; CO_2 is evolved evidently as a result of breakdown of a photosynthetic product. This suggests that respiration rates could be proportional to photosynthesis. If so, shaded leaves would have low respiration rates. In an area of low solar radiation, a genotype that terminates leaf production at the critical LAI would have an advantage in seed production over a genotype which produces excessive foliage at the expense of seed. In a high radiation environment, maximum yield might be achieved by a genotype capable of producing leaf area at the fastest rate. But, cultural practices and field problems, such as disease and low fertility, may limit leaf production in soybeans to less than critical LAI (Jeffers and Shibles 1969).

Shibles and Weber (1966) found a critical LAI of 3.6 for 25cm rows and 4.2 for the standard 100cm rows. The response of crop photosynthesis at low LAI to variations in solar radiation shows that saturation occurs when upper leaves are individually saturated, and that additional radiation is reflected or absorbed at the soil level. In high LAI canopies, increases in radiation cause increases in photosynthesis of leaves in partial light, even when fully exposed leaves are saturated; hence crop photosynthesis increases to highest light levels (Jeffers and Shibles 1969). These responses are somewhat different from those reported by (Sakamoto and Shaw 1967), who observed saturation in high LAI canopies. However radiation saturation appears to occur if temperature exceeds an optimum.

Fukai and Silsbury (1978) reported that LAI was an important determinant of herbage production up to about 2000kg/ha, and that increased maintenance respiration at a dry matter yield above about 6000kg/ha resulted in a decreased growth rate. As the LAI rises, a stage is reached at which the lowest leaves are only sufficiently lit to be at or just above compensation point. Such a LAI has been termed "the optimum leaf area index" (Kasanaga and Monsi 1954; Davidson and Donald 1958) or "the marginal compensation area" (Davidson and Phillips 1958). This is the situation in which all leaves are making a positive or neutral contribution.

If there is a further increase in LAI, the lowest leaves will be so poorly lit that their respiration will exceed their photosynthesis. They are in negative balance, their weight declines, and the rate of dry matter increment of the whole sward is less than it was at the optimum leaf area index. Several experiments at Adelaide (Davidson and Donald 1958; Stern and Donald 1962b; Black 1963) have demonstrated an optimum leaf area index in swards of subterranean clover. For example, in one study the crop growth rate fell by about 30 per cent as the leaf area index rose from 4.5 to about 8.7

2.4 Growth Response of Annual Medics to Climatic Factors

2.4.1 Growth Response of Annual Medics to Temperature and Plant Density

Not only are annual medics of great value in the Mediterranean zones, but also medics have a great potential as winter legumes in agricultural areas of subtropical eastern Australia where the mean winter rainfall (April to September) exceeds 180mm (Clarkson and Russell 1979).

The seasonal pattern of growth is a major feature of the growth of annual pastures in a mediterranean environment. Yield early in the growing season when feed is normally scarce is an important determinant of carrying capacity. Two factors known to influence pasture productivity at this time are plant density and temperature (Adem 1977; Silsbury *et al* 1979). It is known that flowering in medics is greatly affected by the interrelationship between temperature, including vernalization responses, and photoperiod (Aitken 1955; Clarkson and Russell 1975). In some species, such as *M. scutellata*, temperature appears to be the main factor controlling flowering but in others, such as *M. truncatula*, there is an interaction between temperature and other factors (Clarkson and Russell 1979).

In inland West Asia the commercial Australian medic cultivars are susceptible to damage by frost which, in north-west Syria, can occur on up to 50 days (Cocks and Ehrman 1987). Native species such as *Medicago rigidula* (L.), *Medicago rotata* and *M. noeana* have now been selected which combine frost tolerance and adaptation to ley farming (Abd EL Moneim and Cocks 1986; Cocks and Ehrman 1987). The influence of temperature on the growth of temperate pasture species has been measured with spaced plants (Mitchell 1956; Morley 1958; Mitchell and Lucanus 1962; Broue *et al.* 1967; Silsbury 1969; Scott 1970). These temperate species grow fastest at a temperature of about 20-25%. However, Cocks (1973) reported that growth response to temperature depended on the LAI.

The studies of Donald (1951,1954) showed that, whereas the end-of-season yields of plants such as subterranean clover and Wimmera ryegrass were independent of sowing density over the range of about 150-30,000 plants m^2, yield in early winter was strongly density-dependent. The higher the sowing rate, the greater the early growth and the earlier the growth rate became constant (Black 1964). Donald (1954) showed that the number of seeds per burr (inflorescence) and seed size of subterranean clover (*Trifolioum subterranean)* increased with sowing rate, seed size increasing by less than number of seeds per burr. Neither factor affected yield as much as number of burrs per plant which was greatest at low density.

The general assumption has been that plants growing in communities respond to temperature in a similar manner to spaced plants. Morley (1961), in criticizing Black's (1955) conclusions about the non-importance of temperature on pasture growth in the Adelaide environment, relied on data that he collected from spaced plants (Morley 1958). Fitzpatrick and Nix (1970), in their model of dry matter accumulation by pasture communities in temperate Australia, made a similar assumption. But these assumptions may not be true (Cocks 1969). In communities, individuals compete and so their growth rates are slower than those of spaced plants (Stern 1965; White and Harper 1970; Harris 1971). Because of this restriction by other environmental factors, the influence of temperature on the individual grown in a community will almost certainly be less than on a spaced plant. Evidence for this view was provided by Davidson *et al.* (1970) who found that after 16 weeks the dry matter yield of Tallarook subterranean clover was not significantly greater at 22°C than at 12°C. Mitchell (1956) showed that the growth rate of the Mount Barker strain was maximum at about 20°C.

In communities of non-nodulated subterranean clover the optimum temperature for growth has been shown to fall with increase in age and leaf area index (Fukai and Silsbury 1976; McCree and Silsbury 1978). Most data concerning effects of temperature on nitrogen fixation have been obtained from exposure of single plants or nodulated roots to short-term changes in temperature. The ways in which temperature influences nitrogen fixation by mature legume communities have not been widely examined. Early results showed 22°C to be the optimum temperature for nitrogen fixation by single plants of subterranean clover (Gibson 1961), but for communities of the same species similar amounts of nitrogen were fixed at 12°C and 22°C (Davidson, Gibson and Birch 1970). Many estimates of nitrogen fixation have been based on the acetylene reduction (AR) assay method.

There appears to be a general relationship between legume yield and accumulated degree-days above 10°C. The results suggest that an accumulation of approximately 500 degree days within a region's growing season is necessary for yields >6tDM/ha (Hughes and Taylor 1983). Cocks (1973); Greenwood *et al.* (1976); and Fukai and Silsbury (1976) found that there was an optimum temperature of 20-25°C for the growth of swards at low leaf area index.

Two environmental variables are included in the growth model of subterranean clover swards-temperature and solar radiation since no other environmental factors are assumed to be limiting growth for periods not marked by water or nutrient deficiency and pathogen damage. Temperature is known to influence the growth rate and morphology of annual medics. Cocks (1973) pointed out that few data are available quantifying the growth responses to temperature of plant communities. Single plants showed dry matter production to be low at 8-12°C (Millikan 1957; Mitchell and Lucanus 1960) and to have an optimum of 20-25°C (Mitchell 1956a, 1956b; Mitchell and Lucanus 1962), while in communities of Tallarook subterranean clover, root dry weight was greater for the 12°C plants than 22°C (Fukai and Silsbury 1976). Morley found the growth response of isolated plants to temperature to depend on the cultivar. Fukai and Silsbury (1976) found that estimated maximum yield was inversely related to temperature; it was more than doubled by a temperature decrease from 30°C to 15°C and the lower the temperature the higher the maximum crop growth rate (CGR) of subterranean clover. Also they found that crop growth rate was less dependent on temperature when herbage yield 1500kgDM/ha than at 4500kgDM/ha or 6000 kgDM/ha, where the rate decreased very rapidly with increase in temperature.

Temperature may influence maximum yield through effects on both the maximum crop growth rate and the growth period measured as days from sowing to maximum CGR while, decrease in temperature from 30°C to 20°C almost doubled maximum CGR but increased the period from sowing to maximum CGR by only 2 days. A relationship between temperature and dark respiration may be obtained, however, if the dark respiration of undefoliated communities is compared at the same dry matter for different temperatures the respiration rate of young plants, for example, grown at a range of temperatures and measured at the growth temperature, was not much influenced by temperature (Murata *et al.* 1965; Rook 1969; Sawada 1970). This may be due to the fact that plants grown at low temperature have a higher specific respiration rate at the growth temperature than is the case when they are grown at high temperature and dark respiration rate is measured at the low temperature (Strain 1969; Woledge and Jewiss 1969).

Hill and Pearson (1985) reported that primary growth was fastest at higher temperatures (21/16°C and 24/19°C) whereas rate of regrowth was at its highest at low temperature (15/10°C). A period of low temperature following germination, applied either by vernalization or by growth of the seedling in the field in winter or early spring, was found to accelerate flower initiation in *M. tribuloides* syn.*truncatula* (Aitken 1955).

Annual medic is similar to subterranean clover in the shape and rate of development of its stem apex and in its growth structure; well-spaced plants are prostrate because of dominant lateral growth, but crowded plants usually form a main stem only (Aitken 1955).

2.4.2 Growth Response of Annual Medics to Day-length (Solar Radiation)

Seasonal patterns in the environment, particularly temperature and photoperiod, may influence flower initiation and affect medic genotypes differently, as Morley and Davern (1956) and Morley and Evans (1959) found with subterranean clover. They found that flower initiation was controlled by three related processes, viz:

(a) vernalization (low temperature requirements);
(b) inhibition of the dark period (long-day requirements); and
(c) a requirement for high temperature.

Annual medics are known to be vernalizable long-day plants (Aitken 1955). (Clarkson and Russell 1975) found that long photoperiods (18 and 24 hr) accelerated flowering of six medic species (*M. scutellata*, *M. polymorpha*, *M. littoralis*, *M. truncatula*, *M. tornata*, and *M. rugosa*). Also they reported that the effect of long photoperiods (24hr) advanced flowering by a mean of 46 days taken over all species. There was almost no difference in flowering time between plants grown under an 18hr or 24hr photoperiod.

The root nodule development depends on many factors which can be summarized in the following groups: edaphic, climatic, technical and biological factors. Day length, a given natural factor, is one of the climatic factors which affects nodule development. Eaton (1931), Bonnier and Sironval (1956) and Sironval *et al.* (1957) found that nodule development in sojo was correlated with the amount of carbohydrates, which was higher under greater day length due to longer time for photosynthesis. Balatti and Montaldi (1981) ascertained that under 16 hour day length (8hr assimilation and 8hr inductive light) less nodules were developed than under 8hr (only assimilation light). Sironval *et al.* (1957) and Herath and Ormrod (1979) stated that the metabolism of leaves, especially the chlorophyll content, was negatively affected under shorter day-length. Wesselmann and Caesar (1989) reported that the leaf area of faba beans (*Vicia faba* L.) and grass peas (*Lathyrus sativus* L.) was promoted by higher day-length and reached its maximum also early. Vince-Prue (1975) and Sato (1979) came to similar conclusions. Greater leaf areas supplied more assimilates to the nodules (Lawn and Brun 1974).

2.5 Effects of Temperature on Nitrogen Fixation by Swards of Annual Pasture Legumes

Like other pasture legumes, medic species assume importance in agriculture because of symbiotic association with bacteria of the genus *Rhizobium*. Nodule initiation in the root cortex follows the bacterial infection of root hairs, beginning a sequence of developmental changes which lead to nitrogen fixation.

As host tissue develops, it is invaded by bacteria which are later released into the host cytoplasm within membrane envelopes and change into non-reproducing bacteroids: those are the symbiotic form of root nodule bacteria in which the nitrogenase enzyme system develops. External factors may affect nitrogen fixation because all stages in this complex sequence are under host control as follows:

1. The products of photosynthesis are used as respiratory substrate and in the structural compounds of developing nodules.
2. They provide the energy for nitrogen fixation which results in an efflux of amino acids into the roots to be used for further plant development.

Morley (1958) found that growth rates fell sharply below 19°C. We might expect nitrogen fixation to be affected, likewise Gibson (1963) found that symbiotic nitrogen fixation was reduced at temperatures below 22°C, although in test-tube culture the rates of nitrogen fixation were much lower at 12°C than at 22°C and the rates of infection, nodule initiation, and nodule development were about halved at 12°C compared with those at 22°C.

Medics like many other legumes can derive the nitrogen for growth from the reduction of N_2 in root-nodules or by the assimilation of nitrate. In the absence of mineral nitrogen, the rate of nitrogen fixation is largely determined by the growth rate. High acetylene reduction rates are highly correlated with high root fresh weight, nodule count and root score (Smith and Baltensberger 1983).

In addition to effects of temperature on germination and establishment, temperature influences nodulation and the rate of dinitrogen fixation by nodulated plants (Gibson 1963, 1971, 1976; Possingham *et al.* 1964). Further, since it is known that mineral nitrogen both stimulates and depresses nodulation according to concentration but generally has a depressive effect on the activity of nitrogenase (Munns 1977), it is to be expected that the effects of temperature on nodulation and early growth of seedlings would be influenced by the nitrogen available in the soil. Broadly, temperature has a relatively small effect on C_2H_2 reduction and on H_2 evolution. Nitrogenase activity was highest at 10°C (Silsbury *et al.* 1984). They expected that acetylene reduction (AR) activity would also show little change with temperature. In fact their observation that nitrogen fixation was most rapid at 10°C could be due to the accumulation of relatively more dry matter of low N content at 10°C than occurred at higher temperature during the period of N-deficiency before nitrogenase becomes active.

Harding and Sheehy (1980) showed a greater response of nitrogenase activity to temperature. In swards the growth response to temperature can be the reverse of those which apply when plants grow without inter-plant competition (Fukai and Silsbury 1976). Therefore, if responses to temperature are to be applied in the field the effects of temperature on the N_2-fixation of a pasture legume should be measured under sward, rather than under single plant, conditions (Silsbury *et al.* 1984).

The development of the AR assay for measuring nitrogenase activity has provided a convenient method of estimating rates of nitrogen fixation (Hardy *et al* 1968). Most work on nitrogen fixation by pasture legumes with this technique has been done on white clover, viz. *Trifolium repens* L. (Moustafa *et al.* 1969; Chu and Robertson 1974; Sinclair 1975; Halliday and Pate 1976; Masterson and Murphy 1976; Sinclair *et al.* 1976).

2.6 Some Effects of Management on Establishment, Growth and Productivity of Annual Medics

2.6.1 Interspecific and Intraspecific Competition Between Plants

Generally, the deliberate establishment of cultivar mixtures is associated with two main objectives. Firstly, new improved cultivars are sown into areas containing less desirable ones, with a view to broadening the mixture or replacing the existing genotypes. Secondly, cultivar mixtures are formulated and sown with the aim of obtaining greater pasture productivity and/or stability. In both situations an understanding of the factors affecting the performance of genotypes in mixtures is of obvious practical importance. Competition between genotypes is often assumed to have a major effect on their seed production in mixtures. Therefore, competition between genotypes is the main factor affecting plant growth in a mixture.

Plant ecologists are fortunate that an effective analysis and definition of plant competition was given half a century ago. In 1907, Clements wrote: "Competition is purely a physical process. With few exceptions, such as the crowding of tuberous plants when grown too closely, an actual struggle between competing plants never occurs. Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors. In the exact sense, two plants, no matter how close do not compete with each other so long as the water content, the nutrient material, the light and the heat are in excess of the needs of both" (Clements *et al.* 1929: cited by Donald 1963). "When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins" (Clements *et al.* 1929).

Milne (cited by Donald 1963) points out that the original meaning of the Latin verb "competere", which was "to ask or sue for the same thing that another does", is fully preserved in the modern meaning of the word "competition". It must not be assumed that competition necessarily occurs just because a factor is in short supply. All plants in a community may be short of the factor, but if the environment of each plant is independent of that of its neighbours, then there is no interference in the growth of one plant by another. For example, the germination of wheat and growth of wheat seedlings may be delayed and reduced by the poor oxygen supply in over-wet poorly structured soils. The factors governing oxygen supply to the seed is predominantly the gas exchange with the external atmosphere: each seed lies independently in its own micro-atmosphere, uninfluenced by its neighbour some inches away. There is no competition. The same is true for seed lacking sufficient water for germination. But the lack of competition at the seed or seedling stage is the exceptional circumstance in crops and pastures, and competition is likely to begin soon thereafter.

The use of mixtures of strains of subterranean clover (*Trifolium subterranean* L.) has become increasingly common in southern Australian pastures in recent years (Rossiter and Palmer 1981). Collins *et al.* (1983) reported that defoliation up to the commencement of flowering (cut at weekly intervals from 39 days after sowing until the beginning of flowering, 102 days after sowing) had no significant effect on seed yield in the mono culture of sub clover swards, while with severe defoliation (up to the end of flowering, 149 days after sowing), seed yields were reduced. Also, they found that cutting influenced the competitive relations between strains in mixtures.

2.6.2 Effects of Depth of Sowing on Legume Seedling Emergence

The establishment and maintenance of high quality legume pastures requires substantial attention to detail. Certainly a common fault is to sow legume pasture seeds too deep for satisfactory emergence (Carter and Heard 1962; Adem 1977; Carter and Challis 1987; Quigley and Carter 1985). Furthermore, tillage practices often result in burying medic pods/seeds or sub clover burrs/seed too deep for emergence of seedlings (Carter 1974, 1978; Carter *et al.* 1987; Quigley *et al.* 1987; Fulwood and Carter 1989).

Black (1956) defined emergence as the complete appearance of the cotyledons above ground level, and since growth was very even no difficulty was experienced in deciding whether the plants had or had not emerged. He concluded that seed size in a plant having epigeal germination and without endosperm is of importance: firstly, in limiting the maximum hypocotyl elongation and hence depth of sowing, and secondly, in determining cotyledon area. It has previously been shown (Black 1955) that both depth of sowing and temperature affect pre-emergence weight changes in subterranean clover, and that in particular there was a marked effect on the amount of dry matter remaining in the cotyledons at the time of emergence. Also, he suggested that the reduction in cotyledon weight on emergence from deeper sowings might have adverse effects on subsequent growth by limiting the material available for the elaboration of the initial photosynthetic tissue. However, under field conditions, where germination is simultaneous, plants from greater depths of sowing will be at a disadvantage as compared with those from shallower sowings since emergence will be progressively delayed as depth of sowing increases under conditions of deep-sowing of legumes, seedling emergence is reduced as there is a potential maximum-elongation of the hypocotyl (Carter *et al.* 1987; Fulwood and Carter 1989).

2.6.3 Effect of Mechanical Defoliation of Growth and Seed Production of Annual Medics

It is a common observation in southern Australia that some grazing of both subterranean clover and medic pastures increases seed production. The advantages of grazing are especially observed in years with dry spring weather when the pasture legumes suffer severe moisture deficit. Anderson and Metcalfe (1957) and Winch (1959) have shown that pre-harvest clipping, especially if late, decreases seed yield in birdsfoot trefoil (*Lotus corniculatus* L.). Knight and Hollowell (1959) showed that moderate defoliation (from 15cm down to 7.5cm) of crimson clover (*Trifolium incarnatum* L.) had little effect on forage production, but reduced seed yield by about 14%.

McAlister and Krober (1958) examined the effects of two levels of leaf removal (40 and 80%) on soybeans at a similar growth stage. The marked depressions in seed yield resulting from leaf removal were associated with reduced numbers of pods per plant at harvest, and to a smaller extent with reduced weight per seed. Rossiter (1961) showed that subterranean clover swards were capable of fairly high seed production even with repeated defoliation: the outstanding success of this species as an annual pasture plant, without doubt, has been due to its capacity for high seed production under a wide range of conditions, including continuous grazing at moderately high stocking rates.

Over-grazing is a common cause of pasture degradation during the growing season. For maximum production of herbage, the amount of leaves left following mowing or grazing should be sufficient to ensure complete interception of light so that pasture growth is maintained at the maximum rate. However, the defoliation height associated with maximum subsequent rate of growth will vary with pasture type, weather and season of the year. The intensity of defoliation influences leaf efficiency in the early stages of regrowth. The more intense the defoliation the lower the initial leaf efficiency.

Mature plants of pasture legumes die if all their leaves are removed, even when there is plenty of water in the soil (Leigh and Mulham 1971). Brougham (1956) stated that leaf efficiency (the rate of increase of herbage dry weight per unit area of leaf) was greatly influenced by intensity of defoliation. Efficiency was initially lower following severe defoliation than following less severe treatment. Also, the results have shown that as the intensity of defoliation increases, yield of shoot tissue decreases. Similar results have been obtained by varying the frequency of defoliation, the greatest reductions in yield having occurred where the defoliations have been most frequent.

Brougham (1955) showed the nature of the growth curve of a mixed pasture comprising short-rotation ryegrass *(Lolium perenne* X *L. multiflorum)*, red clover *(Trifolium pratense)*, and white clover *(Trifolium repens)* following close defoliation. The curve of re-growth showed three distinct phases: for approximately three weeks following defoliation the growth rate increased, then for five weeks it was constant, and thereafter it declined. In growth of grazed pastures, Davidson (1968) found conflicting responses of yield and tillering to intensity of defoliation (and therefore to its components, frequency, timing and height). The effects of these management factors also influenced botanical composition by affecting the competitiveness of species in mixtures (Harris 1978).

Subterranean clover (*Trifolium subterraneum* L.), hereafter referred to as sub clover, is used extensively as a pasture legume in southern Australia. Its success, measured in terms of both persistence and productivity, depends to a large extent on its ability to produce seed (Donald 1960; Rossiter 1966). The effect of infrequent defoliation (cutting at intervals of three weeks or more) on seed production of sub clover has been investigated by some workers (Rossiter 1961; Scott 1971; Hagon 1973; Walton 1975). Rossiter (1961) found that swards of two strains 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 strains, showed that the effect of defoliation on seed production varied markedly between strains, ranging from a large increase to a decrease in seed yield (Hagon 1973; Walton 1975). It was found that infrequent cutting up to early flowering had no effect on seed production. Rossiter (1976) clearly showed that frequent defoliation enhanced branching in sub clover. However, the possibility exists that cutting also caused a faster rate of leaf and inflorescence production on individual branches.

The indirect effect of defoliation on sub clover appeared to be a result of its influence on burr burial. In the defoliated swards a large proportion of burrs were buried, whereas in the uncut controls the majority were formed above the soil surface. It is now well established (Yeates

1957, 1958; Collins *et al.* 1976) that burr burial of sub clover is directly and positively related to seed yield. In unburied burrs the number of seeds per burr, weight per seed and the proportion of inflorescences forming mature burrs are all lower than for buried burrs. Thus increases in these components associated with cutting up to the commencement of flowering were due largely to the greater degree of burr burial in the defoliated swards as Collins (1978) indicated that frequent and fairly severe grazing of pure swards of subterranean clover prior to flowering will increase seed production. Rossiter (1961) previously found that moderate to heavy grazing of swards up to the commencement of flowering increased seed yields by up to 30%. Increased seed production, in addition to enhancing the potential for herbage production in the following season, is also a key to improving the long-term persistence of subterranean clover. Persistence will also be aided by the higher level of hard-seededness likely to occur in seed from swards which have been grazed prior to flowering.

Cutting decreased the rate of break-down of hard-seededness in sub clover, it seems likely that these responses were due largely to the effect of cutting in markedly increasing the proportion of buried burrs (Collins 1978). Collins *et al.* (1976) found that seed in unburied burrs had a lower initial level and a faster rate of breakdown of hard-seededness than seed in buried burrs. Also, they reported that the effect of infrequent cutting during flowering on the rate of breakdown of hard-seededness also varied between strains. Generally, they found that infrequent cutting increased the initial level of hard-seededness in subterranean clover.

With annual medic Tow and Hodgkins (1982) found that restriction of grazing from mid-late October did not increase the yield of seed to normal levels. In contrast, in a cutting trial where insects and weeds were controlled, seed yields around 550kg/ha were obtained even when plants were defoliated to a height of 5cm at early flowering. At the Waite Agricultural Research Institute haymaking greatly reduced yield of medic seed in a mixed medic stand but did not reduce seed yield of a mixed stand of subterranean clover (Carter *et al.* 1986). If grasses are completely defoliated, almost all the roots stop extending within one or two days (Crider 1955). The less severe the defoliation, the smaller is the reduction and the earlier the recovery of normal rates of root extension (Crider 1955; Evans 1971). Evans (1973a, 1973b) reported that root growth of white and red clover was less inhibited by defoliation than in the case of grasses.

The persistence of any cultivar of sub clover in a given environment is largely determined by its seed yield (Rossiter 1966), and grazing management (Carter 1968, 1990). However, the number of days to flowering is also an important cultivar characteristic. It is closely associated with seed yield, at least in Mediterranean environments (Rossiter 1966), and is strongly correlated with burr burial (Francis *et al.* 1972). Several studies have examined the effects of defoliation on both flowering and seed yield in sub clover (Hagon 1973). In swards, defoliation before floral initiation (FI) delayed flowering (Collins and Aitken 1970), while defoliation after FI slightly accelerated it (Rossiter 1972). For single plants, defoliation before FI, after FI or at both stages delayed flowering (Rossiter 1972). Furthermore Rossiter (1961, 1972) found that defoliation of swards before flowering and at early flowering increased the seed yield and/or the number of inflorescences of several cultivars. Hagon (1973) found that the effect of defoliation on seed production in subterranean clover swards depended more on the cultivar and density of the sward than on the timing of the defoliation, while defoliation increased the rate of leaf appearance above the control.

In sub clover swards cut frequently, the continuance of growth depends primarily upon the continued unfolding of new leaves, and the rate of leaf area increase largely determines the rate (Davidson *et al.* 1970). In uncut, spaced plants, leaf expansion is of less importance; while growth rates will increase with increased rates of leaf expansion, dry matter accumulation can continue in its absence. On the other hand, in uncut swards with large leaf canopies and complete light interception, increased leaf area will not lead to increased production. Even assuming similar rates of photosynthesis per unit of exposed leaf area in cut and uncut swards, different components of growth may control the rate of production in different circumstances; it may be the rate of leaf expansion in frequently-cut swards or the rate of decay within uncut swards. Defoliation may increase or reduce total production of most legume pasture swards.

Frequent defoliation tends to maintain a canopy of young leaves, and net photosynthetic rate for a given leaf area index is high in the frequently defoliated situation (Vickery *et al.* 1971).

2.6.4 Effects of Density on Productivity and Seed Yield of Pasture Legumes

Pasture productivity is directly related to plant density in the autumn-winter period when livestock feed is most limiting. Thereafter green pasture management must concentrate on optimising herbage production and maximising seed production. The same principles apply to annual medics and clovers. At low grazing intensities growth of dense swards would increase exponentially with time and consequently a rapidly accelerating rate of leaf area production would ensure that although swards of low density would have a slow start, they would approach closed canopy at an accelerating rate (Adem 1977; Silsbury *et al.* 1979; Silsbury *et al.* 1984). Donald (1951) has shown that the early production by annual pasture plants depends heavily on the density of the population.

At high plant densities there may be an increase in plant mortality with little effect on the size of the surviving plants, a reduction in growth of the individuals with little mortality, or a combination of both types of response. For example, in experimental population of *Papauer* spp., death of plants occurred at high sowing densities (Harper and McNaughton 1962). In contrast to this, no significant density-dependent mortality occurred in experimental populations of *Agrostemma githago* but the growth rate of the individuals was reduced and a greater population failed to ripen seed (Harper and Gajic, 1961). Both types of response to increased plant density have been observed in a mixed species stand of a pioneer weedy community (Raynal and Bazzaz 1975). Silsbury *et al.* (1979) showed that crop growth rate of *M. truncatula* declined between maximum and average competition evidently resulted in considerable mortality of seedling plants. The second reason could be that high plant density resulted in a low specific leaf area and consequently a low capacity for photosynthesis.

Potential dry matter yield of pure subterranean clover swards at Adelaide is predicted by the model which is designed to simulate the time course of dry matter production by a community dependent for their success on the accuracy with which the rates of the growth processes can be determined; on responses of the processes to environmental variation; and on the interactions between growth process and environmental variable to be strongly influenced by the time of cessation of growth. If the growth is terminated in the middle of October, an early start to growth as well as a high plant density will be advantageous for a high final yield. On the one hand, if the growing season extends until late November, there will be only a small effect of time of commencement of growth on final yield (Fukai and Silsbury 1978).)

The evidence to date is that temperature variation under controlled conditions (Fukai and Silsbury 1976) and density and time of sowing in the field (Silsbury and Fukai 1977) have little effect on the distribution of dry matter between plant parts. A rapid, early increase in LAI and crop growth rate within a constant environment can therefore be attained by increased density. Also, it can equally be achieved by the use of large seeds from which seedlings have a greater cotyledonary area at emergence than in the case of small seeds (Watson 1952; Carter and Challis 1987).

Black (1956) examined the rate of dry matter increment by seedlings of sub clover derived from both large and small seeds. He found that the growth rate depended not on the weight of the cotyledons at emergence, but on their area, which was unaffected by depth of sowing and was linearly related to seed size. The effect of seed size is just the same as the effect of sowing rate except that seedlings from larger seeds can emerge from greater depths in the soil. The two effects are different expressions of the same factor, namely the variations in the total photosynthetic area of the emerging seedlings.

Withers (1975), Porter (1982) and Walton (1982, 1984) demonstrated that when water stress during flowering limited lateral branch development in lupins, an increase in crop density further increased pod set on the primary stem. These results suggest an interaction between crop density and plant development. Allen (1977) suggested a similar interaction between crop density and weed competition after showing a significant yield increase with the higher density in a lupin crop under competition from ryegrass weeds.

2.6.5 Factors Affecting Seed Production of Annual Medics

In evaluating the annual medics, Crawford (1967) pointed out that the highest pod-yielding accessions were earlier-flowering than Jemalong; this is encouraging as high pod yield not only ensures high seed yield for regeneration in subsequent years, but also acts as a source of feed for grazing animals during the dry summer and autumn period. However, care must be exercised to ensure that medic pods (or burrs of sub clover) are not overgrazed during summer thus depleting the seed reserves going into the seed bank (Carter 1980, 1981; Carter *et al.* 1989; de Koning and Carter 1989a, 1989b).

There are a wide range of medic species and cultivars available for sowing on cereal farms. It is important to have a wide mixture of cultivars covering a range of maturity to ensure seed production under the poorest rainfall seasons. Likewise the seed mixture should cater for variation of soil types and may include medics and clovers. Very early maturing lines may be less productive but assured high seed production is most important (Carter 1988). Crawford (1975) reported that flowering within 125 days of germination was optimal for southern Australia, as is indicated by the mean range of 102-104 days for the existing commercial cultivars.

Taylor (1972) reported that the persistence of annuals in a Mediterranean environment depends on the production of adequate seed with suitable germination-regulating mechanisms. Those mechanisms are required to minimize germination before the break of the season (sufficient rain for germination, emergence and establishment) and to conserve some seed over at least one entire growing season. Such carry-over seed is required to guard against failure of seed set in a poor year and, preferably to permit regeneration after a period of cropping. In the evaluation of annual pasture plants, considerable emphasis has usually been placed on seed production with less emphasis on the ultimate recovery of the seed as useful seedlings.

In order to maximise the likelihood of medic seed production in a given environment, it is important that flowering be timely. Timely flowering is generally suggested as a primary criterion in evaluation of annual medics (Crawford 1985; Cornish 1985a). There is a wide genetic diversity in flowering time of annual medics. Crawford (1985) found a 25 day range (99-124 days) in time to-flowering of 9 commercial cultivars sown at Adelaide in late April, whilst Cornish (1985b) found a range of 35 days in 10 genotypes of *Medicago 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 75-132 days. 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. Several workers have noted a tendency of medics to hasten in development following later germination. They also observed that genotypes vary in magnitude of hastening (Aitken 1955; Devitt *et al.* 1978; Cornish 1985b; Hochman 1985).

Hastening of development is a reflection of the interrelationships between temperature promotion, vernalization (cold treatment) and photoperiod (dark period inhibition), which was suggested by Aitken (1955) and confirmed by Clarkson and Russell (1975) who concluded that vernalization and long photoperiod were able to substitute for each other to a great extent and that high temperature acceleration of flowering in several medics occurred only after vernalization. Clarkson and Russell (1976) also found that flowering in medics was influenced by soil moisture. These findings with annual medics are consistent with findings from studies of sub clover (Evans 1959; Morley and Evans 1959). Evans (1959) also found that high temperature promotion (post-vernalization) was independent of photoperiod.

There are two climatic factors influencing seed production by sub clover in Australia. The inland boundary of the species is governed by the length of the growing season in terms of rainfall efficiency (Trumble 1937) while the northern boundary in eastern Australia is defined by the insufficiency of winter cold for flower initiation (Aitken 1955). Seed production varied greatly between varieties and seasons (Donald 1959). The factor governing seed production was not water-related (Donald and Neal-Smith 1937), but the principal factor was temperature during the flowering period. Further analysis showed this to be mean minimum temperature during flowering, and this suggested that frost was the influential factor. Rainfall itself is weakly correlated with minimum temperature (clear, rainless skies giving frosty nights) but the relationship of seed production and rainfall is poor.

Tow and Hodgkins (1982) concluded that insect attacks during flowering markedly reduced seed production potential of Jemalong barrel medic and that lowering stocking rates is unlikely to help. Some insect control measures seem necessary to obtain reasonable seed yields for subsequent regeneration in Jemalong medic pastures.

Annual medics are suitable hosts for both aphid species, viz. spotted alfalfa aphid and blue green aphid (Peters and Painter 1957; Franzman *et al.* 1979), and in glasshouse experiments production losses as a result of aphid infestations have been recorded (Franzman *et al.* 1979). Aphid numbers were relatively low from emergence to establishment and had no effect on the seedling mortalities of the medics in the unsprayed plots. The relatively low aphid numbers through winter also had no effect on dry matter production, but as numbers of aphids increased in the spring the mean yields from all the unsprayed plots at successive harvest in September, October and November were reduced by 50, 54 and 55% respectively (Lodge and Greenup 1980).

Collins (1981) stated that reducing the length of growing season drastically reduced seed yield of sub clover thus when the growing season was only three weeks shorter than the control, seed yields averaged over strains and defoliation were reduced by at least one half. Although early defoliation (before flowering) increased seed yield of sub clover (Collins 1978).

2.7 Seed Dormancy and Hard-seededness

2.7.1 Dormancy in Seed of Annual Pasture Legumes

The word "dormancy" is derived from the latin word for sleep and perfectly describes the condition which allows many types of seed to resist germination even when in the soil under conditions normally considered ideal for germination. Seed germination involves a series of physiological and biochemical processes which commence with water uptake and conclude with the production of the root and shoot. A blockage to any one of these processes will result in dormancy. Seeds may remain dormant for periods of weeks, months or years. Generally, the dormancy period depends upon the species to a large extent, and on the seed being provided with the conditions necessary to overcome the dormancy. The main type of seed dormancy is often referred to as "physiological dormancy". It is best understood if germination is thought of as the result of a series of steps, each of which is a chemical reaction. If even one of these processes is blocked or interrupted, germination will not proceed, notwithstanding the fact that the seed has imbibed water and that all the external conditions of temperature and soil moisture are ideal for germination to proceed. This type of dormancy is not restricted to a single seed type as is the case with hard-seededness. The dormancy found in some cultivars of sub clovers for many weeks after harvesting may be broken by exposure seeds to an atmosphere containing 0.5 percent CO_2 (Ballard 1958). Like hard-seededness, this type of dormancy has evolved with the plant and can be understood as a survival mechanism.

Some plants will not germinate unless the seeds have been adequately washed to remove a chemical from the seed which blocks the germination processes. A very light fall of rain is insufficient for this purpose as the seed has a mechanism which allows it to germinate only when sufficient rain has fallen to wet the soil to depth and provide the plants' total water needs for the season. Many cold-climate plants have another form of dormancy which allows the seed to germinate only after it has experienced a certain minimum period at low temperature. Without this mechanism, seeds which are shed in summer might germinate in autumn and the seedlings be killed by the extreme cold of the winter. This mechanism will only allow the seed to germinate in spring when growing conditions are suitable for the seedling and perennial plants have time to adapt to the following winter. Other types of dormancy exist. Some types of seed will germinate only if they receive a flash of light after they have absorbed water and this explains why 'clean' ground will sometimes produce a crop of weeds after it has been tilled.

Dormancy may be short-lived or it may last for a very long period of time. Subterranean clover seed may have a weak low-temperature requirement which prevents it germinating on summer rains and allows it to germinate in autumn. Many of our cereals are dormant at the time of harvest, but are capable of germination well before the usual sowing time. Some tropical seeds require a period of high temperature before they can germinate. In agriculture, dormancy creates a number of difficulties. The value of agricultural seed for sowing must take account of any short-term dormancy. The fact that 90% of a seed lot is alive (or viable) is of little value if most of those seeds are dormant. Some species may undergo a secondary form of dormancy either as a matter of course or because of the environmental conditions either in store or in the soil.

2.7.2 Hard-seededness in Annual Pasture Legumes

A common form of dormancy occurs at the very earliest step in the germination process and is most frequently seen in legume seeds, particularly clovers, lucerne and medics. The seedcoat is impervious to water so that imbibition of water is prevented. In nature this is reversed only when the seedcoat is ruptured by alternating periods of high and low temperatures or by physical scratching during cultivation. In agriculture this type of dormancy which is commonly referred to as hard-seededness is especially important. It ensures that the important annual legumes such as sub clover, the annual medics and many others including some tropical species will survive from one season to the next. With hard-seededness the seed which is set in spring/summer does not all germinate with the first autumn rains or even in the first year so that there is always a reserve of seed in the soil to ensure the survival of the species and the pastures. Without this reserve these species would be of little use for long-term pastures in

Australia, especially in those areas of unreliable rainfall. It is important that sown seed contain a relatively low level of hard seeds.

Collins (1981) showed that the rate of breakdown of hard-seededness decreased with increasing length of growing season. Several field studies (Aitken 1939; Quinlivan and Millington 1962; Quinlivan 1965, 1966) showed that increasing the growing season available for seed production favoured the development of hard seeds which had a high resistance to subsequent breakdown. In the case of sub clover Loftus Hills (1944) concluded that: (i) varieties differ in their tendency to produce dormant seed, but that hard-seededness is not a varietal character or, if it is, the differences are of a low order and are usually masked by environmental conditions; (ii) dormant seed will germinate rapidly in the absence of the seed coat, the seed coat of sub clover, even when permeable to water, inhibits the germination of the physiologically-immature embryo; (iii) it is improbable that the embryos of naturally-soft seed are less dormant than those of naturally hard seed; and (iv) new season's seed of subterranean clover which showed greatly delayed germination when tested at 22°C, required over twelve months to mature fully when stored indoors. Loftus Hills also, found that delaying harvest up to six weeks after the normal stage of maturity caused a considerable reduction in the percentage of both dormant and hard-seeds.

Aitken (1939) has drawn attention to the large variation in the proportion of hard-seed in different varieties of sub clover grown under Victorian conditions. The development of hard-seeds is an important germination-regulating mechanism in sub clover (Quinlivan 1971). Significant numbers of seeds have been shown to remain hard for up to seven summers when left undisturbed where they were set at the soil surface (Taylor and Rossiter, unpublished data). Aitken recognized that alternating temperatures are important in the process of seed softening in *T. subterraneum*. Quinlivan (1961, 1966) further explored the effects of constant and fluctuating temperatures on seed softening. His conclusions supported Aitken's suggestion that temperature fluctuations are the main cause of seed softening under field conditions.

Taylor and Rossiter (1974) reported that only 17% of the Geraldton sub clover seeds set in 1970 had softened by the middle of March in the following year. Slower rates of softening would probably be desirable in drier regions or in rotation systems involving cropping (Taylor *et al.* 1984).

Taylor (1984) showed that burial of seeds of sub clover can markedly reduce the rate of softening of hard (i.e. impermeable) seeds, which is the mechanism which regulates germination between years in this species and many other legume species. And he found that the rate of seed softening in all eight varieties of sub clovers decreased with increasing depth of burial. Such storage or burial practices have a pre-conditioning effect on hard seeds, making them more amenable to softening once they are subjected to wide temperature fluctuations. Therefore, the soil tillage associated with cropping should build up a useful soil seed reserve of the harder seeded varieties.

Hard-seededness is one aspect of seed physiology which has received some attention because of its importance in regulating germination (Quinlivan 1971). Aitken (1939), Quinlivan and Millington (1962) and Quinlivan (1965, 1966) have indicated that the degree of hard-seededness in sub clover is influenced by genotype, conditions during the growing season and the temperature conditions to which the ripe seed is subjected.

Halloran and Collins (1974) have reported that the sequence of seed softening within burrs of sub clover was related to the position of the seed within the burr which was in turn related to seed size, the larger seeds generally softening first. Softening sequences according to the position of the seed in the burr have also been reported in *Medicago truncatula* by Kirschner and Andrew (1971). Likewise, McComb and Andrews (1974) have described a strong association between the sequence of softening and position of the seed in the pod of several species of *Medicago*.

The association between large seed and seedling vigour in medics increased the possibility of selection for better establishment both in the year of sowing and in subsequent years of natural regeneration (Crawford 1967). Also, he found that significant associations existed between seedling vigour and seed weight. The heavier-seeded genotypes gave the greater seedling vigour, while poor seedling vigour was generally associated with low pod weight and smaller seeds and the most vigourous seedlings produced moderate to very spiny pods. The rate of breakdown of hard-seededness between maturity and the expected opening rains of the subsequent season greatly influences the plant population for that season and there has been deliberate selection for more-rapid breakdown of hard-seededness in some cultivars e.g. Paraggio barrel medic.

Aitken (1939) showed that the hard-seededness in subterranean clover depends on: (i) genotypes; (ii) sustained environmental conditions favourable to plant growth and the development of the seed; and (iii) the subsequent degree of dehydration of the seed, prolonged conditions of high temperature and low humidity giving maximum hard-seededness. Softening of hardseed under natural conditions is attributed to fluctuating temperatures, which Aitken imposed experimentally both above (40-120°F) and across freezing point (freezing and thawing). Andrews (1958) also reports that the exposure of hard seed of *Medicago tribuloides* (now *M. truncatula*) to high temperatures such as one experienced at the soil surface during the summer months, will decrease hard-seededness.

Loftus Hills (1942, 1944) has differentiated physiological dormancy and hard-seededness in subterranean clover. He showed that physiological dormancy prevents the immediate germination of seed and is a heritable character. The dormancy of seedlings on and in the soil during the summer passed much more rapidly than that of seed stored at 22°C and this seemed to be an effect of the high temperature to which such seed was exposed. Loftus Hills found that hard-seededness, which rose to a maximum about two or three months after field ripeness did not differ consistently with variety, i.e. there was apparently an interaction of variety and environment. Values of 80-95% hard-seededness were common in seed harvested at field maturity and held for a few months at room temperature (Donald 1959). The seed dries out during summer and becomes hard and dormant. This prevents germination in summer when conditions are unfavourable for medics. The seed crop gradually loses its dormancy so that by autumn a small proportion can germinate. Hard-seededness is important for the survival of medics through dry seasons when seed may not be produced, but more importantly through cropping phases of the crop-pasture/livestock farming system.

3. ECOLOGICAL CONDITIONS IN JORDAN AND SOUTH AUSTRALIA

3. COMPARATIVE ECOLOGICAL CONDITIONS OF JORDAN AND SOUTH AUSTRALIA AND THE EXISTING STATUS OF MEDICS IN JORDAN

3.1 The Environments of the Near East and southern Australia

The physical environments and agriculture of much of the Near East and North African Region have been described by Nuttonson (1958, 1961a,b) and Clawson, Landsberg and Alexander (1971) while valuable studies on the ecology and land use include those by UNESCO-FAO (1963) and Carter (1978). The climate of the Region has been reviewed by Brichambaut and Wallen (1963) who recognised twelve agro-climatic sub-zones, and by Landsberg *et al.* (1963). The Region is characterised by winter rainfall (or snow) and hot dry summers when evapo-transpiration exceeds precipitation for several months i.e. occur in southern Australia, California, Chile and in South Africa. Nuttonson (1958) and Carter (1974, 1975, 1978) have emphasised the close climatic and edaphic analogies between parts of southern Australia and some countries of the Near East and North African Region. Further supporting evidence is given by Stephens (1957, 1962); Leeper 1970; and Gentillii 1971.

3.2 Climate and Soils

The beginning of the 1986-87 growing season saw the best opening rains since 1938 which was well distributed throughout the Kingdom. Rainfall in all three research stations (Ramtha, Mushagar and Rabbah) was well above average as can be seen in Tables 3.1, 3.2. These figures show that rainfall recorded for the early part of the season was 84% above average for Ramtha, with the majority of rain falling in early November. Rainfall in October and December was good for all areas except that December rains in Rabbah were 50% below average.

Rainfall distribution was excellent during this sowing period allowing the soil to dry out enough for cultivation and sowing between rains without any loss of optimum growing conditions. Mid-season weather conditions saw a continuation of rain which was below average by 30 and 42% respectively in Mushagar and Rabbah, but above average by 22% in Ramtha. Distribution of rainfall was very poor in Rabbah with limited effective rains between the beginning of December through to the middle of February. These rains were confined to the 300mm rainfall zone and did not penetrate into the 200-250mm zones to any extent. In Mushagar, February and March rains were respectively 55% and 30% below average.

The final and major period for pasture development in April and May saw a complete absence of rainfall other than 0.5mm in Rabbah. Effective rainfall ceased on 20 March and whereas good finishing rains in this period would have produced an excellent season, the end of season drought down graded the season to one of only average to below average results in the Mushagar and Rabbah regions which also experienced below average rainfall in the mid-season period. The Ramtha region with above-average rains in mid-season had an above-average to good season. The seasonal comparisons of climatic conditions at the three Research Stations in Jordan and at the Waite Institute are given in Tables 3.1 - 3.7.

Rain in early October, 1986 assisted land preparation in some areas. The rainfall season began properly in early November. Rainfall was sufficient to ensure useful sub-surface moisture storage. Thereafter monthly totals were considerably less, but adequate to maintain growth without stress. Sowing of experiments began in mid-November and was completed by December 17. This ensured establishment before the soil became too cold. Rain ceased abruptly at the end of March. Soil moisture reserves allowed growth and development to continue unchecked until at least mid-April at Ramtha and until the end of April at Rabbah and Mushagar. Overall, seasonal rainfall was slightly above average. This was in contrast to the 1985/1986 season, when rainfall was well-below average.

Chemical and physical analyses on soil samples taken from experiment sites were conducted by Ministry of Agriculture laboratories in Jordan. Soil samples could not be taken until the end of the growing season: samples were taken from the perimeter of the experiment boundaries and lanes between replicates, where the legumes had not been growing. Results are summarized in Table 3.8.

3.3 Medic Surveys in Jordan, 1986 - 1987

3.3.1 Introduction

The principle objective of this field survey was to quantify the effects of typical farming systems on the medic seed reserves, the regeneration of medics, and also yield and botanical composition of native annual medics, by measuring the seed reserve in the top 5cm of the soil of cultivated fields and adjacent uncultivated areas (road sides) in Jordan.

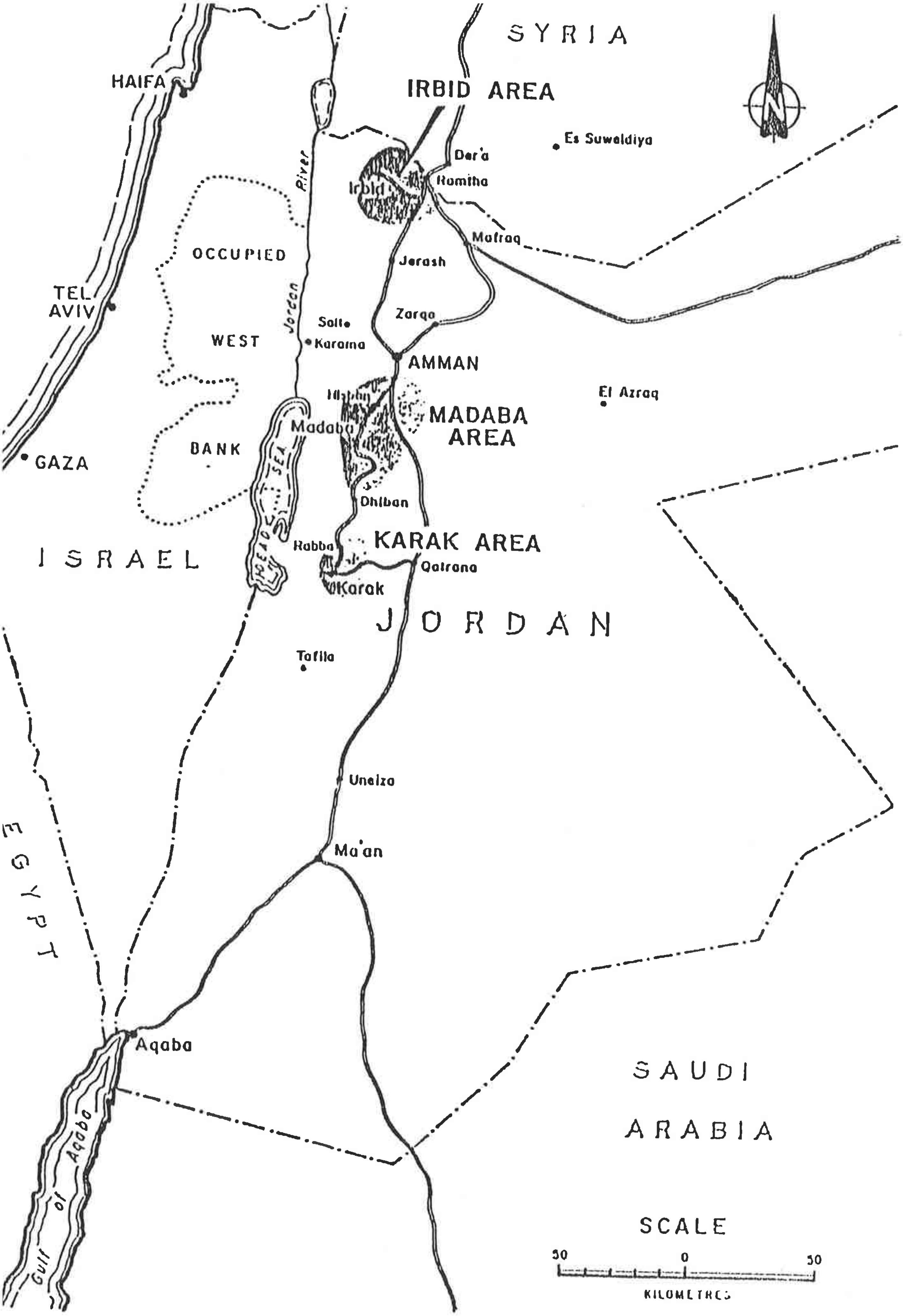
Sampling sites were selected in Northern, Central and Southern Jordan (Irbid-Ramtha, Madaba and Karak districts, respectively). It was known that much of the Karak district had experienced severe drought and heavy grazing during recent decades hence the expectation was that seed reserves would be low.

The methodology adopted for the study was similar to several recent studies by other workers such as Adem (1977), Dahmane (1978) and Carter (1981, 1982). These core-sampling techniques are especially useful for examing the basic reasons for limitations on native pasture legumes. These methods have not been previously used to examine the relationship between pasture management and the medic seedbank in the soil though Carter (1982) in South Australia reports data on this aspect. This survey was intended to be a preliminary assessment of the effects of ecology and management and their interaction on pasture-legume productivity.

3.3.2 Materials and Methods

During the autumn (October) of 1986, a field survey was made to assess the reserve of native annual medic seed reserves in three different districts in Jordan. The area which extended from Irbid to Karak (latitudes 32° 33' to 31° 16' North, Longitudes 36° 01' to 35° 45' East). At each site, paired data were collected from two adjacent areas (cultivated and uncultivated areas).

During October 1986, ten cylindrical samples of soil, 5cm deep, were extracted from each sampling site using a Coile sampler with a diameter of 106mm (Coile 1936). Ten sites were


SYRIA
IRBID AREA
HAIFA
Es Suwaldiya
Der'a
Ramtha
Irbid
River
Mafraq
OCCUPIED
Jerash
TEL AVIV
Jordan
Zarqa
Salt
WEST
Karama
AMMAN
El Azraq
MADABA AREA
Madaba
BANK
GAZA
SEA
DEAD
Dhiban
ISRAEL
Rabba
KARAK AREA
Qatrana
Karak
JORDAN
Tafila
Uneiza
EGYPT
Ma'an
Aqaba
SAUDI ARABIA
Gulf of Aqaba
SCALE
50
0
50
KILOMETRES

selected at random where the native annual medics were the predominant legume in uncultivated areas.

The botanical composition (percentage overlapping cover) of the volunteer pasture in spring also percentage bare ground was assessed using a Levy Point Quadrat (100 points per site). Soil samples were taken along road-sides travelled by car. Other than the name of the nearest village of township, no information was recorded about the site of collection. These soil samples were air dried, crushed and passed through a 2.0mm aperture sieve with medic seed collected on the lower 0.5mm aperture sieve: however, a larger top sieve was used if snail medic seed was present. Seeds were separated from the remaining soil by hand. Seed reserves in the top 5cm of soil are expressed on an area basis without attention to the species.

During March, in the spring of 1987, the same areas were used to assess percentage botanical composition of native annual medic plants using a Levy Point Quadrat (Levy and Madden, 1933). Ten quadrat frames comprising 100 points were recorded at each site to quantify the percentage botanical composition of the volunteer pasture species (medic, grass and other plants).

To obtain some information about relative frequency of the medics, the ten sampling sites were grouped for each of the three contrasting districts (Irbid, Madaba and Karak) which are known to be ecologically different (Refer Map). The frequency of occurrence and percentage contribution of each medic species (both seeds and plants) were calculated for each district and over all districts.

3.3.3 Results

In uncultivated areas (roadsides) four species of annual *Medicago* were recognized in this survey, viz. *M. blancheana, M. polymorpha, M. rigidula* and *M. rotata*. However, on cultivated fields no medics were found. Clearly these had disappeared under the influence of both bare-fallowing and deep ploughing (Carter 1978).

Heyn (1963) classified *M. polymorpha* into three varieties and *M. rigidula* into four varieties. The distribution of the annual species of *Medicago* is influenced by the degree of spininess of pods and by a multitude of climatic and edaphic factors. Species with pods which adhere firmly to the wool of sheep or the hair of other livestock generally have a wider distribution than those smooth or tuberculed pods (Andrew and Hely 1960; Heyn 1963; Crawford 1973). Andrew and Hely (1960) pointed out that within a zone favourable to medics, distribution of species is affected more by soil variation than by variation in climate.

Tables 3.9 and 3.10 show that the seed reserve in the top 5cm of the soil varied between districts and within each district. At southern sites, the seed reserve ranged from 500 to 1312 seeds/m^2. Over all districts the seed reserve in the soil declined from northern to southern Jordan (910 to 746 seeds/m^2). However, these differences in number of seeds reserved is not significant. The same trend was shown in Levy Point Quadrat data on botanical composition. The percentage of medic in vegetative components declined from 45% in the Irbid region to 41% in the Karak region.

3.3.4. Discussion and conclusions

Available information on climatic and soil conditions of the various districts of Jordan (Tables 3.1 - 3.6, 3.8), though limited, allow certain generalizations about the factors controlling distribution of medic types in the survey region. Rainfall over the survey area varies from 203 to 361mm per year and appears to play a minor role in the distribution of medic. It should be mentioned that good persistence of medics on unploughed roadsides is a reflection of the ability of the medics to withstand heavy grazing. These roadside sampling sites are unlikely to have received run-off water. Soil differences and winter temperature seem to be the most important factors affecting species distribution of medics. Altitudinal differences may have indirectly influenced medic distribution through changes in winter temperature. The most fertile red-brown soils dominate over the northern Irbid region and in this area the largest number of medic seeds were found. In addition to that, poor management e.g. heavy grazing, greatly influences reduced numbers of medic seeds in the soil seed bank of the southern region

of Jordan. *M. rotata* and *M. blancheana* appear to be restricted to areas with deep red-brown earth soils at low altitudes (northern region), where the winter temperatures are not too cold (0°C or above).

Medicago rigidula is probably more tolerant then *M. rotata* and *M. scutellata* to altitudinal differences which may affect rainfall and winter temperature. *M. rigidula* was found only in one central region (Madaba district). *Medicago polymorpha* appears to be more frequent in areas of higher elevations (e.g. Karak).

The observations made in this survey point to the need for a more extensive ecological study of the particular climatic, edaphic and management factors governing the distribution of annual medics in Jordan. Such a survey is of great value to pasture development work where the goal is to introduce medic pastures into farming systems in the present land use scheme to increase soil fertility and forage production. The medic survey, though limited in scope, shows that the Irbid district is an ecologically-favourable environment for medics. While the Madaba and Karak districts which are used in dry farming system may be less suitable for medics because of low winter temperatures and lower rainfall. However, there appear to be good prospects for using native genotypes of *M. blancheana, M. polymorpha, M. rigidula* and *M. rotata* that can extend the potential ecological range for medics in Jordan beyond what might be recognized as suitable for imported Australian genotypes. Irrespective of native Jordanian species and genotypes of medics, or imported Australian genotypes, deep ploughing has effectively eliminated these medics from the regularly-cropped areas. A successful ley farming system based on annual medics is incompatible with deep ploughing.

Plate 3.1 **Overgrazing (upper photograph) and deep ploughing (middle photograph) are the main reasons for disappearance of annual legumes (including medics) in the Old World. However, it is possible to grow excellent pasture of medics (lower photograph) also other legume species if correct management procedures are followed.**

Table 3.1 Long-term mean monthly rainfall (mm) for the three experiment sites in Jordan

Period	Site	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Total
1976-1985	Ramtha	0.3	9.5	22.8	35.2	37.3	47.7	47.7	12.1	4.6				217.2
1938-1985	Mushagar	0.2	5.1	38.5	64.8	84.5	73.2	71.0	19.1	4.8	0.1			361.2
1961-1985	Rabba	Tr.	4.2	30.0	64.0	77.5	67.1	62.6	21.7	2.9	Tr.			330.0

Table 3.2 Total rainfall (mm) received in the growing seasons 1985-1986 and 1986-1987 at the three experiment sites in Jordan

Period	Site	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar	Apr	May	June	July	Aug.	Total	% of the average
1985-1986	Ramtha	-	-	-	11.0	31.0	53.6	11.0	18.8	5.2	-	-	-	130.6	60.1
	Mushagar	-	-	-	56.7	45.5	86.7	13.5	4.8	21.4	-	-	-	228.6	63.3
	Rabbah	-	-	-	73.6	31.5	60.3	5.0	13.6	13.4	-	-	-	197.4	59.8
1986-1987	Ramtha	-	7.6	106.4	43.0	44.5	28.1	59.5	0.5	-	-	-	-	289.6	133.3
	Mushagar	-	25.2	136.4	45.9	82.2	32.6	45.6	0.6	-	-	-	-	368.5	102.0
	Rabbah	-	1.8	137.9	32.1	26.2	35.7	92.0	0.5	-	-	-	-	326.2	98.9

Table 3.3 Extreme maximum and minimum air temperature (°C) during 1976-1985, 1969-1985 and 1961-1985 at Ramtha, Mushagar and Rabbah, Jordan, respectively

Extreme Monthly Temp.	Site	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly	Period
Absolute Maximum	Ramtha	21.8	27.0	31.2	37.5	39.4	40.5	41.5	41.5	41.4	36.0	30.1	23.1	41.5	1976-1985
	Mushagar	24.5	27.9	30.5	36.5	40.5	38.8	39.2	41.8	39.8	36.2	30.2	26.8	41.8	1969-1985
	Rabbah	26.4	28.0	32.0	33.8	39.0	38.7	39.0	40.4	38.5	36.0	30.0	25.5	40.4	1961-1985
Absolute Minimum	Ramtha	-3.0	-1.5	-4.5	1.0	4.4	8.5	11.2	10.5	11.0	6.5	1.6	-1.6	-4.5	1976-1985
	Mushagar	-6.8	-2.7	-1.8	0.2	3.1	7.4	10.5	10.8	9.4	4.5	0.4	-7.0	-7.0	1969-1985
	Rabbah	-5.1	-3.0	-3.5	-0.5	3.0	8.0	10.9	10.0	8.0	4.2	0.1	-4.8	-5.1	1961-1985

Table 3.4 Extreme temperature (°C) at experiment sites during the growing season 1985/1986 in Jordan

Temp °C	Sites	1985				1986							
		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Absolute Maximum	Ramtha	-	34.5	27.5	22.5	20.5	21.5	28.0	30.5	32.0	37.0	-	-
	Mushagar	-	33.8	28.2	22.2	27.3	23.0	28.8	30.2	30.3	36.5	-	-
	Rabbah	-	31.9	25.5	22.0	22.4	21.6	27.5	29.5	28.8	31.8	-	-
Absolute Minimum	Ramtha	-	6.0	1.0	0.0	-2.0	0.0	0.0	0.0	1.5	11.0	-	-
	Mushagar	-	5.0	4.8	-1.0	-1.1	0.5	2.8	5.7	7.1	11.1	-	-
	Rabbah	-	8.5	6.3	0.2	-1.8	1.5	0.5	3.6	2.0	15.0	-	-

Table 3.5 Extreme temperature (°C) at experiment sites during the growing season 1986/1987 in Jordan

		1986				1987							
Temp °C	**Sites**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**
Absolute Maximum	Ramtha	-	32.5	24.5	19.7	23.5	25.0	24.0	29.0	36.5	35.5	-	-
	Mushagar	-	32.9	23.4	19.2	24.0	26.2	23.3	27.0	35.8	36.2	-	-
	Rabbah	-	30.6	20.7	21.4	24.0	26.2	19.0	25.8	33.1	34.0	-	-
Absolute Minimum	Ramtha	-	9.5	2.5	1.0	1.5	1.5	2.0	3.0	2.5	11.0	-	-
	Mushagar	-	9.3	1.6	-0.8	-1.0	1.0	-1.2	1.0	2.6	6.2	-	-
	Rabbah	-	9.5	2	0.0	-1.0	2.0	-1.0	0.6	3.2	6.5	-	-

Table 3.6 Average monthly rainfall (mm) during 1925-1989 and total amount of rainfall (mm) during the growing seasons 1988 and 1989 at the experiment site, Waite Institute, South Australia

Period	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Yearly**
1925 - 1989	23.4	24.3	23.8	54.9	80.3	74.6	87.9	74.8	61.9	52.6	36.9	29.9	625.3
1988	32.6	23.4	28.2	15.0	120.6	113.6	76.4	60.0	66.4	14.8	44.6	37.0	632.6
1989	2.6	1.6	2..8	54.0	97.0	104.8	87.0	88.8	51.8	38.2	33.8	13.4	575.8

Table 3.7 Extreme maximum and minimum air temperatures (°C) during 1925-1989, 1988 and 1989 at Waite Institute, South Australia

Period	Absolute Temperature	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1925 - 1989	Maximum	44.3	43.1	41.4	36.6	28.8	25.1	25.5	26.7	33.3	37.3	41.8	42.1	44.3
	Minimum	8.0	8.4	6.0	4.6	3.2	0.9	1.8	2.1	2.1	3.8	4.4	5.8	0.9
1988	Maximum	39.4	37.4	36.7	26.9	27.8	22.7	17.4	24.6	28.4	34.4	37.6	38.1	39.4
	Minimum	10.4	11.4	10.7	7.5	8.3	5.7	3.6	4.5	5.8	8.2	7.7	9.7	3.6
1989	Maximum	37.7	38.3	39.2	32.4	21.8	19.4	17.7	19.6	25.4	27.9	34.8	37.2	39.2
	Minimum	9.7	11.2	9.9	9.0	8.1	2.7	4.0	3.4	5.2	4.6	7.8	10.6	2.7

Table 3.8 Soil chemical and physical data from Experiment Sites in Jordan

Station and Experiment	Depth of Sample (cm)	pH †	Soluble P †† (ppm)	Exchange 1<+ (ppm)	Fine Sand (%)	Silt (%)	Clay (%)	Soil Texture	Bulk Density (g/cc)	Field Capacity (%)	Wilting Point (%)
Ramtha Drill Plot Experiment	0-30	7.5	24.0	360	11.4	42.8	45.8	Silty-Clay	-	-	-
	30-60	7.8	-	330	6.2	38.0	55.8	Clay			
Mushagar Drill-plot Experiment	0-30	7.8	10.8	300	9.8	22.4	67.8	Clay			
	30-60	7.9	-	170	5.7	23.3	71.0	Clay			
Mushagar Hand-sown Experiment	0-30	7.9	7.0	280	10.1	20.2	69.7	Clay	1.66	40.7	23.1
	30-60	8.1	-	190	5.8	27.4	66.8	Clay	1.67	40.8	23.1
Rabbah Drill-plot Experiment	0-30	7.5	13	200	18.2	34.0	47.8	Clay	1.58	37.9	18.5
	30-60	7.6	-	140	8.5	29.4	62.1	Clay	1.63	34.8	18.4

† Determination of pH by soil : water ratio, 1:5
†† Soluble P by the colorimetric method (Ababneh 1983)

Table 3.9 **Medic seed reserves in uncultivated sites in Northern, Central and Southern Jordan, Oct. 1986. (All data for 0-5cm soil)**

Site	IRBID (Seeds/m^2)	Madaba (Seeds/m^2)	Karak (Seeds/m^2)
1	504	625	530
2	770	1227	1203
3	807	960	834
4	1266	750	641
5	908	783	500
6	1045	511	614
7	833	1102	1312
8	1182	983	609
9	856	615	619
10	931	1371	601
Mean	910	892	746

Table 3.10 **Percentage overlapping cover and percentage bare ground in three districts of Jordan, March 1987.**

	IRBD District	Madaba District	Karak District	Mean
Medic	45.1	42.7	40.9	40.9
Grass	28.3	33.5	29.5	30.4
Other spp.	26.6	23.8	29.6	26.7
Bare ground	10	12	14	12

4. FIELD EXPERIMENT 1: MEDICS IN JORDAN

4 FIELD EXPERIMENT 1 : EVALUATION OF MEDIC GENOTYPES UNDER RAINFED CONDITIONS IN JORDAN, 1986-87

4.1 Introduction

In areas of low rainfall throughout the world, new plants are usually introduced into existing pastures because they are expected to increase total production or because they are considered more desirable species. A number of grasses and legumes have been recommended for improving the "Mediterranean-type climate" rangelands of California (Miller *et al.* 1957; Williams 1963) and of southern Australia (Trumble 1949; Morley 1961; Andrew 1962).

Legumes recommendedfor the semi-arid, neutral-alkaline soil areas are medics. Most medics species are winter annuals adapted to Mediterranean climates. Their usual life cycle is to germinate with the onset of the first autumn rains in September to November (Northern Hemisphere = NH) or March to May (Southern Hemisphere = SH) and to grow rapidly while warm temperatures and precipitation coincide. While the growth rate may be reduced during winter, flowering usually is completed during April (NH). In colder-temperature climates these species would have to be used as spring annuals. Self-seeding annual legumes may be better adapted to arid rangelands than are perennial legumes. Quinlivan (1971) showed that medics can survive many years of drought due to the hard seed mechanism. More recently Carter and Challis (1989) have shown the survival of *M. scutellata, M. truncatula* and *M. littoralis* as hard seeds over a period of 14 years. In addition, although annual medics have no means for evading dry season conditions by earlier flowering, their phasic development can be accelerated by drought stress once flowering has begun (Clarkson and Russell 1976). Their successful adaptation to arid environments is evidenced by the presence of several medic species in regions of North Africa receiving less than 250mm of annual precipitation (Francis 1981). However, the economics of crop production alter with changes in technology, cultivars, costs of production, or the value of the produce (Box and Perry 1971).

The 300 - 480 mm rainfall zone of central western Jordan is one such marginal cropping area, where farmers have endeavoured to grow grain as far as possible into the semi-arid rangeland areas. This has been accomplished by the integration of cereal grain cropping (mainly wheat) and food legumes or animal production activities as suggested by Rossiter (1966) for Mediterranean-type environments. The expansion in wheat acreages in this low rainfall belt has encouraged a similar expansion in forages (mainly vetches) in Jordan.

In most areas legumes are desirable for introduction to natural pastures because they produce high quality feed, which are readily acceptable to grazing animals and increase soil nitrogen. Carter (1981) estimated that the 40 million hectares of legume-based pastures in Australia improved the quantity and quality of livestock feed and soil fertility to the value of US$2500 million per year. Forage yields and protein concentrations were increased when forage legume was introduced to grass or cereal pastures in Jordan farming systems (Ababneh 1983).

The objective of the experiment described in this section was to evaluate the yielding ability and the climatic and soil adaptability of five annual medic species which includes 19 commercial cultivars and new genotypes under rainfed conditions in Jordan. Both forage and seed yields are important in annual legumes, which must not only supply feed in the year of sowing but also regenerate from self-sown seed in later years. Winter and spring production are both important.

4.2 Materials and Methods

4.2.1 Location of Experiments

The experiment was conducted in three differing agro-ecological zones in Jordan at Agricultural Research Stations namely Ramtha (Lat. 35° 39'N, Long. 32° 30'E, Altitude 590 m), 80km north of Amman in north east Jordan; at Mushagar (Lat. 31° 43'N, Long. 35° 48'E, Altitude 785 m), 45 km south of Amman in central Jordan and at Rabbah (Lat. 31° 16'N, Long. 35° 45'E, Altitude 920 m), 90 km south of Amman in the southern part of Jordan. Estimated mean annual rainfall is 289, 369 and 326 (mm) respectively at these sites and the growing period normally of 4 to 6 months.

The climate of these three sites is typical Mediterranean, and rain falls from October until May in these locations, mostly from December to March (Table 3.1).

4.2.2 Experimental

This experiment was conducted through the Jordan-Australia Dry Land Farming Project. From 27 accessions and cultivars tested under the same environmental conditions in the 1985 - 1986 season (Table 4.1), further experiments involved a comparison of 19 selections of Australian commercial cultivars and accession of new strains from five *Medicago* species (Tables 4.4 and 4.5). These medics were selected after a one-year (1985-1986) evaluation based on measurement of herbage and seed yield (Tables 4.2 and 4.3). Total amount of rainfall (mm) in 1985 - 1986 was only about 60% of the average annual rainfall for each site (Table 3.3). Therefore, selection under these conditions favoured those which could grow relatively well under dry seasons. A randomized complete block design was used with four replicates at each site. Plot size was 4 x 1.5m plots consisted of six rows, spaced at 25cm. (See Diagram 4.1).

Table 4.1 **Evaluation of medic genotypes tested in 1985-1986 in Jordan**

Series No.	Species	Cultivar or Access'n No.	Weight per 1000 seed (g)
1	*M. truncatula*	Jemalong	4.05
2	"	Cyprus	5.06
3	"	Paraggio	4.78
4	"	Sephi	4.62
5	*M. littoralis*	Harbinger	2.47
6	*M. scutellata*	Robinson	N.R.
7	"	Sava	16.37
8	*M. rigidula*	SEL. 1919	4.62
9	"	SEL. 1865	5.32
10	"	SEL. 1295	4.16
11	"	SEL. 716	5.77
12	"	SEL. 1894	4.17
13	"	SEL. 1900	3.89
14	"	SEL. 1851	3.87
15	"	SEL. 1569	3.52
16	"	SEL. 1310	3.55
17	"	SEL. 734	3.68
18	*M. rotata*	SEL. 1943	6.72
19	"	ACC. 2425	6.76
20	"	ACC. 2475	7.66
21	*M. polymorpha*	Circle Valley	3.82
22	"	Serena	4.32
23	"	SEL. 1041	5.64
24	"	SEL. 1038	6.67
25	"	SEL. 1039	5.79
26	"	COL. 16/1	3.71
27	"	COL. 7/1	3.38

Table 4.2 **Mean dry matter yields (kg/ha) Mushagar, 6-7 May 1986 ranked according to yield**

Species	Cultivar or Acces'n No.	Series No.	Yield	Rank†
M. scutellata	Robinson	6	1984.0	A
M. rotata	SEL 1943	18	1577.0	AB
M. polymorpha	SEL 1041	23	1575.8	AB
M. rigidula	SEL 716	11	1519.0	ABC
M. scutellata	Robinson	28	1472.0	ABCD
M. rotata	ACC 2425	19	1459.0	ABCD
M. rotata	ACC 2475	20	1315.8	BCDE
M. truncatula	Paraggio	3	1301.0	BCDE
M. scutellata	Sava	7	1259.8	BCDEF
M. truncatula	Sephi	4	1252.0	BCDEF
M. polymorpha	SEL 1038	24	1206.4	BCDEF
M. polymorpha	SEL 1039	25	1190.0	BCDEF
M. rigidula	SEL 1919	8	1159.0	BCDEF
M. littoralis	Harbinger	5	965.8	CDEFG
M. rigidula	SEL 1865	9	955.0	DEFG
M. rigidula	SEL 1569	15	931.0	DEFG
M. truncatula	Cyprus	2	884.8	EFGH
M. truncatula	Jemalong	1	845.5	EFGH
M. rigidula	SEL 1894	12	845.0	EFGH
M. rigidula	SEL 1900	13	789.5	EFGH
M. polymorpha	COL 7/1	27	733.0	FGH
M. polymorpha	COL 16/1	26	567.5	GH
M. polymorpha	Circle Valley	21	556.8	GH
M. polymorpha	Serena	22	542.8	GH
M. rigidula	SEL 1295	10	441.0	GH
M. rigidula	SEL 1851	14	438.3	GH
M. rigidula	SEL 734	17	412.8	GH
M. rigidula	SEL 1310	16	340.1	H

† Duncan's Multiple Range Test (P<0.05). Mean yields associated with the same letter are not significantly different.

Table 4.3: **Mean medic clean seed yields (kg/ha) Mushagar, 1986, ranked according to yield**

Species	Cultivar or Acces'n No.	Series No.	Yield	Rank†
M. scutellata	Robinson	~~5~~ 6	562.8	A
M. rotata	ACC 2425	19	390.5	B
M. scutellata	Robinson	28	389.5	B
M. polymorpha	SEL 1038	24	387.8	B
M. rotata	SEL 1943	18	368.8	BC
M. polymorpha	SEL 1039	25	337.3	BCD
M. rotata	ACC 2475	20	334.8	BCD
M. polymorpha	SEL 1041	23	322.5	BCD
M. scutellata	Sava	7	286.3	CDE
M. rigidula	SEL 716	11	248.5	DEF
M. rigidula	SEL 1919	8	219.8	EFG
M. truncatula	Paraggio	3	185.5	FGH
M. polymorpha	Serena	22	184.3	FGH
M. truncatula	Cyprus	2	172.5	FGH
M. truncatula	Sephi	4	166.8	FGH
M. polymorpha	COL 7/1	27	162.0	FGH
M. rigidula	SEL 1865	9	160.5	FGH
M. truncatula	Jemalong	1	146.3	GH
M. polymorpha	Circle Valley	21	133.5	GH
M. rigidula	SEL 734	17	127.5	GH
M. rigidula	SEL 1894	12	127.3	GH
M. rigidula	SEL 1569	15	126.0	GH
M. rigidula	SEL 1900	13	120.3	H
M. rigidula	SEL 1851	14	117.0	H
M. rigidula	SEL 1295	10	114.8	H
M. rigidula	SEL 1310	16	112.2	H
M. polymorpha	COL 16/1	26	108.8	H
M. littoralis	Harbinger	5	101.8	H

† Duncan's Multiple Range Test ($P<0.05$). Mean yields associated with the same letter are not significantly different.

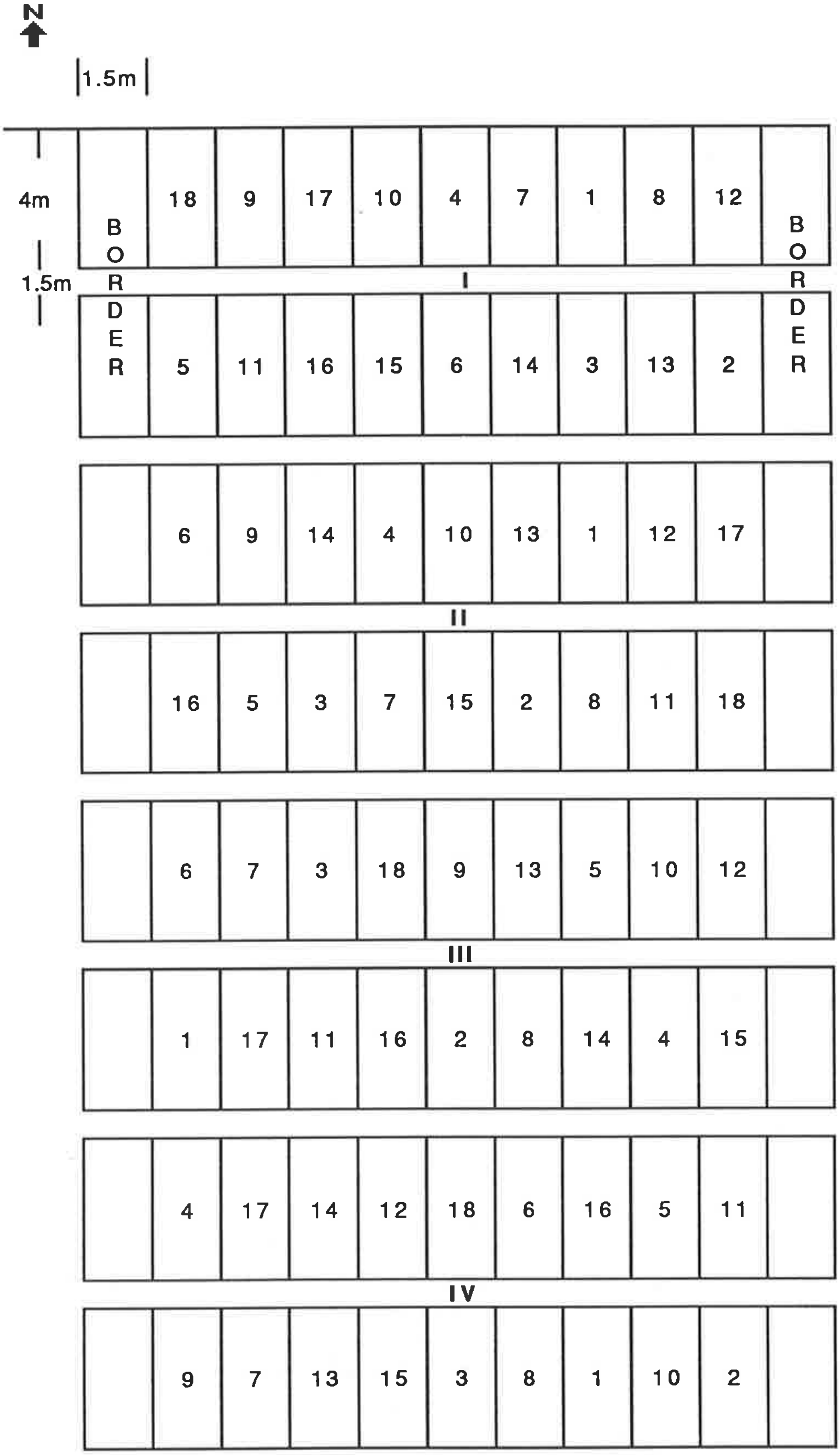


Diagram 4.1 Plan of field experiment at Rabbah, Jordan,1986-87

Seeds of commercial cultivars were obtained from SAGRIC International, Adelaide, South Australia, and seed of the new lines from ICARDA (International Centre for Agricultural Research in the Dry Areas), Aleppo, Syria. Triple superphosphate at 100kg/ha was broadcast by hand and incorporated to a depth of c. 1cm prior to sowing. All seeds were treated with the commercial peat base inoculates of appropriate *Rhizobium meliloti* strains (M29 for *M. rigidula* in 1986-87). WSM 244 was used for *M. rigidula* in 1985-86 as well as used for all other species in both years, immediately before sowing. The inoculant was stuck onto the seed with molasses, and lime was used to dry the seed. A Hege small-plot cone seeder with sowing tynes spaced at 25 cm was used to sow the medic plots at the three sites.

The experiments were sown on 20 November at Rabbah, 10 December at Mushagar and 15 December 1986 at Ramtha. The experiment at Ramtha was resown because of difficulties with the seed-drill on the first sowing occasion, therefore sowing date was relatively late (Table 4.5). The aim was to establish swards with a density equivalent to that given by a sowing rate of 18kg/ha of pure germinating seed of Jemalong barrel medic as standard to give a plant population of 486/m^2. All genotypes were sown on the basis of equal numbers of viable seed (Table 4.4). However, mortality of seedlings due to intraspecific competition might be expected. Weeds were controlled throughout the experiment by hand cultivation.

4.2.3 Data collection

The swards were planned to be of such a size as to permit the removal of two samples, each of one square metre, spaced in order that internal edge effects between sampling areas might be eliminated. Seedlings were counted within a quadrat of 1 m^2 centred on each plot. Two square metres of herbage was harvested to a height of about 3 cm at the end of winter. Then, following regrowth, half the area was harvested to ground level for spring herbage production and seed was harvested from the other half. Furthermore, pod yield, number of pods/m^2, seed yield, seed : pod ratio, number of seeds/pod and pod and seed index were recorded. Duncan's multiple range test was used for statistical analyses.

4.3 Results

Long term average precipitation at the three experiment sites as well as the absolute maximum and minimum air temperature are shown in Tables 3.1 to 3.3 and that for the growing season of the study period 1986 - 1987 is presented in Tables 3.4 to 3.5. It can be seen that the rainfall is about the average at Rabbah and above average at the other sites.

4.3.1 Establishment

All of the *Medicago* species successfully germinated and emerged at all sites. *Medicago rotata* had the highest mean seedling emergence per unit area at both Ramtha and Rabbah sites, while *M. rigidula* had the highest plant emergence (#/m^2) at Mushagar. Between the sites, there was no significant differences even though Mushagar showed the highest plant emergence (plant/m^2) compared to other sites (Table 4.6). At all sites, *M. truncatula* cultivars had the lowest plant density ranging from 247 plants/m^2 for Cyprus at Rabbah, 289 plants/m^2 for Sephi at Ramtha and 316 plants/m^2 for Jemalong at Mushagar.

4.3.2 Herbage production

Winter production : Plant survival and consequent yield reflected tolerance to frost. The observed ranking of medic genotypes in order of decreasing frost susceptibility is summarized in Table 4.7. *M. rigidula* was the only species free of frost damage at all sites. Frost damage was observed at Mushagar and Rabbah but not at Ramtha. Herbage yield was measured with particular emphasis on winter production, which ranged from a low of 170 kg/ha at Mushagar to a high of 1022 kg/ha at Rabbah (Table 4.8). *M. scutellata* followed by most of *M. rotata* genotypes showed superiority in herbage yield at all sites. However, there were no significant differences between *M. rotata* strains in yielding ability for dry matter except for *M. rotata* SA 14104 which appeared very promising at Ramtha and Mushagar. Herbage production is density-dependent in early winter as was discussed by Silsbury *et* al. (1978). Herbage production varied according to species or genotypes: *M. rotata* greatly outyielded *M. truncatula*, while other species e.g. *M. polymorpha* and *M. rigidula* were mostly intermediate. However, different species behaved differently at different sites according to their adaptability and potential productivity under the prevailing environmental conditions during the growing season.

At Ramtha, similar herbage yield was produced by *M. polymorpha* and *M. rotata* SA14104, while *M. rigidula* Sel. 1865 was the least productive line (206 kg/ha). Meanwhile, at Mushagar, the opposite trend occurred: *M. rigidula* Sel 1919 was the third most productive strain (495 kg/ha) after *M. scutellata* and the best *M. rotata* line (SA 14104). Furthermore, at Rabbah where more herbage yield was produced, there were no significant differences between the best *M. rotata* lines, *M. polymorpha* Sel. 1038 and *M. rigidula* Sel. 716 (Table 4.8).

Regrowth of herbage : This was recorded as spring production: the warmer days of spring enhanced growth which was in contrast to the slow growth of winter which was partly a result of frost damage. Maximum herbage yields were produced from *M. rigidula* (2269 kg/ha), *M. scutellata* (2233 kg/ha) and *M. rotata* (1807 kg/ha) grown at Rabbah, Ramtha and Mushagar respectively (Table 4.9). On the other hand *M. polymorpha* was clearly the least productive species at all three sites. Between sites, herbage yield ranged from the lowest (589 kg/ha) at Mushagar to the highest (2269 kg/ha) at Rabbah (see Table 4.9). However, *M. scutellata* and *M. rotata* were the most productive species grown at Ramtha followed by the second comparable group of *M. truncatula* cv. Cyprus, *M. rigidula* Sel. 1919 and *M. polymorpha.* There was no significant differences in terms of spring herbage yield between *M. scutellata* cv Robinson, *M. rotata* and *M. rigidula* grown at Mushagar. The same trends at Mushagar were obtained at Rabbah. Overall, it is obvious that *M. scutellata* and *M. rotata* were the most productive species for spring herbage yield, while good yields were also produced by *M. rigidula* at Rabbah and Mushagar (Table 4.9).

Total herbage production (winter and spring) : The maximum herbage yields were achieved by *M. scutellata* (3061kgDM/ha) at Ramtha and Rabbah, while at Mushagar *M. rotata* (Sel. 2475) gave the highest yield, 2236kgDM/ha (Table 4.10). Furthermore, *M. truncatula* cv. Cyprus was the poorest yielding cultivar or strain (1546 and 894kg/ha) at both Rabbah and Mushagar sites respectively, while *M. rigidula* Sel. 1865 had the lowest herbage yield (1303kg/ha) at Ramtha. However, Rabbah was the best site for total herbage production which ranged from 1546 to 3032 kgDM/ha, followed by Ramtha site where a very similar herbage production was achieved (Table 4.10).

4.3.3 Pod and seed production

Pod yield : Pods are important determinants of seed yield in pasture legumes as well as being an important component of summer feed for livestock. High pod yield normally leads to high seed production. All sites showed a satisfactory pod production. The highest yields of pod were 1637kg/ha produced by *M. scutellata* cv. Robinson grown at Rabbah followed by *M. rigidula* Sel. 1919 grown at Mushagar, while *M. truncatula* cv. Paraggio was the best pod producer (1109 kg/ha) grown at Ramtha (Table 4.11). Pod yield varied widely according to cultivar or strain and site. The lowest pod yield (148 and 348 kg/ha) was obtained by *M. rigidula* Sel. 1865 grown at Ramtha and Rabbah sites respectively, while the same *M. rigidula* strain gave 973 kg/ha when grown at Mushagar site. Also a very big variation in pod production within the same site was obvious. The highest pod yields at any site were about 3 - 4 times as much as the corresponding minimum pod yields at the same site.

Seed yield : Seed production was related to pod yield in most medic genotypes tested in this experiment, especially *M. rigidula* Sel. 1919 and Sel. 1865 which produced the highest and the lowest medic pod and seed yield respectively (Tables 4.11 and 4.12). The seed yields of several genotypes of *M. polymorpha* and *M. truncatula* were lowest at Mushagar. Also, *M. truncatula* and *M. rigidula* gave the lowest seed yield at Ramtha and Rabbah (Table 4.12). In contrast, seed yields of *M. rigidula* were higher at Mushagar compared to other sites. However, *M. rotata* showed a superiority over other genotypes in seed production in most treatments, followed by *M. scutellata* which produced more than double the seed of *M. truncatula* . Furthermore, seed production varied according to climatic factors mainly amount and distribution of rainfall and temperature, with some frost damage at low temperature. For example, seed yields of *M. polymorpha* Sel. 1038 varied widely between sites (406, 311 and 120 kg/ha) when grown at Ramtha, Rabbah and Mushagar respectively. Seed : pod ratios were very satisfactory for most genotypes (Table 4.13).

4.4. Discussion and Conclusions

Seedling establishment : Seedling emergence varied according to genotype, depth of sowing, soil moisture and soil texture. Seedling drought resistance or differing responses of species to moisture stress following germination are well documented by Rossiter (1966). Additionally, initial establishment is often benefited by weed control to reduce competition from other annual species, particularly if late rains and low temperatures create conditions more favourable to grass growth (Kay and Owen 1970; Murphy *et al.* 1973).

If a cultivar or genotype could be found that had superior cold-temperature germination and growth, what would be the possibilities for persistence in the annual communities? We must remember that these legumes are annual. If they are not to be at a competitive disadvantage in the year after initial establishment, they must germinate at an optimum level with the initial flush of germination and emergence, at the time of the first effective rain. Our results indicate that the cold-tolerant genotypes selected by ICARDA (*M. rigidula* and *M. rotata* strains) had the highest plant population per unit area at all sites. Between sites, there was a trend for densities to be higher at Mushagar than the other two sites where less annual effective rainfall was received (Table 4.6).

Herbage production : The pasture available in autumn and winter limits livestock production, e.g. prime lamb production, and the varietal differences in winter herbage production reported here (Table 4.4) are of practical importance in meeting stock needs at this time of the year where animal feed is scarce. Later-maturing cultivars or strains e.g. *M. rotata* in this experiment produced as much dry matter in spring as the commercial snail medic *(M. scutellata)* cultivars and much more than *M. truncatula* cultivars. Thus, the late-maturing lines of annual medic *(M. rotata)* will be more useful in finishing late lambs by extending the period of green feed until late spring. Winter annual legumes grow and persist on many soils, while vetch and vetch-barley mixtures are in common use in Jordan. Medics or medic-oats have a role as forage or hay crops (Sartaj, Carter and Patterson 1989). Certainly the annual medic species are widely adapted (Russell 1969; Clarkson 1970; Jones and Rees 1972).

In explaining the wide differences in productivity of the medic cultivars and genotypes studied among sites and strains, several limiting growth factors must be taken into account. During the growing period (1986/1987), total effective rainfall received from November 1986 to February 1987 ranged from 220 to 300mm at the three sites, so soil moisture should not have been limiting plant growth.

The fact that equal numbers of viable seeds of all genotypes were sown may have given the advantage for initial growth to large-seeded lines. The results of the study described herein show the importance of seed size in determining the early production of annual medic plants.

Where medics are growing in sward conditions, the relative differences between plants of different seed weight are maintained, virtually unchanged until the spring herbage production, where snail medic (large seed size) gave the highest herbage production in most cases (Table 4.10).

Erickson (1946) and Black (1957) came to the same conclusion that the dry weights of the plants (pasture legumes) were proportional to seed weight in the early part of the season. Our results are consistent with the superior performance of the large-seeded genotypes (*M. scutellata* and *M. rotata* especially Sel. 2475) and the poor performance of the small-seeded *M. truncatula* genotypes (Tables 4.8 to 4.10).

Although the incidence of frost depressed plant growth in early winter, our results showed that frost effects were not severe in terms of overall winter herbage production. However, differences in the productivity between medic lines could be attributed to differential effects of particular temperature regimes. It is necessary to identify strains which grow well in winter. Two factors are known to influence winter production, viz. temperature and plant density. One of these could be low temperature. Even in April (mid-spring in Jordan) mean temperatures were 13 to 14°C which is suitable for growth, but could be sub-optimal for temperate pasture legumes.

Overall, in the absence of moisture stress, this season has provided conditions to compare the effects of low temperature and frost on the winter production of a range of annual medic species and lines. Comparing medic lines, *M. scutellata* (cv. Robinson and cv. Sava) and *M. rotata* Sel. 2475 were the most consistently productive. Other lines of *M. rotata* also ranked highly. Between sites, *M. rigidula* Sel. 1865 was relatively productive in winter at Mushagar and the most productive line in spring at Rabbah and Mushagar and at the same time the poorest one at Ramtha, while *M. polymorpha* yielded well at Ramtha.

Generally, herbage yields were 20 to 90% higher at Rabbah, which could be attributed to early sowing and/or favourable conditions for *M. rigidula* and *M. rotata* which are claimed to be cold-tolerant genotypes, as they are natives to the colder Mediterranean climatic areas (Cocks 1969). In addition to that, soil factors may be responsible for yield differences between medic species. Variation in the distribution of individual medic species has been associated with variation in soil fertility and texture (Andrew and Hely 1960; Heyn 1963).

In general, the method of evaluating medic growth response to temperature under field conditions is difficult. Therefore, another experiment was designed to study the effect of temperature on growth under controlled conditions (Experiment 6) which is described later in this thesis.

Seed production : High medic seed yields are necessary to ensure a large seed bank in the soil for good regeneration of pasture. Next to winter herbage production, seed yield is the major issue to be taken into account in evaluation of medic plants. However, seed yield may affect density and herbage production in the following year.

For Mediterranean legumes, little is known of the components affecting seed yield (Cocks 1988). However, Donald (1954) reported that the number of seeds per burr (inflorescence) and seed size of subterranean clover (*T. subterraneum* L.) increased with sowing rate. Neither factor affected seed yield as much as number of burrs per plant which was greatest at low density. Low temperature and long photoperiod accelerate flower initiation in barrel medic as in subterranean clover (Aitken 1955). Furthermore, Rossiter (1961, 1972) found that defoliation of swards before flowering and at early flowering increased the seed yield and/or the number of burrs of several subterranean clover cultivars. The data of medic pod and seed production in Tables 4.11 and 4.12 suggest the occurrence of a Site x Genotype interaction which could be related to Temperature x Moisture interaction. The seed yields of several genotypes of *M. rotata, M. polymorpha* and *M. truncatula* were lowest at Mushagar, compared to other sites, where moisture was least limiting and temperatures lowest. This suggests the importance of temperature variation in inducing seed yield variation between sites, for these lines. In contrast, seed yields of *M. rigidula* Sel. 1919 were higher at Mushagar than at other sites which confirms the tolerance of *M. rigidula* to low temperature for growth and seed production.

Adaptability to prevailing environmental factors is most important to ensure a high level of productivity in pasture legumes. *Medicago rotata* was better adapted to the environment of Jordan, as exemplified by Ramtha, Mushagar and Rabbah sites during 1986/1987, than any of the other annual medic species. Other medics also grew well, e.g. *M. rigidula,* which was the most promising line for pod and seed production at Mushagar but not at other sites. The maximum total herbage yields were produced by *M. scutellata* at Ramtha and Rabbah whereas *M. rotata* was the best at Mushagar. Despite the success of Australian cultivars of *M. scutellata* the Australian commercial cultivars of *M. truncatula* were the least productive over the three sites.

Therefore, selecting the best-adapted medic cultivar or genotype is a most-important issue to ensure good pasture. Cocks (1988) came to the same conclusion when choosing *M. rigidula* and *M. rotata* as the most promising new medics for West Asia.

Table 4.4 **Mean seed weights and sowing rates of pure germinating seed for each medic genotype sown in Experiment 1, 1986**

Species	Genotype	Number	Seed Weight (mg)	Sowing Rate (kg/ha)
Medicago truncatula	Jemalong	1	3.7	18
" "	Cyprus	2	4.8	23
" "	Paraggio	3	5.19	25
	Sephi	4	4.4	21
Medicago scutellata	Robinson	5	16.6	81
	Sava	6	16.9	82
Medicago rigidula	SEL 716	7	5.52	27
" "	" 1865	8	5.4	26
" "	" 1919	9	6.7	33
Medicago polymorpha	" 1038	10	6.3	31
" "	" 1039	11	6.3	31
" "	" 1041	12	5.8	28
Medicago rotata	" 1943	13	6.0	29
" "	" 2425	14	6.9	34
" "	" 2475	15	8.2	40
" "	" 2123	16	5.85	28
" "	1651/1949	17	6.80	33
" "	2284/1953	18	7.30	36
" "	SA 14104	19	8.30	40

Table 4.5 **Details of medic species sown in Experiment 1 on the three sites in Jordan on the dates shown**

Species	Cultivar or Accession Number (Genotype)	Experiment Sites Ramtha 15/12/86	 Mushagar 10/12/86	 Rabbah 20/11/86
Medicago truncatula	Jemalong	1	1	1
" "	Cyprus	2	2	2
" "	Paraggio	3	3	3
" "	Sephi	4	4	4
" *scutellata*	Robinson	5	5	5
" "	Sava	na	na	6
" *rigidula*	SEL 716	7	7	7
" "	SEL 1865	8	8	8
" "	SEL 1919	9	9	9
" *polymorpha*	SEL 1038	10	10	10
" "	SEL 1039	11	11	11
" "	SEL 1041	12	12	12
" *rotata*	SEL 1943	13	13	13
" "	SEL 2425	14	14	14
" "	SEL 2475	15	15	15
" "	SEL 2123	16	16	16
" "	ACC 1651/1949	na	na	17
" "	ACC 2284/1953	na	na	18
" "	SA 14104	19	19	na

na = Seed not available

Table 4.6 Medic evaluation experiments. Mean medic population densities (plants/m^2) at establishment

Ramtha 20/1/1987			Mushagar 18-19/1/1987			Rabbah 13/1/1987		
Genotype	Ranked† Order	Establishment (%)	Genotype	Ranked Order	Establishment (%)	Genotype	Ranked Order	Establishment (%)
15	386 a	79	8	448 a	93	17	395 a	81
19	359 a	74	13	439 a	91	12	381 a	79
14	342 a	70	14	435 a	88	18	381 a	77
3	341 a	70	12	424 ab	88	6	370 ab	76
16	337 a	70	16	424 ab	88	15	367 ab	75
11	332 a	69	15	423 ab	88	14	351 abc	71
13	336 a	69	9	423 ab	86	7	343 abcd	70
12	336 a	69	11	429 abc	86	11	340abcd	69
8	333 a	69	10	390 abcd	79	13	334 abcd	69
9	331 a	67	19	369 bcde	77	16	334 abcd	69
10	331 a	67	7	368 bcde	75	10	330 abcde	67
5	323	66	3	358 cde	74	5	321 abcdef	66
2	317 a	66	5	342 de	70	8	317 abcdef	66
7	308 a	63	4	335 de	70	1	297 bcdef	61
1	299 a	62	2	332 de	69	9	283 cdef	58
4	290 a	60	1	316 e	65	4	269 def	56
						3	256 ef	53
						2	247 f	52

†Duncan's Multiple Range Test. Values associated with the same letter are not significantly different (P<0.05).

Table 4.7 **Observations on relative susceptibility of annual medics to frost during the winter of 1986/87 in Jordan**

Cultivar or Accession	Degree of Frost Damage
M. truncatula cv. Cyprus	Fairly severe
M. truncatula cv. Paraggio	"
M. scutellata cv. Sava	Moderate to fairly severe
M. polymorpha cv. SEL 1041	" "
M. polymorpha cv. SEL 1038	" "
M. polymorpha cv. SEL 1039	Moderate
M. scutellata cv. Robinson	"
M. truncatula cv. Jemalong	Light to moderate
M. rotata SA 14104	" "
M. rotata SE 1943	Light
M. truncatula cv. Sephi	"
M. rotata cv. 1651/1949	"
M. rotata Acc 2425	Slight
M. rotata 2284/1953	Very slight
M. rigidula (all genotypes)	Free of damage
M. rotata Acc. 2475	Free of damage

Table 4.8 **Medic herbage production in winter on dates shown (kgDM/ha)**

Ramtha, 2-3 March		Mushagar, 17 March		Rabbah, 2-3 March	
Genotype	Ranked† Order	Genotype	Ranked Order	Genotype	Ranked Order
5	826 a	5	558 a	6	1022 a
19	700 a	19	509 a	5	925 ab
15	619 c	9	495 a	18	782 bc
11	562 cd	15	472 ab	15	775 bcd
10	498 de	13	439 ab	10	668 cde
14	490 de	7	433 ab	7	642 cde
12	484 de	14	423 ab	14	637 cde
13	463 e	10	320 bc	13	597 def
7	343 f	11	316 bc	12	594 def
16	324 fg	8	314 bc	17	546 efg
2	313 fg	12	221 c	11	546 efg
9	304 fg	16	209 c	9	532 efgh
3	291 fgh	4	198 c	1	432 fghi
1	275 fgh	2	196 c	16	417 fghi
4	238 gh	3	176 c	2	386 ghi
8	206 h	1	170 c	4	380 ghi
				8	351 hi
				3	329 i

† Duncan's Multiple Range Test. Values associated with the same letter are not significantly different ($P<0.05$).

Table 4.9 Medic herbage production in spring 1987 (kgDM/ha)

Ramtha		Mushagar		Rabbah	
Genotype	Ranked† Order	Genotype	Ranked Order	Genotype	Ranked Order
5	2233 a	14	1807 a	8	2269 a
15	2040 ab	8	1794 a	18	2189 a
16	2000 ab	15	1764 a	16	2176 a
13	1975 ab	5	1720 a	15	2013 a
14	1806 bc	9	1645 ab	6	2011 a
19	1753 bcd	19	1476 abc	5	1993 a
2	1592 cde	7	1459 abc	13	1950 ab
9	1586 cde	16	1443 abc	14	1891 ab
10	1571 cde	13	1372 abc	9	1832 ab
3	1541 cde	1	1104 bcd	7	1792 ab
11	1538 cde	3	941 cd	1	1714 abc
12	1496 cde	4	795 d	17	1681 abc
7	1396 def	2	699 d	3	1346 bcd
4	1299 ef	12	683 d	4	1175 cd
1	1273 ef	10	654 d	2	1160 cd
8	1097 f	11	589 d	11	1136 cd
				10	1032 d
				12	1021 d

† Duncan's Multiple Range Test. Values associated with the same letter are not significantly different (P<0.05).

Table 4.10 Total herbage production during 1986/87 in Jordan (kgDM/ha)

Ramtha		Mushagar		Rabbah	
Genotype	Ranked† Order	Genotype	Ranked Order	Genotype	Ranked Order
5	3061 a	15	2236 a	6	3033 a
15	2659 b	14	2230 a	18	2971 ab
19	2454 bc	5	2174 a	5	2918 ab
13	2438 bc	9	2140 a	15	2788 abc
16	2323 bcd	8	2108 a	8	2619 abc
14	2295 bcd	19	1985 a	16	2593 abc
11	2099 cde	7	1892 a	13	2547 abc
10	2069 cde	13	1811 ab	14	2528 abc
12	1979 de	16	1652 abc	7	2434 abc
2	1905 ef	1	1274 bcd	9	2363 bc
9	1890 ef	3	1117 cd	17	2227 cd
3	1832 ef	4	992 d	1	2146 cde
7	1739 ef	10	974 d	10	1699 de
1	1548 fg	11	905 d	11	1682 de
4	1537 fg	12	904 d	3	1675 de
8	1304 g	2	895 d	12	1616 de
				4	1555 e
				2	1547 e

† Duncan's Multiple Range Test. Values associated with the same letter are not significantly different (P<0.05).

Table 4.11 **Yield of medic pods in Jordan, June 1987 (kg/ha)**

Ramtha		Mushagar		Rabbah	
Genotype	**Ranked† Order**	**Genotype**	**Ranked Order**	**Genotype**	**Ranked Order**
3	1109 a	9	1360 a	5	1637 a
10	1106 a	15	1276 ab	6	1442 ab
15	1078 ab	7	1210 ab	1	1264 abc
19	1065 ab	13	1146 ab	13	1200 bc
11	1055 abc	16	1134 ab	18	1199 bc
5	1049 abc	5	1085 abc	15	1156 bc
2	1041 abc	19	1068 abc	14	1144 bc
14	998 abc	8	973 bcd	9	1103 bc
13	929 abcd	14	785 cde	10	1052 bc
12	866 abcd	1	701 def	7	1046 bc
4	836 abcd	3	698 def	3	1024 bc
7	820 abcd	11	591 ef	2	962 c
1	803 bcd	2	538 ef	4	943 c
16	759 cd	4	514 ef	11	923 c
9	697 d	10	452 ef	17	914 c
8	148 e	12	416 f	16	910 c
				12	882 c
				8	348 d

† Duncan's Multiple Range Test. Values associated with the same letter are not significantly different (P<0.05).

Table 4.12 **Yield of medic seed in Jordan, June 1987 from eighteen genotypes (kg/ha)**

Ramtha		Mushagar		Rabbah	
Genotype	**Ranked† Order**	**Genotype**	**Ranked Order**	**Genotype**	**Ranked Order**
15	456 a	9	376 a	13	501 a
14	439 ab	16	371 a	14	501 a
19	429 abc	15	355 ab	18	498 a
10	406 abcd	19	348 ab	5	470 ab
13	397 abcd	13	342 ab	15	464 ab
11	360 abcd	5	310 abc	17	438 abc
16	334 bcde	14	284 bc	6	437 abc
12	324 cdef	8	264 c	16	400 abcd
5	306 defg	7	259 c	9	360 abcd
3	247 efgh	11	164 d	11	328 bcde
9	225 fgh	3	146 de	10	311 cde
2	222 fgh	1	144 de	1	305 cde
7	206 gh	10	120 de	12	303 cde
4	185 h	4	108 de	7	298 cde
1	169 h	12	106 de	3	275 de
8	50 i	2	84 e	4	254 def
				2	195 ef
				8	119 f

† Duncan's Multiple Range Test. Values associated with the same letter are not significantly different (P<0.05).

Table 4.13 Medic seed weight as a percentage of pod weight in Experiment 1, Jordan, 1987

Ramtha		Mushagar		Rabbah	
Genotype	Ranked† Order	Genotype	Ranked Order	Genotype	Ranked Order
16	45 a	14	36 a	17	49 a
14	44 ab	16	35 ab	14	44 ab
13	43 ab	6	33 abc	16	44 ab
15	43 ab	13	30 bcd	18	42 b
6	40 bc	8	29 bcd	13	42 bc
12	38 cd	5	29 bcd	15	40 bcd
10	37 cde	11	29 bcd	11	36 cde
8	34 de	15	29 bcd	8	35 def
11	33 e	9	27 cde	12	34 efg
9	33 ef	10	26 de	9	33 efg
5	29 fg	12	25 def	10	31 efgh
7	26 gh	7	22 ef	6	30 efgh
3	22 hi	4	21 ef	5	29 efgh
4	22 hi	3	21 ef	7	29 fgh
2	21 i	1	19 fg	4	27 gh
1	21 i	2	14 g	3	27 gh
				1	24 hi
				2	21 i

† Duncan's Multiple Range Test. Values associated with the same letter are not significantly different (P<0.05).

5. FIELD EXPERIMENT 2: MEDICS IN JORDAN

5. FIELD EXPERIMENT 2 : COMPARATIVE GROWTH AND SEED PRODUCTION OF FOUR MEDIC GENOTYPES BASED ON EQUAL SOWING RATES AND ON EQUAL SEED NUMBERS PER UNIT AREA IN JORDAN, 1986 - 1987

5.1 Introduction

Herbage production in winter and seed yield of a pasture has a great influence on the livestock carrying capacity of annual medic-based pasture. The main objectives of this experiment were: to quantify the early productivity, growth pattern and seed production of two new cold-tolerant medic genotypes and two commercial Australian medic cultivars, grown under two systems - (i) equal sowing rates and (ii) equal plant populations. These systems gave differing densities. Variation in plant density is a useful tool with which to study intraspecific and inter-specific differences in yield in communities of crop plants. The major factor influencing optimum sowing rate for any particular crop is the genotype (Donald 1951, 1963). At the highest densities, competition becomes more and more intense until growth is completely arrested. Thus, the yield at lower densities may approach progressively that at the higher densities: yield rises sharply with increasing density to a maximum which is constant for all higher densities.

It is important to study the growth pattern of medic genotypes as well as their potential yielding ability because high herbage yield may not necessarily be an advantage in terms of seed production. The two may be antagonistic because excessive shading has been shown to reduce seed yield (Collins *et al.* 1978). From the nineteen cultivars and genotypes tested in Experiment 1 in Jordan, four genotypes were chosen to be studied in more detail. Two genotypes were Australian cultivars (*Medicago scutellata* cv. Sava, hereafter referred to as Sava and *M. truncatula* cv. Paraggio, hereafter referred to as Para.) and two were cold-tolerant genotypes selected in the ICARDA program at Aleppo, Syria viz. *M. rigidula* Sel. 716 hereafter referred to as Rigi. and *M. rotata* Sel. 1943 hereafter referred to as Rota.

5.2. Materials and Methods

5.2.1 Experimental Procedure

Location and preparation of site : The experiment was conducted at Mushagar Research Station, 775m altitude; lat. 31° 43'N and long. 35° 48'E and 45km south-west of Amman. The average annual rainfall is 376mm and the soil type a clay-loam with pH. 7.9. Physical and chemical soil characteristics and climatic data were recorded in Tables 3.1 to 3.8. Prior to sowing, the area was harrowed to mix the superphosphate fertilizer and to give a fine seed bed.

Design of experiment and treatments : Four genotypes (Sava, Para., Rigi. and Rota.) were chosen to study their contrasting field behaviour. The first two genotypes are commercial Australian cultivars which are suited to the environment of southern Australia, and the other two were selected in the ICARDA program for cold tolerance and they are suited to the environment of west Asia. Each genotype was sown at two different rates, firstly on the basis of **equal weight of pure germinating seed** (30kg/ha) and secondly on the basis of **equal seed numbers of pure germinating seed** using 30kg/ha of Para. as standard sowing rate of 825 seeds/m^2. The experiment was of randomized complete block design for sowing rate and genotype. A summary of the experimental design is as follows:

Genotypes (4) x Sowing rates (2) x Blocks (4) = 32 plots. (Diagram 5.1).

Each plot measured 2.5 x 5 metres. Seed was weighed out for each genotype sown at equivalent seed weight, and counted (8250 seeds/plot) for each genotype sown at equivalent number of seeds. All seeds were inoculated prior to sowing. The *Rhizobium inoculum WSM* 244 was used for seed of Sava, Para. and Rota. but Rigi. was inoculated with M29 (ICARDA *Rhizobium* number) in a peat slurry and coated with calcium carbonate to assist drying. Triple superphosphate (46% P_2O_5) equivalent to a rate of 100kg/ha (100 g/plot) was broadcast by hand at sowing time. The plots were lightly raked prior to hand-broadcasting with the seed to clear it of stones and weeds and to level the soil surface, and again following sowing to ensure good coverage of the seed. Eighteen galvanised wire quadrats (25 x 40cm) were placed on each plot immediately after sowing (Diagram 5.2). The plots were divided into north and south sections (i.e. 9 quadrats per half), and harvests were randomized among the nine quadrats according to a master plan (eight of these quadrats were used for the herbage harvests). Harvest 1, corresponded with quadrat position 1 and so on. Quadrat position nine was used for the pod and seed harvest.

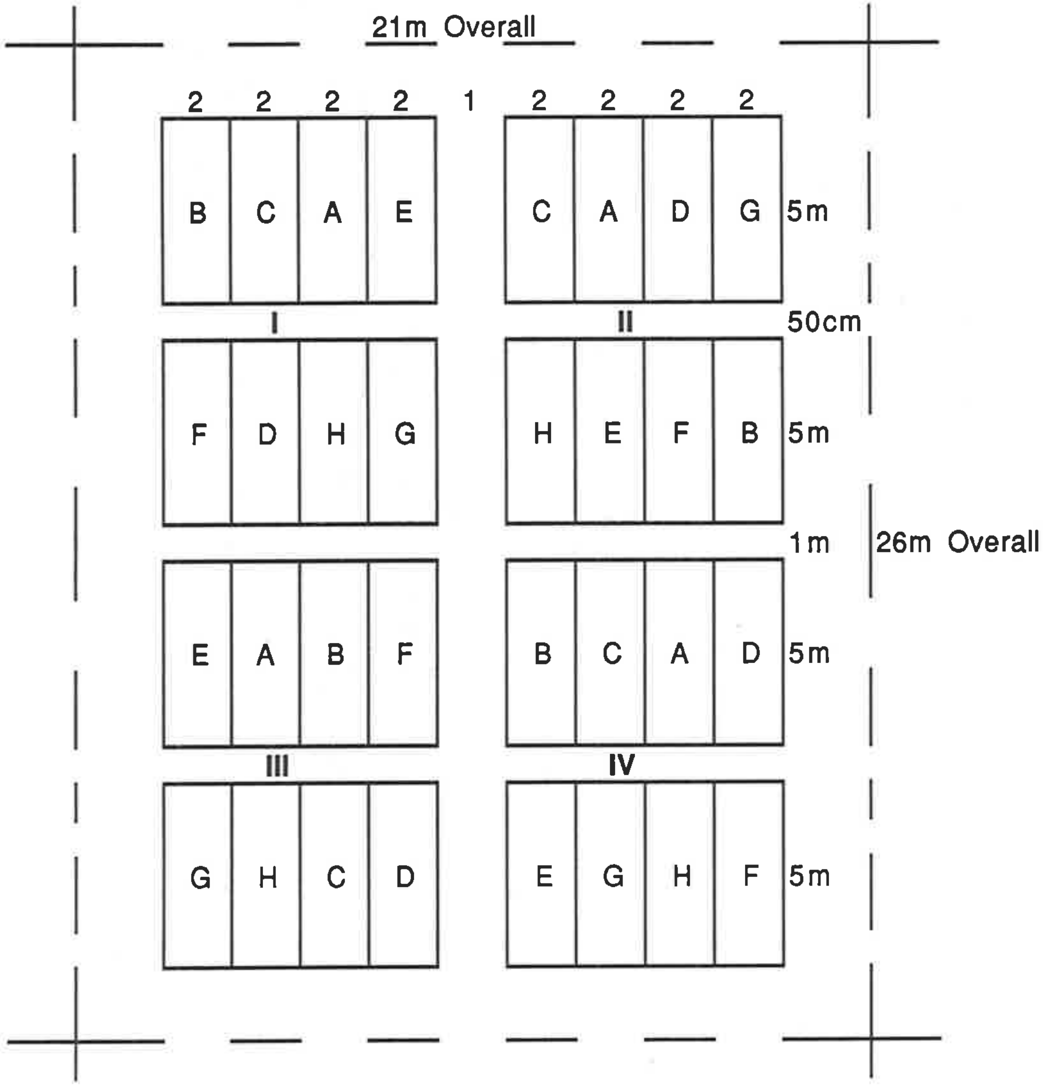
5.2.2. Data Collection

Emergence : Counts of medic (plants/m^2) were made on January 17 for all treatments. Six quadrats ($0.1m^2$) per plot were used to count number of plants (three quadrats from each half).

Herbage yield : The plots were sampled eight times throughout the growing season commencing from Harvest 1 on January 12, 1987 to Harvest 8 on April 21, at 14 day intervals (i.e. 28, 42, 56, 70, 84, 98, 112 and 126 days after emergence respectively). On each harvest occasion two quadrats were taken per plot, one from the northern half and one from the southern half of the plots. The medic plant numbers within each quadrat were recorded at each harvest. To assist counting, plants were harvested at or below soil surface. Any root material was removed from plants, then samples were washed and dried at 85°C for 24 hrs in a forced-draught dehydrator and weighed. Growth curves were constructed from the herbage yield data.

Seed yield : The last two quadrats/plot (one from northern and one from southern plot section) were harvested on June 12, 1987 for measuring pod and seed yield. A strong, fibre hand broom was used to collect the above-ground samples. The samples were oven dried at 40°C in a forced-draught dehydrator for 24 hours. All samples were processed carefully by removing the pods by hand from the dry pasture residues. Yield components measured from the seed harvest were yield of pods (kg/ha), number of pods/m^2, percentage hard seed, percentage soft seed (readily-germinable), percentage dormant seed (permeable, swollen without germination), total clean seed weight (kg/ha) and mean seed index (g/1000 seeds).

Germination tests of seed in pods : Pod germination tests were conducted on intact pods. Twenty five pods were taken at random from each Block and placed in petri dishes with three pieces of filter paper (Whatman Qualitative No.1) on the bottom and one layer of cottonwool on the top of the pods. Each treatment was replicated four times. Ten ml of distilled water containing 1.6 g/l of the fungicide Thiram was added to each dish. Germination tests were of 14 days duration in a humidified incubator at 19°C. Seedlings emerging from the pods were removed daily then after 14 days pods were dissected to determine the proportion of hard and dormant seed.



Treatments

Equal Weight of Pure Germ Seed	A M.scutellata (Sava)) B M.truncatula (Paraggio)) C M.rigidula (Sel.716)) D M.rotata (Sel.1943))	~ 30kg/ha Par
Equal Population Pure Germ Seed	E M.scutellata (Sava) F M.truncatula (Paraggio) G M.rigidula (Sel.716) H M.rotata (Sel.1943)	~ 30kg/ha Par

Diagram 5.1 : Showing lay-out of Expt. 2 in Jordan

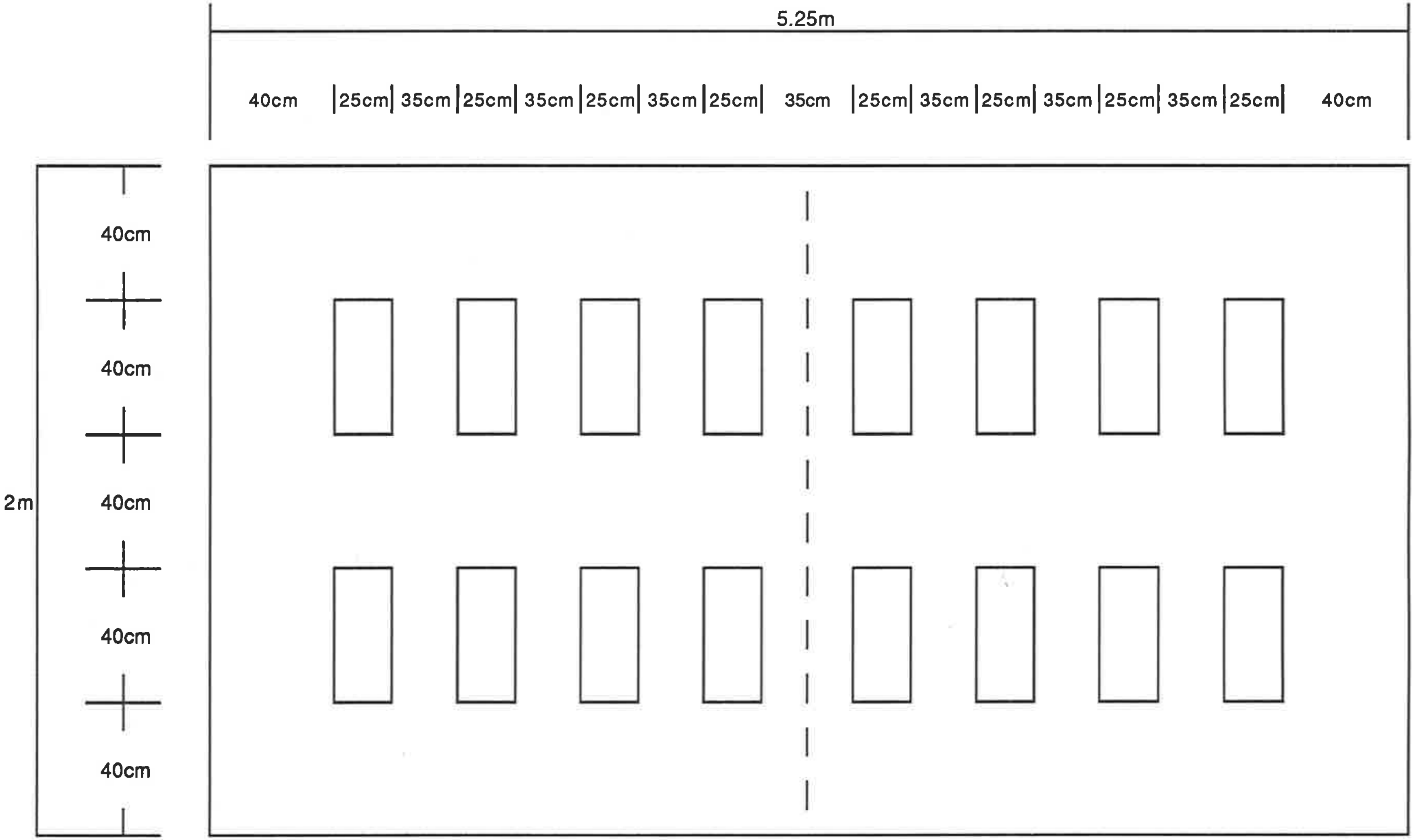


Diagram 5.2 : Showing placement of wire quadrats on a plot

5.3 Results

The results summarise the main effects such as sowing rates and genotype. First order interactions such as Sowing Rate x Genotype are described if they are significant. Tables in Appendix A contain the actual values which have been used for the Figures. Mean monthly minimum and maximum temperature, and monthly rainfall are presented in Tables 3.3 to 3.5 for the 1986/1987 growing season.

5.3.1 Medic Plant Population

The density of medic plants (#/m^2) varied according to the sowing rate, seed size, genotype and time. The mean seed weights of Sava, Para., Rigi. and Rota. were 20.0, 4.0, 5.6 and 6.2mg respectively. Thus on the basis of equal weight of pure germinating seed (hereafter referred to as low density) many more seeds of Para. were sown resulting in higher populations of seedlings than the other genotypes. On the basis of equal number of seeds i.e. 825/m^2 (hereafter referred to as high density), again Para. had the highest population of seedlings in most harvests.

Genotype and sowing rate effects : Separate analyses of variance were made on data from each sowing system so that genotype differences at each sowing rate could be detected. However, the interaction effects of plant Genotype x Sowing Rate were significant (Table 5.1). Plant number/m^2 showed a self-thinning over the growing period at each sowing rate (Tables 5.2 and 5.3). High plant population of Para. in most conditions resulted in highly significant differences in plant density between genotypes. At the end of the season Para. had the greatest decline in plant density when sown at equal seed weight.

Table 5.1 Summary of analyses of variance for medic plant density (based on natural logarithms)

Harvests (H) WAE†	No.	Genotype (Gen.)	Sowing Rate (SR.)	Gen. x SR.	Coefficient of Var. %
4	H1	$P<0.001$	$P<0.05$	$P<0.001$	6.0
6	H2	$P<0.005$	$P<0.05$	ns	6.3
8	H3	$P<0.001$	$P<0.001$	$P<0.001$	5.1
10	H4	$P<0.001$	$P<0.05$	$P<0.001$	4.9
12	H5	$P<0.001$	$P<0.01$	$P<0.01$	5.3
14	H6	$P<0.001$	$P<0.001$	$P<0.01$	4.2
16	H7	$P<0.001$	$P<0.01$	$P<0.001$	4.0
18	H8	$P<0.001$	$P<0.001$	$P<0.001$	5.0

† Weeks after emergence

From Table 5.2 it is clear that there has been self-thinning of the smaller-seeded medics (Para, Rigi. and Rota.) but no obvious reduction in density of Sava. However, in Table 5.3 the data shows a reduction in density of all four genotypes.

Table 5.2 Plant densities (#/m^2) of four medic species sown at equal sowing rates in Jordan 1986

Days after emergence	Genotypes			
	Sava	Para.	Rigi.	Rota
† 28	178	773	625	675
42	255	723	588	548
56	111	658	478	421
70	134	594	381	431
84	116	545	464	536
98	170	586	463	594
112	94	575	471	485
† 126	150	480	359	476

† Dates : Day 28 = 12 Jan 1987; Day 126 = 20 April 1987

Table 5.3 **Plant densities (#/m^2) of four medic species sown to equal seed number (825/m^2) in Jordan 1986**

Days after emergence	Genotypes			
	Sava	Para.	Rigi.	Rota.
28	745	798	633	773
42	605	803	633	610
56	499	690	476	619
70	426	689	499	661
84	320	586	499	609
98	479	639	496	656
112	388	659	488	626
126	378	616	361	643

5.3.2. Herbage Production

Analyses of variance on herbage yield data are summarized in Table 5.4 while growth curves for the two systems of sowing are in Figures 5.1 and 5.2 and supporting data in Appendix Tables A.1 and A.2. The significant interaction between Sowing Rate and Genotype (Tables 5.4 and 5.5) reflects the impact of the large-seeded Sava on herbage production which persisted until 14 weeks after emergence.

Table 5.4 **Summary of analyses of variance for herbage yield of four medic species at equal sowing rates and equal plant populations**

Days after emergence	Genotype (Gen.)	Sowing Rate (SR)	Gen. x SR	Coefficient of variation (%)
28	$P<0.05$	$P<0.01$	$P<0.001$	29.2
42	$P<0.001$	$P<0.001$	$P<0.001$	27.8
56	ns	$O<0.001$	$P<0.001$	42.2
70	$P<0.05$	ns	$P<0.05$	43.6
84	$P<0.05$	$P<0.05$	$P<0.001$	22.1
98	$P<0.05$	$P<0.05$	$P<0.01$	31.8
112	ns	ns	ns	25.0
126	ns	ns	ns	19.2

Table 5.5: **Herbage yield of four medic species sown at equal rates and equal seed numbers per unit area in Jordan 1986**

Days after emergence	Sowing rate	*M. scut.* cv. Sava	*M. trunc.* cv. Para.	*M. rigi.* Sel 716	*M. rota.* Sel 1943	Genotype x Sowing Method
42	30kg/ha	171	143	208	167	
	825 seed/m^2	434	205	204	170	***
84	30kg/ha	722	837	1101	1137	
	825 seeds/m^2	1892	931	1183	1344	***
		EXCLUDING PODS				
† 126	30kg/ha	6148	4662	5169	4074	ns
	825 seeds/m^2	6693	6115	5255	6497	
		INCLUDING PODS				
† 126	30kg/ha	9012	6748	6215	4434	
	825 seed/m^2	9507	7958	6204	7235	na

† This date was 20 April, prior to maturity
na not analysed

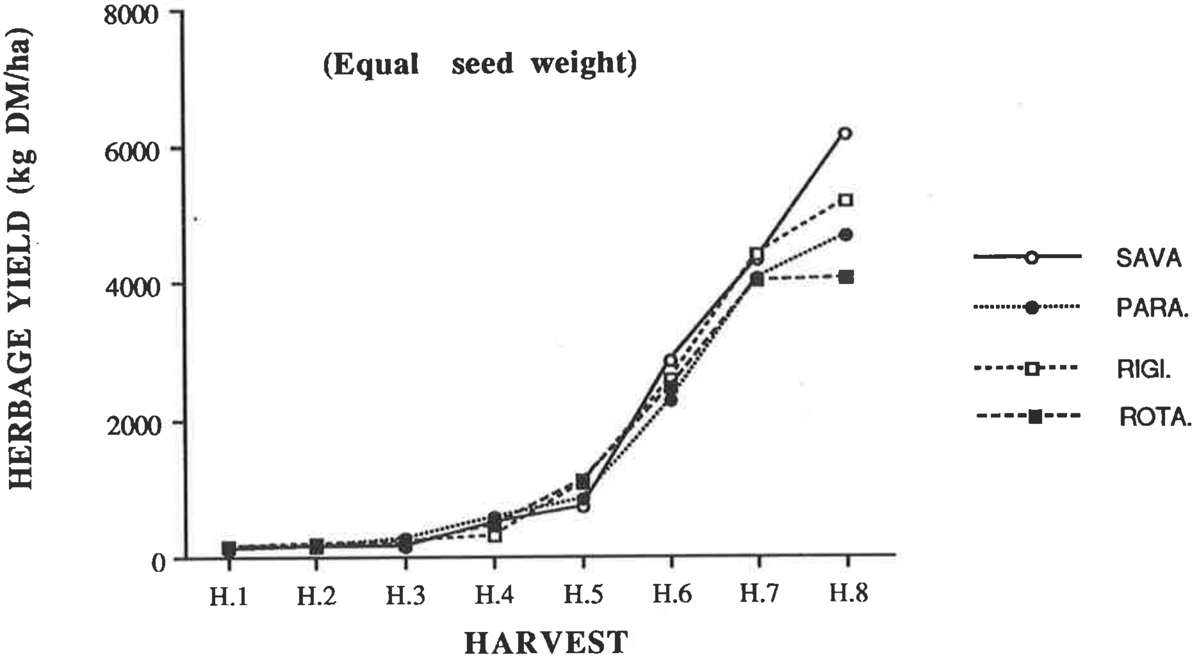

8000
6000
4000
2000
0
HERBAGE YIELD (kg DM/ha)
(Equal seed weight)
H.1
H.2
H.3
H.4
H.5
H.6
H.7
H.8
HARVEST
SAVA
PARA.
RIGI.
ROTA.

Fig. 5.1

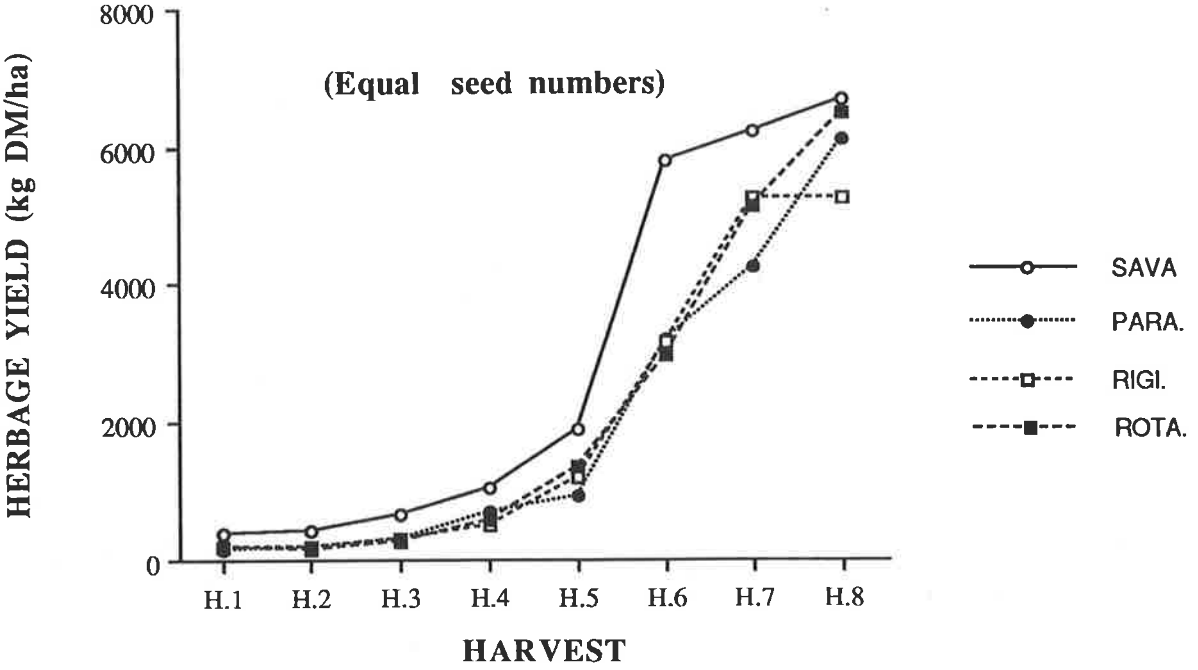

8000
6000
4000
2000
0
HERBAGE YIELD (kg DM/ha)
(Equal seed numbers)
H.1
H.2
H.3
H.4
H.5
H.6
H.7
H.8
HARVEST
SAVA
PARA.
RIGI.
ROTA.

Fig. 5.2

5.3.3 Yields of Pods and Seed in 1987

Pod yield : The summary of analyses of variance on pod and seed data is given in Table 5.6 while actual pod numbers and pod yields are summarized in Table 5.7.

Table 5.6 Summary of the analyses of variance on the parameters of pods/m^2, pod yield (kg/ha), pod index (g/100 pods), seeds/pod, seed yield (kg/ha) and Seed Index (g/1000 seeds)

	Pod #/m^2	Pod yield (kg/ha)	Seeds (#/pod)	Pod index (g/100 pods)	Seed yield (kg/ha)	Seed Index (g/1000 seed
Treatments	–	–	–	–	–	–
Genotype	P<0.001	P<0.001	.001	.001	.01	P<0.001
Sowing Rate	P<0.005	ns	ns	.05	ns	ns
SR.	–	–	–	–	–	–
Gen. x SR.	ns	ns	ns	.05	ns	ns

Table 5.7 Pod yield (kg/ha) and number of pods/m^2 of medic at two sowing rates (equal seed weight and equal seed number) on 12 June

Genotypes	Equivalent seed weight		Equivalent seed number	
	Pods (#/m^2)	Pods (kg/ha)	Pods (#/m^2)	Pods (kg/ha)
Sava	2506	6883	2668	6484
Para.	4818	5355	4977	5519
Rigi.	3821	4153	3860	4164
Rota.	4031	3548	5678	4901

LSD (5%) Pods (# m^2) = 955
LSD (5%) Pods (kg/ha) = 1688

Seed yield : Data on seed yield are summarized in Table 5.8. Sava produced most seed which probably reflected its earlier maturity and drought capability.

Table 5.8 **Seed yield (kg/ha) of medic genotypes at two sowing rates (equivalent seed weight and seed number)**

Genotype	Equiv. Seed Weight	Equiv. Seed Number	Mean seed yield
Sava	1912	1808	1860
Para.	1421	1475	1448
Rigi.	1253	1171	1212
Rota.	1231	1306	1268

LSD (5%) for interaction Genotype x Sowing Method = 434

Seed index : The weight of 1000 seeds at both sowing rates was measured. While the effect of genotype was highly significant ($P<0.0001$) there was no effect of sowing rate. However, mean seed weight decreased slightly with increasing sowing rate for all genotypes. Mean seed indices are in Table 5.9.

Table 5.9 **Seed Index (g/1000 seeds) of four annual medics grown at equal sowing rate and equal seed number**

Genotype	Equivalent seed weight	Equivalent seed number	Average
Sava	13.70	13.30	13.51
Para.	4.59	4.52	4.55
Rigi.	4.78	4.63	4.71
Rota.	6.67	6.38	6.52

Sowing Method	n.s.
Sig. of Diff. Genotype	$P<0.001$

Generally, mean seed weight decreased slightly with increasing sowing rate for all genotypes.

5.3.4 Germination Tests of Seeds in Pods

Clean pods of all four species were brought from Jordan to Adelaide. However, routine fumigation treatment of pods (with high concentration of methyl kromina for a prolonged period) appeared to not only kill all soft seeds but also hard seed which was dissected from pods and still did not germinate following scarification.

5.4 Discussion and Conclusions

Changes in plant density : Para. generally had the highest plant density which is attributed to its smaller seed size. Conversely, Sava with the largest seed size had the lowest plant densities with both methods of establishment. However, there was apparently a high level of competition between plants at higher densities. Competition for light and moisture may have been strong. Donald (1963) noted in subterranean clover swards that mortality was due especially to competition for light. Thus, a great reduction with time in plant number was observed in the medic swards especially at higher density. Similar results were reported by Westoby and Howell (1982): at high density mutual shading occurred resulting in self-thinning. Davidson and Donald (1958) concluded that some plants died in high density communities.

In comparison, the plant density of the genotypes Para. and Rota. was not large enough to create the same level of reduction as found for Sava and Rigi. at the higher sowing rate. Despite the great plasticity of plants, the competition at high densities may be so severe that a considerable number of plants will die (Donald 1963). Donald (1951) found that the higher the density the earlier the growth stage at which the competition starts. This appears to have happened to Sava sown at high density: in some cases there was a rise in plant numbers of Rota. beyond Harvest 4 at both densities. This may have been due to late emergence of seedlings increasing the plant numbers in the following samplings, or to reduced dormancy and breakdown of hard seededness with time, or simply to variability of quadrat sampling sites.

Effects of plant density are most likely due to differences in canopy structure or to differences in photosynthetic capacities of the leaves forming the canopy. Yates (1961) found that as plant density increased, the differences in herbage production between strains declined. The same pattern was found for all genotypes except Sava with high density, (Fig. 5.2) which may be attributed to seed size effect which gave large plants. White and Harper (1970) inferred that the first plants to die in Brassica were the smallest plants.

Medic herbage yield : The early-maturing genotype Sava had the highest yield of herbage at both sowing rates. In winter, herbage yield depends strongly on density (Adem 1977; Silsbury *et al.* 1979). Many research workers came to the same conclusion that, at the end of the season, yields of plants were independent of sowing rate. (Donald 1951, 1954, 1963; Silsbury and Fukai 1977; Silsbury *et al.* 1979, Prioul and Silsbury 1982). The high yield of the genotype Sava can be attributed to large inital plant size even though the plant population was the lowest at low sowing rate.

However, Rota. gave the highest herbage yield by the end of the season at low density, and the lowest yield when sown at high density. It should be noted that a much higher proportion of dead material was present in the high-density stand owing to plant mortality. Our results are consistent with the results of Stern (1965) for subterranean clover.

Overall, the highest medic herbage production at the end of the season was 6693 kg DM/ha for Sava sown at 824 seeds/m^2. However, no significant differences in herbage production were detected between the two sowing rates and the genotypes and their interactions. Lawson and Rossiter (1954) found no differences in yield of sub clover cultivars sown at equivalent weights of pure germinating seed per unit area.

Seed yield : Plants at normal field spacing are smaller, have fewer stems and leaves, fewer inflorescences, and fewer seeds than widely spaced plants. Donald (1963) stated that in sub clover swards, the dry matter yield and the seeds per plant (as well as the number of inflorescences per plant) all fell progressively with increasing density. The seeds per inflorescence and the weight per seed actually rose to a peak value as density was increased and then fell. He also found the same trend with wheat grain yield decreased by 25% at very high density. Donald (1954) also stressed that the relationship between density and seed production depended on season and time of incidence of intraplant and interplant competition. The big loss of plants of Sava and Rigi. at the high density may have influenced their seed yields. The other genotype Rota. had higher seed yield as sowing rate increased, but this did not occur for Para. which had the same sowing rate in each treatment. However, Para. had greater seed numbers per pod compared to the other genotypes, but small seed size limited seed yield. Total seed yield did not significantly change in relation to plant density. The response of seed production to sowing rate was genotype-dependant. Sava and Rigi. showed a negative response to plant density, while the seed yield of Rota. increased as sowing rate increased. Similarly, Donald (1963) reported that a major factor influencing optimum sowing rate for any particular crop is the genotype. The cold-tolerant Rigi. was the only genotype that did not show any significant relationship between seed yield and herbage production. Sava was two weeks earlier in flowering and maturity grading, while Rota. was the latest-maturing genotype used and did not have any reduction in seed yield (highest level of total seed production 1808 kg/ha).

Seed index : Decreases in seed weight as initial sowing rate increased were clear for all genotypes. It has been suggested (Donald 1954) that the greater seed weight and number of seeds per inflorescence will be at intermediate sowing rate, seed size and seed numbers will be reduced with somewhat denser stands of sub clover. Medic plants will enter plant competition earlier as density increases and this will be responsible for seed index reduction. Inter-plant competition may explain why all genotypes had slightly depressed mean seed indices at the higher sowing rates.

As sowing rate increased the mean pod weight and seed weight decreased. However, the number of seeds/pod were increased as sowing rate increased. This confirms the results of

Donald (1963) where the number of seeds per inflorescence rose to a peak as the sowing rate increased and then fell. Differences in numbers of seeds/pod and seed index are not significant for the interaction of Genotype x Sowing Rate.

The results of this experiment have shown that the early season herbage production of annual medic-based pasture strongly depends on seed size and plant density. High plant density is recommended for high early winter production. However, this is partly dependent on the genotype: for example, Sava had less seedlings per unit area than other genotypes sown at equivalent seed weight but still had good herbage production. Results clearly show that there are no differences in early herbage production between genotypes when the sowing rate was equivalent in weight of pure germinating seeds. High medic density in a pasture improves the yielding ability of that pasture; however, high density and high yield does not necessarily produce more pod and seed. Also, high density causes a very big loss in number of plants/m^2, the reduction in plant number (about 50%) was very severe with Sava and Rigi. However, at the end of the season, herbage yield was independent of sowing rate. Yields reach a ceiling depending on density, light interception and soil moisture.

The results from this experiment also show the relationship between herbage production and seed yield. Generally, the genotype Sava, which produced the most herbage, also had the highest seed yield. This was the trend for the highest and the lowest-producing genotypes Sava and Rigi. respectively. In addition, Rota. produced more herbage and seed yield as the plant density increased. The genotypes such as Sava and Rigi. had further increases in herbage yield as sowing rate increased, but seed yield did not follow the same pattern. Management of pastures should aim for high herbage and seed yield at the same time. High production of seed and survival of seed is essential to ensure replenishment of the soil seed bank and provide enough seeds for regeneration in the next season and for summer-autumn livestock feed when there is abundant seed on/in the soil surface.

6. FIELD EXPERIMENT 3: MEDICS IN SOUTH AUSTRALIA

6. FIELD EXPERIMENT 3 : EFFECTS OF TIME AND FREQUENCY OF DEFOLIATION ON HERBAGE AND SEED PRODUCTION OF ANNUAL MEDICS IN SOUTH AUSTRALIA

6.1 Introduction

It is a common belief amongst graziers that grazing of both medic and subterranean clover pastures increases herbage and seed production. On the other hand, most of the experimental evidence for cereals (Holliday 1956; Nishimura and Arata 1957; Aldrich 1959), and for a wide range of crop plants (Chester 1950), indicates that defoliation leads to a reduction in seed yield. There are, however, some cases cited by Holliday (1956) in which cereal grain yields were increased by grazing and these were usually associated with ecological conditions conducive to vigorous vegetative growth. Medic pastures may respond similarly to defoliation.

The growth of all pasture species varies greatly throughout a year : it is governed by seasonal effects and growth rhythms of the plants themselves. Different species exhibit different growth patterns. However, there are four types of genotypes and cultivars distinguishable by their habit of growth. These are : erect, semi-erect, semi-prostrate and prostrate. The effects of grazing or defoliation on dry matter yield and subsequent plant response will be influenced by plant growth habit. Controversy exists as to whether mechanical defoliation simulates grazing or not. When many genotypes with different habits of growth and different canopy structures are tested under cutting or grazing regimes, there will be differential responses to defoliation treatments. Thus, when animals graze pastures, they remove most of the lamina, depending on stock rate and duration of grazing. Mowing plants to a certain height, however, particularly at early stages of growth, may not remove the first extended leaves, especially in the case of cultivars with a prostrate growth habit. Therefore, the remaining leaf area of mechanically-defoliated plants may be greater than that of grazed plants and rate of regrowth may be increased in proportion to the amount of photosynthetic tissue remaining below the height of cut. Differences in responses to defoliation between species and cultivars may be related to growth habit, rate of leaf appearance, leaf area expansion, and carbohydrate levels in roots or stems (Jones *et al.* 1979; Zarrough and Nelson 1980).

In general, the results reported by Donald (1941) showed that as the intensity of defoliation increases, yield of shoot tissue decreases. Similar results have been obtained by varying the frequency of defoliation, the greatest reductions in yield having occurred where the defoliations have been most frequent. Lowe and Bowdler (1980) suggested that damage from severe cutting management could be reduced by lax cutting in subsequent defoliations.

This field experiment at the Waite Institute was designed to examine the herbage and seed production of four annual medic cultivars and genotypes (viz. Sava, Para., Rigi. and Rota.) as affected by the time and number of mechanical defoliations

6.2 Materials and Methods

6.2.1 Site of Experiment: The experiment was located at the Waite Agricultural Research Institute (34" 28'S Latitude 138" 38'E Longitude with an elevation of about 122.5m) near Adelaide, South Australia, on a hard-setting red brown earth soil (Piper 1938; Litchfield 1951). The physical and chemical soil characteristics are given in Table 6.1. Because of the high silt and clay content, this soil has a problem of surface sealing with consequent reduced seedling emergence, especially following excessive tillage or traffic.

Table 6.1: Some physical and chemical data on a typical Urrbrae fine sandy loam (0-10cm)

Water holding capacity		27.3%	Coarse sand	2.1%
Sticky point		22.6%	Fine sand	43.7%
Wilting point		6.9%	Silt	34.8%
Apparent specific gravity		1.32g/cc	Clay	18.0%
Soil pH 1:5 water		6.0	Organic carbon	1.33
Exchangeable cations (m.e.) -	Ca^+	4.50	Nitrogen (N)	0.10
	Mg^{++}	1.37		
	K^+	0.83		
	Na^+	0.32		

Mean climatic data for the Waite Institute and rainfall for 1988 are summarized in Table 6.2

Table 6.2 Monthly rainfall (mm), mean maximum and minimum air temperature (°C) at Waite Agricultural Research Institute, South Australia.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
Rainfall LT†	23.4	24.3	23.8	54.9	80.3	74.6	87.9	74.8	61.9	52.6	36.9	29.9
Rainfall 1988	32.6	23.4	28.2	15.0	120.6	113.6	76.4	60.0	66.4	14.8	44.6	37.0
Max. temp.	29.2	26.2	27.3	22.5	19.2	16.1	14.9	16.1	19.9	22.2	22.1	27.5
Min. temp.	17.4	15.5	17.4	12.9	12.6	10.1	9.1	9.1	11.3	12.2	12.9	16.0

† Long term 1925 - 1989 Max. temp. and Min. temp. °C. for 1988

6.2.2 Experimental design and treatments

The experiment was designed to match Experiment 2 in Jordan. The same seed source was used for each genotype. Seed of *M. scutellata* cv. Sava and *M. truncatula* cv. Paraggio was taken from Adelaide to Jordan while seed of *M. rigidula* and *M. rotata* were taken from Jordan to Adelaide. In this way it was expected that the relative performance of genotypes in Jordan and South Australia could be assessed most accurately.

This field experiment was laid out as a complete randomised block with 4 replications. Treatments comprised: Medic genotypes (4) x Defoliation treatments (4) x Blocks (4) = 64 plots. Individual plot size was 5 x 2m. The four genotypes were : *M. scutellata* cv. Sava (hereafter referred to as Sava), *M. truncatula* cv. Paraggio (hereafter referred to as Para.) *M. rigidula* Sel. 716 (hereafter referred to as Rigi.) and *M. rotata* Sel. 1943 (hereafter referred to as Rota.) Mechanical defoliation treatments were as follows:

(i) No Defoliation (DO) as a control.

(ii) Defoliation Early (DE) at flowering stage (on 19 September, 84 days after emergence).

(iii) Defoliation Late (DL) at pod stage (on 31 October, 126 days after emergence).

(iv) Defoliation Early and Late (DEL) on both dates.

The 16 treatments were allocated at random within each Block (see Diagrams 6.1 and 6.2)

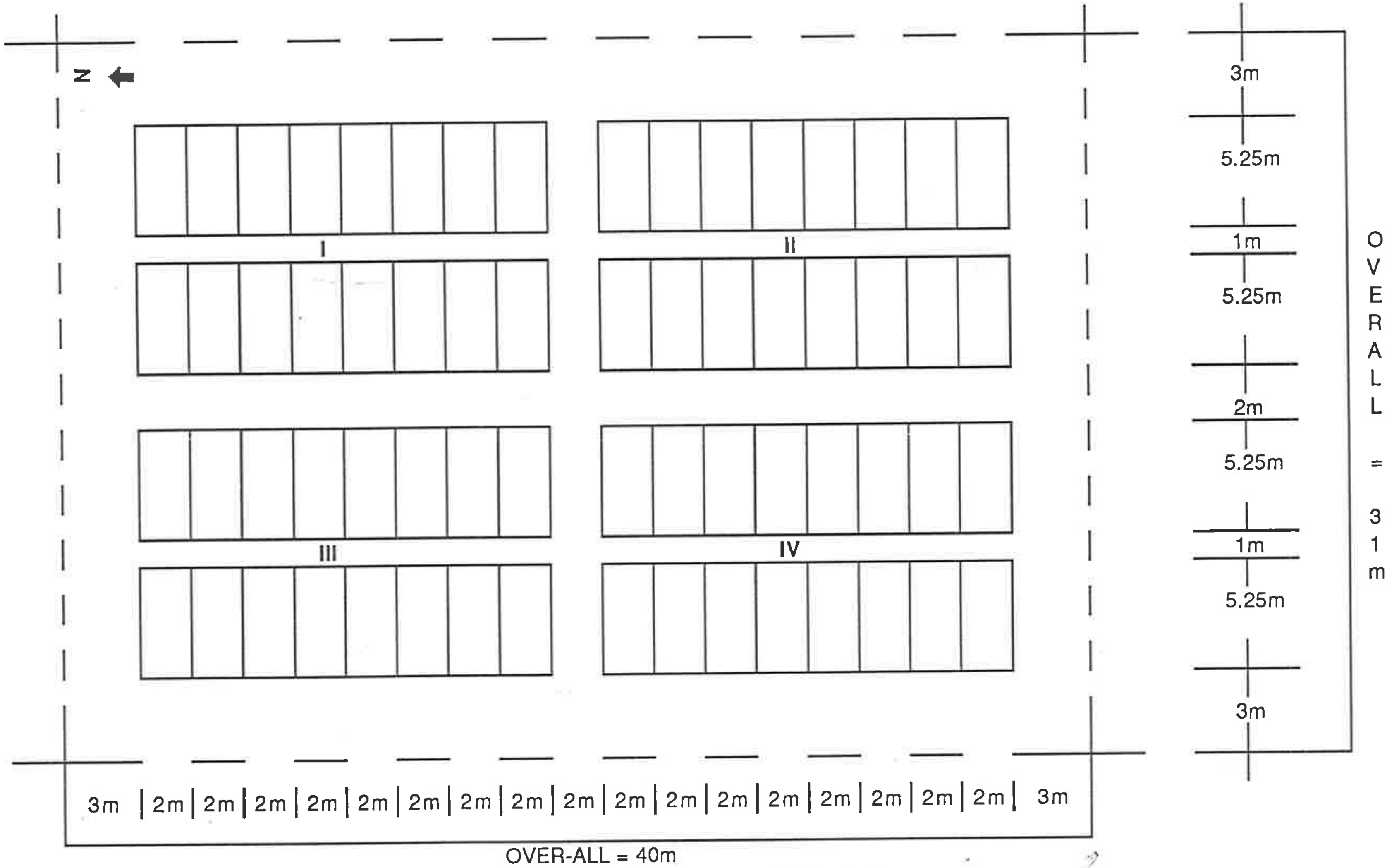


Diagram 6.1: Showing layout of Experiment 3, Waite Institute

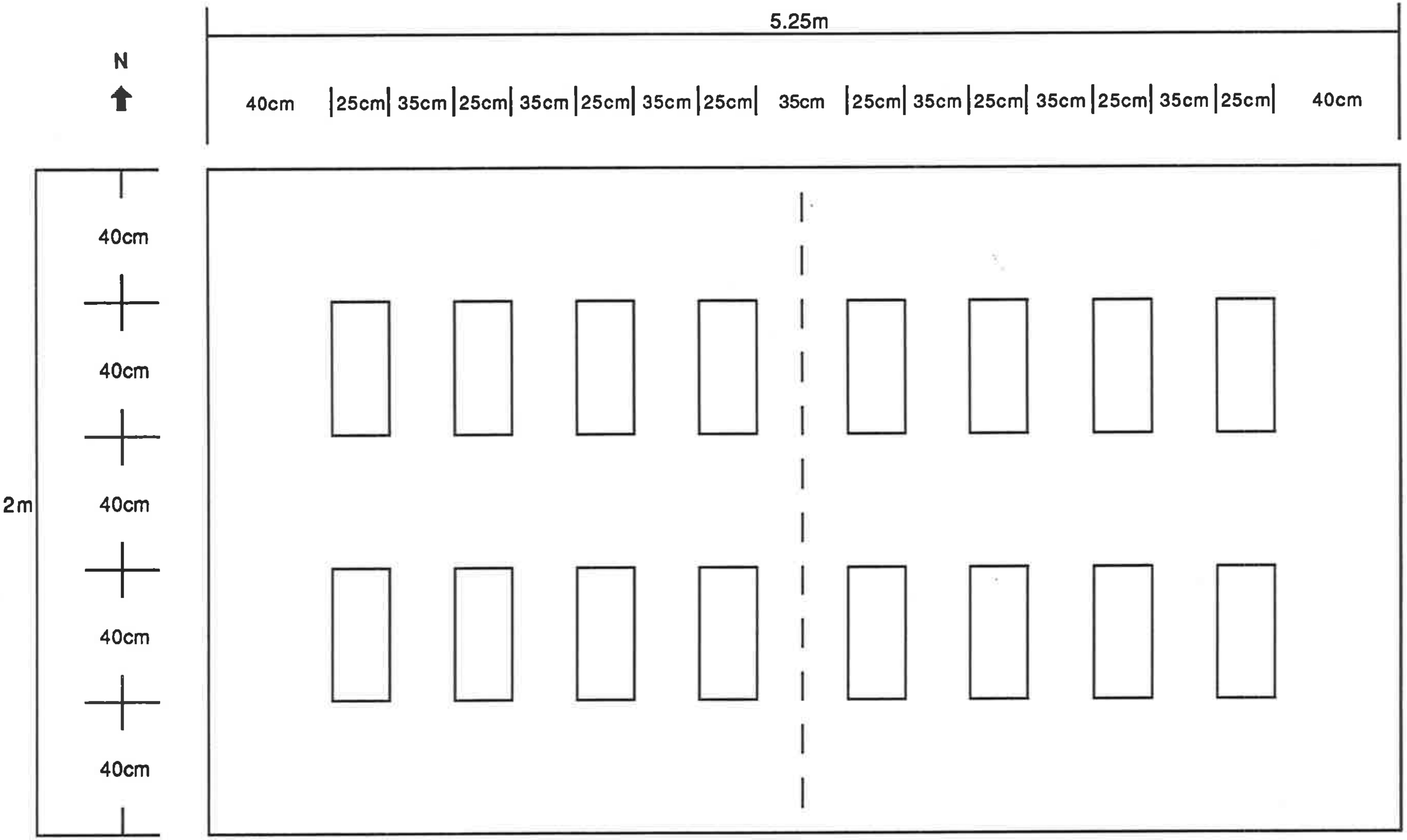


Diagram 6.2: Showing placement of wire quadrats on a plot

6.2.3 Establishing the Experiment

A fine weed-free seed bed was prepared and the experiment was sown in early winter on 17 June 1988, using a sowing rate equivalent to 30kg/ha of pure germinating seed. The same method of sowing and sampling (using pre-placed galvanized quadrats) as used in Experiment 2 was followed but 100kg/ha lime was added to the sand-superphosphate-seed mixture to assist hand-sowing of plots. On 2 July 1988 the experiment was given an irrigation of 20mm to assist germination and emergence, with a further 25mm on 14 July as rainfall was below average (Table 6.2). Sixteen galvanised wire quadrats (25 x 40cm) were arranged shortly after sowing on each treatment plot (see Diagram 6.2). The plots were divided into east and west sections (i.e. 8 quadrats per half-plot).

Establishment counts were made on 28 July, when the medic plants were at the first leaf stage. These mean emergence counts were derived from four $0.1m^2$ quadrats in each plot and the means were an average of 16 random counts for each genotype. On 1 August and 7 September, the experiment was sprayed with Carbetamex® (3kg/ha) to control wireweed and with Fusilade® (500ml/ha) to control grasses. Soursob *(Oxalis pes-caprae)* was controlled by hand weeding on 19 July and 7 September. The experiment was given a supplementary irrigation of 25mm on 27 October.

6.2.4 Mechanical Defoliation and Herbage Sampling

The early defoliation (treatments DE and DEL) of all genotypes was made at flowering time on 19 September (84 days after emergence) when the soil and weather conditions were favourable. A heavy-duty rotary mower was used to defoliate at 5cm above ground level. The cut material was removed from the plots by raking immediately after mowing. Herbage removed by mowing was dried in a forced-draught dehydrator at 85°C for 24 hr and weighed.

The late defoliation treatment (DL) and the second cutting of the (DEL) treatment of all genotypes were carried out at the early pod stage on 31 October (126 days after emergence and

42 days after the early defoliation). Procedures were the same as for early defoliation. The plots were sampled just before and after each defoliation treatment in order to assess the actual harvested dry matter and the residual dry matter after defoliation. Plots were also sampled at intervals throughout the season as for Experiment 2, so that the patterns of growth and regrowth and the effects of defoliation and residual dry matter on regrowth could be assessed. Harvest dates for maximum accumulated herbage dry matter yields and seed production are shown (Table 6.3).

Table 6.3 **Number and dates of samplings for determining herbage and seed yields.** **(All sampling based on 2 x 0.1m^2 quadrats)**

Harvests	Plot Sampling		
	Dates	Days after emergence	Measurements based on dry weight
H1	18 July 1988	21	Medic herbage
H2	8 Aug. 1988	42	" "
H3	29 Aug. 1988	63	" "
H4	19 Sept. 1988	84 (a)	Medic & weed herbage
H5	10 Oct. 1988	105	" " "
H6	31 Oct. 1988	126 (b)	" " "
H7	21 Nov. 1988	147	" " "
H8	12 Dec. 1988	168	" " "
H9	2 Jan. 1989	189	" " "
H10	31 Jan. 1989	210 (c)	Pods only for seed yield

(a) Just before early defoliation (DE)
(b) Just before late defoliation (DL)
(c) Seed yield samples (2 quadrats of 0.1m^2) were taken on 31 January 1989 in each treatment.

6.2.5 Data Collection

Medic emergence : Counts (plants/m^2) were made on four of the sixteen 0.1m^2 sampling sites on each plot and sampling procedure. For assessing pasture production, plots were sampled 9 times throughout the growing season. Medic plants were sampled at random from the areas between quadrats in Harvests 1 and 2 only and harvests were randomized among the eight quadrats (7 of these quadrats were used for the herbage harvests). Harvest 3, corresponded with quadrat position 1 and Harvest 4 corresponded with quadrat position 2 and so on. Quadrat position 8 was used for the seed harvest. In brief, on each harvest occasion two quadrats were taken per plot, one from the eastern half and one from the western half of each plot.

Yield of herbage and seed : Medic plants were cut to just below ground level so that plants could be counted. All herbage samples were dried at 85°C for 24 hours in a forced-draught dehydrator. Other measurements made at each harvest occasion included total herbage yield of medic and yield of weeds. A seed harvest was made on 31 January 1989. East and west samples were taken on each plot. A stiff, fibre hand broom was used to collect the samples (all pod and dry residue materials within the quadrat). The samples were dried at 40°C in a forced-draught dehydrator for 24 hours to ensure uniform drying. All samples were processed by removing the pods by hand from the dry pasture residues prior to weighing, dissecting and threshing operations. Yield components measured from the seed harvest were : pod number/m^2, pod yield (kg/ha), dry weight of 100 pods, seeds/pod, total seed yield (kg/ha) and mean seed index (g/1000 seeds). From subsequent germination studies the following were determined : hard seed percentage, soft seed percentage, (permeable, readily-germinable), dormant seed percentage (permeable, swollen seed but no germination).

6.2.6 Statistical Analyses

A Genstat statistical analysis program was used to analyse the data on dry matter yield and its components from all harvests as well as seed yield and its components. Least significant differences were calculated as in Experiment 2, 1987. Because defoliation treatments were incomplete at samplings up to 31 October, the data were analysed in separate groups as a randomized complete block design.

6.3 Results

Description of the results summarise the main effects such as defoliation levels and genotype. First order interactions such as Defoliation x Genotype are described if they are significant. Tables in Appendix B contain the actual values which have been used for the Figures. Also, there are Appendix tables for the herbage harvest and seed harvest.

6.3.1 Medic Plant Populations

In the year of sowing (1988) emergence counts were made on 12 July. The data required natural log transformation. Counts were made along four transects across each of the four sets of treatment plots (256 counts made).

Genotype effects : The number of medic plants (#/m^2) varied according to the genotype. The mean seed weight of Sava, Para., Rigi. and Rota. were 20.5, 4.0, 5.6 and 6.5mg respectively, hence plant numbers were dependent on seed weight which determined the number of seeds sown for each cultivar. As Para. had considerably smaller seed, there were more seeds sown resulting in higher plant populations of seedlings than the other genotypes (460 plants/m^2) which gave the highest establishment percentage after Sava genotype (Table 6.4). Hence, differences between genotypes were highly significant ($P<0.001$) as shown in Table 6.5. All genotypes showed a decline in plants/m^2 as the plants aged (Table 6.6). Of the genotypes, Paraggio had the highest reduction in plants/m^2 starting with 403 plants/m^2 and finishing with less than 50% of the original plant population at Harvest 1 (H1) by the end of the growing season. Hence, Paraggio was the only genotype which had a significant relationship ($P<0.5$) between plants/m^2 and the time of sampling (Table 6.7).

Defoliation effects : The effects of defoliation treatments on plant numbers per unit area were mostly non-significant as shown in Table 6.5. The same trend of reduction in plants/m^2 was found with all defoliation treatments as the time of sampling progressed and DL had the most severe reduction in plants/m^2 where only a quarter of the plants survived until the end of the growing season (Table 6.8). However, the effect of early defoliation was significant at H5 and H6, while the late defoliation had a significant effect on plants/m^2 at H7 and H9.

Genotype and defoliation interaction effects : Analysis was made on each defoliation level separately, so that genotype differences at each defoliation regime could be clearly seen. According to data in Table 6.9, clear differences in plants/m^2 were between genotypes rather than between defoliation treatments. The genotypes Para. and Rigi. always had the highest plants/m^2 compared to other genotypes, which reflects their small seed size and seed weight but not defoliation effects. However, no significant interaction between genotypes and defoliation regimes was detected in this experiment (Table 6.5).

6.3.2 Medic Herbage Production

Data on the productivity of the four genotypes with and without defoliation are summarised in Tables 6.10 to 6.15 and Appendix B, Figures B.1, B.2, B.3.

Genotype effects : Herbage dry matter production varied according to the productivity and adaptability of the genotype to the environmental conditions. Differences in herbage production between genotypes were highly significant ($P<0.001$ transformed data) during the growing season (Tables 6.10 and 6.11). During winter, Para. and Sava yielded most herbage (Harvest 1 to Harvest 4), while Rota. gave the lowest herbage yield for the full season. However, during spring herbage production, Para. was still the best yielding genotype (7376kgDM/ha) at Harvest 7 followed by Rigi. which gave 6123 kgDM/ha at the same harvest but yielded 7165 kg DM/ha at Harvest 6.

All genotypes showed herbage yield increases with time up to Harvest 6 and then declined rapidly as shown in Appendix B, Fig. 1. By the late winter (just before DL), Undefoliated genotypes had produced much more dry matter than any genotype defoliated early (Table 6.12), but the relative differences between the genotypes was maintained, with Rigi. producing marginally more than other genotypes and Rota. being the lowest-producing genotype over all the treatments.

Defoliation : Although all defoliation treatments decreased the final yield of herbage by the end of the season, the early defoliation (DE), which resulted in a growth curve nearly parallel to that of the non-defoliated plants (Appendix B, Fig. 2), led to a reduction of 2t/ha at Harvest 6, which was highly significant ($P<0.001$) compared to control yield.

At the final Harvest (H9) for total dry matter yield the difference in herbage yield was reduced between the control and early defoliation (Table 6.13). Moreover, this difference was reduced to less than 1t/ha of cumulative dry matter yield when the herbage removal at the early defoliation was added to the maximum final dry matter present at the end of the season (Table 6.14).

On the other hand, the late defoliation (DL) had a severe effect on herbage yield as it removed the growing points and primary and secondary branches of all genotypes. Regrowth, therefore, was carried out by the newly-initiated branches and growing points after defoliation. Although moisture stress and high temperatures were not experienced after the late defoliation under the conditions of the experiments, the short time span from late branch initiation to maturation accelerated crop development and resulted in poor dry matter yields (847kg/ha) at Harvest 9, while the control treatment gave the highest herbage dry matter yield (5560kg/ha) (Table 6.13).

Data in Table 6.12 also show that the Rigi. and Sava genotypes were both superior to Para. and Rota. in their dry matter production in late October and just before the late defoliation (DL). This indicates that Rigi. and Sava are the most productive genotypes for hay cuts or early grazing. Generally, maximum dry matter yield obtained from early-defoliated genotypes was more than double that of the late-defoliated genotypes as shown in Table 6.14.

The average cumulative dry matter yield produced from H5 to H9 (after early defoliation to the end of the season) was reduced only 30% by DE, 54% by DL and 70% by DEL compared to the control treatments DO (Table 6.13). However, there is little doubt that plant senescence with leaf drop and disintegration / rotting would have contributed to the apparent decline in yield. Certainly, realistic yields were recorded only up to Harvest 7.

Genotype and defoliation interaction effects : Table 6.15 shows that the undefoliated Rigi. which grew more slowly than Para. and Sava over winter made faster growth later in spring. Furthermore, the forage genotype Rigi., even with early defoliation which removed most of its photosynthetic material in winter, produced more dry matter than Sava and Rota. over all the defoliation regimes. However, Para. significantly outyielded the other genotypes with all treatments at the end of the season (Harvest 9), while Rota. finished the season with a very poor dry matter production (229kgDM/ha). On the other hand, the interaction between the genotypes and defoliation regimes were not significantly different from Harvest 1 to Harvest 7 but were significantly different at Harvest 8 and 9. The early defoliation (DE) was the most productive defoliation regime for all genotypes. As stated previously, the results for Harvests 8 and 9 must be accepted with caution.

The highest maximum cumulative dry matter yield was 13966kgDM/ha produced by undefoliated Rigi. followed by undefoliated Para. 12643kgDM/ha (Table 6.14). Furthermore, the interaction between genotype and early defoliation were not significant except at Harvest 5 and Harvest 9. No significant interactions were found between cultivar and late defoliation except at Harvest 8 ($P<0.05$). Under the twice-defoliated regimes the only significant differences between herbage yield were found at Harvest 8 ($P<0.01$) and Harvest 9 ($P<0.05$) as shown in Table 6.10.

Table 6.4 Potential and actual plant density and establishment percentage of four annual medic genotypes

Genotypes	Potential (plants/m²)	Actual (plants/m²)	Establishment (%)
Sava	150	118	78.7
Para.	750	460	61.3
Rigi.	535	278	60.0
Rota.	462	117	25.3

Table 6.5 Summary of analyses of variance on establishment data for medic (Based on transformation to natural logarithms)

Treatments	Harvests								
	H1	H2	H3	H4	H5	H6	H7	H8	H9
Genotype (Gen.)	***	***	***	***	***	***	***	***	***
Defoliation Early (DE)	ns	ns	ns	ns	ns	xx	xx	ns	ns
Defoliation Late (DL)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Gen.xDE	ns	ns	ns	ns	ns	x	ns	ns	ns
Gen.xDL	ns	ns	ns	ns	ns	ns	ns	ns	ns
DExDL	ns	ns	ns	ns	x	ns	ns	ns	xx
Gen.xDExDL	ns	ns	x	x	ns	ns	ns	ns	ns
Coeff. of Var. (%)	5.1	9.3	6.2	6.7	5.5	7.2	8.7	7.8	12.6

ns = not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 6.6 **Mean plant densities (plants/m^2) for four genotypes at nine harvests**

Harvest	Sava	Para.	Rigi.	Rota.	LSD (5%)	Sig. of Diff.
H1	91	403	222	81	35	0.001
H2	122	508	279	126	83	.001
H3	138	389	299	129	59	.001
H4	114	448	244	104	61	.001
H5	98	494	288	109	50	.001
H6	89	323	207	88	42	.001
H7	125	362	389	146	100	.001
H8	93	360	207	89	43	.001
H9	64	189	135	36	44	.001

Table 6.7 **Intercept (a) and regression coefficient (b) of the regression of plants/m^2 on time of sampling (days after emergence)**

Genotype	a	b	r	F probability
Sava	124.3	- 4.1	0.492	ns
Para.	509.5	- 24.6	0.698	0.05
Rigi.	287.3	- 7.0	0.266	ns
Rota.	123.6	- 4.6	0.383	ns

Table 6.8 **Medic densities (#/m^2) under four defoliation treatments**

Harvest	DO	DE	DEL	DL	Sig. of Diff.	LSD at 5%
H5	249	265	206	269	*	50
H6	177	155	189	186	ns	-
H7	256	213	185	369	ns	-
H8	193	205	167	184	ns	-
H9	129	108	125	62	**	44

Note: Early defoliation at H4; Late defoliation at H6.

Table 6.9 **Plant density (#/m^2) of four medics under four defoliation regimes**

Genotype	Harvest	Defoliations regime			
		DO	DE (at H4)	DEL	DL (at H6)
Sava	H5	96	105	94	96
	H6	90	81	56	128
	H7	107	103	99	191
	H8	101	85	94	92
	H9	64	79	69	44
	mean	92	91	82	110
Para.	H5	465	545	402	565
	H6	305	265	411	311
	H7	436	291	310	412
	H8	342	432	305	361
	H9	202	180	260	112
	mean	350	343	338	352
Rigi.	H5	336	231	304	280
	H6	195	211	218	205
	H7	347	321	194	194
	H8	238	199	192	198
	H9	202	149	126	65
	mean	264	222	207	188
Rota.	H5	99	106	96	136
	H6	119	62	72	98
	H7	133	136	139	178
	H8	90	105	76	86
	H9	46	22	48	28
	mean	97	86	86	105

Table 6.10 **Summary of analyses of variance on data for medic herbage production (based on transformation to natural logarithms)**

Treatments	H1	H2	H3	H4	H5	H6	H7	H8	H9	Max. Cum. Herb.
Genotype (Gen.)	.001	.001	0.001	.001	.001	.001	.001	.001	.001	.001
Defol. Early (DE) †	ns	ns	ns	ns	.001	.001	ns	ns	ns	0.001
Defol. Late (DL) ††	ns	ns	ns	ns	ns	ns	.001	.001	.001	.001
Gen.x DE	ns	ns	ns	ns	.001	ns	ns	ns	.05	ns
Gen.x DL	ns	ns	ns	ns	ns	ns	ns	ns	.05	ns
DE x DL	ns	ns	ns	ns	ns	ns	ns	ns	.001	ns
Gen.xDExDL	ns	ns	ns	ns	ns	ns	ns	.01	.05	ns
Coeff. of Var. (%)	15.0	8.3	10.6	6.4	7.3	7.8	7.2	7.9	13.4	

† Early defoliation after H4 sampling †† Late defoliation after H6 sampling

Table 6.11 **Differences in herbage production (kgDM/ha) of four annual medic genotypes on eight harvest occasions**

Harvest	Genotype					
	Sava	Para.	Rigi.	Rota.	Signif.	LSD (5%)
July 18 H1	36	39	29	10	***	9
Aug. 8 H2	132	139	87	44	***	24
Aug. 29 H3	361	439	230	71	***	105
Sept. 19 H4	1420	1567	1056	438	***	311
Oct. 10 H5	2129	2955	2012	860	***	579
Oct. 31 H6	6377	6492	7165	2897	***	2299
Nov. 21 H7	5134	7376	6123	2651	***	1655
Dec. 12 H8	3857	4077	3934	1115	***	1312

Table 6.12 Effect of early defoliation on medic herbage yield (kgDM/ha) during spring

Genotype	Defoliation	
	DO	DE
Sava	9182	3572
Para.	8637	4347
Rigi.	9282	4847
Rota.	3251	2543

Table 6.13 Effect of defoliation treatment on the herbage yield (kgDM/ha) of medic (means of four genotypes)

Harvests	Defoliation			
	DO	DE †	DEL ††	DL ††
H5	2630	1272	1266	2790
H6	6701	3967	3688	6975
H7	10532	7341	1679	1731
H8	5656	4074	1417	1834
H9	5560	5100	1364	847
Average	6215	4350	1883	2835

† Early defoliation after H4 †† Late defoliation after H6

Table 6.14 Total yield of medic present at the time of each defoliation and the maximum cumulative medic yield (yield data in kgDM/ha)

Herbage removed at defoliation (kgDM/ha) Defoliation regime				Maximum herbage yield (kgDM/ha) Defoliation regimes				Cumulative herbage yield (kgDM/ha) Defoliation regimes			
Genotypes	DE	DEL	DL	DO	DE	DEL	DL	DO	DE	DEL	DL
Sava	805 -	810 1453	- 4578	10334	6691	1129	2381	10334	7496	3393	6960
Para.	366 -	464 2984	- 5096	12643	11049	3047	2764	12643	11415	6494	7860
Rigi.	320 -	220 3893	- 5145	13966	7547	1728	1253	13966	7867	5842	6399
Rota.	144 -	198 2158	- 3454	5184	4078	810	529	5184	4222	3166	3984

Table 6.15 Pasture availability herbage yield of four medic genotypes grown under four defoliation regimes (kgDM/ha)

	DO				DE				DEL				DL			
Harvests	Sava	Para.	Rigi.	Rota.	Sava	Para.	Rigi.	Rota.	Sava	Para.	Rigi.	Rota.	Sava	Para.	Rigi.	Rota.
H1	23	38	34	12	32	41	26	6	51	39	29	9	39	39	28	14
H2	82	103	76	52	163	130	100	26	167	157	93	61	118	166	78	39
H3	337	514	181	44	393	395	167	58	209	281	316	88	503	564	255	94
H4	1483	1732	973	363	1664	1473	1199	344	1318	1322	952	545	1215	1742	1099	498
H5	3589	3256	2200	1471	712	2003	1863	529	580	2169	1789	528	3635	4392	2197	936
H6	8050	7878	8270	2608	3373	4053	5770	2671	3772	4641	3924	2415	10315	9396	10295	3895
H7	10335	12643	13966	5184	6691	11049	7547	4078	1129	3047	1728	810	2381	2764	1253	529
H8	5028	7451	7713	2434	6514	3762	5146	878	1401	1960	1676	630	2487	3136	1199	516
H9	5940	7062	6287	2949	5730	6926	6085	1659	1292	2580	1194	390	1906	684	568	229

6.3.3 Weeds

A range of broadleaf and grass weeds were established in the treatment plots. Early in the season the main broadleaf weed was sour sob *(Oxalis pes-caprae)*, but other broadleaf weeds such as wireweed *(Polygonum aviculare)* and capeweed *(Arctotheca calendula)* had begun to grow later. Wireweed became more dominant later in the season after the soursob had senesced and matured. In spring, capeweed was the most prevalent in all the treatments. The main grass weed was annual ryegrass *(Lolium rigidum)* which became more dominant together with capeweed as the season progressed. There were also volunteer cereal plants. The yield of weeds was examined to assess the effects of the weeds on the four medics at the various levels of defoliation.

Table 6.16 Summary of analyses of variance of data on yield of weeds

Treatments	Harvests					
	H4	H5	H6	H7	H8	H9
Genotype (Gen.)	P<0.001	.001	0.001	0.01	.001	.001
Defoliation (D)	ns	ns	ns	ns	ns	ns
Gen. x D	ns	ns	ns	ns	ns	ns
Coeff. of Var. (%)	39.2	30.9	50.7	321.0	171.3	144.1

Genotype and defoliation level : Genotypes differed in the inability to suppress weeds (Tables 6.16 and 6.17). The ability to suppress weeds was mainly due to medic plant density and growth habit (height). Generally, Sava and Para. with more-erect habit, gave the best weed control particularly at Harvest 4 and 5 (Table 6.18). Rota. showed a limited ability to compete with weeds during the full growing season at different levels of cutting. This was probably due to large losses of plant numbers. Overall defoliation had little influence on weeds (Table 6.19). There were significant differences in the ability of any medic cultivar tested to suppress weed growth over all the growing season (Harvest 4 to Harvest 9) for each of the cutting levels (Table 6.16). However, there is no significant interaction between genotype and defoliation in terms of suppressing weed growth (Table 6.20). The results also indicate that herbage production of a genotype depends on its ability to control weeds. Medic herbage production was compared with weed DM for Harvests 4 to Harvest 9 to investigate the effect of weed on herbage yield of annual medics. The differences between pasture components are highly significant (Tables 6.17 and 6.18) but there were no significant differences in total yield of the pasture (medic + weed). The available medic herbage yield will depend on the amount of weeds present in the treatment.

Table 6.17 **Available pasture, medics, weeds and the total pasture on 1 January 1989 (Harvest 9)**

	Sava	Para.	Rigi.	Rota.	Signif. of Diff.
Medic	3717	4313	3533	1306	* * *
Weed	1947	1422	1963	3258	* * *
Total	5664	5735	5496	4564	ns

Medic herbage yield, LSD (5%) = 749. Weed yield LSD (5%) = 696. Total ns.

There is a clear significant relationship between the medic yield and yield of weeds (Table 6.21). However, the yield of weed decreased as the herbage yield increased and vice versa for each defoliation level (Table 17). Rota. lost its competitiveness by the end of the season, presumably due to plant losses. Harvest 8 and 9 showed a marked increase in the amount of weed present in Rota. plots (Table 18).

Table 6.18 **Influence of medic genotypes on yield of weeds (kgDM/ha)**

Harvest and Days after Emergence	Genotypes				LSD (5%)	Sig. of Diff.
	Sava	Para.	Rigi.	Rota.		
H4 (84)	602	486	602	1004	xxx	188
H5 (105)	811	728	1176	1574	xxx	236
H6 (126)	806	1379	1228	2047	xxx	493
H7 (147)	1146	1049	906	2653	xx	1040
H8 (168)	1573	1317	1392	2985	xxx	701
H9 (189)	1947	1422	1963	3258	xxx	696

Table 6.19 **Effects of defoliation treatment on yield of weeds (kgDM/ha) Data are means from four medic genotypes**

Harvest	Defoliation Treatment				Signif. of Diff.
	DO	DE	DEL	DL	
H4	766	488	515	925	ns
H5	1195	1148	811	1135	ns
H6	1450	1545	1353	1112	ns
H7	1959	1840	1319	636	ns
H8	1752	2209	1871	1435	ns
H9	1787	2531	2461	1810	ns

Table 6.20 **Yield of weeds (kgDM/ha) in each genotype at each harvest**

Harvests		Sava	Para.	Rigi.	Rota.
DO	H4	639	516	717	1193
	H5	894	743	1419	1724
	H6	502	1981	1184	2131
	H7	1020	1543	1838	3435
	H8	1054	1906	860	3188
	H9	1784	968	1765	2633
DE	H4	315	363	435	841
	H5	805	915	1311	1563
	H6	978	1400	1098	2705
	H7	2366	1109	825	3061
	H8	1596	1274	1225	4740
	H9	2595	2096	1429	4003
DEL	H4	524	569	354	611
	H5	633	463	914	1234
	H6	1134	993	1483	1804
	H7	876	736	679	2986
	H8	2060	1215	2083	2126
	H9	1763	1670	2448	3965
DL	H4	927	497	903	1371
	H5	911	793	1059	1778
	H6	613	1140	1148	1548
	H7	320	809	283	1131
	H8	1581	871	1400	1888
	H9	1645	953	2213	2430

Table 6.21 **The relationship between medic herbage yield (x) and weed yield (Y). A quadratic equation was fitted to the data of the form $Y = a+bx+cx^2$**

Genotype	a	b	c	r	Significance
Sava	- 1012.4	1.3	- 1.6	0.899	.05
Para.	- 616.6	0.8	- 6.9	0.930	0.01
Rigi.	443.0	0.4	- 3.9	0.561	ns
Rota.	- 1131.2	4.9	- 1.3	0.935	0.01

6.3.4 Seed Data

Table 6.22 shows seed yield and its components for the mean of each genotype and defoliation regimes and their interaction. The data give a useful comparison between the four medic genotypes as well as within each genotype under the different defoliation.

(a) Genotype effect : Pod yield improved as the time progressed. All genotypes showed a similarity in their productivity of pods at H5 and H6 except Rota., the least productive genotype in terms of pod yield. Sava had the highest seed yield (1335 kg/ha) which was about double that of any other genotype. The lowest seed yield was obtained by Rota. (212 kg/ha) over all defoliation treatments, compared to other genotypes. However, there was a highly significant interaction between genotype and defoliation for seed yield and its components. There was a significant interaction between genotype and defoliation for seed yield and components except with the seed : pod ratio. Furthermore, there were no significant differences in seed yield and components between defoliation treatments, defoliation early, genotype x defoliation early, genotype x defoliation late and Genotype x DE x DL. The only significant interaction effect between Genotype x DE and Genotype x DE x DL was found on seed number/pod which more likely resulted in high seed yield. All these significant levels are summarised in Table 6.23. Highest seed yield, pod yield, seed : pod ratio and average seed weight (seed index) were obtained from Sava (Table 6.22a). Undefoliated treatments of Para. gave the maximum pod number, pod yield (Fig. 6.11) and seeds/pod (Table 6.22b). However, the maximum seed yield (2994 kg/ha) was obtained from early-defoliated Sava plots

(Figs. 6.11a and 6.11b). Defoliation on two occasions caused a very severe effect on seed yield in all genotypes. Moreover, the interaction effect of cultivar and defoliation was not significant, with Sava having higher seed yields at all the defoliation levels, particularly when it was early defoliated, while Rota. shows the lowest seed yield and yield components (Table 6.22a). Undefoliated treatments of Para. gave the maximum pod number, pod yield and seeds/pod (Table 6.22b). However, the maximum seed yield (1994 kg/ha) was obtained from early-defoliated Sava plots. Defoliation on two occasions caused a very severe depression of seed yield in all genotypes. Rota. gave the lowest seed yield and yield components (Table 6.22a)

b) Defoliation and interaction with genotypes : The early defoliation (DE) of medic genotype caused a non significant average seed yield increment of about 16%, whereas the other defoliations, DEL and DL, brought about a very serious reduction in seed yield of about 88% (Table 6.22b). Defoliation early in winter (DE) brought a 21% reduction in pods/m^2 and pod yield and about a 9% loss in average seed weight. Larger reductions occurred in the other defoliation treatments particularly in DL leading to a sharp decline in the number of pods, pod yield, seeds/pod, seed : pod ratio and 1000 seed weight of about 79%, 83%, 40%, 53% and 26% respectively (Table 6.22b). The seed : pod ratio, on the other hand was increased 34% with the DE treatment leading to a higher seed yield over other treatments. The increase in seed yield following early defoliation was most obvious with Sava and Rigi. (47% and 13% respectively). Early defoliation also improved Rigi. productivity about 10% in pod yield and 15% in number of seeds/pod as shown in Table 6.22c). However, data in Table 6.22 illustrate that seed yield and its components can be improved by early defoliation at flower initiation (84 days after emergence) while defoliation later in the season, at pod formation stage or after, will seriously reduce the seed yield and its components. All genotypes had increased seed yield when pod and herbage production increased, However, Rota showed the smallest increase and Sava the largest.

Table 6.22 Seed yield and yield components of medic genotypes as affected by defoliation

Trait	Seed yield (kg/ha)	Pod (#/m^2)	Pod yield (kg/ha)	Seeds/pod (#/pod)	Seed : pod ratio	Seed index (g/1000 seeds)
(a)						
Genotype						
Sava	1335	1496	3198	4.0	38.0	16.7
Para.	600	3298	3180	4.6	16.3	4.7
Rigi.	583	2448	2899	4.3	13.9	5.8
Rota.	212	1309	923	2.8	16.1	6.4
LSD (0.05)	696	839	804	0.3	18.4	0.9
(b)						
Defoliation						
DO	1115	3698	4738	5.2	23.6	9.9
DE	1339	2919	3720	5.2	35.9	9.0
DEL	136	1139	926	2.8	13.6	7.4
DL	140	795	815	3.1	11.2	7.3
(c)						
Gen. x Defol.						
DO						
Sava	1589	2321	5548	5.0	28.4	19.9
Para.	1318	6030	6489	5.6	20.1	5.3
Rigi.	1024	3894	4852	5.5	20.6	6.3
Rota.	530	2547	2063	4.6	25.2	6.1
DE						
Sava	1994	1671	3834	5.0	29.2	18.0
Para.	898	4397	4441	5.3	19.6	5.0
Rigi.	1180	3852	5369	6.5	21.1	6.4
Rota.	283	1756	1237	3.9	22.8	6.6
DEL						
Sava	291	829	1253	3.5	22.1	14.0
Para.	122	1805	1238	4.0	14.1	4.6
Rigi.	108	1352	978	2.6	9.9	5.6
Rota.	23	570	237	1.0	8.4	5.3
DL						
Sava	466	1163	2155	4.2	21.3	14.9
Para.	64	961	554	3.6	11.6	4.0
Rigi.	20	693	398	2.7	4.1	4.8
Rota.	12	363	155	1.8	7.9	5.7

Table 6.23: Summary of the analysis of variance on the effects of genotype and defoliation on seed parameters

	Seed yield (kg/ha)	Pods (#/m^2)	Pod yield (kg/ha)	Seeds (#/pod)	Seed pod ratio	Seed Index (g/1000 seed)
Genotype (Gen.)	P<0.001	.001	.001	.001	0.5	.001
Defol. Early (DE)	ns	ns	ns	ns	ns	ns
Defol. late (DL)	.001	.001	.001	.001	.01	.001
Gen. x DE	ns	ns	ns	.001	ns	ns
Gen. x DL	0.5	.01	.001	.001	ns	.001
DE x DL	ns	ns	ns	ns	ns	ns
Gen. x DE x DL	ns	ns	ns	.01	ns	ns
Coeff. of Var. (%)	143.1	6.7	6.4	8.9	122.5	14.7

6.4 Discussion and Conclusions

Plant population : Paraggio barrel medic with the smallest seed had clearly the highest plant numbers which were greatly reduced by the end of the season: obviously, there was a high level of intra-plant competition between the numerous but small plants of Paraggio and dramatic self-thinning resulted. At high plant densities, mutual shading is common and often causes self-thinning (Westoby and Howell 1982). A less-spectacular reduction in plant density also occurred in the other three genotypes (Table 6.6). Medic plant density declines most rapidly when initial densities are high (Adem 1977; Silsbury *et al.* 1979; Sartaj 1991). There was no clear evidence that defoliation regimes had a significant effect on medic plant numbers because there was no significant interaction between cultivar and defoliation treatments on plant number.

Medic herbage production : The response to defoliation differed in the species compared in this experiment. Hence, comparisons between species should be made with caution because the species differ greatly in general morphology (Leigh and Mulham 1967). Also, the partial defoliation treatments were not strictly comparable between species. Emphasis in this discussion is therefore placed on treatment responses within, rather than between, species.

The Australian medic cultivars (early-maturing Sava snail medic and Paraggio barrel medic) were the most productive during winter time. *M. rigidula* Sel. 716 made good growth in spring and ffinal yields were similar to that for Paraggio. However, *M. rotata* Sel. 1943 had the poorest yielding ability (Table 6.11). By late spring (just before DL) the undefoliated crop had produced much more dry matter than at the early defoliation, but the relative differences between the cultivars was maintained, with Para. producing marginally more dry matter than Rigi. at Harvest 7, 8 and 9 and both significantly exceeding Rota. From early spring (Harvest 4 onwards), as the temperature rose, all the genotypes, gave a higher dry matter yield. However, at pod formation stage, (Harvest 7) Para. outyielded all the other cultivars (7376 kgDM/ha), although it reached the maturity stage about two weeks later than Sava.

All defoliation treatments decreased the final yield of forage. A major effect of defoliation is on the roots. Crider (1955) reported that root extension slowed down or ceased within 24hr. of defoliation. Davidson and Milthorpe (1966) concluded that following severe defoliation of the grass plant, shoot regrowth is limited by the rate of nutrient uptake. However, plant top dry matter production was halved by doubling the frequency of defoliation (Hill and Pearson 1985). The differences were not significant between defoliation treatments until the time of defoliation (Harvest 5 and 6 at DE and Harvest 7 and 8 at DL). On the other hand, DE shows a parallel growth curve to DO (undefoliated), while the late defoliation (DL) had a severe effect as it removed the primary and secondary branches of all cultivars. Regrowth, therefore, was carried out by the newly initiated branches after defoliation. Although moisture stress and high temperatures were not experienced after late defoliation under the conditions of the field experiment, the short time span from late branch initiation to maturation accelerated crop development and resulted in poor dry matter yields. Data in Table 6.11 also show that Para. was superior to Rota. and Sava in dry matter production. This indicates that Para. was the most suitable early maturing cultivar for early feed or silage cuts. The twice defoliated (DEL) treatment showed better regrowth and recovery than DL at the end of the season. This was probably due to apical retardation of most of the main stems, primary and secondary branches after the first defoliation, so that many of the apices of these branches (but not the main stems) were still below cutting height at the time of the second defoliation.

The good recovery after early defoliation probably contributed to reduce a lodging problem by decreasing plant height and building up stronger (thicker) stems. This could be brought about by the improved canopy structure which allowed better light penetration through the foliage which improved leaf efficiency. Leaf efficiency (the rate of increase of herbage dry weight per unit area of leaf) was greatly influenced by intensity of defoliation. Efficiency was initially lower following severe defoliation than following less severe treatment (Brougham 1956).

In the early-defoliated treatment (DE) Para. produced over 7t/ha more forage dry matter yield than Rota. Furthermore, Para. shows the superiority in herbage dry matter over the other genotypes. However, the general results of Donald (1941, 1952) showed that as the intensity of defoliation increases, yield of shoot tissue decreases. Similar results have been obtained by varying the frequency of defoliation, the greatest reduction in yield occurring where the defoliations have been most frequent (Brougham 1956).

Weeds : The four medics exhibited differing levels of competitiveness with weeds, although this depended on medic establishment and the stage of the growth in the growing season. No cultivar was able to suppress weed growth completely. The ability of a genotype to compete with weeds is greatly affected by the growth habits of the cultivar and the weeds. Scott (1971) found plots of tall cultivars of subterranean clover had significantly fewer weeds than more-prostrate cultivars.

In this 1988 experiment, the tall medic genotypes (Sava, Para. and Rigi.) were the most successful at competing with weeds. The smaller prostrate plants and lower density of Rota were not as competitive. Hence differences in the ability of genotypes to suppress weeds were highly significant ($P<0.001$) (Table 6.16). However, weed numbers were not counted in this experiment, but the canopy height of Sava, Para. and Rigi. were similar or higher than the weeds in the plots, while Rota. was shorter. The maximum production of weeds occurred on Rota. plots (3258 kgDM/ha) while the lowest yield of weed was from Para. plots (1422 kgDM/ha) (Table 6.17). Furthermore, there were no significant differences in total herbage yield (medic plants plus weeds) on medic plots late in the season (Table 6.17).

All had more weeds as the growing season progressed, but there were no significant effects of defoliation on yield of weeds during the season. There were no significant interactions between genotypes and defoliation found in suppressing weed, even though Rota. plots gave the highest yield of weed under all defoliation regimes and Para. plots gave the lowest yield of weeds.

Seed yield and components : In this experiment, the growing season was prolonged using supplementary spray irrigation, to ensure that seed production was not limited by moisture stress. Shortening the growing season will reduce seed yield (Rossiter 1978). Defoliation prior to flowering markedly increased seed yield in two genotypes (Sava and Rigi.) compared with uncut controls because of an increase in the number of inflorescences produced. Rossiter (1961, 1972) showed that defoliation prior to flowering and at early flowering increased the numbers of inflorescences. These extra flowers were largely responsible for the increased seed yields. Furthermore, most of the defoliation effect on flower numbers could be attributed to increases in stem numbers. On the other hand Para. and Rota. seed yields were decreased with early defoliation prior to flowering. However, the effect of defoliation on seed production varied markedly between genotypes, ranging from a large increase to a decrease in seed yield (Scott 1971). The differences in seed yield between medics sown in this experiment were significant . The highest seed yield was obtained by Sava (1335 kg/ha) and the lowest produced by Rota. (212 kg/ha) (Table 6.22). However, with further cutting after flowering the seed yield was decreased markedly for all cultivars compared with the uncut control treatment. As an example, the seed yield of Sava declined from 1589 kg/ha in the undefoliated control to 466 kg/ha and to 291 kg/ha at DL and DEL treatments respectively as shown in Table 5.13.

The finding that defoliation had an effect on seed yield is in contrast to the results of Rossiter (1961) with subterranean clover but supports the data of Carter (1986) who found that haymaking at early flowering greatly reduced seed production of medics but had no effect on sub clover. On the other hand, Collins and Aitken (1970) delayed flowering by defoliations prior to flower initiation. Over all treatments, late defoliation (DL) and double defoliation (DEL) caused a highly significant reduction in seed yield compared with uncut (DO) treatment from 1115 kg/ha to 140 kg/ha and to 136 kg/ha respectively. No significant interaction effects between cultivars and defoliation regimes were found in seed yield and components except in the number of seeds/pod ($P<0.01$). Furthermore, the differences in number of pods/m^2, pod yield, number of seeds/pod and seed index were highly significant ($P<0.001$) due to genotype effect. It would appear that the effects of a defoliation on seed production in medic swards will depend more on the cultivar than on the defoliation within the limits set by Rossiter (1961).

In order to maximize the likelihood of medic seed production in a given environment, it is important that flowering be timely. An analysis of long-term weather data, using a water balance model, led Cornish (1985a) to suggest an ideotype for Condobolin in the central west of New South Wales. This ideotype allows for the variable nature of the likely germination period (true season break can occur between February and June) and the need to optimize between maturation of seed before the summer drought against the general desirability of a later flowering date which increases seed production in wetter years.

The results of this experiment have shown that plant populations (number of plants/m^2) differed greatly between genotypes in accordance with sowing rate and seed size. Hence, medic plant number/m^2 varied according to the genotype. However, Para. had considerably smaller seeds , thus more seeds were sown resulting in higher plant population and Sava, the largest seed size with fewer plants/m^2. Neither defoliation nor the interaction of genotype and defoliation had a significant effect on survival of medic plants. All defoliation treatments decreased the final yield of forage by possibly affecting the growth of root extension which may well have slowed down or ceased by defoliation. However, this is partly dependent on the genotype and timing of defoliation. For example, Para. produced about twice the dry matter of other defoliated genotypes by the end of the season. The early-maturing genotype Sava was the most productive in winter after Para. while Rota. was the least productive during the season. Furthermore, the early defoliation treatments show a parallel growth curve to the undefoliated treatment (DO), while the late defoliation (DL) had a severe effect as it removed the primary and secondary branches of all cultivars. However, the twice defoliated treatment (DEL) showed better regrowth and recovery than (DL) at the end of the season.

The four genotypes exhibited various levels of competitiveness with weeds, although this depended on the establishment and the stage of the growth in the growing season. The ability of medics to compete with weeds is greatly affected by the growth habit of the particular medic and weeds. The tall medics (Sava and Para.) were the most successful at competing with weeds. All genotypes had more weeds on plots as the growing season progressed. There was no significant effect of defoliation on the yield of weeds. Generally, defoliation prior to flowering increase seed production by increasing the number of inflorescences per unit area. Early defoliation (DE) increased seed production in both Sava and Para. However, the effect of defoliation on seed production varied markedly between genotypes, ranging from a large increase to a decrease in seed yield (Scott 1971). The highest seed yield was obtained from Sava (1334 kg/ha) and Rota. gave the lowest seed yield (212 kg/ha). Furthermore, the late (DL) and the twice defoliated (DEL) caused a highly significant reduction in seed yield compared with control plots. It is clear that the effects of defoliation on seed production in medic swards will depend not only on the genotype and its specific growth habit and stage of maturity but also on the frequency and intensity of defoliation. Further studies are needed on these interacting factors in both rainfed (dryland) and irrigated conditions..

7. EXPERIMENT 4: EFFECTS OF SOWING DEPTH AND SOIL TEXTURE

7. EXPERIMENT 4: THE EFFECTS OF DEPTH OF SOWING AND SOIL TEXTURE ON SEEDLING EMERGENCE AND EARLY VEGETATIVE GROWTH OF FOUR MEDIC GENOTYPES IN POTS

7.1 Introduction

In Mediterranean-type environments winter pasture production, especially in colder regions, often limits total seasonal production and livestock carrying capacity. Therefore, management practices must ensure good pasture production and the most important determinant of winter herbage production is pasture density. Management practices must ensure that a high density of seedlings is established as early as possible following the opening rains. In the three previous studies it has been shown that the crucial issue in winter herbage production depends either upon sowing rate or upon cultivar productivity and adaptability to the ecological conditions. However, successful production of winter pastures requires optimum cultural practices such as depth of sowing, rate of sowing and date of sowing.

Haskins and Groz (1975) reported that depth of sowing had a much greater influence on the ability of sweet clover (*Melilotus officinalis* L.) seedlings to emerge from the soil than on their performance after emergence. Furthermore, they found that among numerous interactions, the two-factor interaction involving sowing depth and seed size had the greatest effect on establishment. The percentage establishment from medium and large seeds were greater than counts from small seeds, especially at 57mm sowing depth. This ability of seedlings from larger seeds to emerge from greater depths can be extremely important to establishment of pasture legumes when the moisture supply is limited.

Sowing medic seed too deeply must be avoided because the percentage emergence of the stand and plant vigour are adversely affected (Carter and Challis 1987). Furthermore, seed size influences seedling vigour (Crawford 1970, 1975) and may well influence the number of seedlings. Earlier, Black (1955) reported that both depth of sowing and temperature affected pre-emergence weight changes in subterranean clover, and that, in particular, there was a marked effect on the amount of dry matter remaining in the cotyledons at the time of emergence. However, the optimum depth of sowing depends on soil moisture and temperature (Webb and Stephens 1936) and soil texture (Carter and Challis 1987). However, under field conditions, where germination is simultaneous, plants from greater depths of sowing will be at a disadvantage compared with those from shallower sowings since emergence will be progressively delayed as depth of sowing increases (Black 1955).

Deep sowing of forage grasses has both increased and decreased seedling emergence. Emergence percentage decreased in smooth bromegrass when sown deeper than 1.3cm in a clay loam soil (Lueck *et al.* 1949). In contrast, "Blackwell" switchgrass had a greater probability of emerging when sown at a depth of 5.0 to 7.5cm than when sown at shallow depths in a clay loam of medium or low moisture content (Hudspeth and Taylor 1961). Differences in the rate of utilization of seed reserves may explain why certain species emerge at greater sowing depths than others (Tischler and Voigt 1984).

Little attention seems to have been paid to this factor in the emergence and growth of plants, in particular under experimental conditions comparable to those in the field. Therefore, the objective of this experiment is to assess the effect of depth of sowing and soil texture on the percentage emergence and early vegetative growth of medic seedlings up to the cotyledonary stage. The earlier the seedlings are harvested the more likely is the effect of competition avoided.

7.2 Materials and Methods

Plant culture : The same four medic genotypes as used in Experiment 3, viz. *Medicago scutellata,* cv. Sava (Sava), *M. truncatula,* cv. Paraggio (Para.), *M. rigidula* , Sel. 716 (Rigi.) and *M. rotata,* Sel. 1943 (Rota.) were used in this experiment to represent the four medic species. Seed was sown at three depths, viz 1, 3 and 5 cm at a sowing rate of 25 seeds/pot in a grid pattern of 5 rows x 5 seeds This was equivalent to a plant population of (1111 seeds/m^2). Two soils of contrasting texture were used. Both soils were steam sterilized to kill weed seeds and later sieved (3mm). The first soil was a loamy sand designated 'sand' obtained from the Bolivar Research Farm and the second, a clay-loam designated 'loam', was a red-brown earth collected at the Waite Agricultural Research Institute.

Design of Experiment: A randomized complete block design was used with six replicates. Thus, the following design was applied in this experiment : Species (4) X Sowing depth (3) X Soil texture (2) X Blocks (6) = 144 pots.

Sowing procedure: The black plastic pots (15 x 15 x 13cm) were tared with crushed gum bark to a depth of about 2cm height and filled with either 2.4kg of sand or loam. The three depths of sowing (1, 3 and 5cm) were obtained as follows. A depth gauge consisting of a wooden plate with 25 pins (5 x 5) at 25mm (c/c) spacing was used to indent the soil for sowing: the sowing depth was adjusted by using separate wooden spacers 1cm thick with 25 holes. The pots were watered and allowed to dry to give compact soil in the pots to allow making sets of 25 holes for sowing seed at the required depths. One seed was dropped into each hole and then covered with dry soil. Twenty-five seeds were sown in each pot: all treatments were sown on 31 July. After sowing was completed, all pots were watered with rain water (through a fine sprinkler nozzle on a plastic watering can) to field capacity, rewatered on the second day after sowing and thereafter whenever it was required.

Seed germination tests and emergence counts : One hundred seeds from each species were tested in petri-dishes at 19°C to determine the proportions of readily-germinable (soft), hard and dormant seeds. Daily emergence counts were commenced on 5 August and continued until 17 August. The emergence of seedlings was based on when the cotyledon started to appear above the soil surface. The rate of emergence was plotted for the 14-day period also the percentage survival of seedlings was noted (there were some deaths).

Harvest: A single destructive harvest was made on 22 August, 21 days after the initial watering to field capacity, when all seedlings were at the cotyledonary stage. Plants were cut at soil level with a scalpel then washed and counted. Cotyledons were excised and the cotyledon area measured on an electronic planimeter. All the cotyledons were replaced in the original sample and the whole sample from each pot dried at 85°C for 24 hours for dry weight determination.

Environment: The greenhouse was glass-roofed and four sides walled in glass. There was no control of temperature or humidity. Pots were watered to field capacity every second day, or as necessary with a fine sprinkler or a can. A penetrometer test was made while the soil was at field capacity to assess the soil resistance to emerging seedlings. The data are shown below (Table 7.1).

Table 7.1 Mean soil resistance for two soil types

Soil type	Number of Readings	Average Soil Resistance (kg/cm^2)
Sand	144	0.45
Loam	144	1.12

The results show that the soil resistance (mechanical impedance) met by emerging seedlings in the loam was almost 2.5 times greater than that met by those in the sand.

Statistical Analyses : Analyses of variance were made on the following data: herbage dry weight, seedling number, mean plant dry weight, cotyledon dry weight and cotyledon area index.

7.3 Results

7.3.1 Seed germination data

The data for the germination rate, total germinated seed and the number of dormant and hard seeds are listed in Table 7.2. None of the snail medic (Sava) seeds germinated during the first day after watering whereas species with smaller seed size such as barrel medic (Para.) showed 26% germinating seeds in the first day. However, *Medicago rotata* (Rota.) seeds had the fastest germination rate followed by Para., while Rigi. had the highest percentage of hard seededness (19%) which could reflect the threshing process used in preparing this seed at ICARDA, Syria. Furthermore, Rigi. had the lowest percentage of soft seeds (63%) while

Rota. the highest. No doubt differences in percentage of soft, dormant and hard seeds reflect harvesting and threshing methods as well as storage conditions.

7.3.2 Seedling Emergence Rate

Seedling emergence counts were made from the fifth day after sowing and watering the pots. In both soils, all species showed faster emergence of seedlings as the depth of sowing was progressively more shallow. Thus, the highest percentage of seedlings emerging was at 1cm depth from sand followed by 1cm from loam, then 3cm from sand followed by 3cm on loam and finally the 5cm on sand and loam respectively as shown in Figures 7.1 a,b,c,d). The actual emergence data is in Appendix C, Tables C.1 - C.4. At 10 days from sowing, the percentage of seedling emergence in Sava declined by 15% sand and 25% loam as depth of sowing increased from 1cm to 3cm. The percentage reduction in seedling emergence from 5 cm depth compared to 1cm depth was 20.5% in sand and 42% in loam. The same trends in reduction of the percentage emergence of seedlings of the other cultivars were found as the depth of sowing increased, or the clay content in the soil increased (Plate 7.1).

Plate 7.1 **Showing effects of depth of sowing on emergence of medic seedlings from sand (upper photograph) and loam (lower photograph)**

A = *M. scutellata* cv. Sava

B = *M. truncatula* cv. Paraggio

C = *M. rigidula* Sel. 716

D = *M. rotata* Sel. 1943

Left to right = 1, 3, 5cm depth of sowing


D
C
B
A
1.cm.
3.cm
5.cm.

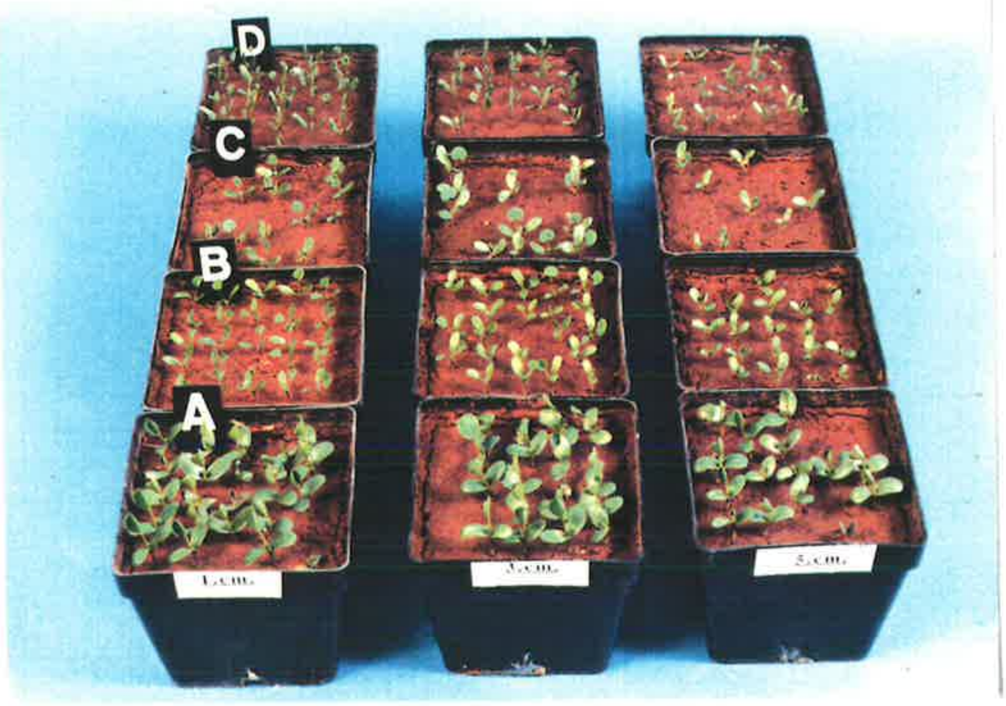

D
C
B
A
1.cm.
3.cm.
5.cm.

Table 7.2 **Rate of germination and percentage of soft, dormant and hard seeds of four medic species**

Medic Species	Days after Watering	Soft seed (%)	Germ (%) Cumulative	Dormant Seed (%)	Hard Seed (%)
Sava	1	–	–		
	2	30	30		
	3	25.5	55.5		
	4	11.8	67.3		
	5	7.2	74.5		
	6	6.8	81.3		
	7	2.2	83.5		
	8	1.0	84.5	3.8	11.7
	Total	84.5			
Para.	1	29.5	29.5		
	2	44.3	73.4		
	3	11.8	85.2		
	4	7.8	93.0		
	5	3.8	93.8	2.9	3.3
	Total	93.8			
Rigi.	1	15.5	15.5		
	2	34.8	50.3		
	3	12.8	63.1		
	4	6.5	69.6		
	5	5.2	74.8	12.8	12.4
	Total	74.8			
Rota.	1	36.2	36.2		
	2	27.1	63.3		
	3	24.2	87.5		
	4	9.9	97.4	2.0	0.6
	Total	97.4			

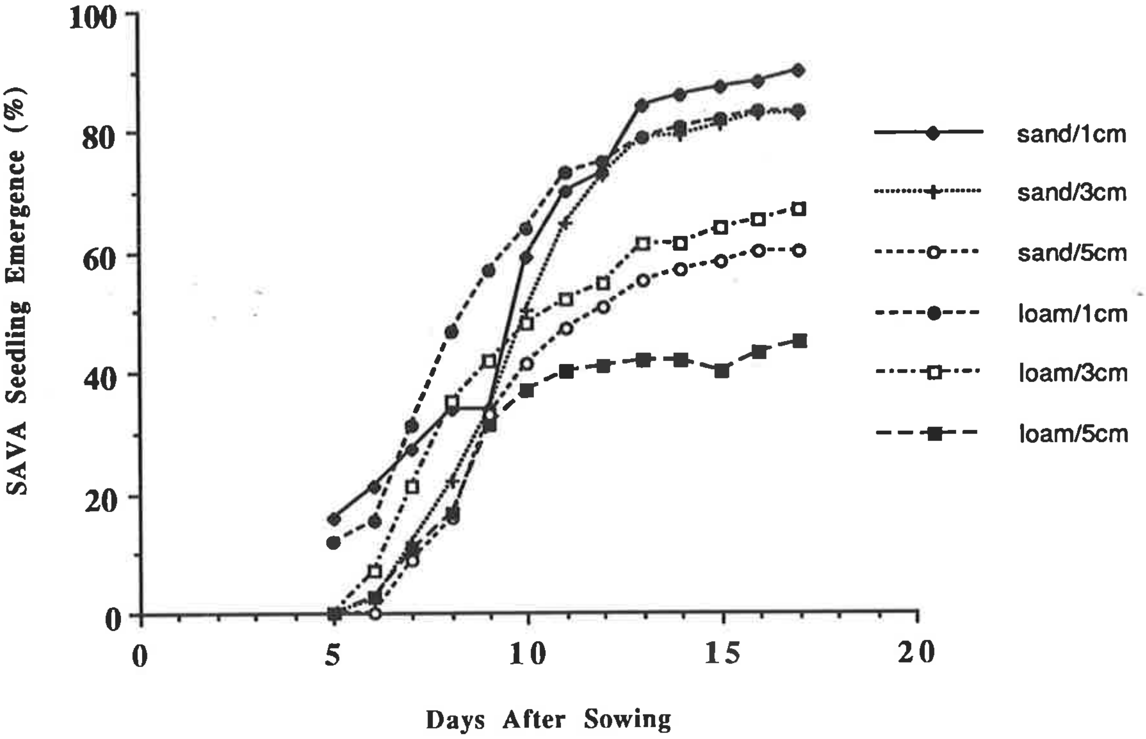


Fig. 7.1(a)

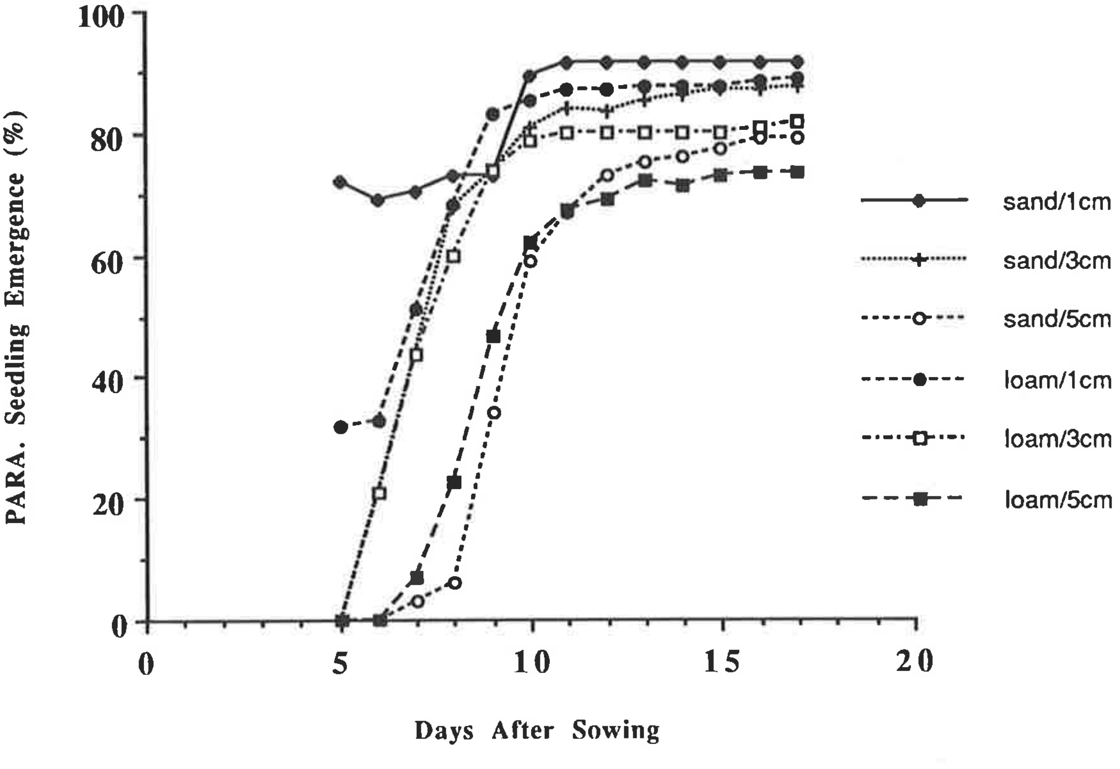


Fig. 7.1(b)

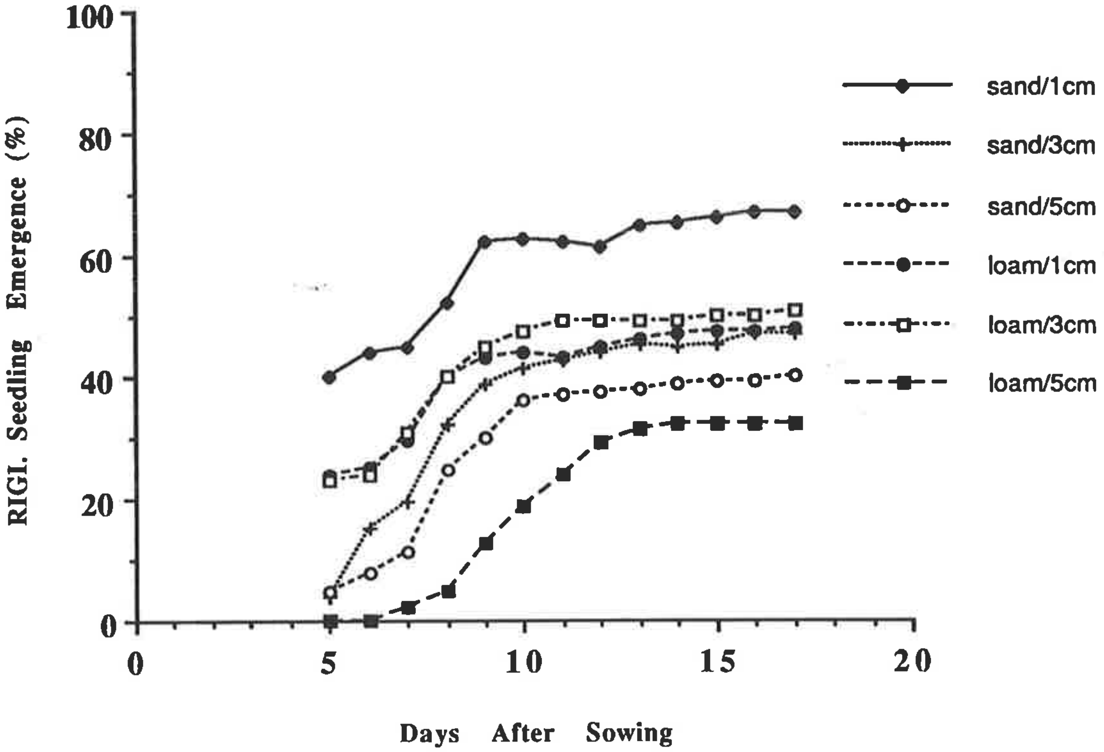


Fig. 7.1(c)

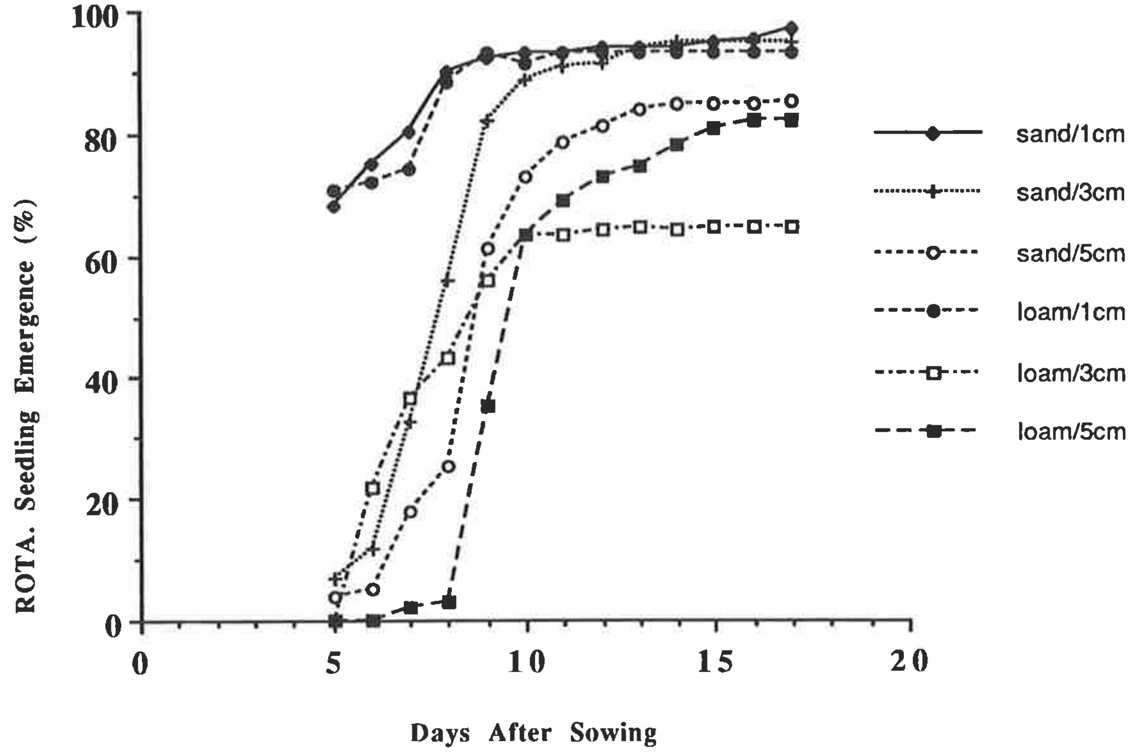


Fig. 7.1(d)

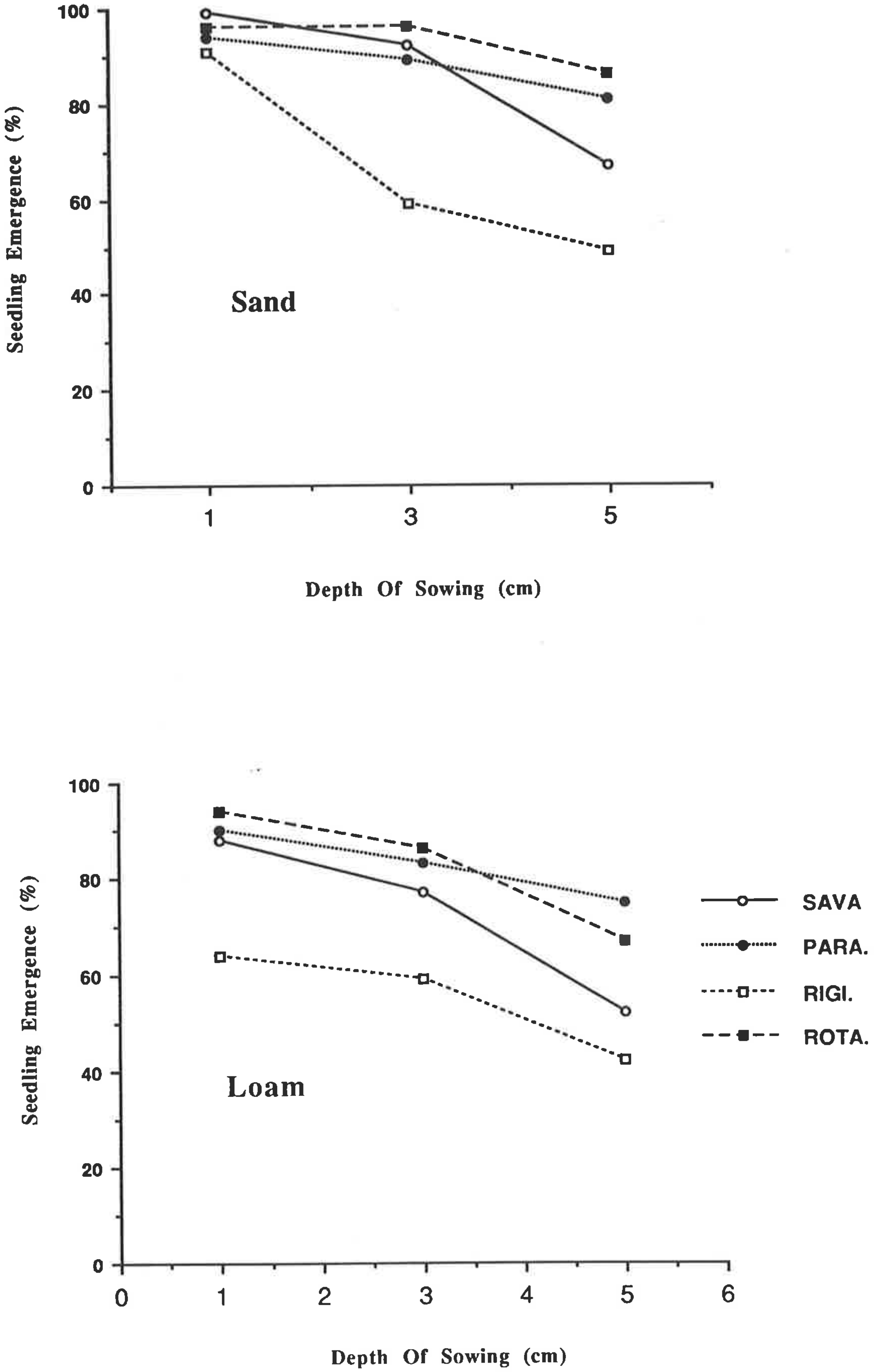

Seedling Emergence (%)
100
80
60
40
20
0
Sand
1
3
5
Depth Of Sowing (cm)
Seedling Emergence (%)
100
80
60
40
20
0
Loam
0
1
2
3
4
5
6
Depth Of Sowing (cm)
SAVA
PARA.
RIGI.
ROTA.

Fig. 7.2

7.3.3 Harvest Results

Seedling Number: The most pronounced effect of sowing depth was on emergence (Tables 7.3, 7.4). The corrected emergence percentage of seedling numbers are summarized in Fig. 7.2. Plant numbers were significantly affected by Species, Soil Texture and Depth of Sowing as well as the interaction of Cultivar x Depth of Sowing and Species x Soil Texture x Depth of Sowing ($P<0.001$) (Tables 7.3, 7.4). The highest number of plants (959/m^2) was produced by Rota.. followed by Para. (925/m^2), while the lowest plant number was obtained from Rigi. which produced less plants (524/m^2) (Appendix Fig. C.1a). All cultivars showed a decline in plant number as the depth of sowing increased from 1 to 5cm in both soils (Table 7.4). Thus, the shallower the depth of sowing, the higher the number of plants and vice versa. Plant number also decreased as the clay percentage increased in the soil. Hence, the highest number of plants was obtained from the sandy soil treatment with a 1cm depth of sowing (Fig. 7.2). The reduction in plant number (9-29%) as the depth of sowing increased from 1 cm to 5cm was least in Rota., while the reduction in plant number was greatest in Rigi. (38-41%). The actual and potential seedling emergence are summarized in Table 7.5.

Herbage yield : Highly significant differences were found in herbage yield due to the effects of Species, Soil Texture, Depth of Sowing on seedlings, as well as the interaction of Species x Depth of Sowing (Table 7.3). On the other hand there were no significant differences in herbage yield due to the interaction of Species x Soil Texture, Soil x Depth of Sowing and Species x Soil x Depth (Table 7.3). The highest mean seedling yield was produced by Sava (28.5g/m^2) followed by Rigi. (13.2g/m^2), while Rigi. gave the lowest herbage yield (9.5g/m^2). However, shallow sowing (1cm) produced nearly double the early herbage yield compared with deep sowing (5cm) with all cultivars (Appendix Fig C.1b). All species showed a significant reduction ($P<0.05$) in seedling yield (Table 7.6) as the depth of sowing increased from 1cm to 5cm. Sava was the most productive genotype, while Rigi. was the lowest yielding at all depths of sowing (Table 7.7). The decrement in seedling yield with deeper sowing in sandy soil was not significant at all depths of sowing. As well, the plant number decreased dramatically by increasing the depth of sowing resulting in a herbage yield decline for all genotypes. Even though the interaction Species x Depth of Sowing x Soil was not significant, the shallower the depth of sowing, the greater the production in herbage yield for all species in both soils. However, the highest herbage yield was produced by Sava and ranged between 18.2 g/m^2 and 35.6 at 5cm depth of sowing in loamy soil to 35.6 g/m^2 at 1cm depth in sandy soil, while the lowest seedling yield was given by Rigi. which ranged from 4.4g/m^2 in loamy soil with 5cm depth of sowing to 14.5g/m^2 in sandy soil at 1cm depth of sowing (Table 7.7). Over all treatments, sandy soil had better emergence which resulted in higher early production than loamy soil and shallow sowing wasmuch better than deep sowing in terms of herbage yield for all genotypes (Table 7.7).

Individual seedling dry weight: Data on mean weight of individual seedlings are summarized in Table 7.8. The differences in seedling dry weight were highly significant as affected by species and depth of sowing. The average seedling dry weight depends on the original seed weight which produces the seedling. A direct relationship was found between the seedling dry weight and the seed weight. Seedling dry weight ranged from 13mg/plant to 35.2mg/plant, depending on species, soil and depth. The differences due to Species or Depth of Sowing are highly significant (Table 7.3). However, the differences due to Soil Type are not significant. Furthermore, the interaction between Species x Soil Type x Depth of Sowing was not significant even though the mean weight of individual seedlings of all species decreased by increasing the depth of sowing in both soils (Table 7.8). Increasing the depth of sowing from 1cm to 3cm decreased seedling dry weight by 7.9% on sand and 12.6% on loam. Sowing at 5cm depth reduced dry weight by 14.5% on sand and 26.3% on loam compared to the corresponding 1cm depth (Table 7.8).

Cotyledon area and weight : The mean cotyledon areas are summarized in Table 7.9. The differences in cotyledon area are highly significant between species and between depth of sowing (Table 7.3). All species showed a marked reduction in cotyledon area as the depth of sowing increased from 1cm to 5cm in both soils (Table 7.9). The reduction was more marked in snail medic than with the other species. Similar trends were found in cotyledon dry weight

(Table 7.10) as for cotyledon areas. The only significant differences were found due to species and depth of sowing. Cotyledon dry weight followed the weight of the original seeds sown.

Table 7.3 Summary of analyses of variance of data in pot experiment for four medic species

	Number of plants (#/pot)	Cotyledon area (cm)	Cotyledon dry weight (mg)	Dry matter yield (gDM/m^2)	Mean dry weight (mg/plant)
Species (sp)	***	***	***	***	***
Soil (S)	***	ns	ns	**	ns
Depth (D)	***	***	***	***	***
Sp x S	ns	ns	ns	ns	ns
Sp x D	***	ns	ns	*	ns
S x D	ns	ns	ns	ns	ns
Sp x S x D	**	ns	ns	ns	ns

ns = not significant; *= $p<0.05$; **= $p<0.01$; ***= $p<0.001$

Table 7.4 Effects of soil texture and depth of sowing on final emergence of medic seedlings (plants/m^2)

	Sand			Loam		
	Depth of Sowing (cm)			Depth of Sowing (cm)		
Species	1	3	5	1	3	5
Sava	1007	941	689	904	793	533
Para.	1015	963	874	978	904	815
Rigi.	726	526	430	598	570	371
Rota.	1052	1005	948	1030	941	733

LSD (5%) Species x Depth x Soil = 137

Table 7.5 Potential, actual and establishment percentage of four annual medic species (plant/m^2)

Species	Germinating Seed %	Potential Plant/m^2	Actual Plant/m^2	Establishment (%)
Sava	84.5	938	811	86.5
Para.	93.8	1042	925	88.8
Rigi.	74.8	831	537	64.6
Rota.	97.4	1082	952	88.0

Table 7.6 Effect of depth of sowing on seedling yield (g/m^2) of four annual medic species

	Depth of Sowing (cm)		
Species	1cm	3cm	5cm
Sava	34.8	29.7	21.0
Para.	15.1	13.2	8.2
Rigi.	12.0	10.3	6.3
Rota.	18.2	11.6	9.9

LSD (5%) Species x Depth of Sowing = 3.6

Table 7.7 Effect of soil texture and depth of sowing on seedling yield (g/m^2) of four annual medic species

	Sand			Loam		
	Depth of Sowing (cm)			Depth of Sowing (cm)		
Species	1	3	5	1	3	5
Sava	35.6	32.9	23.9	34.1	26.5	18.2
Para	17.1	13.1	8.1	13.1	13.2	8.4
Rigi	14.5	9.9	8.2	9.5	10.6	4.4
Rota	15.9	13.7	10.9	20.5	9.4	8.8

Table 7.8 **The dry weight of individual seedlings (mg/plant) of four annual medic species**

Species	Soil	Depth of Sowing (cm) 1	3	5
Sava	Sand	35.5	35.3	35.2
Para.		16.7	13.5	9.3
Rigi.		19.8	19.2	18.8
Rota.		15.2	13.0	11.5
Sava	Loam	37.7	33.2	34.7
Para.		13.5	14.5	10.3
Rigi.		18.7	18.7	11.8
Rota.		19.8	13.0	9.3

Table 7.9 **The effects of soil texture and sowing depth on cotyledon area of seedlings of four species of medics growing in pots 21 days after watering**

	Sand			Loam		
	Depth of Sowing (cm)			Depth of Sowing (cm)		
species	1	3	5	1	3	5
Sava	0.31	0.30	0.21	0.28	0.22	0.16
Para.	0.10	0.10	0.07	0.10	0.09	0.07
Rigi.	0.10	0.08	0.06	0.08	0.08	0.06
Rota.	0.13	0.10	0.08	0.12	0.07	0.07

Table 7.10 **The effects of soil texture and sowing depth on cotyledon dry weight (gDM/m^2) of four species of annual medics**

	Sand			Loam		
	Depth of Sowing (cm)			Depth of Sowing (cm)		
Species	1	3	5	1	3	5
Sava	13.8	13.9	9.4	13.7	10.1	7.2
Para.	4.6	4.1	3.1	4.6	5.6	3.4
Rigi.	4.4	3.5	2.8	3.5	3.4	1.7
Rota.	5.1	5.4	4.2	10.9	3.7	3.5

7.4 Discussion and Conclusions

Laboratory germination : The variability in genotypes and in their seed size and seed weight resulted in a varied germination percentage for soft seed. The snail medic (Sava) with the largest seed weight of the species tested in this experiment reached the maximum percentage germination seeds (soft seed) after 8 days, while other species took only 4-5 days to reach maximum percentage of germination. This result was in agreement with Andrew (1965) who found that small-seeded *M. minima* germinated faster than the relatively large-seeded *M. polymorpha*. However, rate of germination is an important attribute of annual legumes (Maguire 1962). Thus, rapid germination allows seedling medics to emerge early, and make best use of rainfall and escape weed competition and frost damage. However, under field conditions, where germination is simultaneous, plants emerging from greater depths of sowing will be at a disadvantage compared with those emerging from shallower sowings since emergence will be progressively delayed as depth of sowing increases.

Emergence : Seedling emergence is defined as the complete appearance of the cotyledons above ground level, and since growth was very even, no difficulty was experienced in deciding whether the plants had or had not emerged (Black 1956). Emergence started earlier from large seeds and from shallow sowing. All species showed a delay in plant emergence and low emergence rate as the depth of sowing increased in both soils. The optimum depth of sowing for emergence depends on soil moisture and soil temperature (Webb and Stephens 1936). However, shallow sowing (1cm depth) gave the best medic stand, particularly on sand, while depressions in emergence were associated with deep sowing. Eriksan (1946) found that sowing lucerne at 0.7cm and 1.3cm was the best for emergence of small and large seeds while sowing large seeds of lucerne at 2cm prevented the small seeds emerging. For medics, it is important for seeds to be buried under a soil cover. Amor and Mann (1966) found a very low percentage emergence when seed of Hannaford barrel medic was sown on the soil surface compared to buried seeds, but reduced emergence would occur with deep sowing.

Seedling dry weight (herbage yield) : The penetrometer test in the present study has shown clearly the different soil resistances (mechanical impedance) to seedling emergence. This effect was greater for a heavy soil compared with a light soil; it had a significant effect on the seedling number and seedling growth, i.e. seedling dry weight. Seedling dry weight was greater on sandy soil than on loam. Seedling weight was highly correlated with seed weight. However, shallow sowing resulted in significantly higher yields than deep sowing; deep sowing never produced a yield advantage in this study. The absence of a species by depth of sowing interaction indicated that all species responded similarly to changes in sowing depths. The present study has shown that establishment and vigour of medics were adversely affected by deep-sowing of medic seed. Similarly, important cereal agronomic characters such as grain yield, top growth weight, tillering capacity and plant height were reduced by increasing depth of sowing (Hadji Christodoulou *et al.* 1977).

Cotyledon area and cotyledon dry weight : In medics, cotyledon area and dry weight are influenced by seed size and depth of sowing. The medic species used in this study show marked differences in seed weight which resulted in significant differences in emergence, seedling number and seedling dry weight. In general, the larger the seed size (or seed weight), the better the emergence from depth and the larger the cotyledon area. Crawford (1970) found a direct relationship between seed weight and seedling vigour. Black (1955) suggested that a reduction in cotyledon weight was a consequence of increased translocation to the hypocotyl as depth of sowing increased. He further argued that this might have lasting adverse effects on the subsequent growth of the plants, since less material would be available for the elaboration of the initial photosynthetic surface. A plant emerging from 1 cm, as compared with one emerging from 5 cm, has a higher cotyledon dry weight but an identical cotyledon area. This result is in agreement with results from Black (1956) who found cotyledon weight decreased as sowing depth increased, but cotyledon area was not affected. It has been shown, moreover, that seedling growth depends directly on cotyledon area. Thus, depth of sowing has no effect on subsequent growth, provided that a certain critical depth, determined by the size of seed, is not exceeded (Black 1956). The crucial issue is whether or not seedling emergence and pasture density is affected.

The location of seed within the soil profile has an important influence on its ability to germinate and emerge. Carter *et al.* (1987) and Quigley *et al.* (1987) suggested that as a large proportion of medic seeds are buried too deep to allow emergence, there would be insufficient thermal stimulus for breakdown of hard-seededness and emergence of seedlings from seed that did soften. Seeds that did germinate would be constrained because of insufficient elongation of the hypocotyl. Carter *et al.* (1987) and Taylor (1985) reported that the germination of annual pasture legume seeds and emergence and productivity of the pasture were greatly influenced by tillage practices. Similarly, Fulwood and Carter (1987) found that with increasing depth of tillage there is an increased depth of burial of medic pods and a decreased emergence of seedlings. Carter and Challis (1987) reported that emergence of medic seedlings ranged from 99% to 0% depending on medic species, seed size, depth of sowing and soil texture. This highlights the need to avoid deep burial of medic seed by ploughing and to avoid sowing the smaller-seeded medics below 1cm in loams.

Conclusion : Under field conditions, where germination is simultaneous, medic seedlings emerging from seed at greater depths will be at a disadvantage as compared with those from shallower sowings since emergence will be progressively delayed as depth of sowing and/or clay content in soil increased. Therefore, the best recommendation for sowing medics is to aim for a sowing depth of 10-15mm with an alkaline soil of sandy loam texture. There was no evidence to suggest that different genotypes of medic responded differently to soil depth or texture other than as influenced by seed size.

8. EXPERIMENT 5: GROWTH IN MONOCULTURES AND MIXTURES

8. EXPERIMENT 5: EARLY VEGETATIVE GROWTH OF FOUR MEDIC GENOTYPES GROWN IN MICRO-PLOTS AS MONOCULTURES, BINARY MIXTURES AND FOUR-WAY MIXTURES

8.1 Introduction

A better understanding of competition among plants requires, almost by definition, a greater knowledge of the response of plants to their environment, and especially of the response to those environmental stresses created by neighbouring plants. It seems at first surprising that we know so little of this basic relationship among plants within a crop, yet the reason is perhaps not too far to seek - studies of the behaviour of interacting plants are so much more difficult than those of either the isolated plants or the community as a whole.

Plant physiologists have studied single plants, and agronomists have looked at the whole crop or sward but the plant within the community has scarcely been investigated. Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors (Donald 1963). In the exact sense, two plants, no matter how close, do not compete with each other so long as the water content, the nutrient material, the light and temperature are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins.

The use of mixtures of cultivars of subterranean clover (*Trifolium subterranean* L.) or annual medics (*Medicago* spp.) has become increasingly common in southern Australian pastures in recent years (Rossiter and Palmer 1981). Generally, the deliberate establishment of cultivar mixtures is associated with two main objectives. Firstly, new improved cultivars are sown in areas containing undesirable ones, with a view to replacing the latter: secondly, cultivar mixtures are formulated and sown with the aim of obtaining greater pasture productivity and/or persistance: the components of mixtures fit the range of ecological niches at any site. In both cases, an understanding of the factors affecting the performance of cultivars in mixtures is of obvious practical importance.

Although the contribution of medics in mixed farming areas of temperate Australia is well known (Amor 1965), there is an ongoing need to evaluate new medic genotypes alone and in mixed swards with commercial Australian cultivars under Australian conditions. Evaluation of medics grown in monoculture versus mixtures indicates considerable potential for expanding the use of annual medics in dryland pastures in southern Australia and elsewhere. So far as medic seed production is concerned, there is an important need to evaluate cold-tolerant genotypes for export as well as for potential use in parts of southern Australia. Clearly, further studies are required before any generalization can be put forward regarding the effects of competition on establishment of plant populations and early growth of medic plants.

In this part of the thesis, research on evaluation of medic genotypes and mixtures in micro-swards were used in an experiment established in raised beds (Plate 8.1) at the Waite Institute. All possible combinations of species were used in a factorial experiment in comparison with the monoculture of each species sown as a pure sward. The experiment was designed to compare the monoculture swards with their mixtures to study the effects of competition between genotypes in mixtures on the early growth and plant population of a sward of annual medics.

8.2 Materials and Methods

Design of Experiment : Four medic species, viz. *Medicago scutellata* cv. Sava, *M. truncatula* cv. Paraggio, *M. rigidula* Sel. 716 and *M. rotata* Sel. 1943 as used in previous experiments and hereafter abbreviated; Sava Para., Rigi. and Rota. were used in this experiment. All species were sown in pure swards (monocultures) and mixed swards (binary mixtures), or all species mixed together (four-way mixtures). For the monocultures and binary mixtures a sowing rate of 60kg/ha of pure germinating seed was used.

For the four-way mixtures, seed of the four genotypes were mixed on the basis of 25% of each to give 60 and 600kg/ha of pure germinating seed for low and high density respectively. All genotypes and mixtures were established in micro-plots of 400cm^2 in a randomized complete block design (Diagrams 8.1 and 8.2). In the case of mixtures, an equal proportion of seed weight based on pure germinating seed from each mixture component was used. The raised-beds were orientated lengthwise north-south. Three blocks were arranged within the two raised beds (Diagram 8.1). Six harvest areas were set aside within each block. Within each harvest area the four genotypes and the eight combination of mixtures were arranged at random. Due to winter-spring shading effects the harvest areas were not randomized within a block. Thus the first harvest was taken from the northern end of each block. Consecutive harvests moved progressively southward. This method has been successfully used by several previous researchers who used the same raised beds. The total experiment involved Treatments (12) x Harvests (6) x Blocks (3) = 216 micro-plots.

Preparation of Raised Beds: The raised beds located at the Waite Institute and filled with sandy loam were levelled and a complete mineral-mix fertilizer applied by hand-broadcasting at 300kg/ha and mixed with the soil. The surface was carefully levelled and a galvanized mesh with 20cm x 20cm openings (surrounded by a 10cm buffer area from each side used as a buffer area between each two treatments) placed flat upon the surface of the soil. The 20cm x 20cm micro-plots in which the different treatments were sown, were made by cutting some wire from the 10cm x 10cm mesh prior to placement.

Preparation of seed and sowing: The same seed stock as used in previous experiments was used without any special treatments. At the start of sowing on 6 September 1988, seed from each of the four genotypes was inoculated with the commercial Nodulaid Peat Inoculum Group 'A' except Rigi. which was inoculated with M29 *Rhizobia*. All seeds were broadcast carefully by hand inside the micro-plot using a metal frame 20cm x 20cm with 3cm height to ensure that all seeds were within the micro-plot area. Seeds were rearranged as needed by forceps to ensure even distribution, then covered by 1cm of sieved-sterilized sandy-loam soil spread carefully and evenly to keep seeds at 1cm depth of sowing before removing the metal frame. All treatments were sown and covered in the same day. The buffer zone which entirely surrounded each micro-plot was sown with Paraggio medic at the rate of 60kg/ha of pure germinating seed following the same procedure as used for sowing micro-plot treatments.

In the early stages it was necessary to water twice a day to ensure that soil moisture was not limiting. Emergence commenced on 11 September, but full emergence was reached on 16 September 1988. At this stage seedlings were counted daily in monoculture plots only between 11 and 16 September and this date was used for the base point (Days) for timing of the harvests.

Harvests: Six harvests were taken over a period of six weeks, viz. one harvest every week. The first harvest was taken at the first canopy (11 days after full emergence). The remaining harvests were made every seven days. At each harvest, plants were cut with a scalpel to soil level. All plants were washed, counted (for each genotype separately in the mixtures) and dried for 24hrs at 84°C and weighed. Herbage dry matter, number of plants and average individual plant dry weight were recorded for each genotype in both monocultures and mixtures.

8.3 Results

8.3.1 Plant population

Plant number per unit area varied according to genotype, rate of sowing and proportions in mixtures. Sava had the highest establishment counts percentage (93.2%) after Para. (94.4%), (Table 8.1). Meanwhile, Para. had the highest number mean of 1404 plants/m^2 over the six harvests compared to the other genotypes which is nearly double that from Rigi. or Rota. and more than triple the Sava plant numbers. However, there was no significant interaction between genotype and time of sampling on plant population (Table 8.2). Thus, there were no significant changes in plant population as the plants aged (Table 8.3), while some variations including highly significant differences were recorded in plant numbers between genotypes ($P<0.001$). These differences are obvious in micro-plots sown at 60kg/ha of pure germinating seed (Table 8.4). Over-all, plant populations slightly decreased as plants aged or were grown in mixed swards compared to monoculture (Table. 8.5).

Plate 8.1 Experiment 5 showing vegetative growth of medic genotypes and mixtures at early growth stage (lower photograph) and later harvested micro-plots (upper photograph)

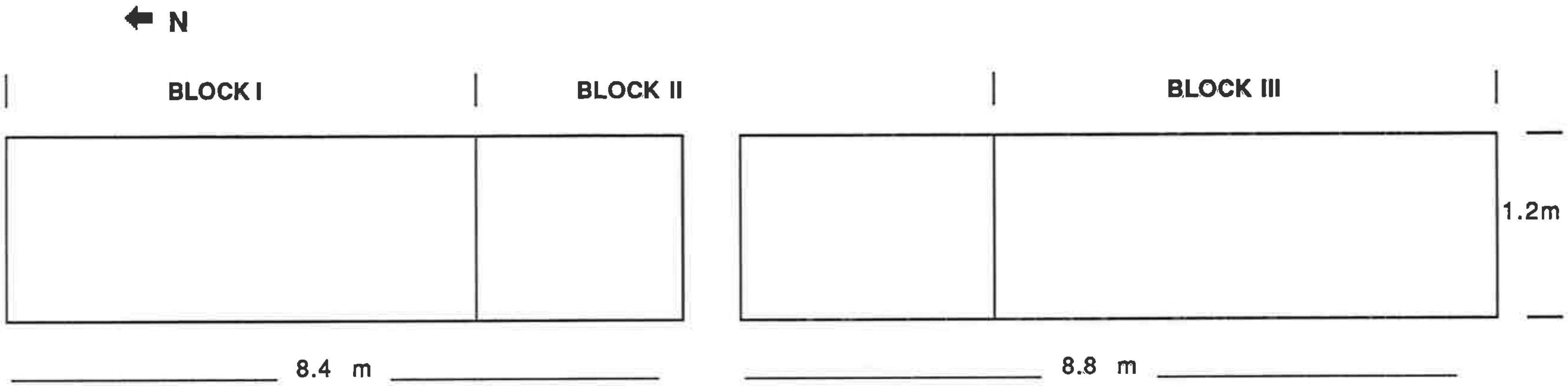
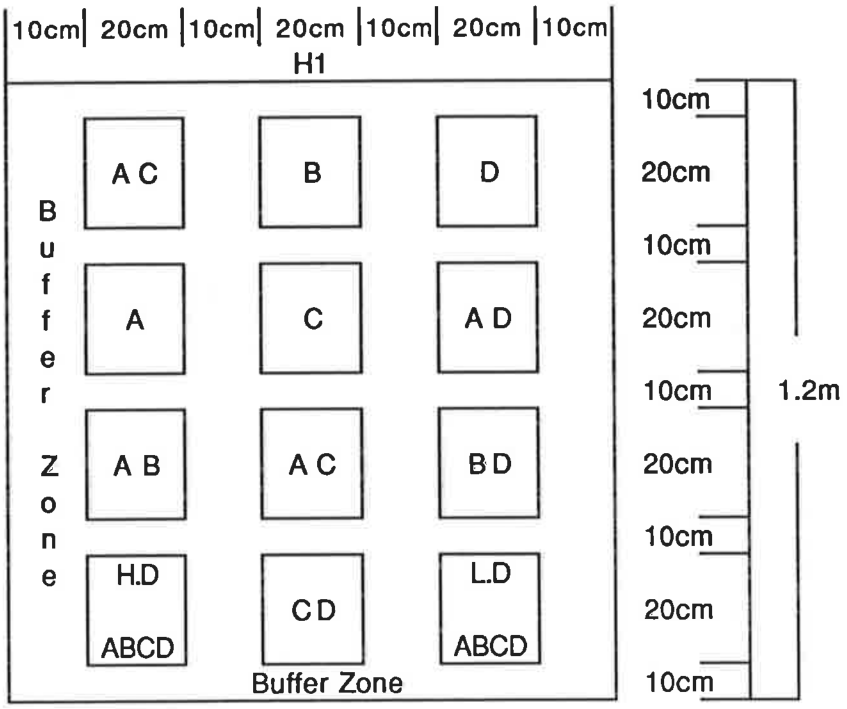


Diagram 8.1 Layout of Experiment 5



LEGEND

A = Medicago scutellata cv. Sava
B = Medicago truncatula cv. Paraggio
C = Medicago rigidula Sel. 716
D = Medicago rotata Sel. 1943

LD.= Low Density (60kg/ha pure germinating seed)
HD = High Density (600kg/ha pure germinating seed)
H = Harvest

Diagram 8.2 Layout of 12 random treatments within a harvest site

8.3.2. Herbage Yield

Irrespective of mixtures or plant population, the interaction between genotype and time of sampling was highly significant ($P<0.001$) herbage production (Table 8.2). The most productive genotype was Para. with mean yield of 145.3gDM/m^2 over the six harvests. Para. grown in monoculture showed a superiority in terms of herbage yield over all other genotypes or treatments during the growing period (Table 8.6). As time progressed, differences between genotype productivity developed (Table. 8.6). Para. had the highest herbage yield starting from Harvest 2 and showed its superiority until Harvest 6, while Rigi. and Rota. had the lowest herbage yield. Sava was not much higher yielding than other genotypes particularly Para. and Rigi. Herbage yield was dramatically increased as plants aged from 10.9gDM/m^2 at Harvest 1 to 273.5gDM/m^2 at Harvest 6 (Table 8.3). Furthermore, the minimum herbage yield (7.8gDM/m^2) at Harvest 1 and the maximum (360.1gDM/m^2) at Harvest 6 were produced by Rota. and Para. genotypes, respectively.

8.3.3 Individual plant weight

To ensure that differences in herbage yield of genotypes were due to some factor other than differences in plant numbers, total yield of plant tops (mgDM/plant) was recorded for each harvest (Table 8.7). In all genotypes, plant weight was significantly increased over the time of sampling (Table 8.3). The Genotype x Harvest interaction was highly significant ($P<0.001$) as shown in the summary of analyses of variance (Table 8.2). However, the highest mean plant yield of tops was obtained from Sava (306mgDM/plant) over the six harvests (Table 8.4). According to data in Table 8.4, it can be seen that the mean weight of individual plants of Para., Rigi. and Rota. did not differ significantly. However, Sava plant weight was more than three times as great as any of the other genotypes. The only variation in plant weight was between Sava and other genotypes (Para. Rigi. and Rota.). Variations in plant weight ranged widely from 10.3mgDM/plant for Rota. at Harvest 1 to 793.7mgDM/plant of Sava at the end of the growing period (Harvest 6) as shown in Table 8.7 where plant weight was plotted as a function of time of sampling (days after sowing).

8.3.4 Effect of Mixtures

Plant population : Seedling establishment percentage, (viz. the actual seedling emergence as a percentage of the potential emergence of seedlings) declined in mixed swards compared to monoculture. Sava had the highest seedling establishment percentage 93.2% after Para. 94.4% grown in monoculture swards (Table 8.2). Also Sava and Para. grown as a binary mixture had the highest percentage of the seedlings establishment 89.3% compared to any other mixed swards. However, percentage seed germinations ranged from 75% for Rigi. to 98% for Rota. Therefore, approximately 20 - 40% of all seeds sown failed to germinate and/or seedlings failed to emerge and establish under the competitive conditions of mixed swards (Table 8.4).

Herbage yield : Herbage production decreased in the binary mixtures compared to the mixture components (the two genotypes involved) were grown separately in pure stands. Herbage yield reduction was obvious at the end of the growing period (Harvests 5 and 6), especially when Sava was mixed with Rigi. or Rota. The same trend of herbage yield reduction was found in the binary mixtures when the Para. genotype was grown with Rigi. or Rota. genotypes compared to Para. herbage yield grown in pure stands, while not much yield reduction occurred in herbage yield when Rigi. and Rota. genotypes were mixed together (Fig. 8.2) compared to their yield as separate monocultures. Also, yield from the four-way mixture was less than the Para. yield in monoculture at the later harvests H5 and H6.

Individual plant weight : The average plant weight varied according to the genotype and spacing between plants. Mixtures containing Sava resulted in reduction of the average plant weight compared to the pure stands of Sava. Meanwhile, the average plant weights were steady in mixtures excluding Sava.

8.3.5 Effect of sowing rate

Sowing rate had a great influence on the variables examined, viz. number of plants per unit area which were highly significant ($P<0.001$) (Table 8.1), the total herbage yield and mean plant weight. In the case of the four-way mixture, as expected, the lowest herbage yield resulted from low density swards. On the other hand, the mean plant weight was inversely influenced by density (Table 8.8). Individual plant weight was depressed at high density and this effect became more pronounced with time when average plant weight in low density swards (127mg/plant) was more than double average plant weight over the six harvests at high density (52mg/plant). However, differences in plant population per unit area between low and high densities becomes narrower with time (Table 8.8). These differences were at high density 10 times that at low density at Harvest 1 while only about 7 times later at Harvest 6 (Table 8.9).

Herbage yield had the same trend for the differences between low and high densities with time (Table 8.10). Also, differences in mean plant weight between low and high densities followed the same trend as plant population and herbage yield but in opposite direction where plants grown at low rate of sowing are heavier than those grown at high sowing rate (Table 8.11).

8.4 Discussion and Conclusions

In crowded populations, the outcome of competition may result either in death of plants (mortality effect), reduction in growth rate of individuals (plasticity effect) or both (Bazzaz and Harper 1976). The most important finding from this experiment was that competitive relations between annual medics in binary mixtures can be influenced by the genotype. All binary mixtures which included Sava showed a decline in herbage yield per unit area compared to monocultures of Sava, presumably due to the shading effects of the taller Sava genotype, allowing less light interception by plants resulting in depressed photosynthetic activity.

In the other binary mixtures, not much variation was found between monoculture and mixed swards, where the growth habit and plant height of the different genotypes were very similar to each other. However, there were no differences in the percentage of seedling emergence and establishment in most binary mixture and monoculture swards, which is attributed to the availability of most of the plant growth resources particularly in the early growth stages. Thus, the advantages of high sowing rate is to ensure good pasture growth giving early winter feed, when animal feed is scarce. The high sowing rate used in this experiment is very similar to that which might be obtained from the natural regeneration of pasture in the next year. Furthermore, results from this raised-bed experiment indicate that early growth (winter growth) is density-dependent: this result is consistent with the results of Silsbury *et al.* (1979).

In the four-way mixture swards density was highly significant ($P<0.001$). Herbage yield increased 600 - 700% in high-density plots compared to low-density plots, as the plant density increased particularly at Harvest 1. The differences in herbage yield due to density decreased with time: mixtures at high density produced only 250% - 300% of the low-density mixture plot by Harvest 6 (Table 8.10). The explanation for this is because the high density communities were initially capable of a high crop growth rate soon after emergence; however, the rate declined throughout the season, while low density communities showed an accelerating crop growth rate during the season so that final yields were similar for the two treatments (Prioul and Silsbury 1982). The higher the density, then the smaller the plant at any time during ontogeny, and the higher the water content at which shortage of water is experienced (Donald 1963). Also, he found in mixed associations, that individuals of one or more species (the suppressed species) are likely to suffer long before the other species, while in pure culture, all individuals will tend to be affected together.

It is concluded from this Waite Institute experiment that the success of any plant or species (when grown in mixed swards) in competition for water, nutrients and light depend on the genotype itself and early crop growth rate is strongly density-dependant. Sava shows superior competitiveness with other genotypes which may derive from its large seed size, initial large seedling size, taller growth habit and strong root system. Therefore, despite the lowest plant population of Sava, it produced more herbage yield than Rigi. and Rota. which are considered cold-tolerant genotypes.

Table 8.1 **Differences in potential and actual plant population and establishment**

Elements	Sava A	Para. B	Rigi. C	Rota. D	AB	AC	AD	BC	BD	CD	LD ABCD	HD ABCD
Potential plants (#/m^2)	340	1488	1050	1078	914	695	709	1269	1283	1064	989	9890
Actual plants (#/m^2)	317	1404	814	811	817	536	575	1034	1072	801	835	6518
Seedling establishment (%)	93.2	94.4	77.5	75.2	89.3	77.1	81.1	81.5	83.5	75.3	84.4	65.9
Soft Seed (%)	85	93	75	98								

LD = Low density HD = High density

Table 8.2 **Summary of analyses of variance for plant population, herbage yield and plant weight**

	Plant pop. (#/m^2)	Herb. yield (gDM/m^2)	Plant weight (mg/plant)
Harvests (H)	ns	***	***
Genotypes (Gen.)	***	***	***
H x Gen.	ns	***	***

ns = Not significant; *** = P<0.001

Table 8.3 **Effect of time of sampling on herbage yields (g/m^2), plants (#/m^2) and plant weight (mg/plant) in monoculture and binary mixtures**

	H1	H2	H3	H4	H5	H6	Signif. Level	5% LSD
Herbage yield (g/m^2)	10.9	23.1	52.8	93.9	157.3	273.5	***	13.2
Plant (#/m^2)	808	825	836	837	784	796	ns	--
Average plant weight (mg/plant)	15.5	30.6	69.5	126.9	234.2	335.3	xxx	27.2

ns = Not significant; *** = P<0.001

Table 8.4 **Effects of annual medic genotypes on plant population, herbage yield and mean plant weight in pure and mixed swards (Averaged over six harvests)**

	A	B	C	D	AB	AC	AD	BC	BD	CD	LD ABCD	HD ABCD
Seeds sown (#/m^2)	400	1600	1400	1100	1000	900	750	1500	1350	1250	1125	11250
Plant popul. (#/m^2)	317	1404	814	811	817	536	575	1034	1072	801	835	6518
Seedling emergence (%)	79.2	87.8	58.4	73.7	81.7	59.6	76.7	68.9	79.4	64.1	74.2	57.9
Herbage yield (gDM/m^2)	96.9	145.3	71.6	73.2	112.1	75.8	71.2	107.9	104.9	69.9	100.5	309.6
Plant weight (mg/plant)	306	103	88	90	137	141	124	104	105	87	120	47

LD = Low density. HD = High density.

Plant populations significant different at $P<0.001$, LSD (5%) = 104
Seedling emergence (%) ns. Herbage yield significant at $P<0.001$. LSD (5%) = 19.5
Plant weight significant at $P<0.001$. LSD (5%) = 2.4.

Table 8.5 **Effects of genotypes and time of sampling on medic plant population (#/m^2) grown in monoculture and mixed swards**

Harvests (H)	DAS	Sava (A)	Para. (B)	Rigi. (C)	Rota. (D)	AB	AC	AD	BC	BD	CD	LD ABCD
H1	21	325	1233	900	750	808	492	658	1008	1108	825	775
H2	28	325	1283	842	842	671	583	633	1100	1083	833	875
H3	35	358	1200	758	933	758	567	558	1150	1183	908	825
H4	42	283	1383	825	867	942	567	625	1084	1175	725	933
H5	49	292	1183	833	800	858	567	508	848	1092	758	883
H6	56	317	1183	625	675	867	442	467	1017	1392	758	717

Treatment x Harvest interaction not significant
DAS = Days after sowing. LD = Low density

Table 8.6 **Herbage yield of four annual medics as influenced by genotype and time of sampling when grown in monocultures and mixtures (gDM/m^2)**

Harvests (H)	DAS	A	B	C	D	AB	AC	AD	BC	BD	CD	LD ABCD
H1	21	13.9	12.3	11.3	7.8	11.8	9.6	10.1	11.3	12.0	9.7	10.5
H2	28	20.6	35.4	21.2	19.1	19.3	21.5	17.4	24.6	25.7	21.8	27.1
H3	35	45.8	72.7	39.4	39.5	61.0	41.0	43.4	59.0.	78.3	44.1	56.4
H4	42	82.3	122.3	68.4	70.6	125.6	77.9	90.2	112.8	113.1	62.0	107.6
H5	49	169.4	268.9	131.8	115.0	193.9	143.7	106.8	187.0	144.3	116.0	153.8
H6	56	249.4	360.1	157.5	187.5	260.8	161.3	159.6	253.0	255.8	166.0	247.6

Treatment x Harvest interaction significant at $P<0.001$. LSD (5%) = 44.4
DAS = Days after sowing. LD = Low density

Table 8.7 **Effects of genotypes and time of sampling on individual plant weight (mgDM/plant) of annual medics grown in monoculture and mixed swards**

Harvests (H)	DAS	Sava (A)	Para. (B)	Rigi. (C)	Rota. (D)	AxB	AxC	AxD	BxC	BxD	CxD	LD ABCD
H1	21	41.0	10.0	12.3	10.3	14.7	19.3	15.3	11.3	10.7	11.7	13.7
H2	28	63.7	28.0	25.7	22.7	28.3	37.0	27.7	22.7	24.3	26.0	31.0
H3	35	127.0	61.3	55.3	42.7	81.7	78.7	79.0	51.3	67.3	48.3	72.0
H4	42	291.0	88.3	109.7	81.7	132.7	142.3	143.0	103.7	97.7	90.3	115.7
H5	49	582.7	263.0	157.7	142.3	225.0	267.7	209.0	262.3	133.0	160.3	172.7
H6	56	793.7	309.0	184.7	295.3	303.0	376.3	371.0	250.0	218.0	228.7	358.7

Treatment x Harvest interaction significant at $P<0.001$. LSD (5%) = 85.8
DAS = Days after sowing. LD = Low density

Table 8.8 **Effects of sowing density on plant population, percentage emergence, herbage yield and plant weight of mixed medic swards**

	ABCD Low density	ABCD High density
Seed sown (#/m^2)	1125	11250
Plant pop. (#/m^2)	835	6518
Emergence (%)	74.2	57.9
Herbage yield (gDM/m^2)	100.4	309.6
Plant weight (mg/plant)	127	52

Table 8.9 **Effects of sowing density and time of sampling on plant population (#/m^2) of mixed medic swards**

Harvests (H)	Days after Sowing	ABCD Low density	ABCD High density
H1	21	775	7008
H2	28	875	7617
H3	35	825	6333
H4	42	933	5967
H5	49	883	6625
H6	56	717	5558

Table 8.10 Effects of plant density and time of sampling on herbage yield (gDM/m^{2}) of mixed medic swards

Harvests (H)	Days after Sowing	ABCD Low density	ABCD High density
H1	21	10.5	72.4
H2	28	27.1	131.1
H3	35	56.4	211.1
H4	42	107.6	335.9
H5	49	153.8	533.3
H6	56	247.6	573.7

Table 8.11 Effects of plant density and time of sampling on plant weight (mgDM/plant)

Harvests (H)	Days after Sowing	ABCD Low density	ABCD High density
H1	21	14	10
H2	28	31	17
H3	35	72	34
H4	42	116	59
H5	49	173	82
H6	56	359	108

9. EXPERIMENTS 6 AND 7: GROWTH CABINET STUDIES

9. GROWTH CABINET STUDIES

EXPERIMENT 6: GROWTH RESPONSE OF FOUR ANNUAL MEDIC GENOTYPES TO TEMPERATURE UNDER CONTROLLED CONDITIONS

9.1 Introduction

The growth of plant communities is influenced both by environment and genotype. The effects of environmental factors on the growth rate of plants will vary according to the growth stage (e.g. Cocks 1973) due to the changing role of each plant attribute in the community growth process and the changing response of these plants to environmental conditions. Temperature greatly affects the growth and development of pastures in Mediterranean-type environments, although its importance may vary between species. In *M. scutellata*, for example, temperature appears to be the main factor controlling flowering but in *M. truncatula*, there is an interaction between temperature and other factors (Clarkson and Russell 1979). The effects of the physical environment on the growth of legumes are influenced by the nitrogen source used, whether symbiotic nitrogen fixation or combined nitrogen. If there are differences, it is important to ascertain the environmental factors responsible, and to determine the optimum temperature for growth and nitrogen fixation . Furthermore, the degree of genetic variation in response to environmental factors such as temperature should be known.

Investigations by Gibson (1963) have shown that both low and moderately-high temperatures (5°C and 30°C respectively), imposed on either the whole plant or the root system only, adversely influence symbiotic nitrogen fixation. Interactions between environmental factors (temperature, light, rainfall) make it difficult to predict the effect of any one separately on the growth of pastures. In contrast to the field, controlled environment facilities can provide conditions in which the level of a single factor can be varied independently of other factors and so allow the effects of different environmental factors in the growth of pasture plants to the quantified.

The present study was designed to examine the effect of temperature regimes on growth and nitrogen fixation by nodulated plants of four annual *Medicago spp.* and to investigate cold tolerant genotypes. The specific objectives of this experiment were:

(i) to quantify the growth response of annual medics to temperature by establishing a dry matter growth curve for each medic genotype at each temperature regime (10°C, 15°C and 20°C), using the method of frequent small harvests as used by Silsbury (1976).

(ii) to investigate the cold tolerant cultivars in terms of dry matter production

9.2 Materials and Methods

9.2.1 Plant Material:

Four annual species of Medicago, namely *M. scutellata* cv. Sava, *M. truncatula* cv. Paraggio, *M. rigidula* and *M. rotata* (abbreviated Sava, Para., Rigi., Rota., respectively) were chosen for this experiment. The first two species represent commercial Australian cultivars adapted to the environment of southern Australia, while *M. rigidula* and *M.rotata* are cold tolerant species from Syria and Turkey and were selected in the ICARDA program during the 1970's.

Germination tests on seeds: Replicated germination tests on each species were conducted by placing 100 seeds in petri dishes with three filter papers (Whatman Qualitative No.1) on the bottom and one filter paper on the top. Five ml of distilled water containing 1.6 g/litre of the fungicide (Thiram) was added to each dish when it was needed. The seeds were germinated for fourteen days in a humidified incubator at 19°C. The germinated seeds (soft seeds) were recorded (Table 9.1) as the radical emerged and the weight of seed sown per pot adjusted accordingly.

Table 9.1 **Medic species used in Experiment 6, showing total germination and rate of germination of seed and plant population/pot (15 x 15cm)**

Species	Abbreviated Name	Germination (%) tested	Days required for germ.	Plant Population/ Pot 15 x 15cm
M. scutellata Cv. Sava	Sava	83	5	20
M. truncatula Cv. Paraggio	Para.	96	2	100
M. rigidula Sel. 716	Rigi.	75	11	72
M. rotata Sel. 1943	Rota.	98	4	64

Sowing methods : All genotypes were sown with an equal weight of germinable seed (17.5g/m^2) to give a plant density of 20, 100, 72 and 64 plants/pot for Sava , Para., Rigi. and Rota. respectively. All seeds were sown in square (15 x 15cm) black plastic pots of 2l. capacity which had been sterilised with 95% ethanol, dried, and filled with 3.1kg of a coarse, washed river sand which had previously been sieved and steam sterilised. The sand drains rapidly to a water holding capacity of 11% at field capacity. $CaCO_3$ (4g/kg sand) was mixed into each pot to adjust the pH to 7.8. Seeds were arranged evenly in pairs on the levelled sand surface using templates which had the required number of equally spaced holes for each genotype. Seeds were covered with a further 0.3 kg sand/pot to give an effective sowing depth of 1cm.

Seedlings were thinned to one seedling/hole 11, 9 and 7 days after sowing for temperatures 10°C, 15°C and 20°C respectively. This corresponded to the expansion of the first leaf. After thinning, seedlings were inoculated by adding cultures of *Rhizobium trifolii* WSM 244 or M 29 to the nutrient solution. WSM 244 is an effective strain of *R.* meliloti *trifolii* for Sava, Para. and Rota., while M 29 is effective on Rigi. (ICARDA Report, 1985). The two strains of *Rhizobium* (WSM 244 and M 29) were supplied by Dr. P. Cocks (ICARDA - Aleppo, Syria, 1987). The pots were re-inoculated, one week later.

Nutrient solutions were prepared regularly from stock solutions with deionised water. KOH was used to adjust the pH of the solutions to 7.0. Five basic solutions were used, namely $\frac{1}{4}$ strength Hoaglands solution with NO_3^-N at 0.0 (–N) and 5.0 mM(+N). K_2SO_4 and $Ca\ SO_4$ were used to maintain the same concentration of K^+ and Ca^{++}. The various compositions are shown in Appendix Table D.1. Medic swards received nutrient solution containing 5mM NO_3^- (+N) for 15 days after emergence. After 15 days, plants were watered with 0.0 mM (–N) nutrient solution each day. Deionised water was flushed through once each week to prevent the accumulation of salt in rooting zone.

Plants were grown in controlled environment cabinets at three temperatures: 10°C, 15°C and 20°C, with a 12h photoperiod. The experiment ran for 87, 58 and 51 days at each temperature respectively The pots were arranged so as to receive a photosynthetic photon flux density (PPFD) of 400μ mol quanta/m^2 /s^1 measured at the centre of each pot. Ten pots of each genotype were distributed across the cabinet floor.

Pots were re-randomised after each harvest. Wire-mesh sleeves 18.5cm high were fitted to the pots to confine developing leaf canopies to a constant area of 225 cm^2. The PPFD was adjusted as the canopies grew vertically inside the sleeves by moving the cabinet floor up or down. Four high pressure sodium lucalox lamps of 400W each were used as a source of the light.

Dew point control was not possible inside the cabinet but regular watering ensured that plants were not water stressed. The swards were sampled regularly for total biomass (root and shoot) and for nitrogenase activity. The first harvest was made after the first trifoliate leaf had expanded (22, 15 and 13 days after sowing for 10°C, 15°C and 20°C, respectively). One pot of each plant genotype was harvested every 3 to 7 days. On each occasion, a single pot from each temperature was selected and the data analysed using Genstat V.

Estimation of nitrogenase activity by acetylene reduction assay : The reduction of acetylene (C_2H_2) to ethylene (C_2H_4), (Dilworth 1966) is a popular assay for the estimation of nitrogenase activity (Hardy *et al.* 1973) and its application to pasture legume swards similar to those used in this experiment has been described for subterranean clover by Silsbury (1981). However, it was desirable to examine certain aspects of the AR-assay.

After 3h in the light, plants were removed from the pots by gently washing off the sand with water at the growth temperature within about one minute. Excess water was blotted from the nodulated roots and whole plants were placed in 1.06l glass jars with screw-down metal lids each penetrated by a suba-seal. The jars were held at the growth temperature in water baths..

The vessels were sealed and C_2H_2(110ml) was added to each jar to give a partial pressure (P) 0.1 C_2H_2. A needle (1mm x 38mm) was inserted in the suba-seal during the injection to allow excess gases to escape and prevent pressure build up in the jar. The rates of AR were calculated from the C_2H_4 concentrations in 500µl gas samples taken at 10 minutes and 40 minutes (after C_2H_2 was added) in 1ml syringes fitted with 0.5mm x 25mm needles. Samples were injected into a Varian Aerograph model 940 gas chromatograph equipped with a flame ionisation detector (Varian Instrument Division) and a column of 80-100 mesh porapak R. Column, detector and injector temperatures were 50°C, 150°C and 150°C respectively. With the carrier gas (N_2) flowing at 65 ml per minute, C_2H_4 was estimated from peak height displayed on a flat bed Omniscribe recorder (Houston Instruments). Standards of C_2H_4 were made up (usually 100µl) using gas tight glass syringes (S.G.E. Scientific Pty. Ltd.) and injected into a jar of 10% acetylene in air at 20°C. No C_2H_4 was detected in C_2H_2 cylinders so that making up C_2H_4 standards in 10% C_2H_2 in air standardised all calculations for the rate of C_2H_4 accumulation.

The volume of gas in an assay vessel containing plants was measured by air displacement with water. The differences in peak heights between the average of three sample injections taken at 10 minutes and three taken at 40 minutes was converted to µmol $C_2H_4/m^2/h$ by reference to the peak heights given by injections from standards of known quantity of C_2H_4 in air at 20°C. The rate of C_2H_4 accumulation was calculated as:

$$\mu\text{mol } C_2H_4 \text{ m}^2/\text{h} = \frac{a \times d \times f \times 2}{b \times c \times e} \times 44.4$$

where a = known quantity of C_2H_4 (standard conc.)

b = volume of standard jar (l)

c = volume of 1mol of gas at the assay temperature

d = differences in peak heights between the mean of 3 samples at 10 and 40 minutes

e = peak height of standard

f = volume of gas in assay vessel (l) containing plants measured by displacement with water.

The value 44.4 was the correction factor converting results for the micro-swards to a m^2 basis. After estimation of nitrogenase activity plants were separated into leaf, cotyledon, stem and root and dried after measuring leaf area using a Paton Electronic Planimeter (Paton Industries Pty. Ltd.). Dry weight was determined after drying plant fractions in a forced draught oven at 85°C for 24 hours, then weighed separately .

9.3 Results

9.3.1 Data Analysis

Analysis of variance (Genstat V format) were conducted on all data for dry weight of root, shoot and total plant (g/m^2), leaf area index (LAI) and acetylene reduction assay (AR assay). Natural logarithm transformations were made where the data was not homogeneous. An overall analysis was made at each temperature regime so that Sowing Rate and Sowing Rate x Genotype effects could be detected. Each sowing rate was analysed separately so that genotype differences within a sowing rate could be detected. However, least significant differences were not calculated for each sowing rate but Species x Sowing Rate interactions could be found. Summaries of the analyses of variance are given in Table 9.2, Experiment 6 (1988).

Table 9.2 **Summary of analyses of variance for medic species grown at three temperatures**

Parameter	Source of Variation	Probability level		
		10°C	15°C	20°C
Root DM	Time (T)	.010	ns	.001
	Genotype (G)	.001	.001	ns
	G x T	.050	ns	.050
Shoot DM	T	.001	.001	.001
	G	.001	.001	.050
	G x T	.001	.001	.001
Total DM	T	.001	.001	.001
	G	.001	.001	ns
	G x T	.001	.001	.010
LAI	T	.001	.001	.001
	G	.001	.001	.010
	G x T	.001	.001	.050
AR	T	.050	.001	.050
	G	.001	ns	.010
	G x T	ns	.050	.010

9.3.2 Seedling Emergence

Seedlings of all species emerged more rapidly as the temperature increased from 10°C to 20°C: 50% of seedlings emerged within 4-5 days at 20°C, while 7-8 days were required at 10°C. There were no clear differences between genotypes in the rate of emergence as measured by the time required to reach 50% emergence, except *M. rigidula* which had a high percentage of hard-seed, resulting in a low germination rate. However, *M. rigidula* is the slower genotype in terms of seedling emergence at each treatment in both experiments followed by Sava which emerged 2 days after all the other genotypes tested.

9.3.3 Cotyledon Area

Cotyledon area was directly related to the seed weight of the species (Table 9.3). Temperature had a major effect on both cotyledon area and specific cotyledon area as the temperature increased from 10 °C to 15 °C, but at 20°C they both declined. (Tables 9.3 and 9.4).

All genotypes showed a maximum cotyledon area and specific cotyledon area at 15°C at early emergence of 15 days after sowing rather than when grown at 10°C or 20°C. Therefore, 15°C was the optimum temperature for maximum cotyledon area and maximum specific cotyledon area.

Table 9.3 **Seed weight and unit cotyledon area (mm^2) of annual medic genotypes grown at three temperatures**

Genotypes	**Weight of seed**	**Unit area of one Cotyledon (mm^2)**		
		10°C	**15°C**	**20°C**
Sava	19.98	60	123	88
Para	4.01	19	41	28
Rigi	5.55	29	57	32
Rota	6.20	23	40	36

Table 9.4 Average specific cotyledon area (cm^2/g) of annual medics at three temperatures

Genotypes	Temperature		
	10°C	15°C	20°C
Sava	103.9	183.3	159.3
Para.	108.6	203.3	244.8
Rigi.	132.2	263.6	225.1
Rota.	117.6	196.6	190.9

9.3.4 Root Growth

The average percentage of total plant dry weight which occurred as root dry matter varied with the genotype, although the root proportion was inversely related to temperature This was true for all genotypes tested for their growth response to temperature (Table 9.5). All genotypes showed an increase in the relative amount of root dry weight with time when plants were grown at 10°C, while a significant reduction in root proportion with time occurred at 20°C (Fig. 9.1). The highest reduction in root proportion due to temperature decrease from 20°C to 10°C was shown by Para.

Root dry matter production varied according to the plant population and genotype. Paraggio had a significantly greater average root dry weight than other genotypes. The dry matter yield of root increased with time. At 10°C and 20°C (Table 9.2), but not at 15°C, the interaction between time and genotype was significant. The average root dry weight for each variety fell as temperature increased (Table 9.6).

Straight lines were fitted to the dry matter data to derive the root growth rate. The straight lines described a great deal of the variation ($r^2 = 0.76$ to 0.98). Growth rates for roots are given in Table 9.7. Each genotype had a constant root growth rate(1.7g/m^2/day) at 15°C in this experiment (Table 9.7), but Para. had the highest root growth rate (2.38g/m^2/day) at low temperature. They show a tendency to decrease as temperature increased beyond 15°C. This is most noticeable at high temperature particularly for Para. and Rigi.

Table 9.5 **The average percentage of the total plant dry weight which occurred as root**

Genotypes	Temperature		
	10°C	15°C	20°C
Sava	36	35	23
Para.	39	34	22
Rigi.	30	27	25
Rota.	39	34	25

Table 9.6: **The average dry weight (gDM/m^2) of medic root grown at three temperatures**

Genotypes	Temperature		
	10°C	15°C	20°C
Sava	54.3	54.2	35.8
Para.	91.9	67.8	37.7
Rigid-.	62.1	57.2	35.3
Rota.	60.8	45.1	38.8

Table 9.7: **Root growth rate (gDM/m^2/day) of four annual medic genotypes grown at three temperatures**

Genotype	Temperature		
	10°C	15°C	20°C
Sava	1.62	1.70	1.33
Para.	2.38	1.70	0.76
Rigi.	1.50	1.70	0.54
Rota.	1.79	1.70	1.03

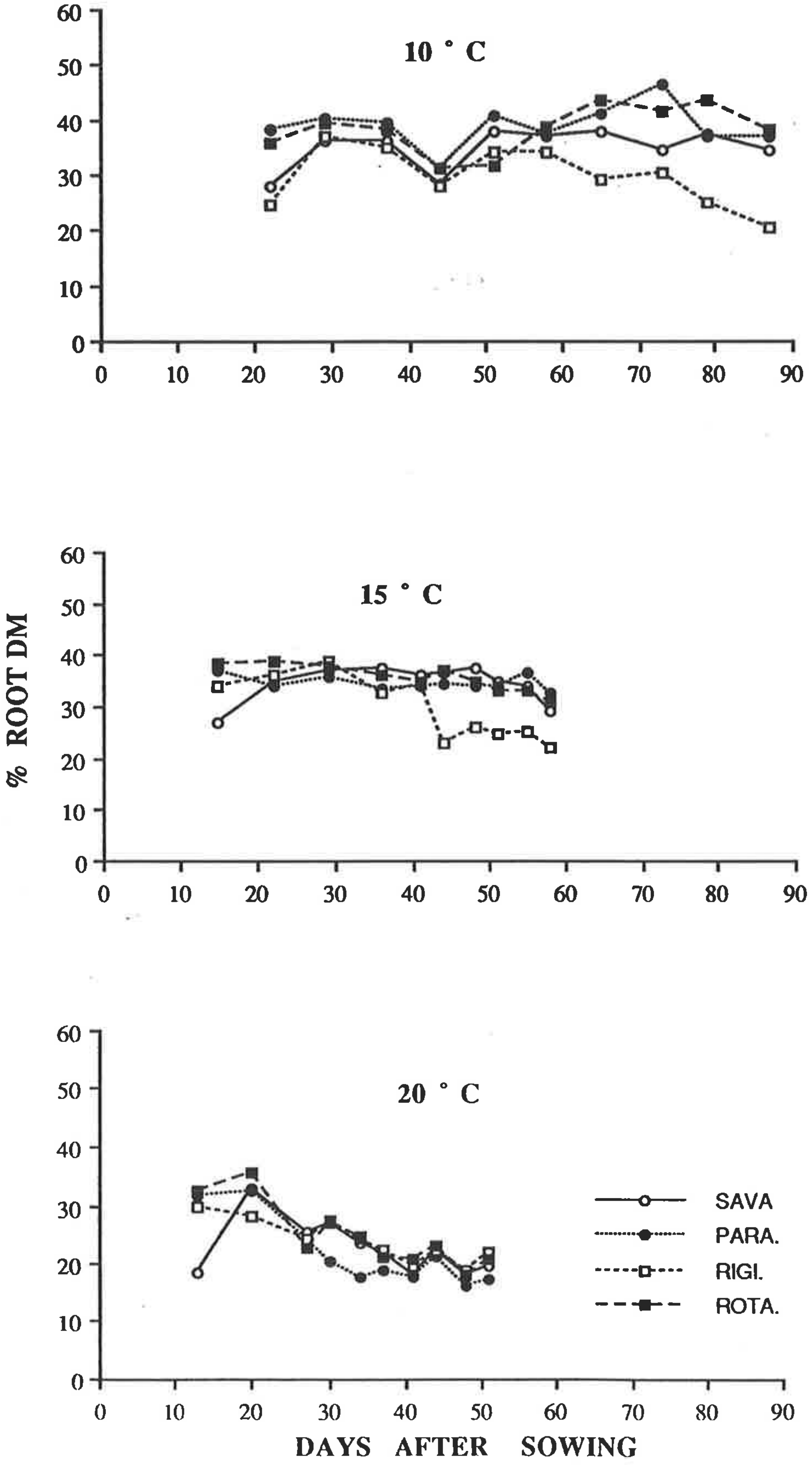

10 ° C
15 ° C
20 ° C
% ROOT DM
DAYS AFTER SOWING
0
10
20
30
40
50
60
70
80
90
SAVA
PARA.
RIGI.
ROTA.

Fig. 9.1

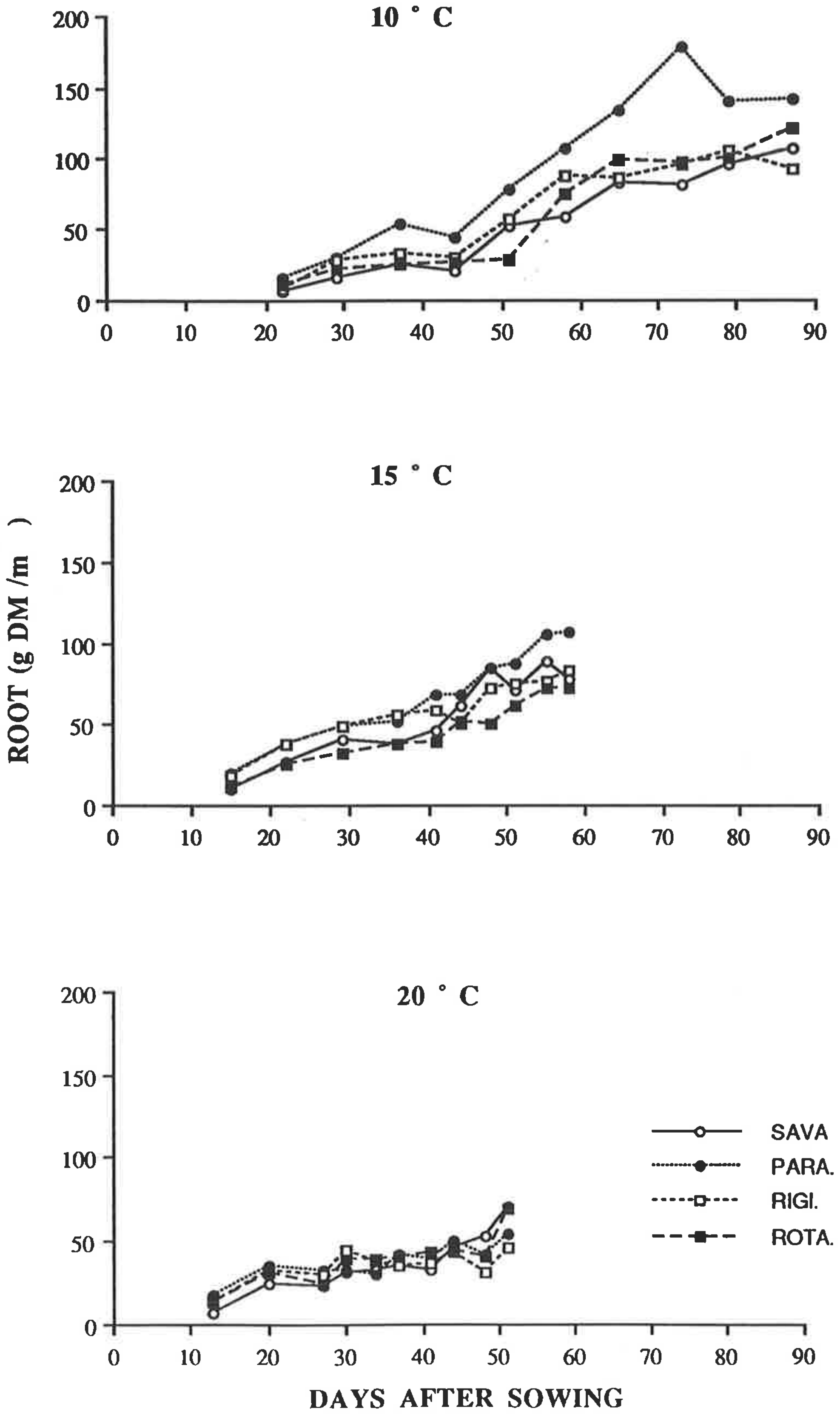

10 ° C
15 ° C
20 ° C
ROOT (g DM /m 2)
DAYS AFTER SOWING
0
50
100
150
200
0
10
20
30
40
50
60
70
80
90
SAVA
PARA.
RIGI.
ROTA.

Fig. 9.2

9.3.5. Shoot Growth

Shoot dry matter was significantly influenced by genotype and time of sampling (Table 9.2). At low temperature (10°C), the interaction between genotype and time was highly significant. Growth rates were estimated by fitting linear equations to the changes in dry matter over time. Growth rates varied with genotype and temperature regime (Table 9.8, Fig 9.3). However the growth rate of the shoots showed a different pattern from growth rate of root (Table 9.8). Shoot growth increased substantially as temperature was increased in all species except Rigi. which had its maximum growth rate at 15°C (5.6 $g/m^2/day$). Rigi. had the highest shoot growth rate of the four species at 10°C and 15°C while Sava showed the greatest growth rate (6.56$g/m^2/day$) at 20 °C.

Plots of shoot weight versus time fitted a straight line very well (Fig. 9.3). The r values ranged between 0.95-0.99, although shoot growth rates measured by DM data of biomass were relatively constant from one day to the next, they showed a general trend to increase with time as temperature increased, i.e. shoot growth rate was more dependent on temperature.

Throughout the experiment the interactions between genotype and temperature show that *M. rigidula* gave the highest growth rate (5.1 $g/m^2/day$) at 10°C and inversely responded to temperature increments, while other genotypes positively responded to increases in temperature.

Table 9.8 Shoot growth rate ($gDM/m^2/day$) of annual medics grown at three temperatures

Genotypes	Temperature		
	10°C	15°C	20°C
Sava	2.72	3.62	6.56
Para.	3.56	3.92	5.56
Rigi.	5.09	5.64	4.07
Rota.	2.53	3.11	5.36

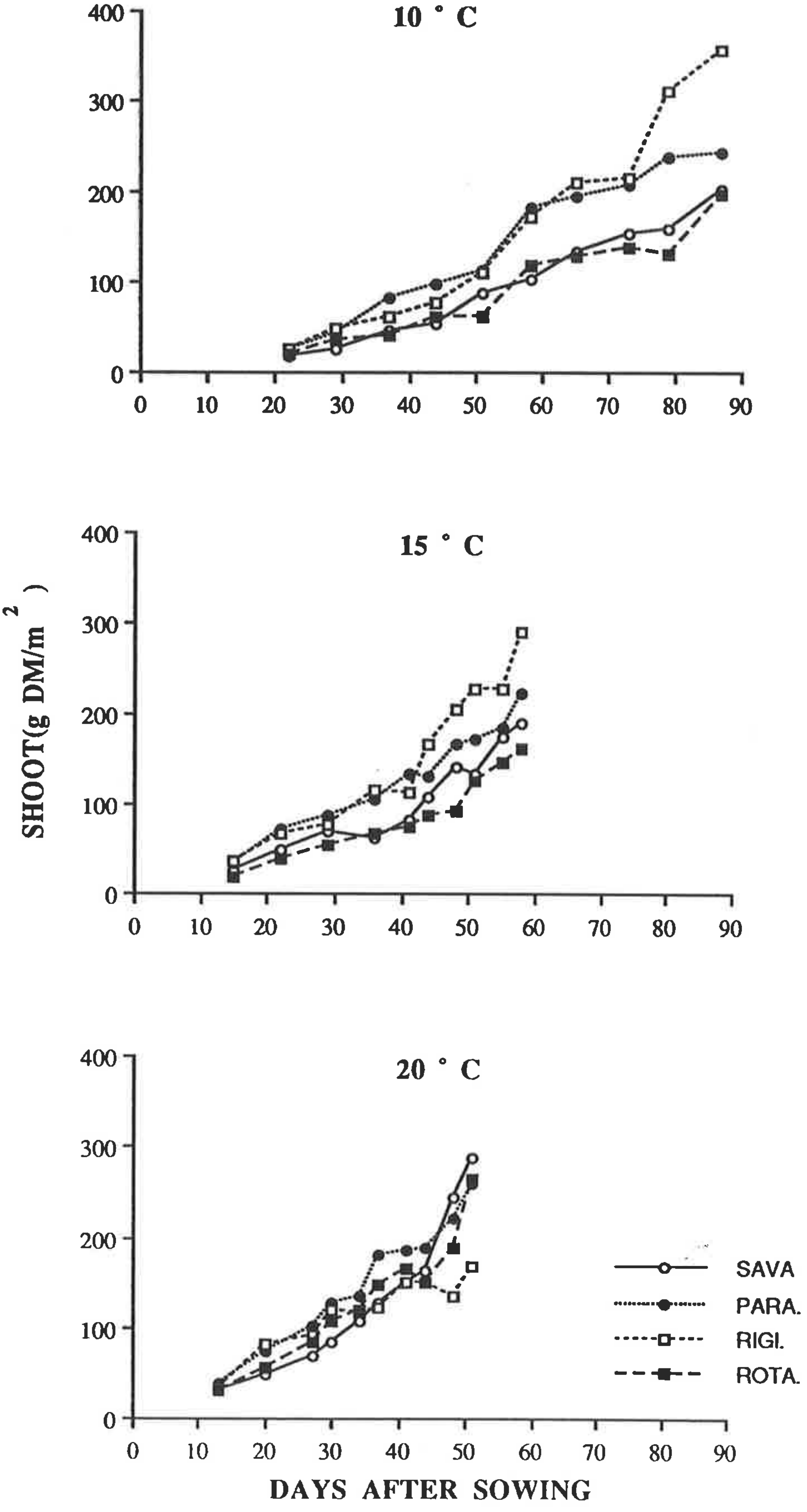

10 ° C
15 ° C
20 ° C
SHOOT(g DM/m^2)
DAYS AFTER SOWING
0
100
200
300
400
0
10
20
30
40
50
60
70
80
90
SAVA
PARA.
RIGI.
ROTA.

Fig. 9.3

9.3.6 Leaf Area Index (LAI)

LAI varied significantly according to genotype and time of sampling. There was a significant interaction between species and time for all temperature regimes (Table 9.2). Data on LAI plotted against time are shown in Fig. 9.4. Plants grown at different temperatures reached the same LAI at different dates. The increase in LAI with time is similar to that of shoot dry matter. LAI was improved by increasing the growth temperature from 10°C to 20°C (Table 9.9).

Relationships between LAI and shoot weight are shown in Fig. 9.5. LAI increased linearly with increase in shoot weight. LAI per unit shoot DM was much higher at 20°C than at 15°C and 10°C. Specific leaf area (SLA) increased as the temperature increased, which means temperature had the same effects on both LAI and SLA (Fig.9.6).

Table 9.9 The average Leaf Area Index of annual medics grown at three temperatures

Genotypes	Temperature		
	10°C	15°C	20°C
Sava	0.96	1.68	2.90
Para.	1.35	1.68	3.28
Rigi.	2.43	1.68	2.66
Rota.	0.97	1.68	2.48

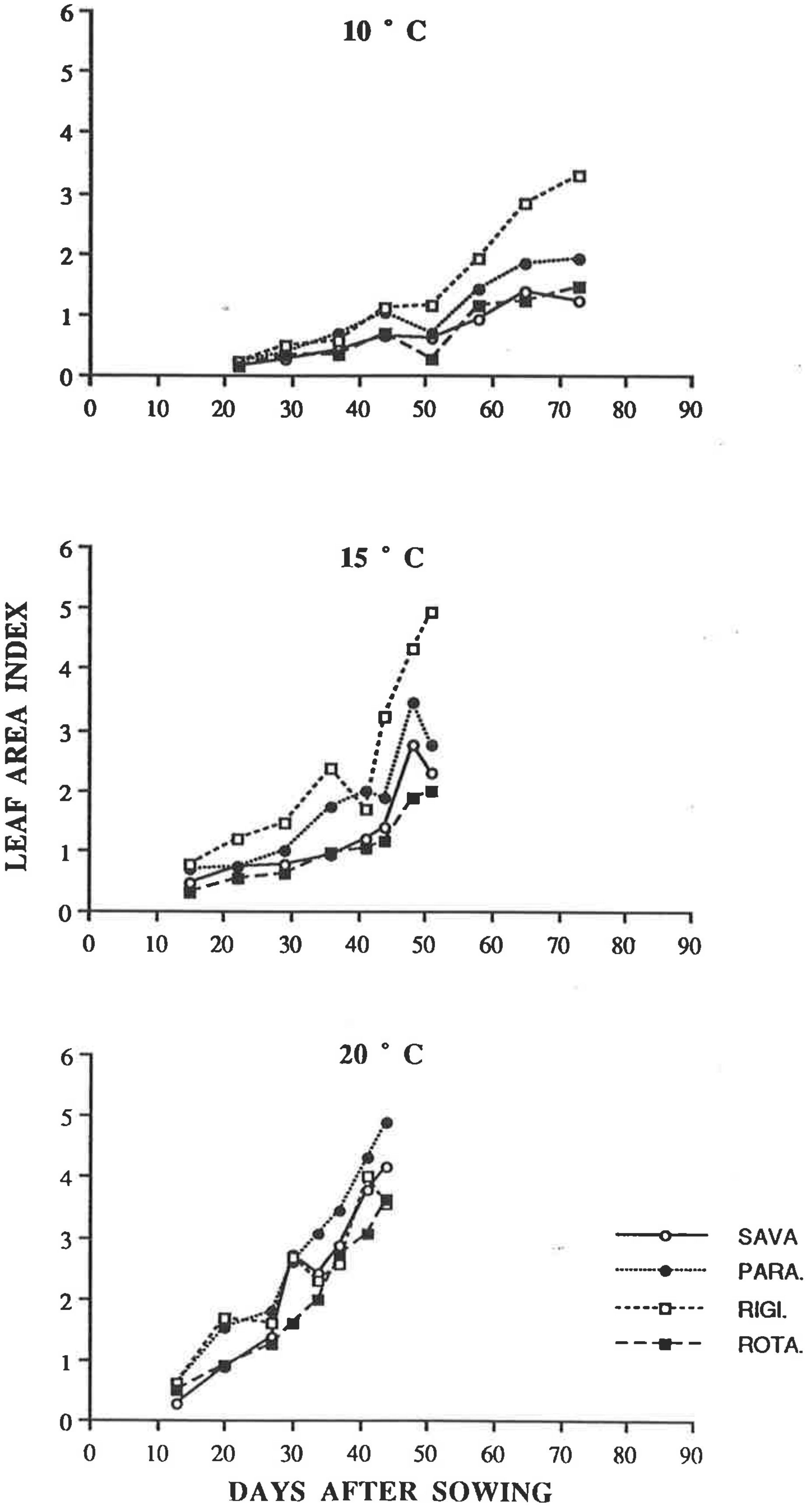

10 ° C
15 ° C
20 ° C
LEAF AREA INDEX
DAYS AFTER SOWING
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
SAVA
PARA.
RIGI.
ROTA.

Fig. 9.4

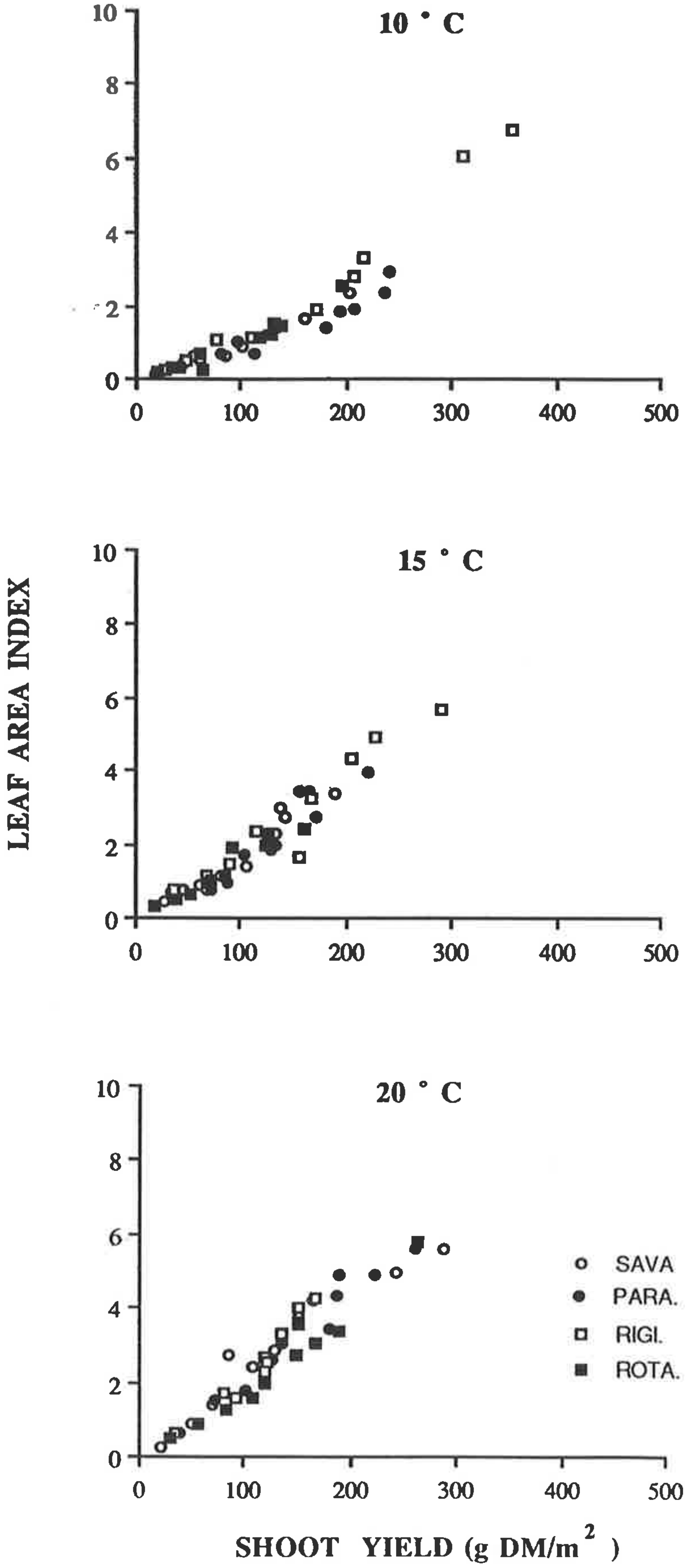

10 ° C
15 ° C
20 ° C
LEAF AREA INDEX
SHOOT YIELD (g DM/m²)
0
2
4
6
8
10
0
100
200
300
400
500
○ SAVA
● PARA.
□ RIGI.
■ ROTA.

Fig. 9.5

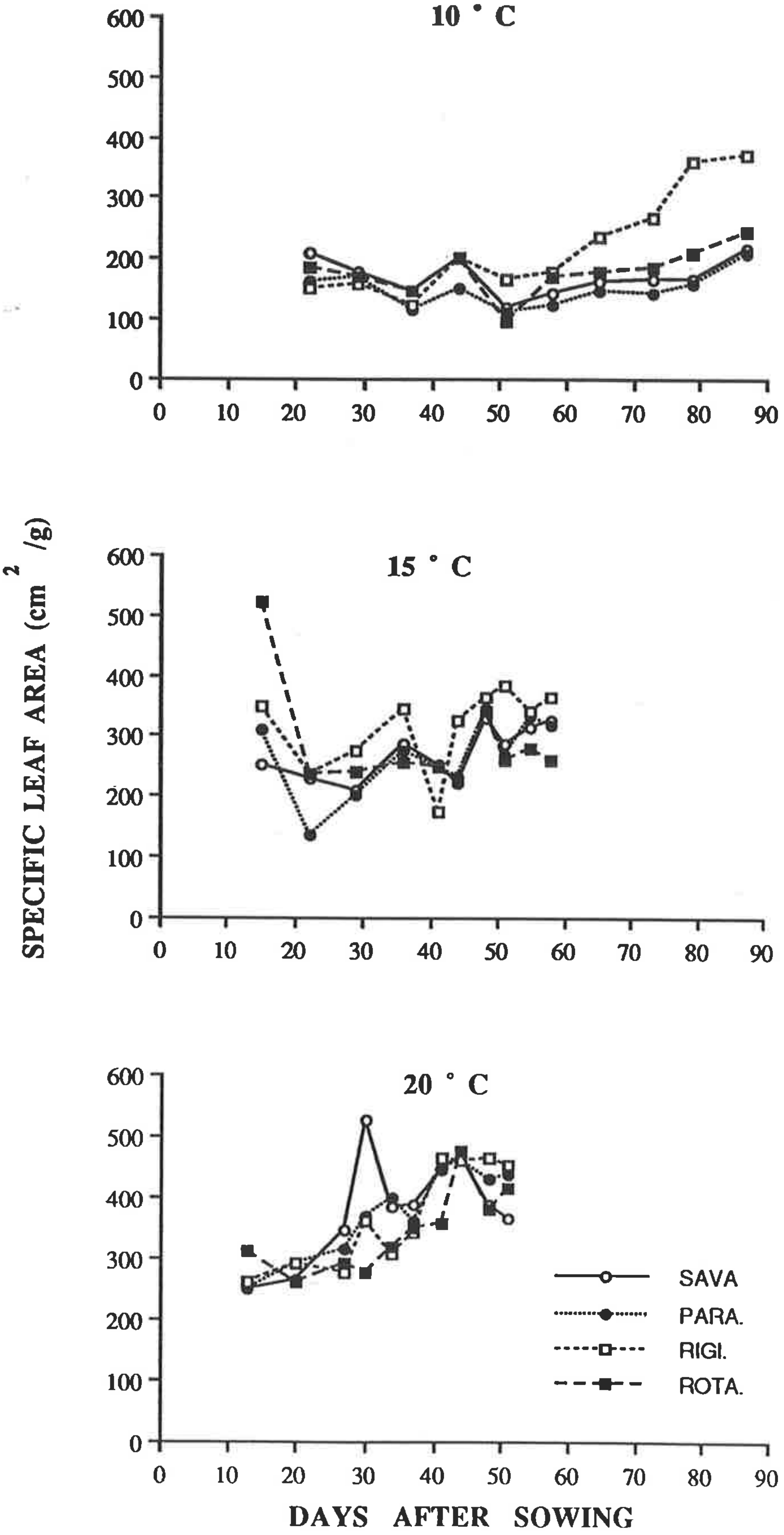

10 ° C
15 ° C
20 ° C
SPECIFIC LEAF AREA (cm^2 /g)
0
100
200
300
400
500
600
0
10
20
30
40
50
60
70
80
90
SAVA
PARA.
RIGI.
ROTA.
DAYS AFTER SOWING

Fig. 9.6

9.3.7 Acetylene Reduction (AR) Assay

AR assay values are plotted against time for each temperature (Fig. 9.7). Nitrogenase activity was directly affected by temperature. At 10°C nitrogen fixation occurred approximately 15 days later than at 15°C or 20°C. There was little difference between plants grown at 15°C or 20°C; at both temperatures nitrogen fixation occurred 26-30 days after sowing. AR assay varied according to genotype or time of sampling and with time. The interaction between genotype and time was significant at 15°C and 20°C (Table 9.2).

The average AR over the experiment (Table 9.10) shows the optimum temperature for nitrogenase activity to be 15°C. Sava produced the highest amount of C_2H_4 (1011 and 763μmol/m^2/h) at 15°C and 20°C respectively, while maximum C_2H_4 production (627μmol/m^2/h) at low temperature was obtained by Rigi..

Table 9.10 **The average C_2H_4 produced (μmol/m^2/hr) by annual medics grown at three temperatures**

Genotypes	Temperature		
	10°C	15°C	20°C
Sava	162	1011	763
Para.	72	782	288
Rigi.	627	756	281
Rota.	80	610	371

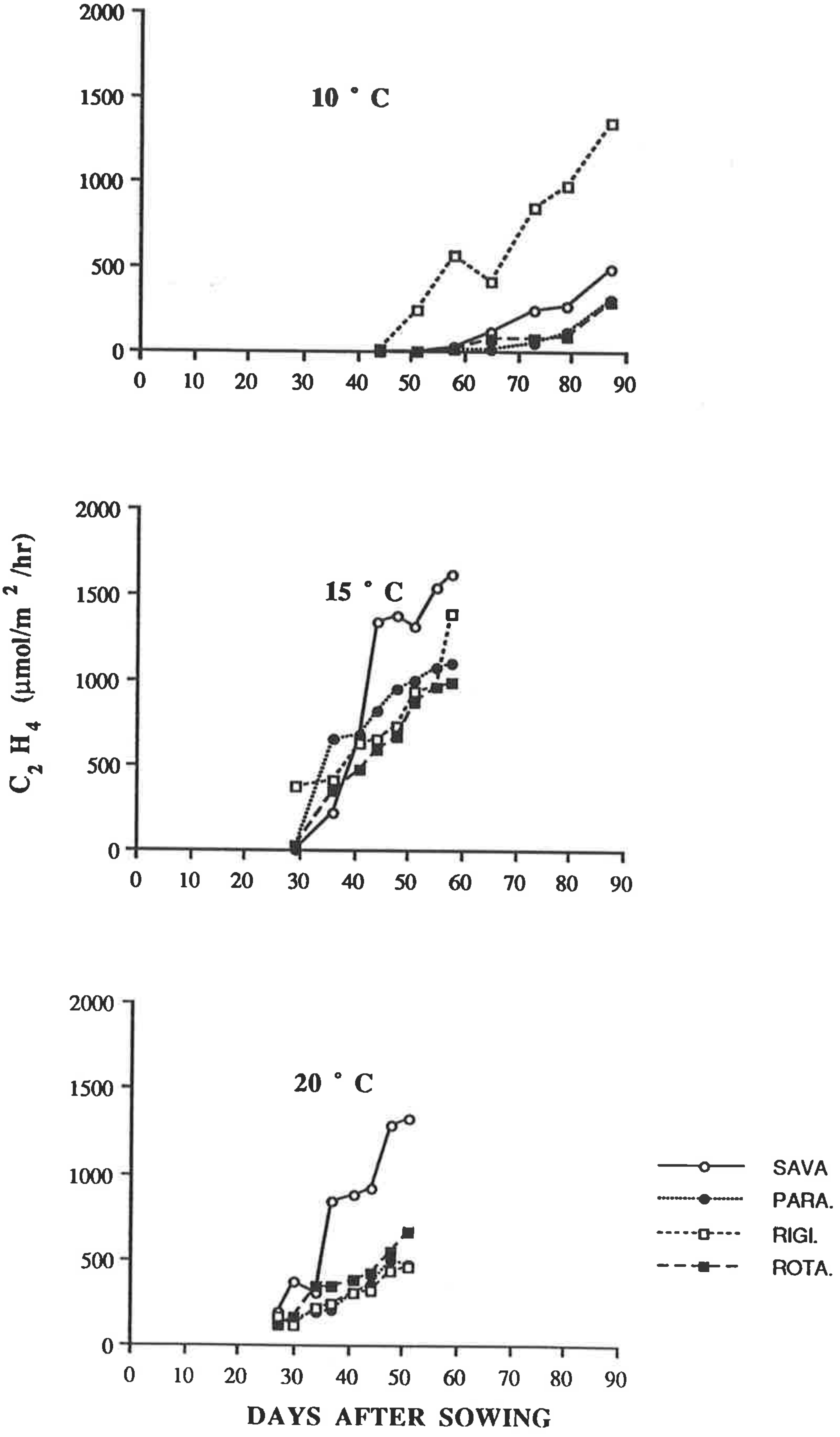

10 ° C
15 ° C
20 ° C
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90
C_2H_4 (µmol/m^2/hr)
DAYS AFTER SOWING
SAVA
PARA.
RIGI.
ROTA.

Fig. 9.7

EXPERIMENT 7: THE INFLUENCE OF TEMPERATURE AND PLANT DENSITY ON GROWTH AND NITROGEN FIXATION BY TWO ANNUAL MEDIC GENOTYPES

9.4 Introduction

Variation in plant density is a useful tool for studying intraspecific and interspecific competition in communities of crop and pasture plants. The growth responses of undefoliated plants of subterranean clover to temperature depend on plant density, the amount of biomass present and on incident (solar) radiation (Silsbury 1990). Better knowledge of the factors affecting the field behaviour of medics is necessary if they are to be used effectively as components of pastures. Two factors known to influence pasture productivity at this time are plant density and temperature (Adem 1977; Silsbury *et al.* 1979). The influence of temperature on the growth of temperate pasture species has been measured with spaced plants (Mitchel 1956; Morley 1958; Mitchell and Lucanus 1962; Broue *et al.* 1967; Silsbury 1969; Scott 1970). These temperate species grew fastest at a temperature of about 20-25°C. The general assumption has been that plants growing as communities respond to temperature in a similar manner to spaced plants. This assumption may not be true (Cocks 1969). In plant communities, individuals compete against one another and so their growth rates are slower than those of spaced plants (Stern 1965; White and Harper 1970; Harris 1971). Because of this restriction by inter-plant competition, the influence of temperature on the individual grown in a community will almost certainly be less than on a spaced plant. Evidence for this view was provided by Davidson *et al.*(1970), who found that after 16 weeks the dry matter yield of Tallarook subterranean clover was not significantly greater at 22°C than at 12°C. Further evidence is provided by the studies of Donald (1951, 1954). His work showed that dry matter production at the end of the season of plants such as subterranean clover and Wimmera ryegrass was independent of sowing density over the range of 150-30,000plants/m^2, although yield in early winter was strongly dependent on density. The higher the sowing rate, the earlier the growth rate becomes constant (Black 1964). Therefore, the hypothesis is that high density communities are initially capable of a high crop growth rate soon after emergence but the rate declines throughout the season, while low density communities showed an accelerating crop growth rate during the season so that final yields were similar in both treatments. The objective of this experiment was to (i) confirm the results of the effect of temperature on growth response of annual medics investigated in the previous experiment and (ii) explore further the interactions between temperature, plant genotypes and plant density in influencing the growth and nitrogen fixation by a sward of medics.

9.5 Materials and methods

Genotypes : Two genotypes (*Medicago scutellata* cv.Sava and *M. rigidula* Sel. 716 abbreviated to Sava and Rigi.) out of the four used in Experiments 2 to 6 were chosen to examine the influence of temperature on the growth rate of medics when sown at different densities. Sava was selected because it responded positively to temperature, while Rigi. was selected because of its tolerance to low temperatures.

Treatments : Plants were grown at three densities and three temperatures. Seeds were graded to remove very small, broken and damaged seed and sown to give a low density of 888 plants/m^2, a medium density of 2222 plants/m^2 and a high plant density of 22220 plants/m^2. An excess of seed was used at the lower and medium densities and emerged seedlings thinned to give the required number of seedlings of uniform size and evenly spaced. Allowance was made at the higher density according to emergence percentage and seed weight of each genotype, i.e. sowing was on the basis of equal number rather than equal weight (Table 9.11). The day/night temperatures were 10°C, 15°C and 20°C with a fluctuation of about 0.5°C at each level.

Growing the Medic Communities and Data Recorded : The communities were grown in a controlled environment cabinet. The same procedures were adopted and parameters measured as in the previous experiment (No. 6) except that organic nitrogen in root and shoot plant tissue was estimated separately. Plant material to be analysed for organic nitrogen was ground to less than 1 mm particle size in a mill and 250 mg samples digested with a Technicon BD-40 Block Digester using 4 ml conc.H_2SO_4 for 20 minutes at 400°C with a further 15 minutes at 350°C. Samples were allowed to cool, and diluted to 50 ml with distilled water. Nitrogen was estimated by colorimetric method using a Technicon Autoanalyser. Harvests were made at 4 to 7 day intervals commencing after emergence. The first harvest occurred 28, 21 and 17 days after sowing for temperature regimes 10°C, 15°C and 20°C respectively and continued up to 77, 59 and 49 days. One pot of each genotype and treatment was harvested each time.

Table 9.11 Experimental details of Experiment 7

Genotype	Plant Density	Weight of seeds (g/m^2)	Number of plants/pot †
Sava	Low	17.78	20
	Medium	44.45	50
	High	533.28	450
Rigi.	Low	4.90	20
	Medium	12.25	50
	High	147.91	450

† Self-thinning reduced plants from 500 to 450/pot at high density

9.6 Results

The main reponses to temperature, plant density and interactions are summarized in Table 9.12.

9.6.1 Cotyledon Area and Specific Cotyledon Area

From the previous study, the area of the cotyledons showed no response to temperature (Table 9.3). The Specific Cotyledon Area increased as the rate of sowing increased regardless of temperature regimes or genotype (Table 9.13). The average Specific Cotyledon Area increased as temperature increased from 10°C to 15°C. However, above 15°C. the response varied between species and density (Table 9.13). Maximum average Specific Cotyledon Area (306cm^2/gDM) was obtained from Sava at 20°C, followed by Rigi.which gave the highest value (274cm^2/gDM) at 15°C with high sowing rate.


M RIGIDULA
Low Density


M.RIGIDULA
Medium Density


M RIGIDULA
High Density

9.6.2 Plant Population

The number of plants was determined at each harvest. Temperature did not have any significant effect on plant number per unit area. Plant number remained constant at low and medium densities respectively during the growing period. At the high density, a small amount of self thinning occurred (Table 9.11) due to inter-plant competition. The population density decreased from 500 to 450 plants/pot.

Plate 9.1 **Showing the contrasting growth of *Medicago rigidula* at three densities in Experiment 7**

Table 9.12 **Summary of analyses of variance for Experiment 7 showing medic genotype responses to temperature, plant density and interactions**

Parameters measured	Source of Variation	Temperatures		
		10°C	15°C	20°C
Root yield	Genotype (G)	.001	.010	ns
	Time (T)	.001	ns	.001
	Density (D)	.001	.01	.001
	G x T	.001	ns	ns
	G x D	ns	ns	ns
	T x D	.001	.050	ns
	G x T x D	ns	ns	ns
Shoot yield	G	.001	.001	.001
	T	.001	.001	.001
	D	.001	.001	.001
	G x T	.010	ns	ns
	G x D	.001	.010	ns
	T x D	.001	ns	.010
	G x T x D	ns	.050	.050
Total plant	G	.001	.001	ns
	T	.001	.001	.001
	D	.001	.001	.001
	G x T	.001	ns	ns
	G x D	.001	.010	ns
	T x D	.001	ns	.001
	G x T x D	ns	.050	.010
AR assay	G	.001	.001	ns
	T	.001	.001	.001
	D	ns	.001	.050
	G x T	.001	.050	ns
	G x D	ns	ns	ns
	T x D	ns	.001	ns
	G x T x D	ns	ns	ns
LAI	G	.001	.001	ns
	T	.001	.001	.001
	D	.001	.001	.001
	G x T	ns	.050	ns
	G x D	.001	ns	ns
	T x D	.050	ns	.010
	G x T x D	ns	ns	.010
% N in Root	G	.001	.001	.050
	T	ns	ns	.001
	D	.001	.050	.001
	G x T	.001	ns	.001
	G x D	ns	ns	.001
	T x D	.001	.001	.001
% N in Shoot	G	.001	.001	.050
	T	.050	.050	ns
	D	.001	.001	.001
	G x T	.001	.050	.010
	G x D	.050	.010	.010
	T x D	.001	.050	ns

9.6.3 Root Growth

Root proportion : Fig. 9.8 shows the changes over time in percentage of the total plant dry weight which occurred as root. At 10°C the proportion of DM in root was nearly constant during the growing period for both genotypes and densities (Fig. 9..8), whereas at the higher temperatures it tended to fall with age. The average root proportion fell as temperature increased and also decreased slightly as the plant density increased for both genotypes regardless of temperature (Table 9.14). Sava responded negatively to temperature, the root proportion (0.37) was higher at 10°C with low density and declined sharply to 0.24 at 20°C with high density.

Root dry matter yield : Root dry matter production varied according to genotype, density, root medium and temperature. The effect of time on root weight was highly significant ($P<0.001$) at both 10ºC and 20°C (Table 9.12). Table 9.15 shows that the average root weight (over 8 harvests) of both genotypes decreased as temperature increased from 10°C to 20°C and increased significantly as plant density increased regardless of temperature. Sava was superior to *M. rigidula* in root weight in all conditions. Both genotypes had the greatest average root weight at low temperature with high density and the minimum at high temperature with low density shown in (Table 9.15).

Root growth rate: The changes in root dry matter over time are shown in Figs. 9.9 and 9.10. The root growth rate was generally constant during the experiment, but there was a tendency for it to decrease with time at the high density. Average growth rates determined from linear regression are given in Table 9.16. At 10°C, average growth rates increased as density increased for both genotypes. Both genotypes had the same root growth rates, 1.19gDM/m^2/day at 20°C and there was no significant interaction between genotype and density at 20°C. At 15°C both genotypes had the same root growth rate at each plant density. Root growth rate was depressed by increasing temperature from 10°C to 20°C irrespective of the plant density. Maximum growth rate was (3.367gDM/m^{2}day) for Sava occurred when it was grown at low temperature with high density (Table 9.16).

Table 9.13 **Average Specific Cotyledon Area (cm^2/g) of annual medics grown at three temperatures and three plant densities**

Genotype	Plant Density	Temperature (°C)		
		10	15	20
Sava	Low	123.5	164.0	182.0
	Medium	141.4	185.2	168.1
	High	242.1	279.9	306.1
Rigi	Low	142.3	171.9	142.9
	Medium	125.0	218.7	142.8
	High	229.6	274.1	172.0

Table 9.14 **The average percentage of the total plant dry weight which occurred as root**

Genotype	Plant Density (#/m^2)	Temperature		
		10°C	15°C	20°C
Sava	20	37	31	27
	50	36	31	26
	450	26	24	26
Rigi.	20	34	31	29
	50	34	29	28
	450	33	28	26

Table 9.15 **The average dry weight (gDM/m^2) of medic root grown at three temperature levels with three rates of sowing**

Temperature (°C)	Genotype	Densities		
		Low	Medium	High
10	Sava	78.5	123.7	202.5
	Rigi	31.1	60.0	145.2
15	Sava	60.3	101.1	137.3
	Rigi	39.6	58.2	110.9
20	Sava	47.1	60.2	118.8
	Rigi	36.3	55.6	92.3

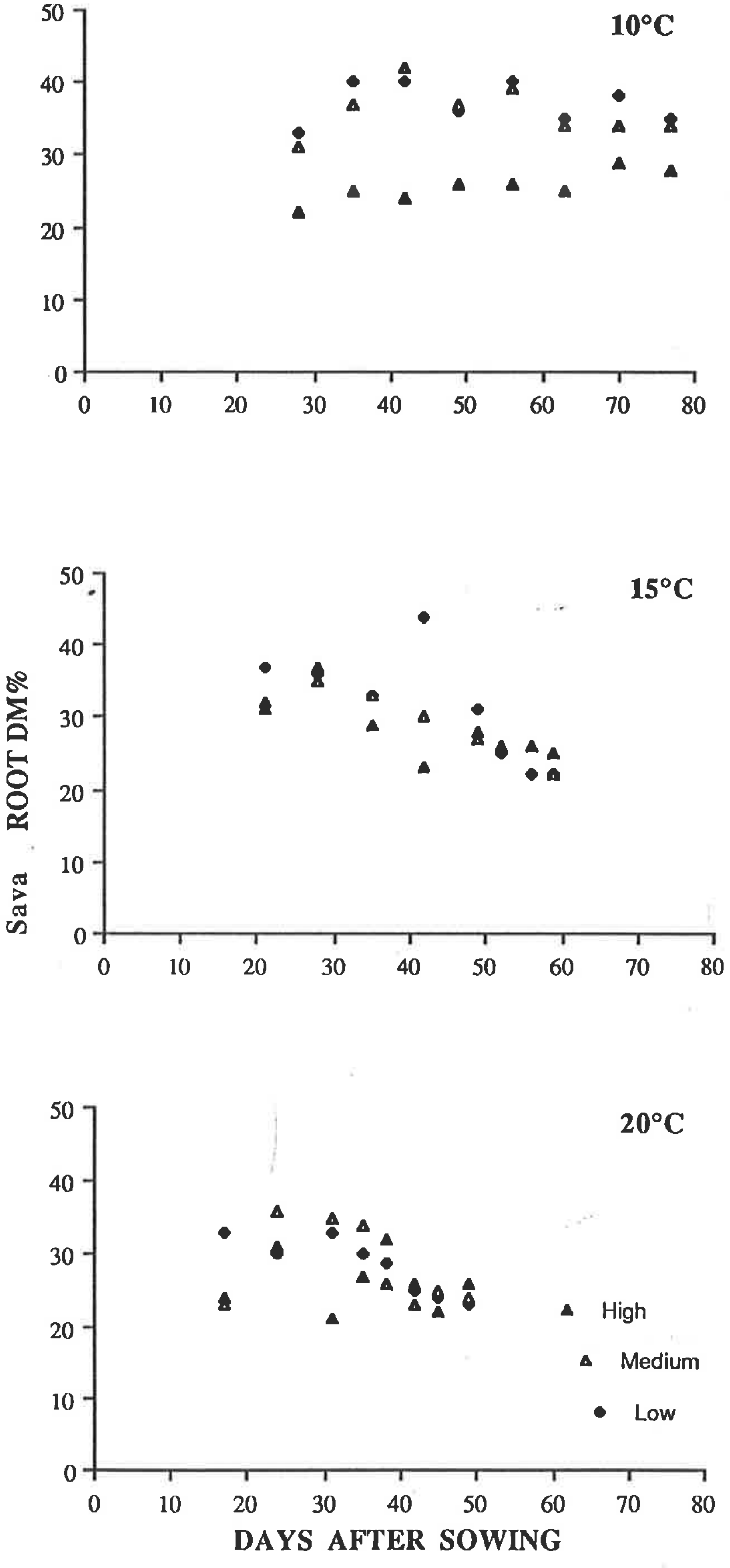

10°C
15°C
20°C
Sava ROOT DM%
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
High
Medium
Low
DAYS AFTER SOWING

Fig.9.8 a

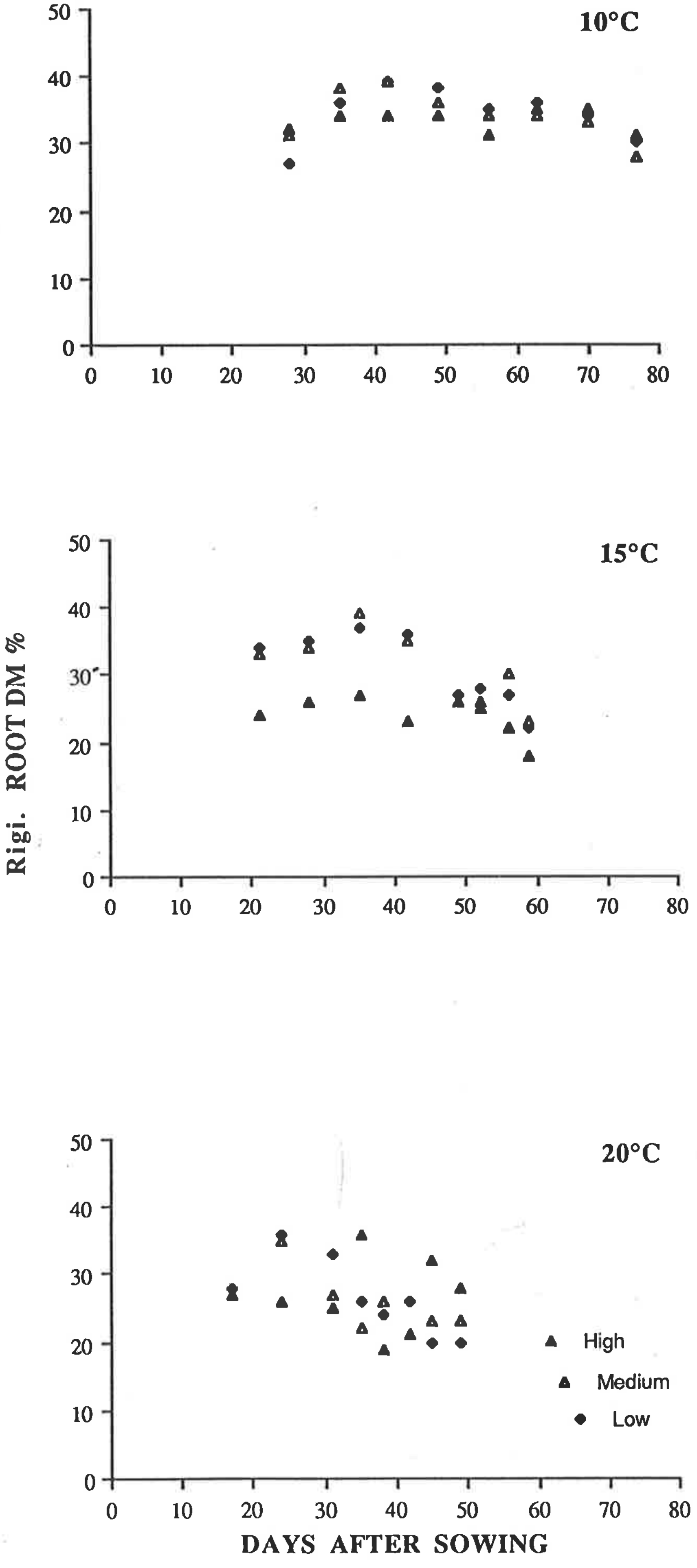

10°C
15°C
20°C
Rigi. ROOT DM %
DAYS AFTER SOWING
0
10
20
30
40
50
60
70
80
High
Medium
Low

Fig.9.8 b

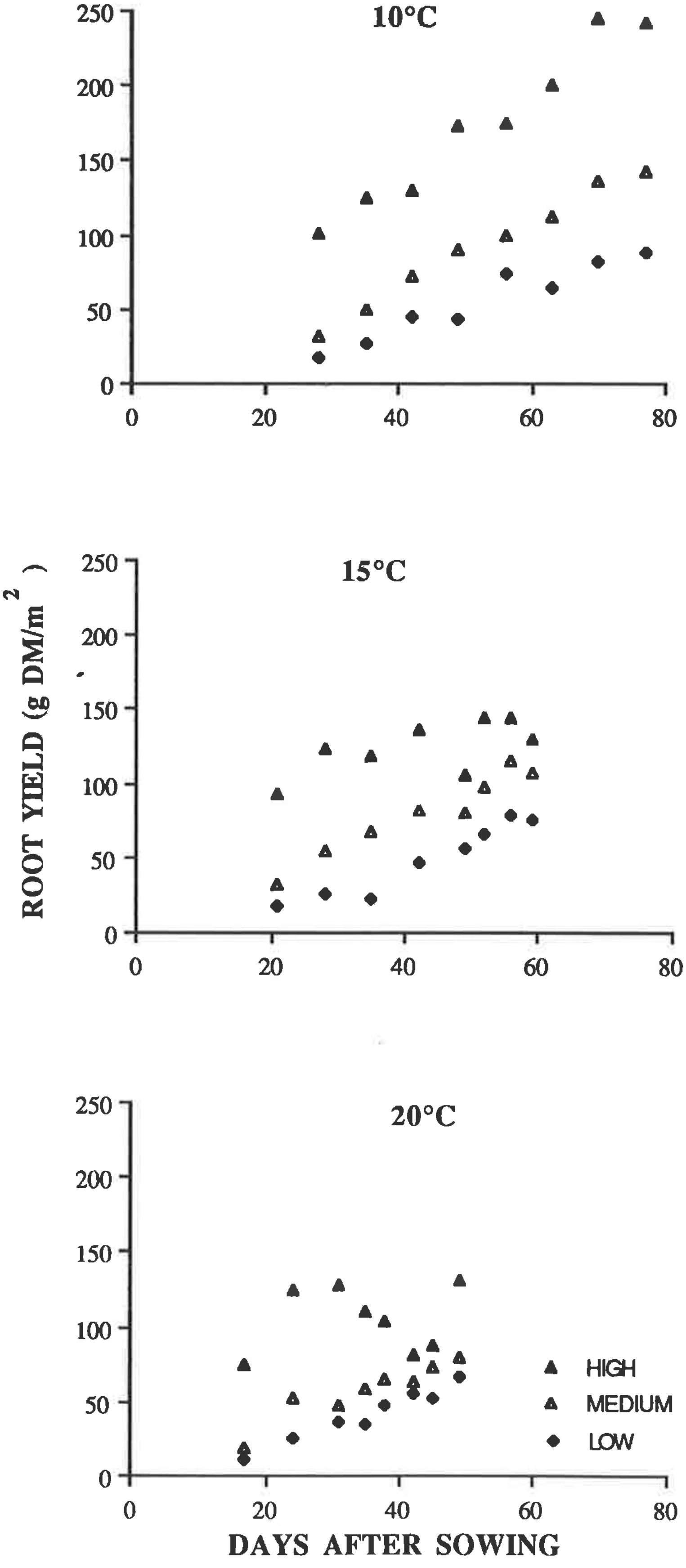

10°C
15°C
20°C
ROOT YIELD (g DM/m^2)
250
200
150
100
50
0
0
20
40
60
80
HIGH
MEDIUM
LOW
DAYS AFTER SOWING

Fig.9.9

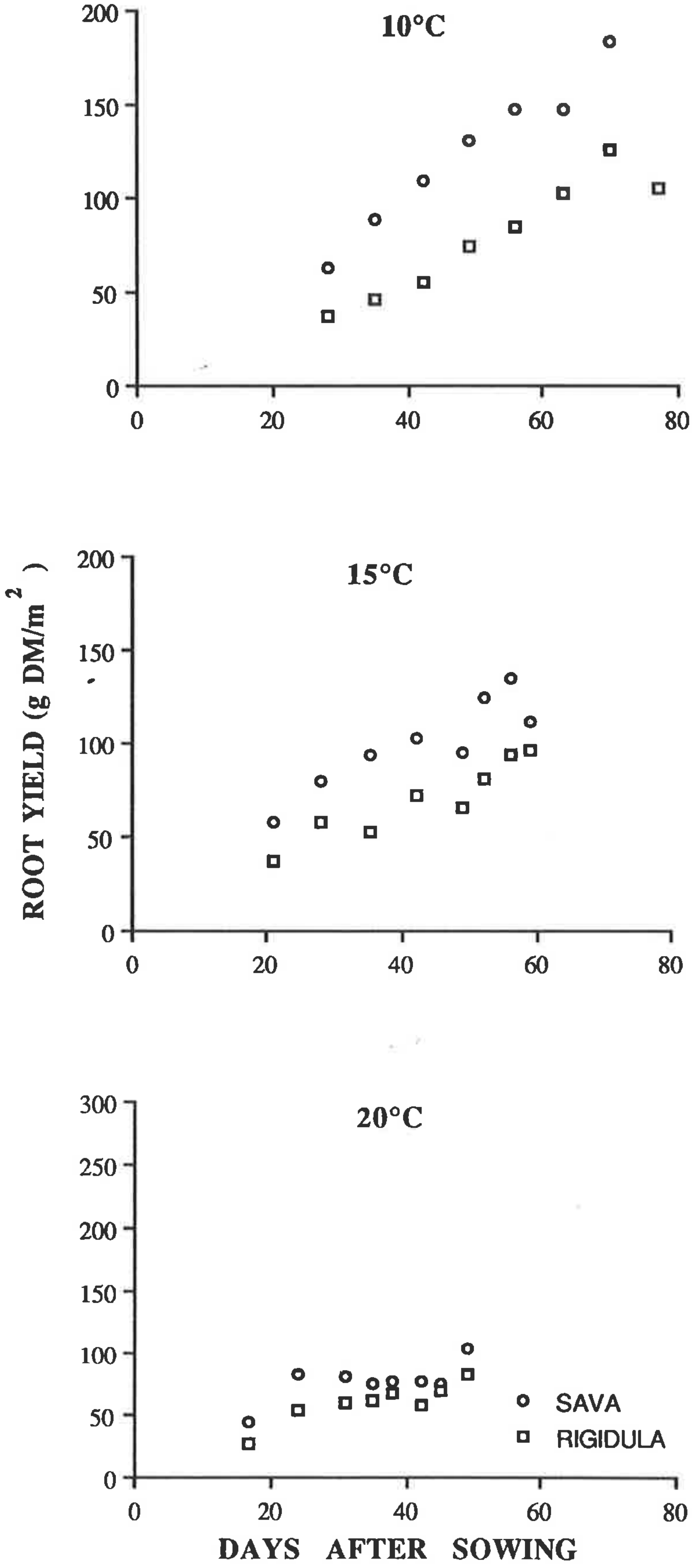

10°C
15°C
20°C
ROOT YIELD (g DM/m^2)
0
50
100
150
200
250
300
0
20
40
60
80
DAYS AFTER SOWING
SAVA
RIGIDULA

Fig.9.10

9.6.4 Shoot dry matter and growth rate

Plots of shoot weight versus time (Figs. 9.11 and 9.12) fitted a linear line very well at 10°C, but although the growth rates of the shoot at the other temperatures were relatively constant too, they showed a general trend to increase over the growing period as temperature increased. This tendency was most apparent at low density in this experiment as well as in the previous experiment.

At 10°C, the interactive effects between any two variables of time, genotype and plant density were highly significant. The growth rate of the shoot (Table 9.17) showed a different pattern from that of the root. Shoot growth increased with temperature and plant density. At low and medium densities, Sava was greater than Rigi. at all temperatures (Figs. 9.13 and 9.14). Comparing genotypes, Sava responded positively to temperature at low density and negatively at high density. Growth rate of Rigi. increased as temperature increased from 10°C to 15°C and declined above 15°C at all densities (Table 9.17).

Sava had the highest shoot weight (577g/m^2) at 10°C and high density (Table 9.18). Also shoot weight of Sava was markedly decreased as temperature increased from 10°C to 20°C at high density. Therefore, the interaction between genotype and density was found to be highly significant at 10°C and 15°C. The interaction between genotype, density and time was also significant at 15°C and 20°C (Table 9.12).

The lowest value of shoot growth rate was was produced by Rigi. (2.0gDM/m^{2}day) at low density and temperature 10°C and the maximum value (8.9gDM/m^2/day) by Sava at medium density and temperature 15°C (Table 9.17).

9.6.5 Leaf Area Index (LAI) and Growth Rate

LAI varied significantly according to genotype, plant density and time of sampling. Leaf area index is plotted against time and growth curves fitted as shown in Figs 9.15 and 9.16. Plants at different temperatures and at different densities reached the same LAI at different times . The higher the rate of sowing, the faster an optimum of LAI was reached. LAI increased as the plants aged regardless of the genotype, plant density or temperature. The average LAI over the growing period was greater at 20°C than at 15°C and 10°C (Table 9.19). At 10°C, the increase in LAI was almost linear with time, whereas the increase in LAI at 20°C tended to be sigmoidal.

The average LAI of both genotypes showed the same pattern of increase during the growing period with increased rate of sowing within each temperature. Low plant density resulted in the lowest average of LAI, irrespectiveof plant density. Fig. 9.17 shows that there is a close linear relationship between LAI and the shoot weight . LAI per unit shoot weight was higher at 20°C than at 15°C and 10°C. The interaction between Genotype x Time x Plant Density for LAI was significant only at 20°C (Table 9.12). Specific leaf area (SLA) increased as the temperature and/or plant density increased which confirms that the interaction between temperature and plant density had a positive influence on SLA as well as on LAI (Fig. 9.18).

9.6.6 Acetylene Reduction (AR) Assay

The AR assay values are plotted against time at every temperature regime as shown in Fig. 9.19. Nitrogenase activity responded positively to temperature. At 10°C the start of nodule activity was later than at 15°C or 20°C. AR assay varied according to genotype, temperature, plant density and time of sampling. Nodules became more active as the time progressed in most instances. There was no significant Genotype x Time x Plant Density interaction at any temperature (Table 9.12). Nitrogenase activity for Sava was depressed severely at low temperature (Table 9.20, Fig. 9.19).

The average AR assay values (Table 9.19) show the optimum temperature for nitrogenase activity varied between the two cultivars: greatest activity occurred at 10°C and 20°C for Rigi. and Sava, respectively. AR assay followed the same trend as the growth rate of each genotype. In this experiment, there was no significant interaction either between genotype and density or between genotype and density and time. The only significant interaction between any two variables was between time and density at 15°C, and between genotype and time at 10°C and 15°C level of temperature (Table 9.12).

9.6.7 Relations between Nitrogen Accumulation and AR assay

The AR and N_2- fixation rates (calculated from organic nitrogen accumulation), are given in (Tables 9.19 and 9.20). Means for each variable have been compared between temperatures for a range of biomass common to all temperatures. The N_2-fixation rates were similar at 10°C and 20°C and were greatest at 15°C in most instances, i.e. nitrogen accumulation responded positively to temperature from 10°C to 15°C and negatively after 15°C. Thus showing the same general trend as observed for shoot growth rate (Table 9.17). Therefore, clearly the N_2-fixation rate was in the long term, a function of the effects of temperature on community growth. However, at all temperature regimes, plant density has a great influence on total accumulation of nitrogen. Accumulated nitrogen increased as plant density increased regardless of temperature regimes. Between 10°C and 15°C, the effects of temperature on N_2-fixation can be seen to have been parallelled in those on AR, but at 20°C N_2-fixation was depressed whereas AR was stimulated (Tables 9.20 and 9.21). Similarly, AR appears not to have been a reliable index with which to have measured the response of N_2 fixation to temperature.

Table 9.16 **Root growth rate (gDM/m^2/day) of two annual medic genotypes grown at three temperatures using three rates of sowing**

Genotype	Plant Density 1 (#/m^2)	Temperature		
		10°C	15°C	20°C
Sava	20	1.99	1.64	1.19
	50	2.79	1.95	1.19
	450	3.57	1.89	1.19
Rigi.	20	0.95	1.64	1.19
	50	1.75	1.95	1.19
	450	2.53	0.89	1.19

Table 9.17 Shoot growth rate (gDM/m^2/day) of annual medics grown at three temperatures using three different plant densities

Genotype	Plant Density (#/m^2)	Temperature		
		10°C	15°C	20°C
Sava	20	3.64	6.67	8.53
	50	5.76	8.94	7.88
	450	6.93	4.88	2.52
Rig.	20	2.02	5.37	5.15
	50	4.14	5.78	5.46
	450	5.31	6.50	4.82

Table 9.18 The effects of genotype and plant density on shoot production (g/m^2) of annual medics grown at three temperatures

Temp. (°C)	·Genotype	Densities			LSD 5%	P Pr
		Low	Medium	High		
10	Sava	133.6	222.8	576.7	33.8	
	Rigi.	78.8	120.5	291.3		
15	Sava	153.3	246.4	441.2	48	
	Rigi.	132.6	154.8	292.0		
20	Sava	147	184.3	321.8	–	ns
	Rigi.	101.1	145.1	260.2	–	ns

Table 9.19 The effect of cultivar and plant density on average Leaf Area Index of annual medics when grown at three temperatures

Genotype	Plant Density	Temperature		
		10°C	15°C	20°C
Sava	Low	1.55	2.85	2.69
	Medium	2.88	4.44	3.78
	High	9.01	7.14	6.58
Rigi	Low	0.77	1.65	1.80
	Medium	1.52	2.75	2.84
	High	3.96	4.75	5.36

Table 9.20 **The average C_2H_4 produced (μmol/m^2/hr) of annual medics grown at three levels of temperature and plant density**

Genotype	Plant Density	Temperature		
		10°C	15°C	20°C
Sava	Low	28	172	485
	Medium	43	118	462
	High	49	56	276
Rigi.	Low	549	316	474
	Medium	795	173	600
	High	769	111	413

Table: 9.21 **Nitrogen accumulated (gN/m^2) in plant tissue of medics grown at three levels of temperature and plant density**

Genotype	Plant Density	Temperature		
		10°C	15°C	20°C
Sava	Low	2.9	3.7	3.6
	Medium	4.3	5.6	4.7
	High	17.5	17.9	12.4
Rigi.	Low	1.5	3.3	2.7
	Medium	3.1	4.4	3.5
	High	7.6	8.0	6.9

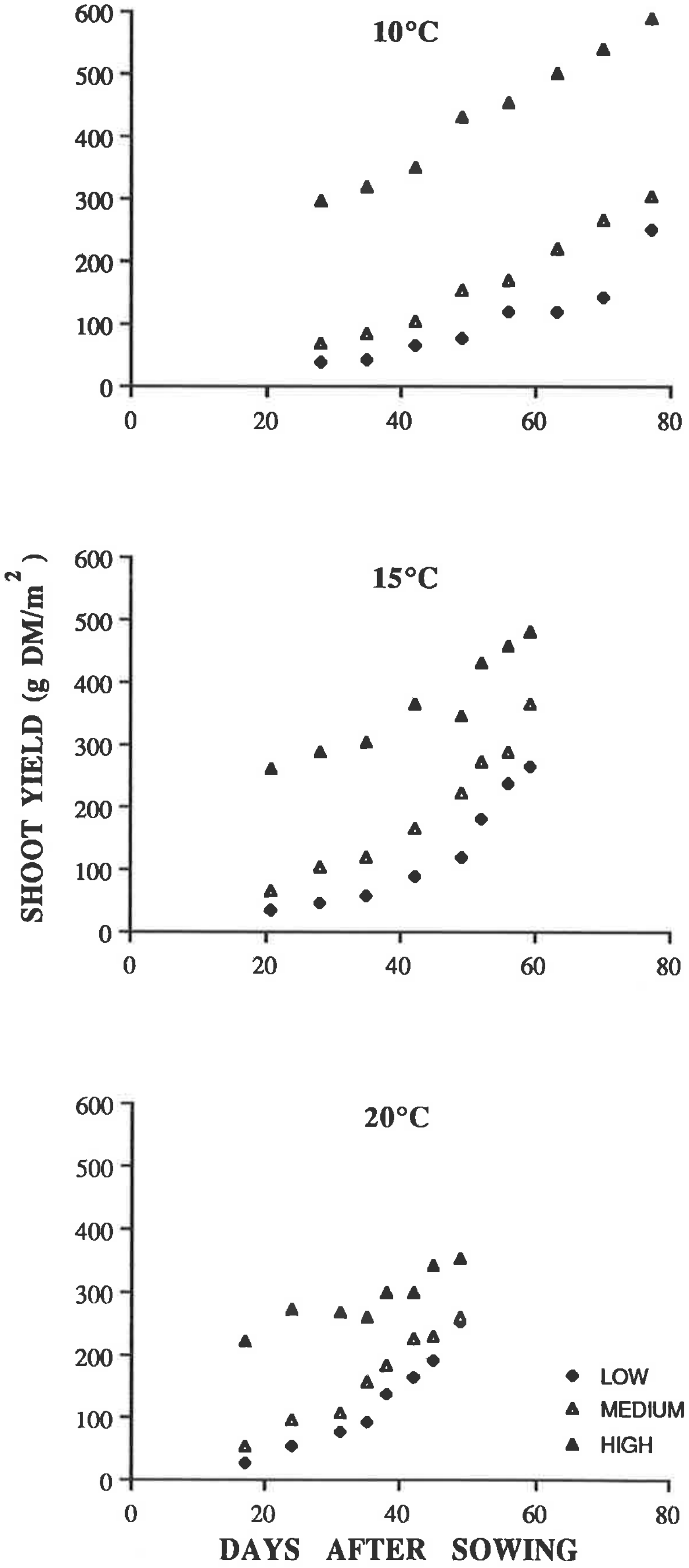

10°C
15°C
20°C
SHOOT YIELD (g DM/m^2)
DAYS AFTER SOWING
0
100
200
300
400
500
600
0
20
40
60
80
LOW
MEDIUM
HIGH

Fig.9.11

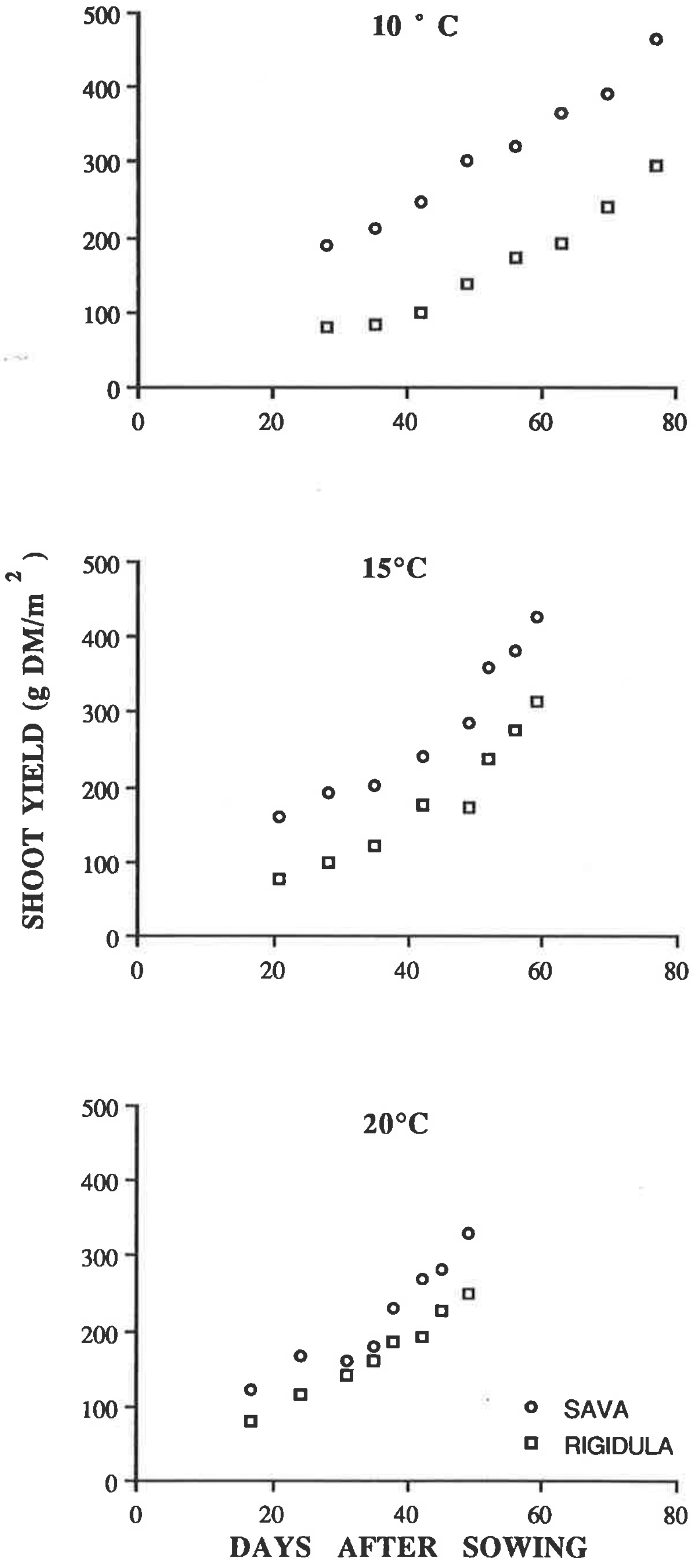

10 ° C
15°C
20°C
SHOOT YIELD (g DM/m^2)
0
100
200
300
400
500
0
20
40
60
80
DAYS AFTER SOWING
SAVA
RIGIDULA

Fig.9.12

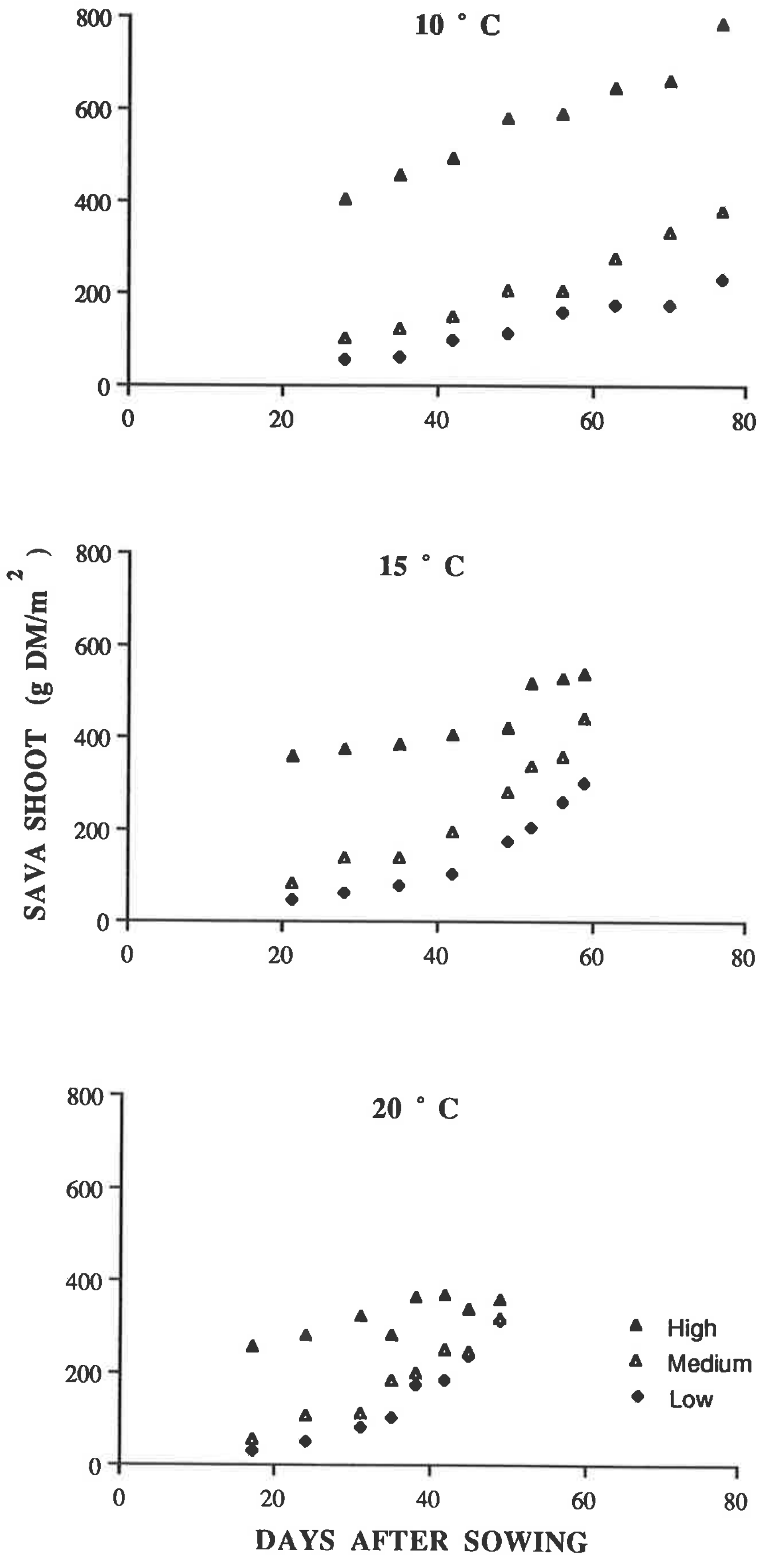

10 ° C
15 ° C
20 ° C
SAVA SHOOT (g DM/m2)
DAYS AFTER SOWING
0
200
400
600
800
0
20
40
60
80
▲ High
△ Medium
◆ Low

Fig.9.13

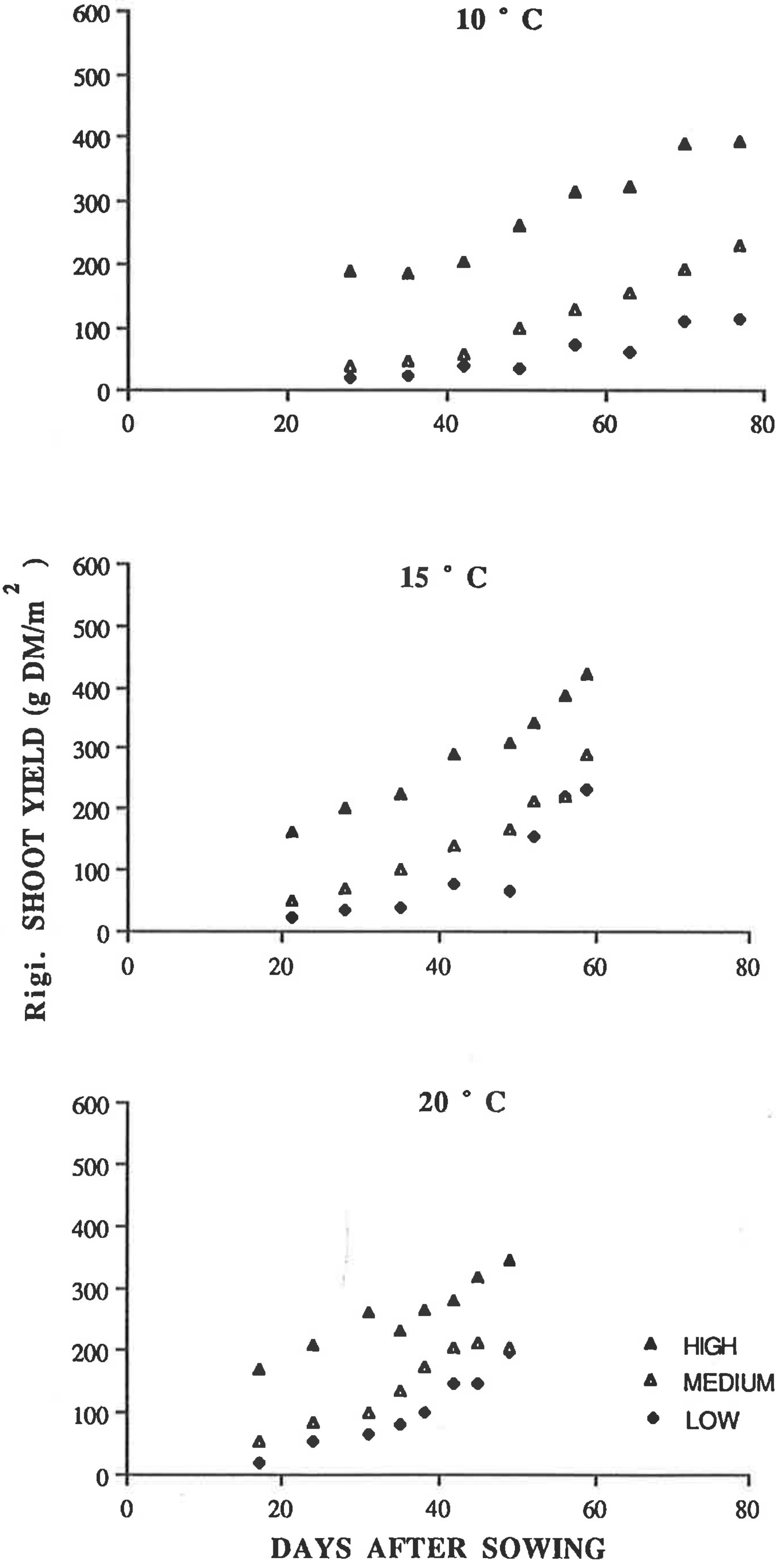

10 ° C
15 ° C
20 ° C
Rigi. SHOOT YIELD (g DM/m^2)
DAYS AFTER SOWING
0
100
200
300
400
500
600
0
20
40
60
80
▲ HIGH
△ MEDIUM
◆ LOW

Fig.9.14

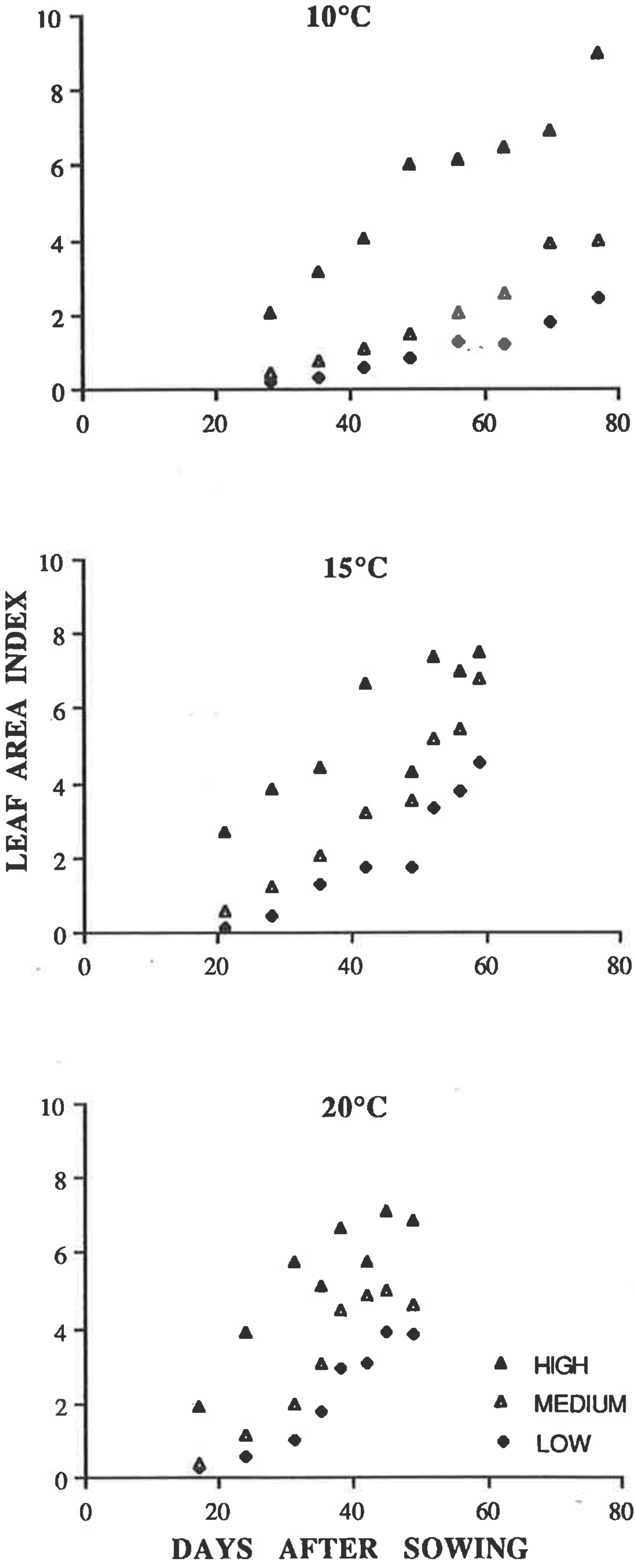

10°C
15°C
20°C
LEAF AREA INDEX
0
2
4
6
8
10
0
20
40
60
80
DAYS AFTER SOWING
▲ HIGH
△ MEDIUM
● LOW

Fig.9.15

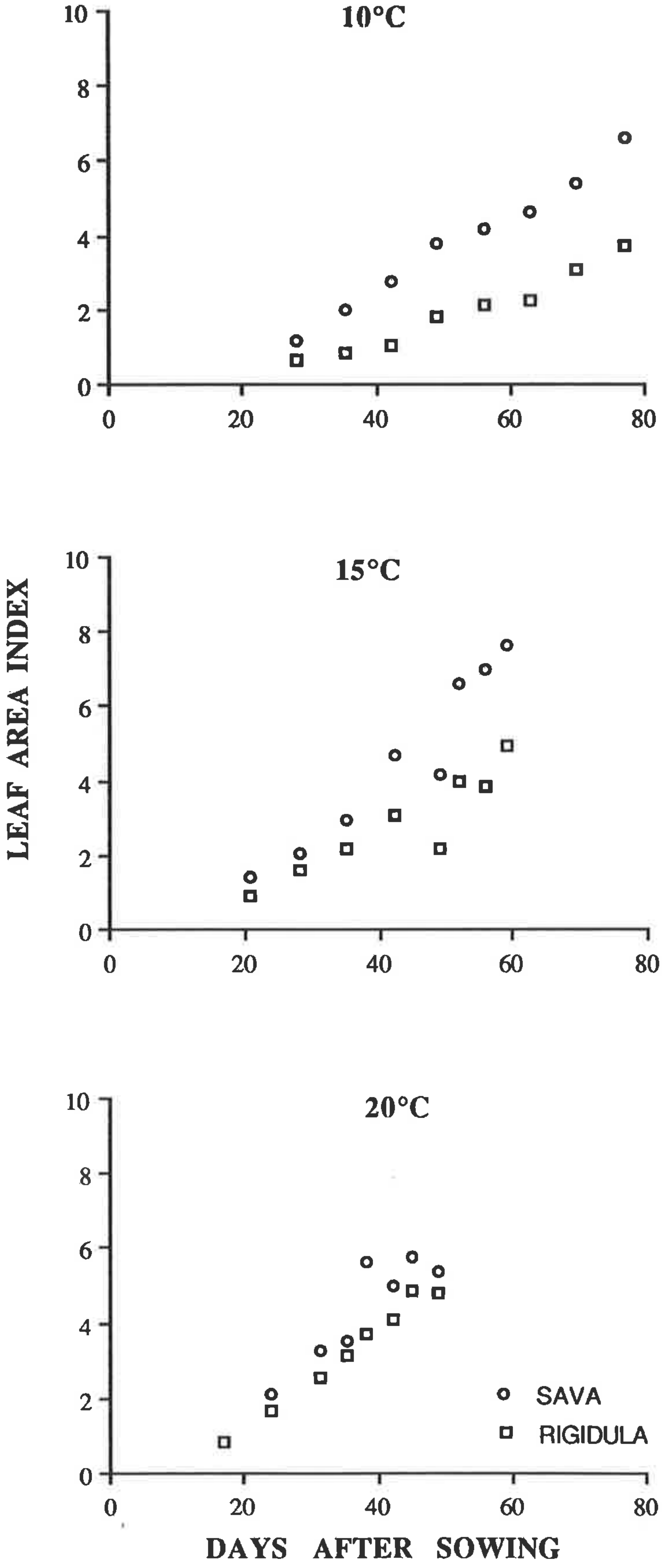

10°C
15°C
20°C
LEAF AREA INDEX
0
2
4
6
8
10
0
20
40
60
80
DAYS AFTER SOWING
SAVA
RIGIDULA

Fig.9.16

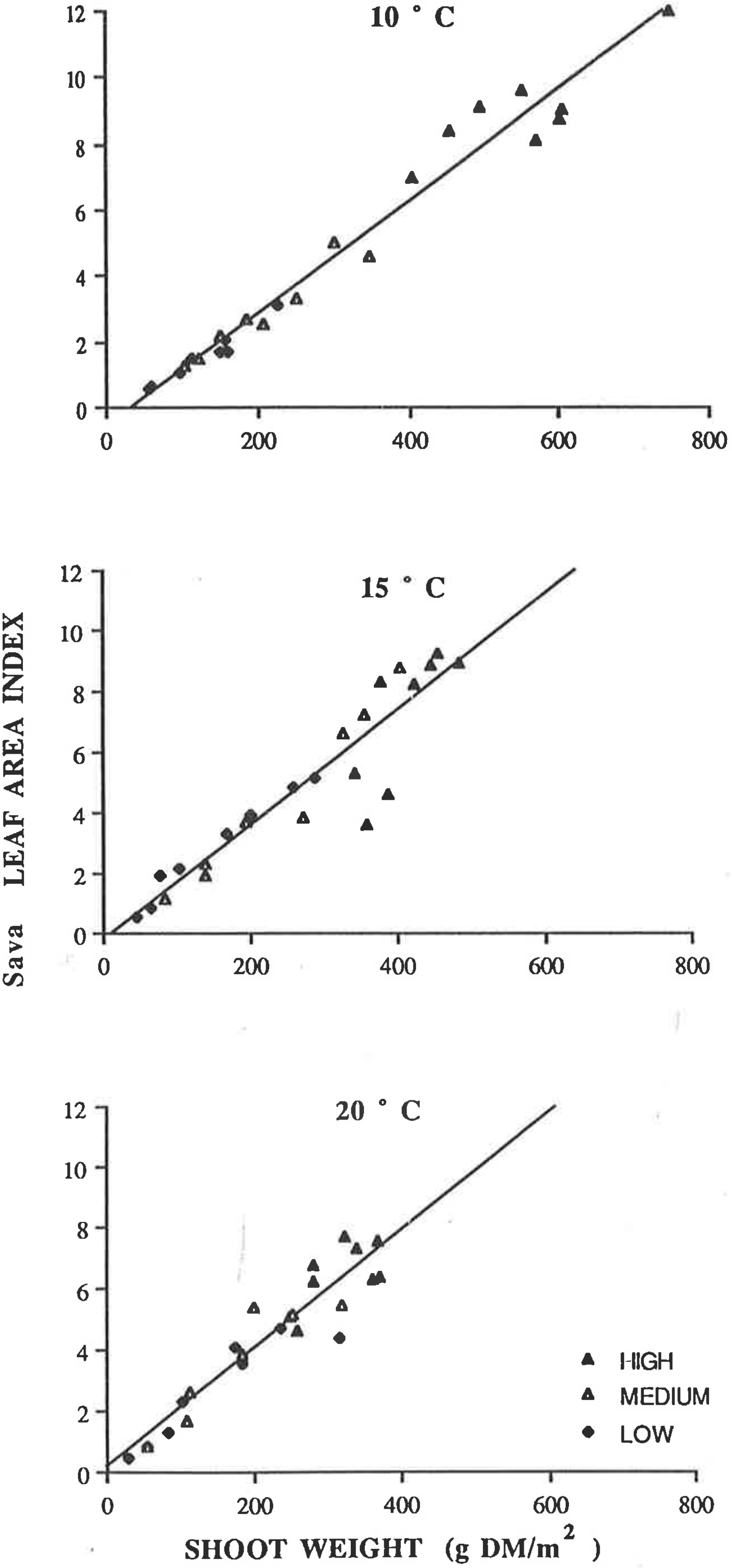

10 ° C
15 ° C
20 ° C
12
10
8
6
4
2
0
0
200
400
600
800
Sava LEAF AREA INDEX
SHOOT WEIGHT (g DM/m^2)
▲ HIGH
△ MEDIUM
◆ LOW

Fig.9.17 a

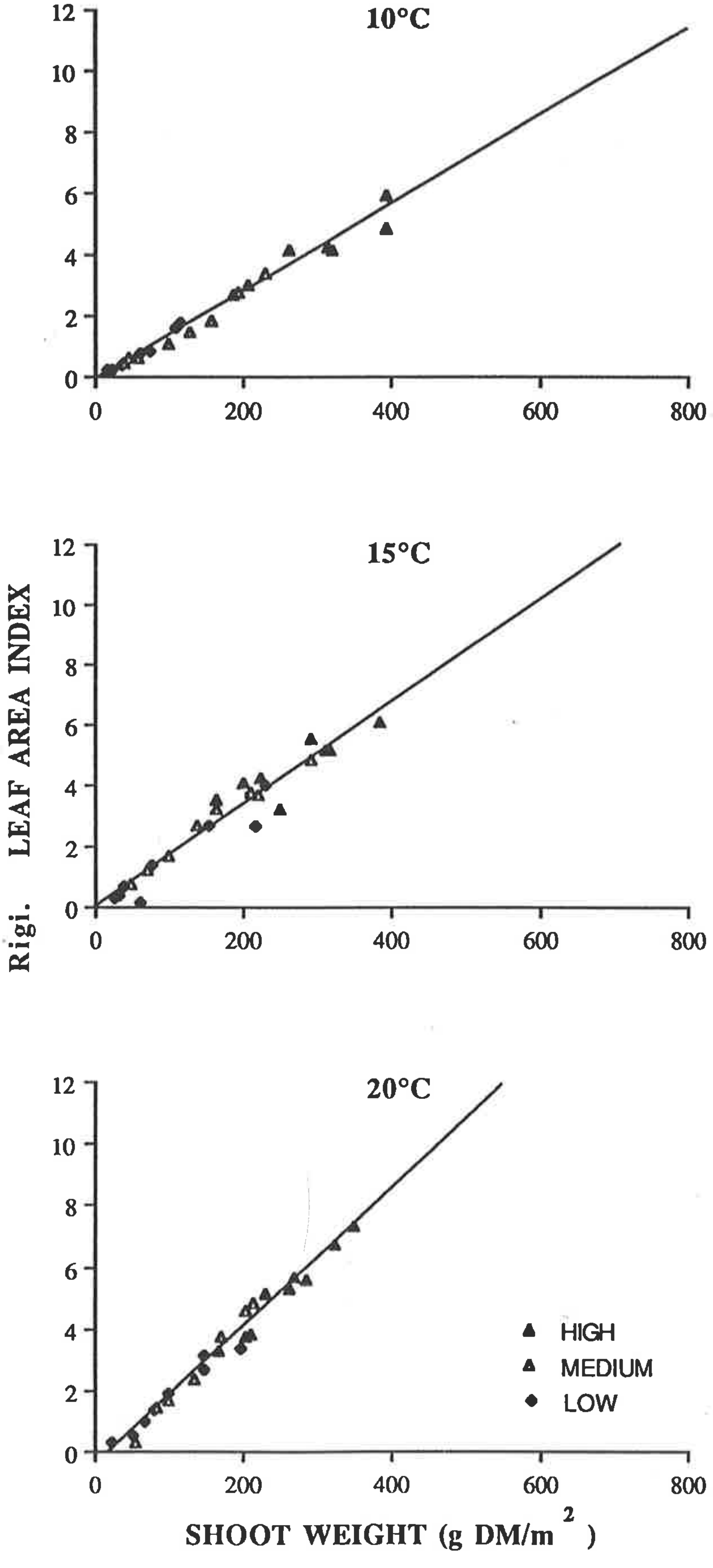

10°C
15°C
20°C
Rigi. LEAF AREA INDEX
0
2
4
6
8
10
12
0
200
400
600
800
▲ HIGH
△ MEDIUM
◆ LOW
SHOOT WEIGHT (g DM/m^2)

Fig.9.17 b

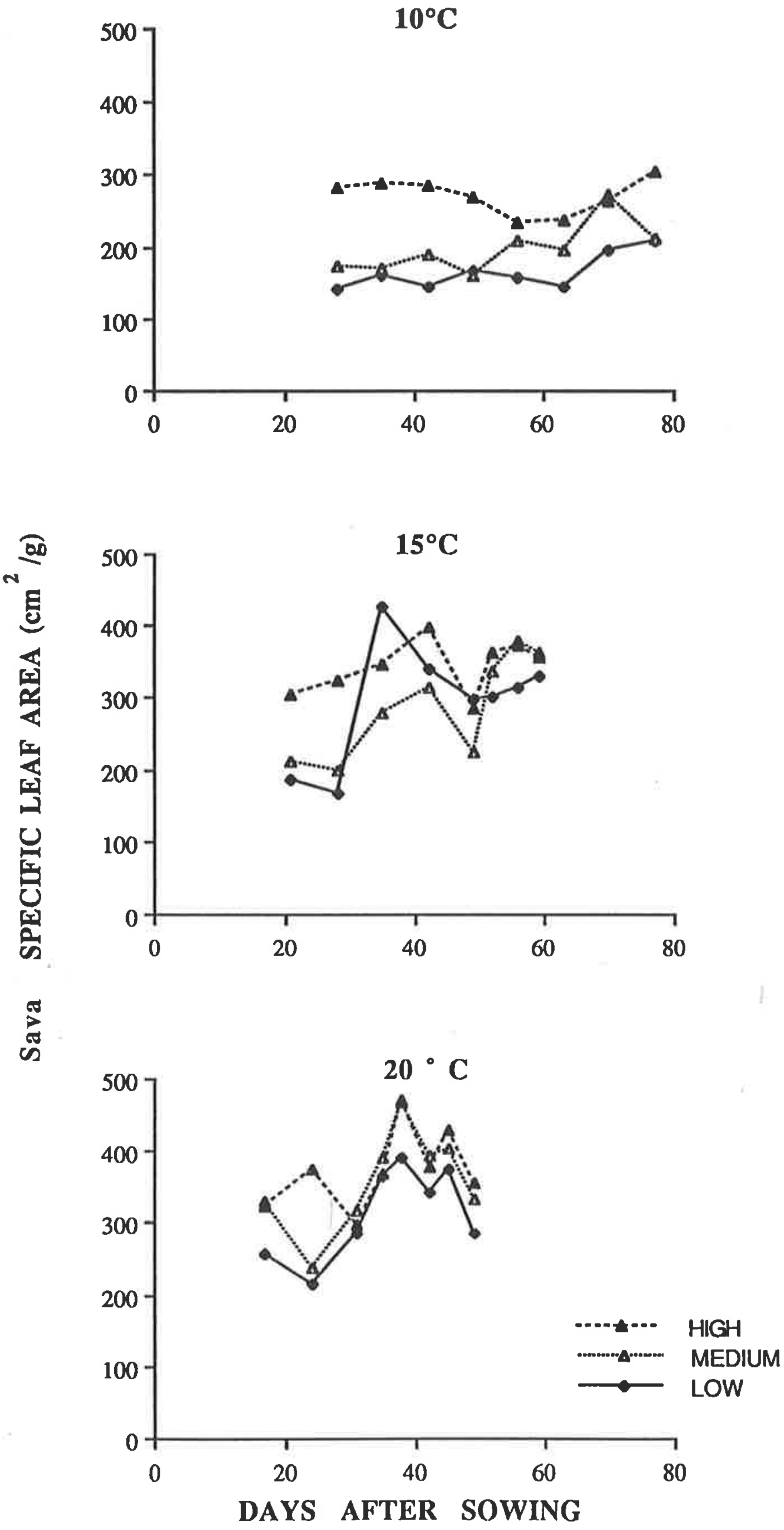

10°C
15°C
20 ° C
Sava SPECIFIC LEAF AREA (cm 2 /g)
0
100
200
300
400
500
0
20
40
60
80
DAYS AFTER SOWING
HIGH
MEDIUM
LOW

Fig.9.18 a

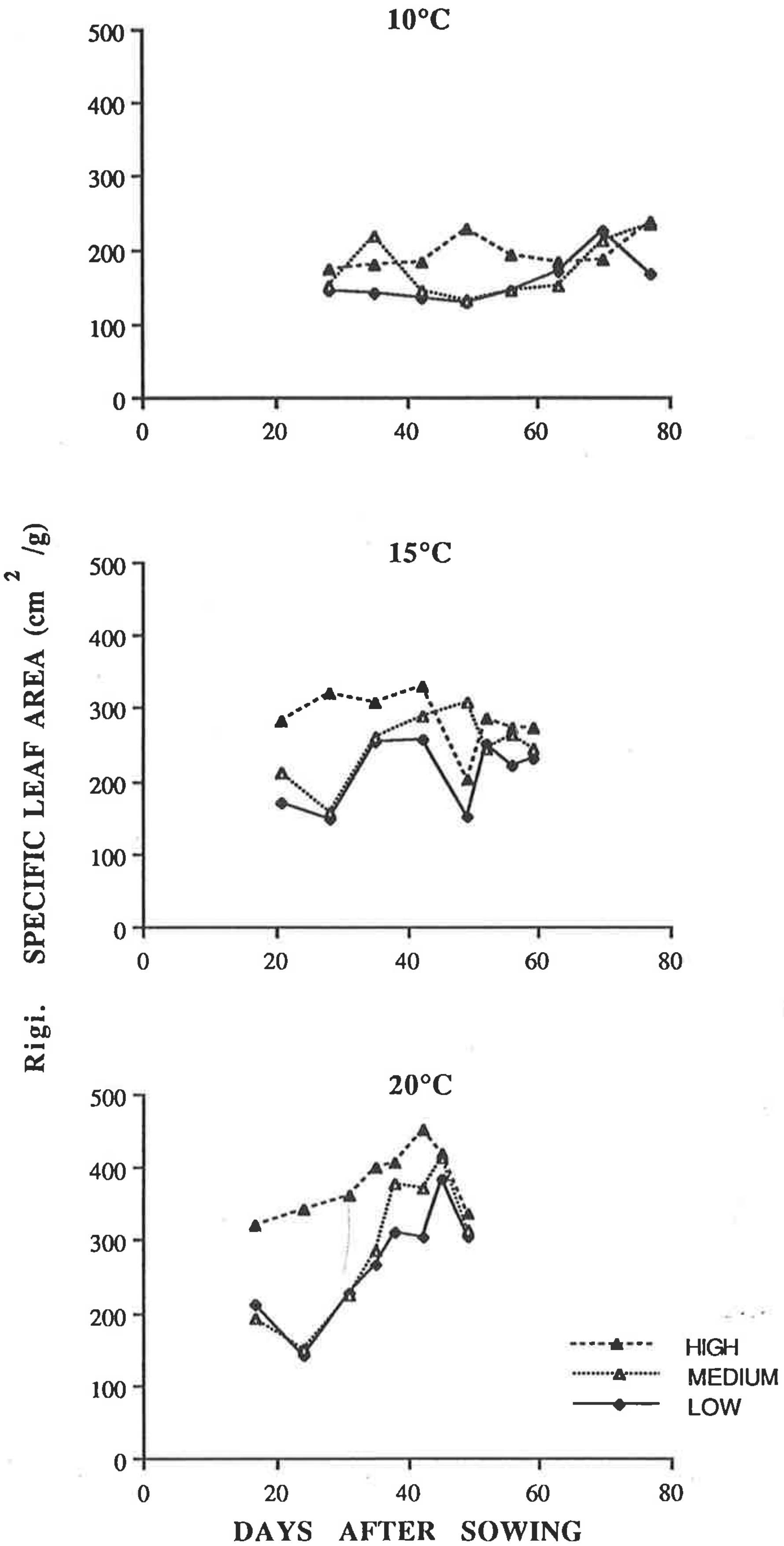

10°C
15°C
20°C
Rigi. SPECIFIC LEAF AREA (cm² /g)
0
100
200
300
400
500
0
20
40
60
80
DAYS AFTER SOWING
HIGH
MEDIUM
LOW

Fig.9.18 b

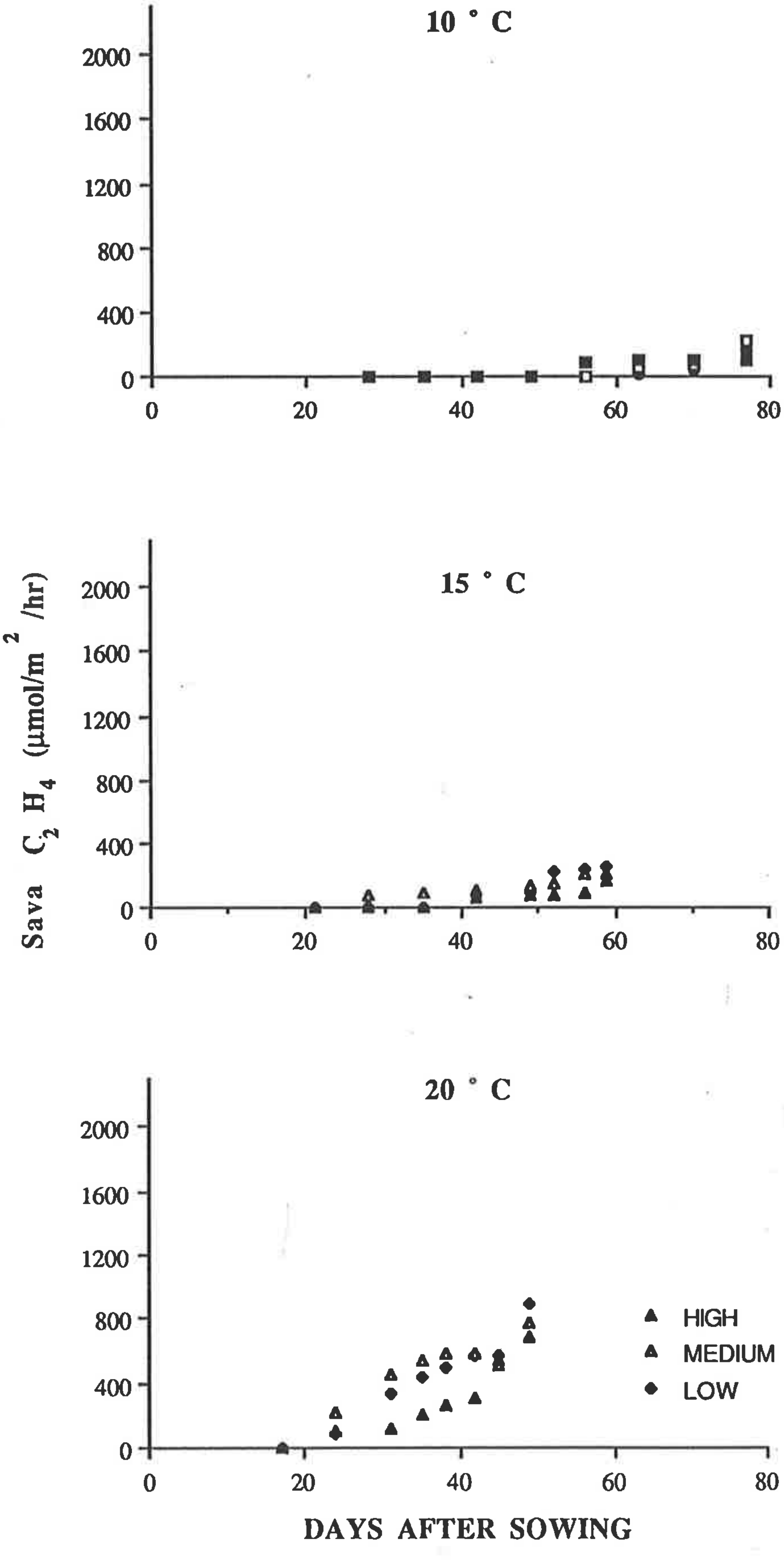

10 ° C
15 ° C
20 ° C
Sava C2 H4 (µmol/m2 /hr)
0
400
800
1200
1600
2000
0
20
40
60
80
▲ HIGH
△ MEDIUM
◆ LOW
DAYS AFTER SOWING

Fig.9.19 a

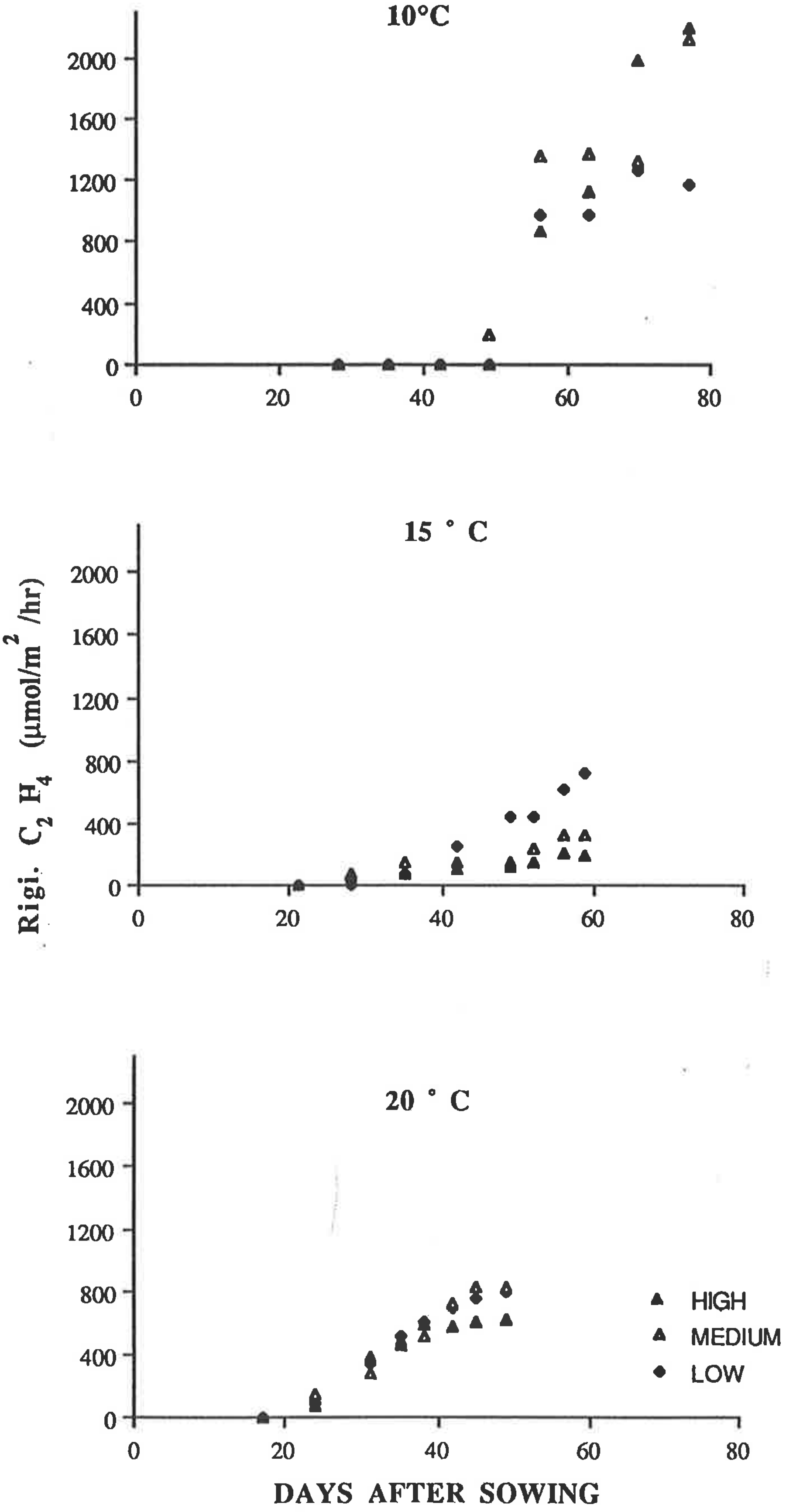

10°C
15 ° C
20 ° C
Rigi. C_2H_4 (µmol/m^2/hr)
0
400
800
1200
1600
2000
0
20
40
60
80
DAYS AFTER SOWING
▲ HIGH
△ MEDIUM
● LOW

Fig.9.19 b

9.7 Discussion and Conclusions (Experiments 6 and 7)

9.7.1 Discussion

The small swards used in this investigation were intended to simulate the growth of pasture legumes in the field. Measuring the effects of temperature variation on crop growth rate is difficult in a field experiment since change in temperature is associated with change in climatic factors such as light and soil moisture, whilst controlled environments provide a way in which temperature can be varied as an independent factor. The effects of temperature can therefore be clearly seen, where other factors (light, plant nutrient) are constant. Three constant temperature regimes (10°C, 15°C and 20°C) were used here whereas in the field early in growing period (June, July and August), temperature fluctuated and changed diurnally. Although the plants were grown under controlled conditions for relatively short periods of time (ranged from 56 days at 20°C to 87 days after sowing at 10°C), they were grown as swards irradiated entirely from above with a constant light intensity 400µmolquanta/m^2/s at the plant canopy for 12h daylight. McCree and Amthor (1982) showed the growth of clover to be the same when there was a difference between the day and night temperature as when the temperature was constant at an average between the two.

Response of plant community to temperature and density: There are no inherent differences in plant response to temperature if they grow in the field or in the growth cabinet. The main differences between the two probably are due to soil condition, water supply, transpiration and mineral nutrient. There is no way for equating these factors between environments. Hence, these results must be used as a guide to field performance. New information has been obtained in this study concerning the effects of temperature on both dry matter production of root and shoot of annual medic communities in relation to ambient temperature (Figs 9.2 and 9.3 in Experiment 6 and Figs. 9.9 to 9.12 in Experiment 7).

Growth rate and dry matter production: Under the growth conditions employed, the optimum growth temperature was found to be 15°C. In both experiments root growth was depressed by increasing temperature above 15°C, whilst shoot growth improved by increasing temperature except with *M. rigidula* (the cold tolerant genotype) which yielded less above 15°C. Genotypes responded differently to temperature and plant density. The highest herbage yield obtained was 577 gDM/m^2 within 87 days after sowing. These results show the growth responses of annual medic plants to temperature are clearly changed by the amount of dry matter present.

In Experiment 7, where plant density was involved, the high temperature of 20°C depressed the crop growth rate for root and shoot (except for Sava at low density) compared with a low temperature of 10°C (Tables 9.16 and 9.17) because the cost of maintaining biomass were least at low temperature. Similarly, Cocks (1973) found that subterranean clover communities at the highest temperature (27°C day/22°C night) grew at only half the rate of those at the lowest temperature 12°C day/7°C night. The same trend was found in these experiments with a high temperature resulting in a reduction in herbage yield of about 33% compared with low temperature of 10°C at high density (Fig. 9.11). Growth was found to be inversely related to temperature over the range 10°C to 20°C for swards at seedling stage as it was for swards of more mature plants. However, shoot growth requirement of temperature is different from root, where the highest shoot growth rate was (8.9g/m^2/day) at 15°C while the highest root growth rate obtained 2.8g/m^2/day at 10°C from the same genotype at constant density. The four genotypes of medic tested in both experiments behaved similarly in that root growth rates were depressed by about 50% with a temperature rise from 10°C to 20°C.

These effects of temperature could have been due to the high dark respiration of covered roots. It has been shown by Fukai and Silsbury (1977) that the dark respiration rate of a subterranean clover community at any temperature is linearly related to the amount of shoot dry matter present, and increases exponentially with increase in the temperature. Also, they found high temperature to be more depressive of growth rate the lower the irradiance. Temperatures in excess of 10°C could therefore be more depressive of growth than we have currently quantified for a pasture under South Austualian field conditions during June, July and August, when solar radiation is lower than the PPFD used in these experiments.

Influence of LAI on the temperature response of communities of annual medics : The results show the LAI influences on the temperature response of communities of annual medics. While temperature had a strong positive influence on growth rate when LAI was low, this influence rapidly weakened as LAI increased, finally becoming negative at high values of LAI. Davidson *et al.* (1970) present the only other data on the temperature response of subterranean clover communities. However, instead of growing the communities at a specified temperature from germination, they grew them together for six weeks before applying the treatments. In doing so they eliminated temperature-induced morphological and physiological differences initiated before the onset of competition. However, at high LAI a second limitation, that of high temperature, became apparent. At the high density in the second experiment the maximum LAI was 9 at 10°C and decreased dramatically to 7.5 and finally to 6.8 when the temperature rose to 15°C and to 20°C respectively (Fig. 9.15).

The interaction between LAI and temperature was probably due to a change in the balance between photosynthesis and respiration. At low LAI, where growth was faster or higher, high temperature increased photosynthesis more rapidly than it did respiration whilst at medium LAI photosynthesis became restricted by competition for light, so that its increase with temperature was balanced by an increase in respiration. At high LAI, respiration (including the respiration of non-living tissue by micro-organisms) responded to temperature at a faster rate than photosynthesis, so that the whole community growth rate fell (Cocks 1973). These effects could have been due to the high respiration of shaded leaves, so that as LAI increased some leaves became more dependent on the rest of the plant (Davidson and Donald 1958), or they could have been due to the more rapid death of some shaded leaves or plants so that apparent net photosynthesis declined. Real net photosynthesis would have remained constant, and the apparent decline was possibly due to the disappearance of dead material (McCree and Troughton 1966; Davidson and Birch 1972). At high LAI and dry weight, the distribution of plant weight became so strongly skewed at high temperature that the loss in weight and life of the smaller plants approached, equalled, and eventually exceeded the continuing gain of the larger plants (Cocks 1973). Although at low temperature the distribution remained symmetrical and all plants continued to grow, this resulted in continued maximum growth rate.

It is commonly concluded from observations in the field that the growth rates of annual medic swards are limited by low temperature. Whilst this was found to be true in the first experiment and at low plant density in the second experiment where three rates of sowing were applied, (which might be the case in the field when a low sowing rate is used or where regeneration is poor), my results suggest that high-density swards do not exhibit such a restriction. Swards established from high sowing rates or after good regeneration at densities of about 20,000 plants/m^2 will not only give high early production of herbage, but their growth rates will be slightly increased rather than decreased as temperature decreases over the range 20°C to 10°C. High density swards appear to be less sensitive to low temperature than are low density swards.

Acetylene reduction and nitrogen fixation : The acetylene reduction technique is widely used to measure relative rates of nitrogen fixation in both the laboratory and the field (Masterson and Murphy 1976; Hardy and Holsten 1977). However, although the method is sensitive, it has limitations for the quantitative determination of nitrogen fixation (Bergerson 1970; Sinclair and Hannagan 1976). Nitrogen fixation by legumes has sometimes been studied as an isolated topic, either in the field (Carran *et al.* 1982) or under controlled conditions (Fyson and Sprent 1982). Thus Hardy *et al.* (1973) found that although the ratio of acetylene reduced to nitrogen fixed is theoretically 3:1, the experimental ratio of approximately 2.9 : 1 obtained in the present experiment is based on two assumptions: (i) that the Kjeldahl-N value represents the nitrogen actually fixed and (ii) that fixation proceeds at the same rate at night as during the day (as suggested by the data of Masterson and Murphy 1976). The method appears to offer considerable scope for measurement of the effects of environment on the physiological process of nitrogen fixation. Since no plants died, the constant rate of acetylene reduction observed per pot or per m^2 implies that a decrease occurred in the rate of fixation per unit root weight as the total dry weight of shoot and root increased or root proportion decreased.

Three major conclusions arise from the above results. Firstly, it appears possible to estimate the growth rate of medic swards with considerable accuracy by the sequential harvest of single pots provided seedling plants are selected for uniformity at emergence. Secondly, measurement of the rate of acetylene reduction by the swards appears to provide an accurate estimate of the rate of nitrogen fixation during growth. Thirdly, the growth coefficient appears to be affected markedly by the amount of dry matter present over the range 85.9-158.4 gDM/m^2 in Experiment 6, and 60.2-576.7 gDM/m^2 of shoot dry weight in Experiment 7.

9.7.2 Conclusions

Experiment 6

- Growth rate varied according to genotype and temperature regime.
- Growth rate nearly doubled by increasing temperature from 10°C to 20°C with all genotypes except *M. rigidula* which inversely responded above 15°C.
- Temperature requirement varied according to genotypes, where the highest growth rate obtained was from *M. rigidula* (5.1 g/m^2/day) and from *M. scutellata* (6.6 g/m^2/day) at 10°C and 20°C respectively.
- *M. rigidula* was the most cold-tolerant genotype tested in this experiment: it gave the highest shoot growth rate at 10°C and 15°C (Table 9.8).

Experiment 7

- Growth rate varied according to plant density in addition to genotype and temperature as in Experiment 6.
- The maximum shoot growth rate (8.9 g/m^2/day) was obtained from *M. scutellata* with a medium plant density and temperature (15°C) whilst the lowest shoot growth rate value was from *M. scutellata* (2.5 g/m/day) at high density and temperature (20°C).

- *M. rigidula,* a cold-tolerant genotype showed the same trend as in Experiment 6 and produced the highest shoot growth rate at 15°C at high plant densities.
- Growth rate increased with increasing sowing rate for both genotypes at low temperature (10°C).
- The optimum temperature for both genotypes was 15°C when *M. scutellata* and *M. rigidula* were grown at a medium and high plant density respectively. *M. scutellata* growth rate is strongly density-dependent, and *M. rigidula* growth rate is influenced directly by temperature and density.

10. GENERAL DISCUSSION AND CONCLUSIONS

10. GENERAL DISCUSSION AND CONCLUSIONS

10.1 Annual Medic Plant Adaptation to the Climatic Environment of Jordan

The responses of annual medics to the Jordanian climatic environment, although considered important, had not been quantified before the work for this thesis was undertaken. Alternate studies had been considered to account for the negative effects of environmental factors on annual medics and the ones investigated were those most likely to account for the field observations. When the relative significance of these alternatives (ecological and management factors such as temperature, plant density, mechanical defoliation, depth of sowing and soil texture) is understood in detail, it will be possible to develop effective plans to minimise or reduce the deleterious impact of ecological and management factors on medic pastures and to reduce the harmful effects of those factors on medic seed production which contributes to poor seed reserves.

In Mediterranean regions, the main determinant of ecological success of annual medics is the population of germinable seed present in autumn when available moisture ensures germination, emergence and growth of medic-plants. This also determines agricultural success where medic-stand regeneration is required. It is well known that the germinable seed population in any one year is determined by seed production in previous years, together with the subsequent fate of that seed which is largely a function of seed dormancy, hard-seededness and the opportunities for summer or early autumn germination and desiccation and death of emerging seedlings (Quinlivan and Millington 1962; Rossiter 1966a). The probability of plant establishment and survival must be added to these characters as primary criteria for success in areas like Jordan with unreliable rainfall within the growing season (Tables 3.1 - 3.5). These latter qualities, however, may be addressed ultimately through seed production, along with adaptation to other climatic factors, edaphic factors and response to pest and disease. Thus the characteristics of primary importance in assessing adaptation to regions typified by Jordan will be capacity for seed production; dormancy and hard-seededness; germination, emergence and seedling survival; and drought resistance/avoidance in established plants.

The large differences in yielding ability of different cultivars at the three sites (Ramtha, Mushagar and Rabbah) can be attributed to differences in climatic and edaphic conditions. On average, Mushagar and Rabbah receive more rainfall than Ramtha. The additional rainfall gives the Mushagar the advantage of a more-reliable autumn break, which promotes the growth of winter annuals before the onset of winter. Soil phosphate levels differ between sites: Ramtha soils are low in phosphorus (7-8ppm), whereas Madaba or Rabba soils have medium phosphorus status (15-24ppm). The interaction of these factors has resulted in the differing productivity of commercial Australian cultivars and cold-tolerant genotypes at the three sites.

In the absence of moisture stress, *M. rotata* and *M. rigidula* (cold-tolerant species) were the most productive in terms of winter dry matter production (Table 4.7), while *M. scutellata* gave greater herbage production as the temperature rose in springtime. However, the herbage yield of 2-3t DM/ha is low: these levels of medic yield could be due to frost damage during March. However, temperature variation was very important in inducing variation in seed yield between sites. Overall, most cultivars yielded better at Mushagar and Rabbah than at the Ramtha site. *M. rotata* Sel. 1919 consistently gave the best yields, while the very-late-flowering sel. 1865 gave the lowest seed yield.

On the other hand, seed : pod ratio was only close to being constant in *M. scutellata* cv. Robinson (29%) at the three sites, while the ratio values for the other species were much lower at Mushagar than the other two sites, indicating adverse environmental conditions for seed production at Mushagar.

10.2 Influence of Annual Medic Plant Density on Herbage and Seed Production

Herbage production : Plant density played an important role in herbage production or seed yield in the small-plot experiment in Jordan during 1987 and in the pot experiment under controlled conditions in 1989. Early in the growing season pasture production was density-dependent. Low pasture density gave low autumn-winter production. Later, seed production varied according to genotypes and plant density. In the absence of weeds, low plant density has the potential to give high herbage production and seed yield except in the case of *M. rotata* Sel. 1943 where seed production responded directly to plant density. However, all cultivars gave increased seed yield when herbage yield increased.

While there is no doubt that high density medic swards are more productive early in the season, total herbage production will vary according to cultivar and plant density as the actual differences decrease because of competition for light and soil moisture. Sava showed superiority in terms of herbage production particularly when at high plant density. The performance of Sava may be attributed to its large seed size. Black (1958) found that plants derived from large seed maintained their superiority in productivity. However, high-density stands of small-seeded cultivars such as Para. can lose a high proportion of plants later in the season.

In summary, we can see that the density required to give the maximum yield per unit area will depend on the stage of growth. If the sward is to proceed to maturity, then a wide range of densities will give maximum biological yield attainable by the genotype within that particular environment, and a relatively low population will suffice. On the other hand if a sward is to be used at an early date, then the greater the density required to maximise yield of that genotype. Nevertheless, variation in growth rate is greatest at high densities (Stern, 1960). However, the interaction between cultivar and plant density was found to be significant from Harvest 1 to Harvest 6.

Seed yield : Plants at normal field spacing are smaller, have fewer stems and leaves, fewer inflorescences, and fewer seeds than widely-spaced plants. Yet there is not a downward trend in all plant characters as density is increased. Therefore, seed yield depends on cultivar and density on their interaction. Seed yield of Sava and Rigi. were decreased by increasing plant density, while Rota. seed yield increased by increasing density.

In most subterranean clover cultivars mid-late maturing strains had reduced seed yield (Donald 1954; Rossiter 1959; Taylor and Rossiter 1967). In the small-plot experiments in Jordan (1987) similar results were found with Rigi. but not with Rota. even though both are mid-late maturing cold-tolerant genotypes. Rota. did not show any reduction in seed yield in the high-density stands. The reason for that is possibly due to the larger initial seed size, so even though both cultivars were sown at equivalent number of pure germinating seeds (high density) Rota. had the greatest number of seedlings.

10.3 Influence of Mechanical Defoliation on Herbage and Seed Production of Annual Medic Swards

Herbage production : At the Waite Institute, defoliation treatments were the same for all genotypes on each occasion, hence differences in the rate of regrowth must be due to either (a) genotypic differences in the rate of re-establishment of a photosynthetic area, or (b) genotypic difference in the remobilization of root "reserves"; or (c) genotypic differences in assimilation rates which are not likely to operate against all cultivars.

Cumulative herbage yield was decreased after all defoliation treatments compared to the undefoliated control treatment. In conclusion, the four annual medics which have been examined appeared to fall into three groups, according to their behaviour in swards defoliated at different times.

The first group, Sava and Para. with high yielding ability at early defoliation (H4) followed by Rigi. with intermediate yielding capacity and finally Rota. which had the lowest herbage production (Table 6.14). Three weeks after early defoliation (Harvest 5), good recovery from defoliation was shown by Rigi. first 84.7% followed by Para. which gave 61.5%. In contrast to the control treatments for those two genotypes it seems to be they are well adapted to early defoliation while Sava and Rota. showed a very poor capacity in recovery growth from defoliation, 19.8% and 36.0% respectively.

However, three weeks after the late defoliation (DL) which was carried out at H6, Para. gave the highest percentage, 24.1% and 21.9% of recovery after the double defoliation (DEL) and (DL) respectively followed by Rigi. while Rota. was very poor in percentage recovery growth at both DEL and DL treatments, being 15.6% and 10.2% respectively.

Botanical composition : Botanical composition is influenced by several elements such as plant density, plant growth habit, plant competitiveness (for soil moisture, plant nutrient and light), grazing pressure or time and frequency of mechanical defoliation. However, time and number of defoliations had no significant effect on density of annual medic. The results from the defoliation experiment indicate how rapidly changes in botanical composition can occur. Cultivars exhibited various levels of competitiveness with weeds, although this depended on the cultivar growth habit and its ability to recover from defoliation.

The relationship between herbage yield and weed yield was negative. Therefore a genotype with a very poor capacity to recover from defoliation such as Rota. will allow increased weed growth. However, differences in the ability of genotypes to suppress weeds were highly significant (Table 5.10) on all harvest occasions.

Seed production : Reference has already been made to the general depressive effect of defoliation on seed production (Rossiter 1961). The recent evidence from annual medic results in this study supports this contention. Knight and Hollowell (1959) showed that moderate defoliation (from 6 inches down to 3 inches i.e. 15cm to 7.5cm) of *T. incarnatum* L. had little effect on forage production, but reduced seed yield by 14%. The effect of late defoliation and/or early and late defoliation on seed yield in this defoliation experiment reported here is in agreement with these findings. On the other hand early defoliation (DE) prior to flowering markedly increased seed yield in both cultivars (Sava and Rigi.) compared to the control treatment which was attributed to an increase in number of inflorescences produced. Therefore, extra flowers will be largely responsible for increasing seed yield. Similar results were reported by Rossiter (1961, 1972).

10.4 Influence of Sowing Depth and Soil texture on Seedling Emergence of Annual Medics

Placing the seed deeply in contact with moist soil could be an advantage only in regions where such moisture can be secured before sowing. In the rain-fed areas of most of the Near-East, North Africa and other Mediterranean countries the summer and early autumn are usually dry and there is very little moisture stored in the surface soil layer where seed is normally sown. However, when annual medics are sown under field conditions, where germination is simultaneous, plants from greater depths of sowing will be at a disadvantage as compared with those from shallower sowing, since emergence will be progressively delayed as depth of sowing increases. The absence of a cultivar by seeding depth interaction indicated that all cultivars responded similarly to changes in sowing depth. Compared to shallow sowing deep sowing resulted in a highly significant reduction in emergence ranging from a 10% to 40% reduction in number of seedlings emerged. Similar decreases in number of subterranean clover emergence were reported by Black (1956) for deep sowing. However, the optimum depth of sowing depends on soil moisture and soil temperature (Webb and Stephens 1936). Therefore, the present study showed that medic emergence and plant vigour were adversely affected by deep sowing.

10.5 Seedling Emergence and Herbage Production Differences between Genotypes and the Mixture of Annual Medic Swards

In the absence of water stress, seedling emergence and herbage production varied between genotypes grown in micro-plots of the raised-bed experiment 1988. As commercial Australian genotypes and cold-tolerant lines with a range of seed weight (4-20mg/seed) and hard-seededness were used in this experiment, it was expected that there would be differences in seedlings emergence and herbage production.

Seedling emergence : Differences in seedling emergence will be directly influenced by number of germinable seed sown/unit area, hard-seededness, seed size and depth of sowing as well as the soil texture around the seed. However, irrespective of plant density and mixtures, cultivar effects were significant, and the highest plant population was Para with 1244/m^2 (the smallest seed size) which had the highest number of seed sown on the basis of equivalent seed weight compared to other genotypes. However, not much variation was found in the percentage of the seed that germinated and seedlings emerged and established in binary mixtures compared to monocultures.

Herbage production : In the raised-bed experiment in 1988, there was a significant interaction between medic genotypes and harvest occasion in terms of herbage yield but not in plant density which is attributed mainly to mixture effects. However, all binary mixtures which included Sava showed a decline in herbage yield compared to the mixture components in monoculture swards due to shading effect of taller cultivars such as Sava. This result supports the contention of Bazzaz and Harper (1976) who found the competition may result either in death of plants, reduction in growth rate, or both. Sava medic seedlings had greater dry weight in all treatments which result is attributed to its large seed size : this resulted in mean plant dry weights four times greater than any of other cultivars used.

However, while total herbage production did not differ significantly in the beginning of the season, clear differences were observed by the end of the experiment (Harvests 5 and 6). Furthermore, in comparing genotypes, total herbage production was independent of number of plants, Sava with the lowest number of plants was the most productive in terms of herbage yield after Para.

10.6 Growth Responses of Annual Medic Cultivars to Temperature and Plant Density

The micro-swards in pots used in these two experiments were intended to simulate the growth of medic species in the field. The controlled environments in which growth and nitrogen fixation were measured differed from the field in several aspects such as variation in temperature and solar radiation. Temperature variation in the field is associated with other climatic factors and it is difficult to be controlled. Whilst the controlled environments provide a method in which temperature can be varied as independent factors. Plants had no water stress and an adequate supply of plant nutrients.

All evidence recorded in the literature suggests that the growth of annual medic is well adapted to a cool environment. Both the growth rate and the N_2-fixation rate were high at 10°C to 15°C, and decreased beyond that especially the cold-tolerant genotype - Rigi. Nitrogen deficiency may not have an effect on growth when legumes are establishing early in the season because the deficiency seems to be exacerbated at high PPFD. For herbage production in the biomass range 85-158g/m_2/day in Experiment 6 and 60-577g/m_2/day in Experiment 7, the N_2-fixation rate was depressed more by increasing the temperature than was the growth rate.

At low temperature, in particular 10°C, the data indicate that there was ample carbon available to support synthetic activities of nodulated roots, because the rate of maintenance respiration was low. In both experiments root growth rate was inversely influenced by temperature, whilst shoot growth rate was improved by increasing temperature in Experiment 1, except where Rigi. which declined above 15°C in both experiments. However, a temperature of 15°C is the temperature optimum in most cases as shown in Figures 9.3 - 9.6b and Tables 9.9a and 9.9b for Experiments 6 and 7 respectively. Similar results were reported by Fukai and Silsbury (1976).

The range of plant densities used in this experiment extends far beyond the level resulting from normal farm practice of sowing at about 10kg/ha. The reason for extension to very high rates (20,000 plants/m^2) is that seed yields of up to 1000kg/ha are common in established medic pastures, and in very favourable seasons regeneration may begin with a 'sowing rate' of this order. However, because of hard seed levels natural regeneration from mixed aged seed is rarely more than 30% of the total seed reserve (Carter 1981).

Our data therefore cover the range of densities likely to be encountered in the field. Medics sown at high density showed more than fourfold differences in dry matter yield (434 g/m^2 at low temperature compared to low-density plots (96g/m^2). However, the differences in dry matter yield between high and low plant density swards were decreased as the temperature increased. However, as shown for subterranean clover by Silsbury *et al.* (1979), the present data demonstrate a marked effect of sowing density on the seasonal growth pattern. In the present case, the maximum Sava crop growth rate was depressed by very high plant densities such that the rate at the lowest density (6.9) is about double that obtained at the highest density (2.5g/m^2/day).

Two explanations are proposed for the decline in crop growth rate with increase in plant density. The first is that shoot dry matter production at the highest sowing rate (20,000 plants/m^2) may have consistently have been underestimated. Intense inter-plant competition evidently resulted in considerable mortality of seedling plants, and some of rotting plants of the resultant dead material may have been lost during the sampling. Similarly Hunt (1970) found leaf senescence to be associated with a decelerating growth rate. The second explanation is that high plant density resulted in a low specific leaf area (Leaf lamina area per unit weight) and consequently a low capacity for photosynthesis.

Since light flux density influences (SLA) appreciably and because leaves of different (SLA) exhibit differences in carbon dioxide exchange rate (Silsbury 1968; Pearce *et al.* 1969), it is possible that high plant density results in a relatively low capacity for canopy photosynthesis.

The highest maximum crop growth rate was recorded here for snail medic cv. Sava, i.e. 8.9 g/m^2/day at medium plant density (2200 plants/m^2) and temperature 15°C, while the lowest growth rate was 2.5 g/m^2/day at high plant density and temperature of 20°C from the same Sava genotype.

10.7 Future Research Required

Jordanian studies : The plant density experiment conducted at Mushagar and the evaluation of annual medics experiment conducted at three different locations (Ramtha, Mushagar and Rabba) in Jordan, 1987. In both experiments, one date of sowing was used for each experiment and two rates of sowing were used in the plant density experiment (Mushagar). A similar study is required with several plant densities and times of sowing. Seed/seedling survival is expected to vary according to genotype, plant density time of sowing and other environmental factors. Therefore, to cover all these characteristics much more detailed studies are needed on rate of sowing, date of sowing and the environmental factors such as climatic and edaphic which affect seed soil contact for moisture exchange for germination, emergence and establishment and the consequent length of growing season. The limiting factor for livestock feed supply is the winter production which is mainly influenced by medic seed reserves to ensure a dense stand of medics.

Where medic seed is sown at different times there is a need for monitoring the time of flowering, flower abortion, seed set and seed production. However, the real value of commercial medics has to be assessed by comparing sward productivity and adaptability with the local pasture types (native pasture legume mainly medics) or other forage crops.

Furthermore, despite the importance of hard-seededness and seed dormancy, it appears that particular emphasis on these characters is unlikely to be warranted in any future medic evaluation. Therefore, emphasis should be placed mainly on seed production to ensure good levels of seed reserves for subsequent regeneration of pastures, seedling establishment and plant survival. This problem of low seed reserves and medic pasture production is widespread over large portions of the cereal-livestock zone of South Australia (Carter 1981, 1982; Carter *et al.* 1982).

Research work in South Australia : The growth rate (g/m^2) of recovery plant growth from mechanical defoliation of medic swards is difficult to judge by measuring plant dry weight after a certain time, but a satisfactory analysis of regrowth can be made by calculating the time taken or required for each genotype to reach a specified percentage of its weight at defoliation. However, a number of aspects must be considered when suitable varieties for productivity studies involving defoliation are being chosen. It would be desirable to find two varieties contrasting in height and recovery from defoliation. Since studies on seed production were also proposed, contrasting seed size and hard-seededness would be an advantage.

Future pasture studies would be the most beneficial if both the pasture and the animal parameters were measured, thereby to give more knowledge for the pasture factors which affect animal production and *vice versa*. Therefore, it is worthwhile, with reference to the defoliation experiment, to design an experiment to compare the impact of mechanical defoliation versus grazing on herbage and seed production.

Controlled environment work at Waite Institute

In contrast to the ample data for subterranean clover which shows the time course of dry matter growth to be strongly influenced by plant density, time of sowing and temperature, few data appear to be available for the annual medics (as shown in Literature Review). There appears to be a need to describe and quantify the growth of annual medics which are of considerable importance on the neutral-alkaline soils in regions of Mediterranean climate.

In order to maximise the likelihood of medic seed production in a given environment, it is important that flowering be timely. Therefore, there is need to study the quantifying vernalization and temperature promotion effects on time of flowering of annual medic cultivars. However, there is a wide genetic diversity in flowering time of annual medics. Annual medics (*Medicago* spp.) have potential as winter legumes in agricultural areas of cereal-livestock zone (Carter 1974, 1975). Much better knowledge of the factors affecting field behaviour of medics is necessary if they are to be used effectively. Flowering in medics is greatly affected by the interrelationship between temperature, including vernalization responses and photoperiod (Aitken 1955; Clarkson and Russell 1975).

On the other hand, little is known of the effects of plant density on the carbon dioxide exchange capacity of annual medics or the response of specific leaf area (SLA) to variation in plant density, although temperature and the age of the swards have a marked influence on SLA.

As the ability to predict development is an important requirement in modelling plant growth in field situations (Russell 1977), it appears worthwhile to study the growth and development of medics under controlled conditions, thereby establishing the values of parameters to use in a function describing their field behaviour.

10.8 Main Findings

10.8.1 Experiment 1: Evaluation of Annual Medic Genotypes in Jordan

The recommended pasture legumes are medics because of their ability to fit in ley farming sytem and low water requirements compared to other legumes. Most medic species are winter annuals adapted to Mediterranean climates. The main finding in this experiment are:

- **Plant population :** Medic density was higher at Mushagar than the other two sites.
- **Dry matter yield :** *M. rotata* (one or more strains) gave the best herbage production. However, for spring herbage production *M. Scurellata* was the best as well as the *M. rotata* genotypes. Therefore, the total dry matter data clearly show the superiority of *M. scutellata* and many of the newer strains (particularly *M. rotata* Sel. 2284/1953) over the commercial strains *M. truncatula.*
- **Seed production :** With reference to site effect, seed yield was better at Mushagar and Rabbah than at Ramtha (drier site). *M. rotata* Sel. 1943 consistently gave the best seed yields (50kg/ha) at Rabbah.

10.8.2 Experiment 2 : Influence of Plant Population on the Growth and Seed Production of Annual Medics

- **Dry matter yield :** The most critical time for herbage production is winter time when the temperature is low and the feed is scarce. However, winter herbage production was found to be strongly dependent on seed size and/or plant density. Similar results were found in the controlled-environment conditions. As the time progressed, the herbage production became less dependent on plant density and by the end of the growing season herbage yield was independent of plant density.
- **Pod and seed yield :** Pod yield is very important as the source of seed yield and for summer feed in dry seasons. All genotypes showed increased in number of pods/m^2 as

plant density increased and the highest productive cultivar for pods (5678 pods/m^2) was obtained from *M. rotata* Sel. 1943 at high density. However, seed yield showed a similar trend as shown for pod yield. Seed yield was varied according to genotype and plant density, whilst all genotypes show a positive correlation between herbage yield and seed yield. Furthermore, *M. rotata* was the only cultivar that responded significantly to plant density.

10.8.3 Experiment 3 : Effect of Time and Number of Mechanical Defoliations on Growth and Seed Production of Annual Medics.

From work done in the defoliation experiment and literature reviewed, recommendations can be made for the range of situations likely to be encountered. The importance and value of herbage production and seed yield of annual medics will always vary between farms, districts and seasons, but broadly the requirements would be for one of the following cases:

1. **Early defoliation :** For good recovery and high herbage yield at, or prior to the flowering stage (H_4), Para. would be preferred over other genotypes. The desirable characteristics of Para. are greater regrowth efficiency after defoliation than Rigi. and generally higher herbage yield for winter production. Although there were few differences in seed yield between Para. and Rigi. defoliation in this case is an extra bonus, possibly as a way of reducing lodging or disease or delaying stem elongation and flowering of an early sowing, until more favourable weather. Therefore, early-flowering cultivars escape from frost damage. However, Para. and Rigi. showed more tolerance of mechanical defoliation for herbage yield than Sava and Rota.

2. **Late defoliation :** To provide maximum forage in late winter Para. and Rigi. would be the most productive if seed production is not needed at all or seed is needed but not at maximum yield, otherwise Sava was the highest producer of seed, especially after early defoliations. However, all genotypes depressed in terms of seed production at late and/or twice (early + late) defoliations. Therefore, the early defoliation (before flowering) is the only recommended one for maximum herbage and seed production in annual medic swards.

10.8.4 Experiment 4 : Differences in Seedling Emergence and Survival Between Annual Medic Genotypes in Monoculture and Binary Mixture Swards

Mixtures of medic genotypes resulted in decreasing the average plant dry weight of Sava in all mixtures compared to Sava grown in monoculture swards. However, the average plant weights of other cultivars were steady where Sava genotype was not involved. Furthermore, not much variation was found in the percentage of the seed that emerged and established in binary mixtures compared to monocultures. Herbage production was also suffering from yield reduction in mixture swards, especially when Sava was one of the mixture components in high density mixture swards where the four genotypes were mixed at equal ratio (on the basis of 600 kg/ha of pure germinating seeds of Para.) 20% - 36% of all seeds sown failed to germinate or seedlings emerge and/or establish under the high-density competitive conditions.

10.8.5 Experiment 5 : Effects of Depth of Sowing and Soil Texture on Seedling Emergence of Annual Medic Genotypes

The results of these studies emphasize the importance of sowing seed at shallow depths (10-15mm) in an alkaline sandy-loam soil unless there is a water deficit when slightly deeper sowing may be warranted. Of course the optimum date of sowing will allow good plant establishment prior to cold and/or excessively wet soil conditions or even to avoid freezing and soil heavy and frost damage.

10.8.6 Experiments 6 & 7 : Growth Responses of Annual Medic Genotypes to Temperature and Plant Density

Root proportion and dry matter yield which occurred as root : Root proportion and dry matter yield which occurred as root were inversely related to increase in temperature from 10°C to 20°C in both experiments - i.e. Experiments 6 & 7. However, plant density had a positive influence on the root dry matter yield. Therefore, root : shoot ratio is dependent on temperature. Generally, root proportion decreased as the time progressed, particularly beyond 15°C, while at 10°C root percentages were more steady.

Growth rate and shoot yield : Growth rate was more dependent on temperature as well as on plant density. Shoot dry matter varied according to temperature, genotype, plant density and plant age which highly significant affecting shoot production. Shoot yield positively responded to plant density at an early growth stage which means herbage production early in the growing season is density dependent and which ensures high winter herbage production where feed is needed.

Rigi. the cold-tolerant genotype showed the highest growth rate (5.09 $g/m^2/day$) at low temperature and an inverse response as temperature increased beyond 15°C, while the commercial cultivars Sava and Rota. became more productive as the temperature increased from 10°C to 20°C. The shoot growth requirement of temperature is different from root, where the highest shoot growth rate was 5.6 $g/m^2/day$ in the first experiment and 8.9 $g/m^2/day$ in the second experiment when at 15°C throughout the period of measurement for both experiments.

Leaf Area Index (LAI) : Plants at different temperatures reached the same LAI at different rates. LAI increased as the plant got older. Also LAI improved by increasing temperature level, and/or plant density. LAI increased as shoot dry matter yield increased. Thus, the relationship between LAI and shoot yield varied significantly according to genotype, plant density and time of sampling. Furthermore, specific leaf area (SLA) values were increased as the temperature or/and plant density increased which confirm that the interaction of temperature and plant density have a positive influence on SLA as well as on LAI.

AR Assay : Nitrogenase activity was enhanced as temperature increased. The optimum temperature level for nitrogenase activity was 15°C in the first experiment, while in the second experiment the optimum level of temperature for nitrogenase activity depended on the particular cultivar. The AR assay followed the same trend as the growth rate of each genotype. On the other hand, accumulated nitrogen increased as plant density increased and/or temperature increased from 10°C to 15°C and inversely affected beyond 15°C.

10.8.7 Conclusions and Recommendations

It is commonly concluded from observations in this study (controlled conditions experiments) that the growth rates of annual medic swards are limited by low temperature in most cultivars tested. Whilst this was found to be true at low density, which might be the case in the field when a low rate of sowing is used or when regenerating pasture is poor, our results suggest that high density swards do not exhibit such a restriction. Swards established from high sowing rates, or after good regeneration at densities of 22,000 plants/m^2 will not only give high early production of dry matter, but their growth rates will be slightly increased rather than decreases as temperature decreases over the range 20°C to 10°C. High-density swards appear to be less sensitive to low temperature than are low-density swards at early growth stages (winter herbage production) where the negative growth increases with higher density.

However, for maximum herbage production, seed yield and high seedling emergence and establishment and survival to ensure optimum levels of pasture production shallow sowing (10 - 15mm) at alkaline sandy loam soil with an early defoliation or grazing (before flowering) is recommended.

11. APPENDICES

Appendix A

Table A.1 Herbage yield (kg DM/ha) of four medic species sown at equal sowing rate (30kg/ha) in Jordan 1987.

Weeks after emergence	Genotypes			
	Sava	Para.	Rigi.	Rota.
4	129	159	164	172
6	171	143	208	167
8	155	267	225	191
10	497	565	399	470
12	722	837	1101	1137
14	2842	2291	2581	2485
16	4319	4055	4406	4006
18	6148	4662	5169	4074

Table A.2 Herbage yield (kg DM/ha) of four medic species sown at equal seed number ($825/m^2$) in Jordan 1987.

Weeks after emergence	Genotypes			
	Sava	Para.	Rigi.	Rota.
4	373	165	178	197
6	434	205	204	170
8	652	298	298	269
10	1036	684	495	970
12	1892	931	1183	1344
14	5804	3206	3162	2995
16	6235	4255	5260	5131
18	6693	6115	5255	6497

Appendix B

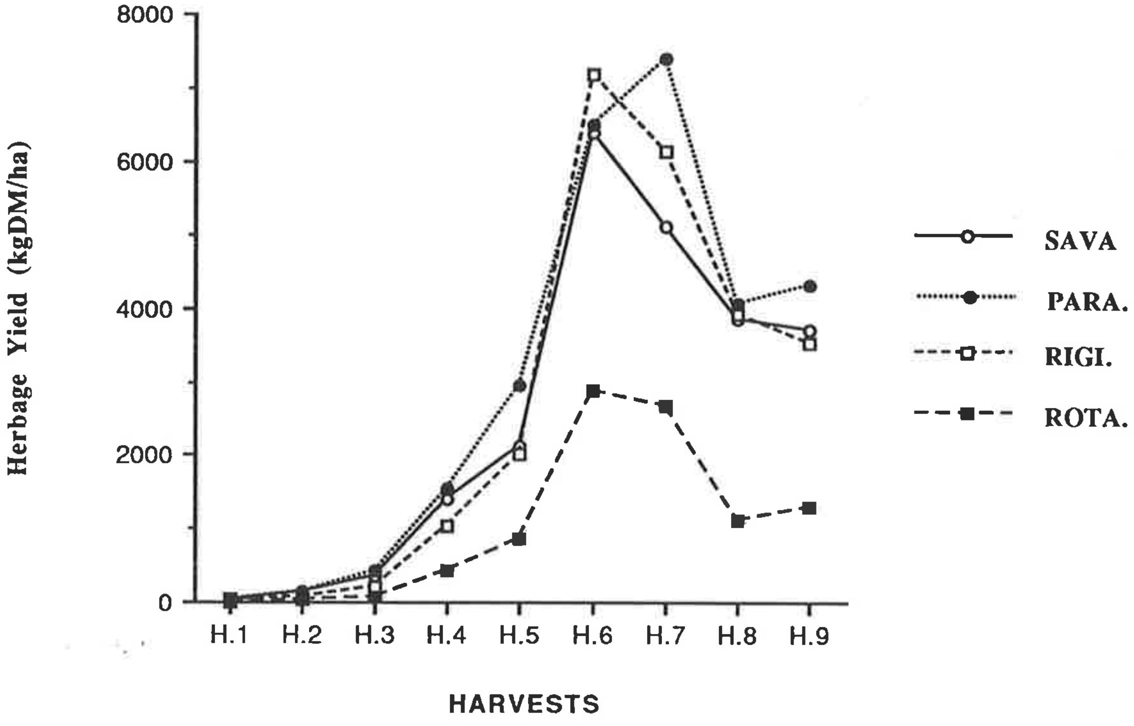


Fig. B.1

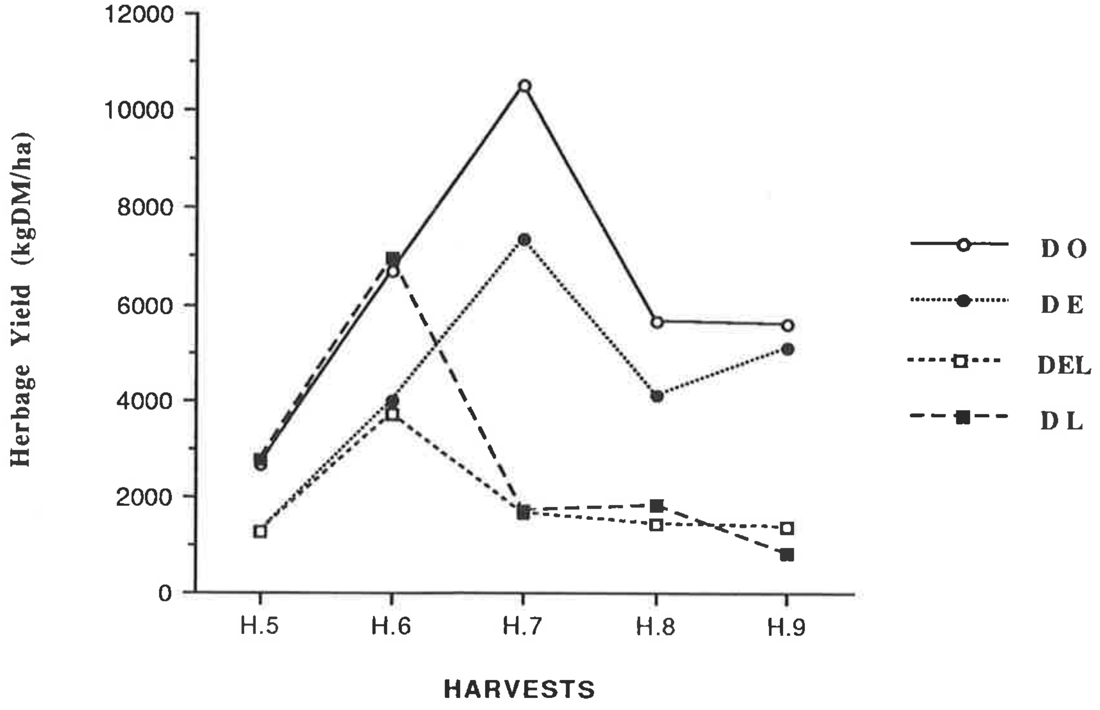


Fig. B.2

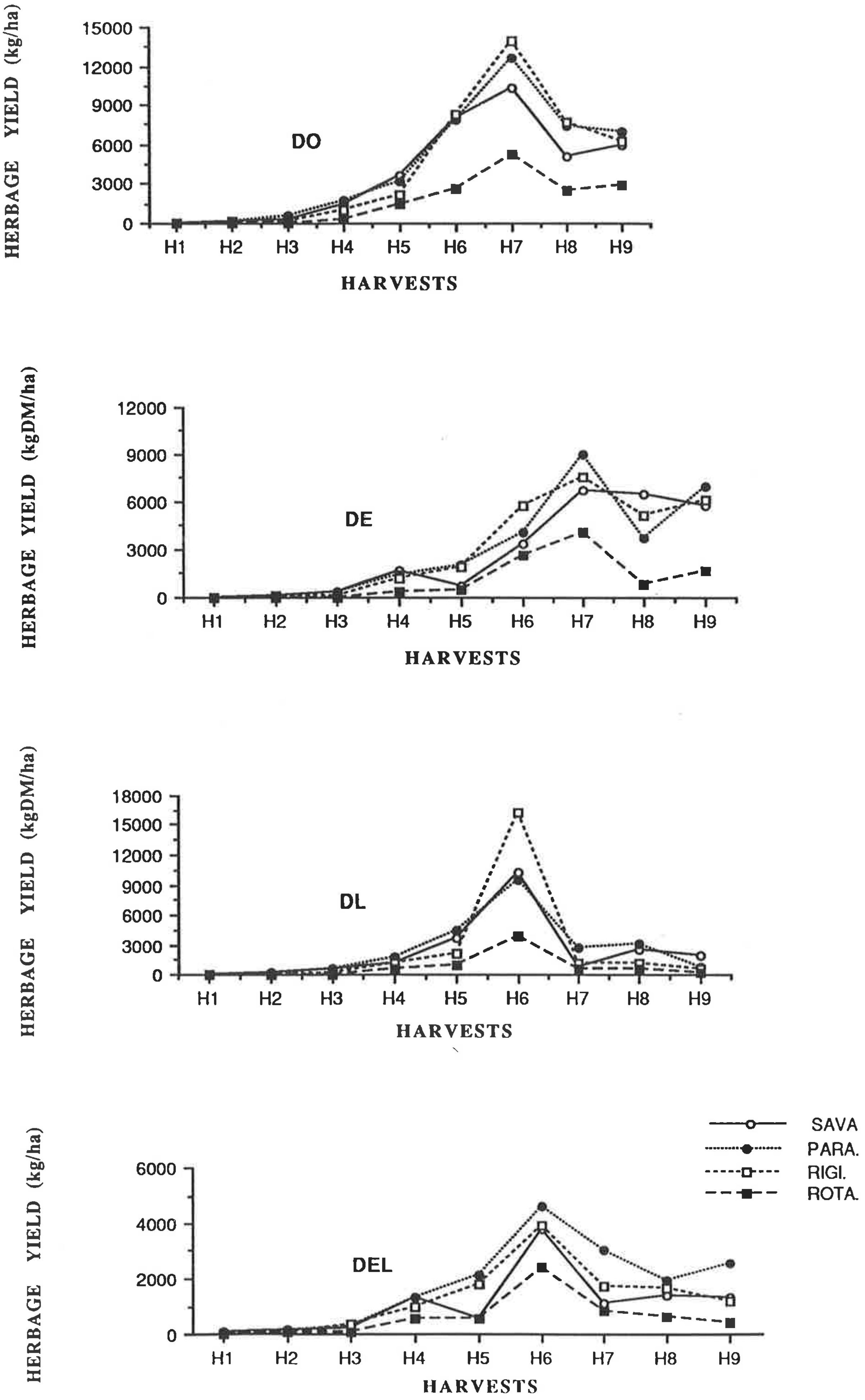

HERBAGE YIELD (kg/ha)
15000
12000
9000
6000
3000
0
DO
H1
H2
H3
H4
H5
H6
H7
H8
H9
HARVESTS
HERBAGE YIELD (kgDM/ha)
12000
9000
6000
3000
0
DE
H1
H2
H3
H4
H5
H6
H7
H8
H9
HARVESTS
HERBAGE YIELD (kgDM/ha)
18000
15000
12000
9000
6000
3000
0
DL
H1
H2
H3
H4
H5
H6
H7
H8
H9
HARVESTS
SAVA
PARA.
RIGI.
ROTA.
HERBAGE YIELD (kg/ha)
6000
4000
2000
0
DEL
H1
H2
H3
H4
H5
H6
H7
H8
H9
HARVESTS

Fig. B.3

Appendix C

Table C.1 Mean emergence of *M. scutellata* cv. Sava seedlings per pot (25 seeds sown)

	Sand			Loam		
Days after Sowing	1cm	3cm	5cm	1cm	3cm	5cm
5	4	–	–	3	–	–
6	5.3	0.5	–	3.8	1.8	0.7
7	6.8	3.0	2.2	7.8	5.3	2.6
8	8.5	5.5	4.0	11.7	8.8	4.2
9	8.5	8.5	8.3	14.2	10.5	7.8
10	14.8	12.6	10.3	16.0	12.0	9.3
11	17.5	16.2	11.8	18.3	13.0	10.0
12	18.3	18.2	12.7	18.7	13.7	10.2
13	21.0	19.7	13.8	19.7	15.3	10.5
14	21.5	19.8	14.2	20.2	15.3	10.5
15	21.8	20.3	14.5	20.5	16.0	10.0
16	22.0	20.7	15.0	20.8	16.3	10.8
17	22.5	20.7	15.0	20.8	16.7	11.2

Table C.2 Mean emergence of *M. truncatula* cv. Paraggio seedlings per pot (25 seeds sown)

	Sand			Loam		
Days after Sowing	1cm	3cm	5cm	1cm	3cm	5cm
5	18	–	–	18	–	–
6	17.2	5.3	–	8.2	5.2	–
7	17.5	11.0	0.8	12.8	10.9	1.7
8	18.2	16.9	1.5	17.0	15.0	5.7
9	18.2	18.5	8.5	20.7	18.4	11.7
10	22.3	20.2	14.7	21.3	19.6	15.5
11	22.8	21.0	16.7	21.7	20.0	16.8
12	22.8	20.8	18.2	21.7	20.0	17.2
13	22.8	21.3	18.8	21.8	20.0	18.0
14	22.8	21.5	19.0	21.8	20.0	17.8
15	22.8	21.7	19.3	21.8	20.0	18.2
16	22.8	21.7	19.8	22.0	20.2	18.3
17	22.8	21.8	19.8	22.2	20.4	18.3

Table C.3 Mean emergence of *M. rigidula* Sel. 716 seedlings per pot (25 seeds sown)

	Sand			Loam		
Days after Sowing	1cm	3cm	5cm	1cm	3cm	5cm
5	11.0	1.0	2.0	6.0	6.0	–
6	10.0	3.8	1.2	6.3	5.8	–
7	11.2	4.9	2.8	7.4	7.7	0.5
8	13.0	8.0	6.2	10.0	10.0	1.2
9	15.5	9.7	7.5	10.8	11.2	3.2
10	15.7	10.3	9.0	11.0	11.8	4.7
11	15.5	10.7	9.2	10.8	12.3	6.0
12	15.3	11.0	9.3	11.2	12.3	7.3
13	16.2	11.3	9.5	11.5	12.3	7.8
14	16.3	11.2	9.7	11.7	12.3	8.0
15	16.5	11.3	9.8	11.8	12.5	8
16	16.7	11.7	9.8	11.8	12.5	8
17	16.7	11.7	10.0	12.0	12.7	8

Table C.4 Mean emergence of *M. rotata* Sel. 1943 seedlings per pot (25 seeds sown)

	Sand			Loam		
Days after Sowing	1cm	3cm	5cm	1cm	3cm	5cm
5	17	3	1	18	–	–
6	18.8	1.8	1.3	17.7	5.5	–
7	20.1	8.2	4.5	18.6	9.2	0.5
8	22.5	14.0	6.3	22.0	10.8	0.8
9	23.0	20.5	15.3	23.2	14.0	8.8
10	23.2	22.2	18.2	22.8	15.8	15.8
11	23.2	22.7	19.7	23.2	15.8	17.3
12	23.5	22.8	20.3	23.2	16.0	18.2
13	23.5	23.5	21.0	23.2	16.2	18.7
14	23.5	23.7	21.2	23.2	16.0	19.5
15	23.7	23.7	21.2	23.2	16.2	20.2
16	23.8	23.7	21.2	23.2	16.2	20.5
17	24.2	23.7	21.3	23.2	16.2	20.5

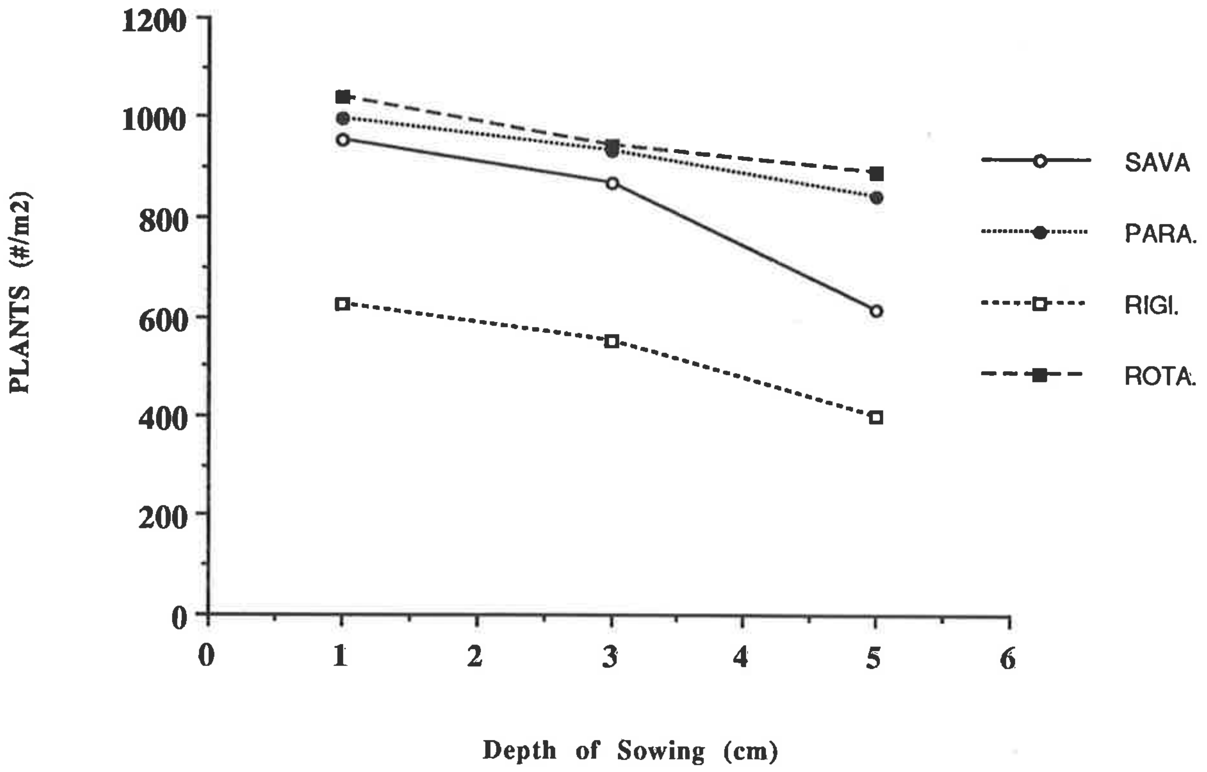


Fig. C.1(a)

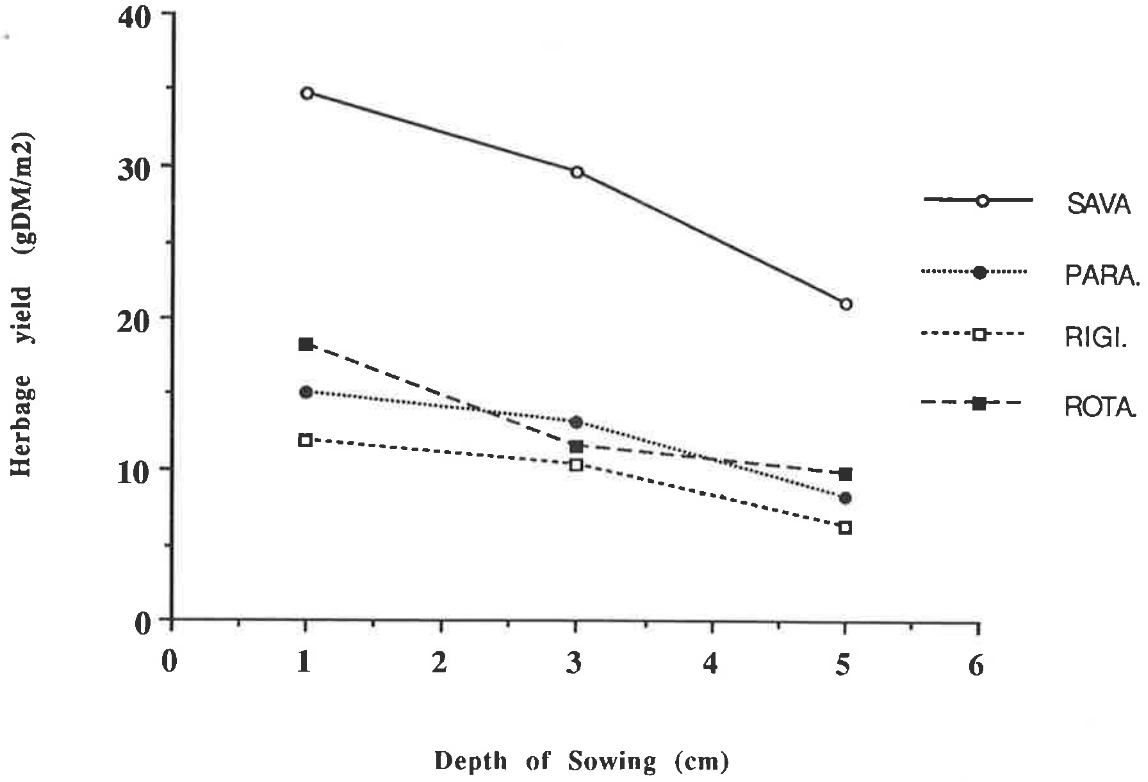


Fig. C.1(b)

Appendix D

Table D.1 Composition of Nutrient Solutions Molarity (nM)

Compound	(–N) 0.0 mM mg/l	(+N) 5.0 mM mg/l
KNO_3	–	168.34
$Ca(NO_3)_2 - 4H_2O$	–	393.18
$MgSO_4 - 7H_2O$	246.38	246.38
KH_2PO_4	34.00	34.00
H_3BO_3	2.86	2.86
$MnCl_2 - 4H_2O$	1.81	1.81
$ZnSO_4 - 7H_2O$	0.22	0.22
$CuSO_4 - 5H_2O$	0.08	0.08
$Na_2MoO_4 - 2H_2O$	0.12	0.12
EDTA	23.82	23.82
$FeSO_4 - 7H_2O$	19.92	19.92
K_2SO_4	217.75	72.51
$CaSO_4 - 2H_2O$	372.50	–

12. BIBLIOGRAPHY

12. BIBLIOGRAPHY

Ababneh, M.H. (1983). Studies on barley-forage legume mixtures under rainfed conditions in Jordan. M. Ag. Sc. Thesis, University of Jordan.

Ababneh, M.H. (1989). Comparative production of annual medics in Jordan and South Australia. Proc. Aust. Agron. Conf. Perth, W.A. September, p.427.

Abd El Moneim, A.M. and Cocks, P.S. (1986). Adaptation of *Medicago rigidula* to a Cereal-Pasture rotation in north-west Syria. Journal of Agricultural Science. Cambridge. **107**:179-186.

Addison, K.B., Cameron, D.G. and Blight, G.W. (1984a). Bieret, Sorghum and cottonseed meal as supplements for weaner cattle grazing native pastures in subcoastal south-east Queensland. Tropical Grasslands. **18**:113-120.

Addison, K.B., Cameron, D.G. (1984b). Effect of lencaena and peanut meal supplements fed to steers grazing native pasture in subcoastal south-east Queensland. Tropical Grasslands. **18**:121-130.

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

Agata, W., Kubota, F. and Kamata, E. (1971). Dry matter production of forage plants. I. Comparison of the amount of dry matter calculated from Co_2 balance with one observed in forage plant populations. J. Jap. Soc. Grassl. Sci. **17**:223-228.

Aitken, Y. (1939). Hard seeds in subterranean clover. Proc.-Roy. Soc. Vict. **51** (ii) 187-210.

Aitken, Y. (1955). Flower initiation in pasture legumes. III. Flower initiation in *Medicago Tribuloides Desr.* and other annual medics. Aust. J. Agric. Res. 6258-264.

Aldrich, D.T.A. (1959). The effect of grazing management on the response of winter wheat to spring defoliation. Emp. J. Exp. Agric. **27**:10.

Alexander, G.I. and Beattie, A.W. (1968). Studies on factors in beef cattle production in a subtropical environment. 3. Growth from weaning to yearling. Qld. J. of Agric. and Ani. Sci. **25**:7-17.

Allen, J.M. (1977). Weeds in grain lupins. I. The effects of weeds on grain-lupin yields. Aust. J. Exp. Agric. Anim. Husb. **17**:112-

Amor, R.L. (1965). Barrel medic *(Medicago tribuloides Desr.)* in the Australian wheat belt. J. Aust. Inst. Agric. Sci. **31**:25-35.

Amor, R.L. (1966). Herbage and seed production of three barrel medic *(Medicago trumcatula)* cultivars and harbinger medic *(Medicago Littoralis)* in the Victorian Mallee. Aust. J. Exp. Agric. Ani. Husb. **6**:361-364.

Amor, R.L. and Mann, A.P. (1966). Establishing medics on mallee wheat farms. J. Dep. Agric. Vic. **64**:446-448.

Anderson, S.R. and Metcalfe, D.S. (1957). Seed yields of birdsfoot trefoil (*Lotus corniculaturs* L.) as affected by pre-harvest clipping and by growing in association with three adapted grasses. Agric. J. **49**:52.

Andrew, W.D. and Hudson, W.J. (1954). A superior strain of medic-Barrel medic 173. Agricultural Gazette of N.S.W. **65**:76.

Andrew, W.D. (1958). The influence of climate, soil and management upon regeneration of barrel medic (*Medicago tribuloides* desr.) in the wheat belt of Australia. Proc. Aust. Agron. Conf. Armidale, 1958, paper No. 16, p. 10.

Andrew, W.D. and Hely, F.W. (1960). Frequency of annual species of *Medicago* on the Macquarie region of New South Wales. Aust. J. Agric. Res. **11**:705-714.

Andrew, W.D. (1962). Behaviour of annual species of *Medicago* introduced into a *Medicago minima* (L) Bast. dominant community. Aust. J. Agric. Res. **13**:212-219.

Andrew, W.D. (1965). Moisture and temperature requirements for germination of three annual species of *Medicago*. Aust. J. Exp. Anim. Husb. **5**:450-452.

Anon. (1963). Cereal investigation in the Wimmera. Victorian Department of Agriculture publication.

Antonovics, J. (1972). Population dynamics of the grass *Anthoxanthum odorantum* on a zinc mine. J. Ecol. **60**:351-365.

Argyle, D.B. (1962). Barrel medics for the eastern wheat belt pastures. J. of the Dep. of Agric. W.A. 4th Series. **3**:333.

Ashraf, M. and Taylor, G.A. (1974). Morpho-developmental factors related to winter survival of wheat. I. Association of characteristics of dark grown seedlings and winter survial. Crop Sci. **14**:499-502.

Bailey, E.T. (1967). Pasture and fodder plant introduction and establishment problems. Report to the Government of Jordan. Food and Agriculture Organization. Report No. 2405. Rome.

Balatti, P.A. and Montaldi, E.R. (1981). Efecto del foto periodo sobre la noduylacion y fijacion de nitrogeno en plantas de sojo. Revisto de la facultad de agronomia 57/58 : 23-29.

Barnard, C. (1972). Register of Australian herbage plant cultivars. Division of Plant Industry, CSIRO, Canberra, Australia. 260 p.

Bazzaz, F.A. and Harper, J.L. (1976). Relationship between plant weight and numbers in mixed populations of *Sinapsis alba* L. Rabenh. and *Lepidium satium* L. J. Appl. Ecol., **134(1)**:211-216.

Beadle, N.C.W. (1948). "The Vegetation and Pastures of Western New South Wales, with special reference to soil erosion". (Govt. Printer, Sydney).

Berdahl, J.D. Ramusson, D.C. and Moss, D.N. (1972). Effect of leaf area on photosynthetic rate, light penetration and grain yield in barley. Crop Sci. **12**:177-180.

Bergenson, F.J. (1970). The quantitative relationship between nitrogen fixation and the acetylene reduction system. Aust. J. Biol. Sci. **23**:1015-1025.

Bhagsari, A.S. (1981). Relation of photosynthetic rates to yield in sweet potato genotypes. Hortic. Sci. **16**:779-780.

Bicknell, K.G. (1973). Agron. Branch Rep., Dep. Agric., S. Australia, pp 8-15.

Black, J.N. (1955a). The influence of depth of sowing and temperature on pre-emergence weight changes in subterranean clover (T. subterraneaum L.). Aust. J. Agric. Res. **6**:203-211.

Black, J.N. (1955b). The interaction of light and temperatuer in determining the growth rate of subterranean clover (*Trifolium subterraneum* L.). Aust. J. biol. Sci. **8**:330.

Black, J.N. (1956). The influence of seed size and depth of sowing on pre-emergence and early vegetative growth of subterranean clover (*T. subterraneum* L.). Aust. J. Agric. Res. **7**:98-109.

Black, J.N. (1957). Seed size as a factor in the growth of subterranean clover (*T. subterraneun* L.) under spaced and swards conditions. Aust. J. Agric. Res. **8**:335-351.

Black, J.N. (1958). Competition between plants of different initial seed sizes in swards of subterranean clover (*T. subterraneum* L.) with particular reference to leaf area and the light microclimate. Aust. J. Agric. Res.) **9**:299-319.

Black, J.N. (1963). The interrelationship of solar radiation and leaf area index in determining the rate of dry matter production of swards of subterranean clover (*Trifolium subterraneum* L.). Aust. J. Agric. Res. **14**:20-38.

Black, J.N. (1964). An analysis of the potential production of subterranean clover (*Trifolium subterraneum* L.) at Adelaide, Sth. Aust. J. Appl. Ecol. **1**:3-18.

Bonnier, C.H. and Sironval, C. (1956). Influence of day-length on nodule formation in soja hispida by specific Rhizobium strains. Nature **177**:93-94.

Bowdler, T.M. and Lowe, K.F. (1980). Forage production from irrigated oats or ryegrass grown with annual legumes or nitrogen in south-eastern Queensland. Queensland Journal of Agricultural and Animal Sciences. **37**:133-140.

Box, T.W. and Perry, R.A. (1971). Rangeland management in Australia. J. Range anage. **24**:167-171.

Brichambaut, G., Perrin de and Wallén, C.C. (1963). A study of agroclimatology in semi-arid and arid zones of the Near East. World Meteorological Organization, Geneva, Technical Note No. 56. 64 pp.

Broue, P., Williams, C.N., Neal-Smith, C.A. and Albrecht, L. (1967). Temperature and daylength response of some cocksfoot populations. Aust. J. Agric. Res. **18**:1-13.

Brougham, R.W. (1955). A study in rate of pasture growth. Aust. J. Agric. Res. **6**:804-812.

Brougham, R.W. (1956). Effect of intensity of defoliation on regrowth of pasture. Aust. J. Agric. Res. **7**:377-387.

Brown, R.F. (1987). Defoliation regrowth and dry matter partitioning in the two arid zone grasses, *Aristida armata* and *Thyridolepis mitchelliana*. Aust. J. Agric. Res. **38**:881-893

Brownlee, H and Scott, B.J. (1977). Annual medic pastures in New South Wales (NSW). Agricultural Gazette of NSW. **88(1)**:40-43.

Buckley, K.S. (1960). Plant testing for soil conservation at Inverall. 3. Winter growing species. Journal of the Soil Conservation Service of New South Wales. **16**:77.

Bull, B.C. (1984). Notes and observations from the Jordan / Australia Dryland Farming project, pp. 1-13.

Carran, R.A., Rumball. P.J., Tough, H.J., Brock, J.L. and Crush, J.R. (1982). Diurnal variation in acetylene reduction by white clover. N.Z. J. Agric. Res. **25**:295-299.

Carter, E.D. and Heard, T.G. (1962). Land development on southern Yorke Peninsula. J. Dept. Agric., S. Aust., **65**:392-395; 448-457.

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

Carter, E.D. (1974). The potential for increasing cereal and livestock production in Algeria. A report prepared for CIMMYT, Mexico and the Ministry of Agriculture and Agrarian Reform, Algeria. 64 p.

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/FAO Regional project on improvement and production of field food crops : Regional meeting - Lahore - Peshawar - Karachi, Pakistan. 35p.

Carter, E.D. (1977). A review of the existing and potential role of legumes in farming systems of the Near East and North African Region. A preliminary report of 17 pages prepared for ICARDA, Syria and Iran.

Carter E.D. (1978). Stocking rate and the ecosystem : some interrelationship of pasture availability, grazing behaviour and productivity of Merino sheep on sown annual pasture in South Australia. Proc. IV World Conf. on Animal Production, Buenos Aires, Argentina.

Carter, E.D. (1980). The survival of medic seeds following ingestion of intact pods by sheep. Proc. Aust. Agron. Conf., Lawes, Queensland. p.178.

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

Carter, E.D. (1981b). The role of medics in livestock and crop production. Symposium Roseworthy Agric. College, South Australia, Sept. 1981.

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. Aust. Agron. Conf., Wagga Wagga, NSW. p.180.

Carter, E.D., Wolfe, E.C. and Francis, C.M. (1982). Problems of maintaining pastures in the cereal-livestock areas of southern Australia. Proc. Aust. Agron. Conf., Wagga Wagga, NSW, July 1982. pp 68-82.

Carter, E.D., Mary, Armstrong and Sommer, K.J. (1986). Effects of minimum tillage practices for wheat on survival and productivity of annual pasture legumes. Biennial Report 1986-87, pp. 58-59.

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

Carter, E.D., Thomas, P., Fletcher, E. and Cotze, E. (1987). Effects of tillage practices on annual medics. Waite Agricultural Research Institute, Biennial Report 1986-1987, p.53.

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

Carter, E.D. (1988). The production and management of pastures based on annual medics and clovers. Hart Field Day, Mid-North, SA. 27 September 1988. 12p.

Carter, E.D. and Challis, S. (1989). Residual hard-seededness in annual medics. Waite Agric. Res. Inst., Biennial Report 1988-89, p. 47.

Carter, E.D., LeLeu, 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, p. 438.

Carter, E.D. (Ed.) (1990). Better legume pastures for more cereal-livestock profits. Pasture Symposium No. 2, Waite Agricultural Research Institute, 6 February 1990. 72p.

Carter, E.D. (1990). Better pastures, more profitable crops. Notes for meeting at University of Jordan, Amman, 12p.

Chester, K.S. (1950). Plant disease losses : their appraisal and interpretation. Plant Dis. Reptr. Suppl. No. 193.

Chowdhry, A.R. And Allan, R.E. (1966). Culm length and differential development of the coleoptile, root and sub-crown internode of near iso-genic wheat lines. Crop Sci. **6**:49-51.

Chu, A.C.P. and Robertson, A.G. (1974). The effects of shading and defoliation on nodulation and nitrogen fixation by white clover. Plant soil, **41**:509-519.

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**:909-916.

Clawson, M., Landsberg, H.H. and Alexander, L.T. (1971). The Agricultural Potential of the Middle East. American Elsevier Publishing Company, Inc. New York, 1971. 312 p.

Cocks, P.S. (1969). Germination, establishment and interspecific competition in two annual pasture grasses. Ph.D. Thesis, University of Adelaide, p. 61.

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

Cocks, P.S. (1980). Origin and ecology of pasture legumes. Proc. Int. Cong. Dryland farming, Adelaide, South Australia. pp 282-314.

Cocks, P.S., Mathison, M.J. and Crawford, E.J. (1980). 'From wild plants to pasture cultivars : Annual medics and subterranean clovers in Southern Australia'. In: 'Advances in Legume Science'. (R.J. Summerfield and A.H. Bunting, eds). pp 569-596. (Royal Bot. Gardens : Kew).

Cocks, P.S., Craig, A.D. and Kenyon, R.V. (1982). Evaluation of subterranean clover in South Australia. II. Change in genetic composition of a mixed population after 19 years grazing on a commercial farm. Aust. J. Agric. Res. **33** :679-695.

Cocks, P.S., Craig, A.D. and Kenyon, R.V. (1982). Evolution of subterranean clover in South Australis. II Change in genetic composition of a mixed population after 19 years grazing on a commercial farm. Australian Journal of Agricultural Research, **33**:679-695.

Cocks, P.S. (1985). Selection of improved pasture and forage species at ICARDA. Proccedings of Expert Consultation on Rangeland Rehabilitation and Development in the Near East, FAO, Rome.

Cocks, P.S. (1985). The role of annual medics in cereal farming systems, Proceedings of Science Week, Damascus, 1985.

Cocks, P.S. (1985). Utilization of local resources for pasture plant cultivars. Trop. Agric. Res. Ser. **18**:99-107.

Cocks, P.S. (1987). Annual report of pasture forage and livestock programme, ICARDA, Syria. 288p.

Cocks, P.S. (1987). The need for seed production of pasture and forage species, in 'Seed Production in and for Mediterranean Countries', eds. A.J.G. van Gastel and J.D. Hopkins, European Economic Community and ICARDA, Aleppo, pages 143-153.

Cocks, P.S. and Ehram, T.A.M. (1987). The effect of geographic origin on frost tolerance of pasture legumes in Syria. Journal of Applied Ecology. **24**:673-683.

Cocks, P.S. (1988). Introducing pasture legumes to farming systems in north Syria - a case study. University of Cukorova/FRMP Seminar on Farming Systems Research, Adana, Turkey.

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. (1988). The role of pasture and forage legumes in livestock based farming systems in 'Nitrogen Fixation by Legumes in Mediterranean Agriculture', eds D.P. Back and L.A. Mataron, Martinus Nijhoff, Dordrecht, The Netherlands, pages 3-10.

Coile, T.S. (1936). Soil samplers. Soil Sci. **42**:139-142.

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., Francis, C.M. and Quinlivan, B.J. (1976). 'The Interrelation of Burr Burial Seed Yield and Dormancy in Strains of Subterranean Clover'. Aust. J. of Agric. Res. **27**:787-797.

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**:789-801.

Collins, W.J., Rossiter, R.C. and Monreal, A.R. (1978). The influence of shading on seed yield in subterranean clover. Aust. J. AGric. Res. **29**:1167-75.

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

Collins, W.J., Rhodes, I., Rossiter, R.C. and Palmer, M.J. (1983). Theeffect of defoliation on seed yield of two strains of subterranean clover grown in monocultures and in binary mixtures.

Cornish, P.S. (1982). Root development in seedlings of ryegrass (*Lolium perenne* L.) and Phalaris (*Phalaris aquatica* L.) sown onto the soil surface. Aust. J. Agric. Res. **33**:665-677.

Cornish, P.S. (1985). Adaptation of annual Medicago to a non-Mediterranean climate. I. The growing season defined by available soil water. In 'The Ecology and Agronomy of Annual Medics'. (Ed. Z. Hodiman). Tech. Bull 32, Dep. Agric. NSW. pp 13-16.

Cornish, P.S. (1985). Adaptation of annual Medicago to a non-Mediterranean climate. II. Relationships between maturity grading and forage production, seedpod production and pasture regeneration. In 'The Ecology and Agronomy of Annual Medics'. (Ed. Z. Hochman). Tech. Bull. No. 32, Dep. Agric. NSW. pp 17-22.

Crawford, E.J. (1962a). Another new medic, harbinger medic, for the lower rainfall wheat belt. J. Dept. Agric. South Aust. **65**:268.

Crawford, E.J. (1962b). Barrle medic 173. A new strain of medic for the wheat belt. J. Dept. Agric. S. Aust. **65**:214.

Crawford, E.J. (1963). Early Cyprus barrel medic. J. Dept. Agric. South Aust. **66**:228.

Crawford, E.J. (1967). General report on overseas pasture seed collecting mission. Aust. Plant Introduction Review (CSIRO). **4**:25-31.

Crawford, E.J. (1970). 'Variability in a large Mediterranean collection of introduced lines of *Medicago truncatula* Gaertn'. Proc. of the XI International Grassland Congress. p 188.

Crawford, E.J. (1973). Annual medics : establishment, management and general utilization. Agron. Branch Rep. No. 51. Dep. Agric. S. Aust. p 101.

Crawford, E.J. (1975). 'Data bank and genetic conservation in annual species of the genus *Medicago* L.' Aust. Pl. Int. Rev. Vol. **10**: No. 3.

Crawford, E.J. (1981). 'Development of Gama medic (*Medicago rugosa* Desr.) as an annual leguminous species for dry land farming systems in Southern Australia'. Proc. XIVth Internat. Grass Cong., Kentury, USA. p 224-226.

Crawford, E.J. (1985). 'Variability in six major characteristics of 12 annual medic species'. 3rd Australian Agronomy Conference, Tasmania. p 25.

Crider, F.J. (1955). Root growth stoppage resulting from defoliation of grass. U.S.D.A. Tech. Bull. No. 1102.

Dahmane, A.B.K. (1978). The influence of soil, climatic and management factors on nitrogen accretion by annual Medicago species in a semi-arid environment of South Australia. Ph.D. Thesis, University of Adelaide.

Davidson, J.L. and Donald, C.M. (1958). The growth of swards of subterranean clover with particular reference to leaf area. **9**:53-72.

Davidson, J.L. and Philip, J.R. (1958). Light and Pasture growth Symp., "Climatology and Micro-Climatology", Proc. Canberra, 1956. pp. 181-187. UNESCO, Paris.

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

Davidson, J.L. (1968). Growth of grazed plants. Proceedings Australian Grasslands Conference, Perth. Vol. 2. pp 125-140.

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. XIth Int. Grassl. Congr., P. 542.

Davidson, J.L. and Birch, J.W. (1972). Effects of defoliation on growth and CO_2 exchange of subterranean clover swards. Aust. J. Agric. Res. **23**:981-93.

Davidson, J.L., Bremner, P.M. and Christian, K.R. (1987). Variation among spring wheats in winter feed production : An application association between growth and floral development. Proc. 4th Aust. Agron. Conf. Melbourne, Australia.

Davis, J.H. Gangstad, E.O. and Hackerott, H.L. (1957). Button clover Hoblitzelle Agr. lab. Texas Res.Sound., Bull. 6.

Day, H.R. and Michelmore, W.A. (1952). Barrel medic for low rainfall areas. J. Dept. Agric. S. Aust. **56**:179-185.

de Koning, C.T. and Carter, E.D. (1989). Losses of subterranean clover seed from dry pasture residues during grazing by sheep in Summer-Autumn. Proc. 5th Aust. Agron. Conf., Perth. p. 408.

de Koning, C.T. and Carter, E.D. (1989). The survival of seed of subterranean clover following ingestion by sheep. Proc. XVI Int. Grassl. Cong., Nice, France. pp. 1031-1032.

de Wit, C.T. (1965). Photosynthesis of leaf canopies. Agric. Res. Rep. (Wageningen) **63**:1-57.

de Wit, C.T. (1965). Photosynthesis of leaf canopies. Agric. Res. Rep. (Wageningen), **63**:1-57.

Delaney, R.H. and Dobrenz, A.K. (1974). Morphological and anatomical features of alfalfa leaves as related to Co_2 exchange. Crop Sci. **14**:444-447.

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. Anim. Husb. **18**:75-80.

Dilworth, M.J. (1966). Acetylene reduction by nitrogen fixing preparations from *Clostridium Pasteurianum*. Biochem. Biophys. Acta. **127**:285-94.

Donald, C.M. and Neal Smith, C.A. (1937). Strain variation in subterranean clover (*Trifolium subterraneum* L.). J. of the Council for Scientific and Industrial Research. **10**:277-290.

Donald, C.M. (1941). Pastures and Pasture research. Publ. Uni. Sydney.

Donald C.M. (1951). Competition among pasture plants. I. Intraspecific competition among annual pasture plants. Aust. J. Agric. Res. **2**:355-376.

Donald, C.M. (1954). Competiton among pasture plants. II. The influence of density on flowering and seed production in annual pasture plants. Aust. J. Agric. Res. **5**:585-597.

Donald, C.M. (1959). The production and life span of seed of subterranean clover (*T. subterranean* L.). Aust. J. Agric. Res. **10**:771-787.

Donald C.M. (1960). The influence of climatic factors on the distribution of Subterranean clover in Australia. Herb Abstracts. **30**:81-90.

Donald C.M. (1963). Competition among crop and pasture plants. Adv. Agron. **15**:1-118.

Donald, C.M. (1965). The progress of Australian afgriculture and the role of pastures in environmental change. Aust. J. Sci. **27**:187-198.

Donald C.M. (1970a). The pastures of southern Australia. In 'The Australian Environment', 4th edition, 1970. Ed. G.W. Leeper. CSIRO Aust./Melbourne Univ. Press. pp68-82.

Donald, C.M. (1970b). Temperate pasture species. In 'Australian Grasslands'. Ed. R. Milton Moore. ANU Press, pp 303-320.

Dornhoff, G.M. and Shibles, R.M. (1970). Varietal differences in net photosynthesis of Soybean leaves. Crop Sci. **10**:42-45.

Dornhoff, G.M. and Shibles, R.M. (1976). Leaf morphology and anatomy in relation to Co_2 exchange rate of Soybean leaves. Crop Sci. **16**:377-381.

Downes, R.G. (1969). Proceeding of International Conference on Mechanized Dry Land farming held in 1968 at Moline, Illinois, U.S.A. pp. 20-30.

Eaton, S.V. (1931). Effects of variation in day length and clipping of plants on nodule development and growth of soybean. Bot. Gaz. **91**:113-143.

Erickson, L.C. (1946). The effect of alfalfa seed size and depth of seeding upon the subsequent procurement of stand. J. Amer. Soc. Agron. **38**:964-973.

Evans, L.T. (1959). Flower initation in I. *subterraneaum* L. I. Analysis of the partial processes involved. Aust. J. Agric. Res. **10**:1-16.

Evans, L.T. (1960). The influence of temperature on flowering in species of Lolium and in Poa Pratensis. J. Agric. Sci. **54**:410-416.

Evans, P.S. (1971). Root growth of *Lolium perenne* L. II. Effects of defoliation and shading. N.Z. J. AGric. Res. **14**:552-562.

Evans, P.S. (1973a). The effect of repeated defoliation to three different levels on root growth of five pasture species. N.Z. J. Agric. Res. **16**:31-34.

Evans, P.S. (1973b). Effect of seed size and defoliation at three development stages on root and shoot growth of seedlings of same common pasture species. N.Z. J. Agric. Res. **16**:389-394.

Ewing, M.A. (1983). Medics return to favour. J. of Agriculture W.A. **24**:27-31.

Feather, J.T., Qualset, C.O. and Vogt, H.E. (1968). Planting depth critical for short-statured wheat varieties, California Agriculture, **22, No. 9**:12-14.

Fitzpatrick, E.A. and Nix, H.A. (1970). The climatic factor in Australian grassland ecology. In "Australian Grassland", Ed. R.M. Moore, p. 3. (A. Nill Press: Canberra).

Forrester, M.L., Krothov, G. and Nelson, C.D. (1966). Effect of oxygen on photosynthesis, photorespiration and respiration in detached leaves. Soybeans Plant Physiol. **41**:422-427.

Francis, C.M. Quinlivan, B.J. and Nicol, H.I. (1972). Variation in burr burial ability in subterranean clover. Aust. J. Agric. Res. **23**:605-610.

Francis, C.M. and Gillespie, D.J. (1977). "Ecology and distribution of subterranean clover and *Medicago* species in Sardinia". West Australian Department of Agriculture publication.

Francis, C.M. (1981). The distribution and ecology of annual *Medicago* species in north west Libya. A report based on a plant collection tour. Aust. Plant Introd. Rev. **13**:3-14.

Franzmann, B.A., Scattini, W.F., Rynne, K.P. and Johnson, B. (1979). Lucerne aphid effects on 18 pasture legumes in southern Queensland: a glasshouse study. Aust. J. Exp. Agric. Anim. Husb. **19**:59-63.

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

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

Fukai, S. and Silsbury, J.H. (1978). A growth model for I. *subterraneum* L. swards. Aust. J. Agric. Res. **29**:51-65.

Fulbright, T.E. Wilson, A.M. and Redente, E.F. (1985). Green needlegrass seedling morphology in relation to planting depth. J. Range. Manage. **38**:266-270.

Fulwood, P.G. and Carter, E.D. (1989). Effects of tillage on burial of pasture legume seed and seedling emergence. Proc. 5th Aust. Agron. Conf., Perth. p.580

Fulwood, P.G. and Carter, E.D. (1989). Effects of tillage on burial of pasture legume seed and seedling emergence. Proc. 5th Aust. Agron. Conf. Perth. p. 580.

Fyson, A. and Sprent, J.L. (1982). The development of primary root nodules on *Vicia faba* L. grown at two temperatures. Ann. Bot. **50**:681-692.

Gentilli, J. (ed.) (1971). Climates of Australia and New Zealand. World Survey of Climatology Volume 13. Elsevier Pub. Co. Amsterdam, London, New York, 1971. 405 p.

Geytenbeek, P.E. (1974). The integration of cereals, pastures and sheep in the agriculture of southern Australia. The Arid Lands Agricultural Development programme. The Ford Foundation, Beirut, Lebanon, February 1974. 12p. plus appendices.

Gibson, A.H. (1961). Root temperature and symbiotic nitrogen fixation. Nature **191**:1080-1081.

Gibson, A.H. (1963). Physical environment and symbiotic nitrogen fixation. I. The effect of root temperature on recently nodulated *I. Subterraneum* plants. Aust. J. Biol. Sci. **16**:28-42.

Gibson, A.H. (1971). Factors in the physical and biological environment affecting nodulation and nitrogen fixation by legumes. Plant Soil, Spec. Vol., **1971**:139-152.

Gibson, A.H. (1976). Recovery and compensation by nodulated legumes to environmental stress. In "Symbiotic nitrogen fixation in plants". (Ed. P.S. Nutman). PP. 385-403. (Cambridge Uni. Press: Cambridge, G.B.).

Glatzle, A., Cocks, P.S., Muller, S. and Becker, K. (1988) Yield and performance of self regenerating medic pastures in a cereal - ley farming system in north Syria, in Tropicale Weiden and Futter Resourcen' ed. J. Alkampar, Giessen, Federal Republic of Germany, pages 141-150.

Graham, T.W.G., Webb, A.A. and Waring, S.A. (1981). Soil nitrogen status and pasture productivity after clearing of brigalow (Acacia harpophylla). Aust. J. of Expt. Agric. and Ani. Husb. **21**:109-118.

Graves, W.L., Kay, B.L., Jones, M.B., Jarrel, W.M. and Burton, J.C. (??). Potential use of annual legumes in a winter-rainfall California. Type climate for cereal ley farming system. Symposium on the role of legumes in conservation tillage systems. "University of Georgia, Athens. pp. 1-5.

Green, J.A. and Evand, T.A. (1956). Manuring and grazing for seed production in S.37 cocksfoot and S.215 meadow fescue. J. Brit. Grassl. Soc. **11**:165.

Greenland, D.J. (1971). Changes in the nitrogen status and physical condition of soils under pastures with special reference to the maintenance of fertility of Australian soils used for growing wheat. Soils Fert. **34**:237-251.

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.

Hadjichristodoulou, A., Della, A. and Photiades, J. (1977). Effect of sowing depth on plant establishment, tillering capacity and other agronomic characters of cereals. J. Agric. Sci. Camb. **89**:161-167.

Hagon, M.W. (1973). The effect of defoliation on flowering and seed yield of subterranean clover. Aust. J. Agric. Res. **24**:211-217.

Hagon, M.W. (1974). Regeneration of annual winter legumes at Tamworth, N.S.W. Aust. J. Exp. Agric. Anim. Husb. **14**:57-64.

Halliday, J. and Pate, J.S. (1976). The acetylene reduction assay as a means of studying nitrogen fixation in white clover under sward and laboratory conditions. J. Br. Grassl. Soc. **31**:29-35.

Halloran, G.M. and Collins, W.J. (1974). Physiologyical predetermination of the order of hard seededness breakdown in subterranean clover (*T. subterraneum* L.). Ann. Bot. **38**:1039-1044.

Harding, S.C. and Sheehy, J.E. (1980). Influence of shoot and root temperature on leaf growth, photosynthesis and nitrogen fixation of lucerne. Ann. Bot. **45**:229-233.

Hardy, R.W.F., Holsten, R.D. Jackson, E.K. and Burns, R.C. (1968). The acetylene-ethylene assay for N_2-fixation : Laboratory and field evaluation. Plant Physiol. **43**:1185-1205.

Hardy, R.W.F., Burns, R.C. and Holsten, R.D. (1973). Applications of the acetylene-ethylene assay for measurement of nitrogen fixation. Soil Biol. Biochem. **5**:47-81

Hardy, R.W.F. and Holsten, R.D. (1977). Methods for measurement of N_2-fixation. In 'A Treatise on dinitrogen fixation', (Eds. R.W.F. Hardy, A. Gibson and W. Silver), pp. 451-486. (Wiley : New York).

Harper, J.L. and Gajic, D. (1961). Experimental studies on the mortality and plasticity of a weed. Weed Res. **1**:91-104.

Harper, J.L. and McNoughton, I.H. (1962). The comparative biology of closely related species living in the same area. New phtol. **61**:175-188.

Harris, W. (1971). The effect of density, cutting height and white clover (*Trifolium repens* L.) on the structure of a ryegrass *(Lolium spp.)* population. J. Agric. Sci. Camb. **77**:385.

Harris, W. (1978). Defoliation as a determinant of the growth, persistence and composition of pasture. In 'Plant Relations in Pastures', (Ed. J.R. Wilson), pp. 67-85. (CSIRO : Melbourne).

Haskins, F.A. and Groz, H.J. (1975). Influence of seed size, planting depth and companion crop on emergence and vigor of seedlings in sweet clover. Agron. J. **67**:652-654.

Heichel, G.H. and Musgrave, R.B. (1969). Varietal differences in net photosynthesis of *Zea mays* L. Crop Sci. **9**:483-486.

Henson, P.R. and Hollowell, E.A. (1960). Winter annual legumes for the South USDA Farmers' Bull., No. 2146.

Herath, H.M.W. and Ormrod, D.P. (1979). Effect of temperature and photoperiod on winged beans. [*Psophocarpus tetrogonolobus* (L) D.C.]. Ann. Bot. **43**:729-736.

Hesketh, J.D., Ogren, W.L., Hageman, M.E. and Peters, D.B. (1981). Correlations among leaf Co_2 exchange rates, areas and enzyme activities among soybean cultivars. Photosynth. Res. **2**:21-30.

Heyn, C.C. (1963). "The annual species of *Medicago*" Scripta Hierosoly-mitana. (XII Magnes press. The Hebrew University, Jerusalem), **12**:1-154.

Hider, E.J. and Spencer, K. (1954). The influence of sulphur on a natural Medicago pasture. J. of the Aust. Instit. of Agric. Sci. **20**:171-176.

Hill, M.J. Pearson, C.J. and Kirby, A.C. (1985). Germination and seedling growth of prairie grass, tall fescue and italian ryegrass at different temperatures. Aust. J. Agric. Res. **36**:13-24.

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. No. 32, Dept. Agric. N.S.W. pp. 29-33.

Holliday, R. (1956). Fodder production from winter sown cereals and its effect upon grain yield. Field crop. Abstr. **9**:207.

Hoskins, F.A. and Gorz, H.J. (1975). Influence of seed size, planting depth and companion on emergence and vigour of seedlings in Sweetclover. Agro. J. **67**:652-654.

Hudspeth, E.B. and Taylor, H..M. (1961). Factors affecting seedling emergence of 'Blackwell' switchgrass. Agron. J. **53**:331-335.

Hughes, K.A. and Taylor, A.O. (1979). Forage production from cool-season annual legumes as affected by planting date and temperature. Proc. Agron. Soc. N.Z. **9**:1-4.

Hunt, W.F. (1970). The influence of leaf death on the rate of accumulation of green herbage during pasture regrowth. J. Appl. Ecol. **7**:41-50

Hunt, L.A., McKersie, B.C. and Tanner, D.G. (1983). Grown depth in soft white winter wheats. Crop Sci. **23**: 613-614.

Hutchinson, K.J. (1971). Productivity and energy flow in grazing/fodder conservation systems. Herb. Abst. **41**:1-10.

Hyder, D.N. Everson, A.C. and Bement, R.E. (1971). Seedling morphology and seedling failures with blue gama. J. Range. Manage. **24**:287-292.

Jeffers, D.L. and Shibles, R.M. (1969). Some effects of leaf area, solar radiation, air temperature, and variety on net photosynthesis in field-grown soybeans. Crop Sci. **9**:762-764.

Jones, R.J., Nelson, C.J. and Sleper, D.A. (1979). Seedling selection for morphological characters associated with yield of tall fescue. Crop Sci. **19**:631-634.

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.

Kasanaga, H. and Monsi, M. (1954). On the light-transmission of leaves, and its meaning for the production of matter in plant communities. Jap. Journ. Bot. **14**:301-324.

Kay, B.L. and Owen, R.E. (1970). Paraquat for range seeding in cismontane California. Weed Sci. **14**:238-244.

Keating, C. (1967). The Queensland beef cattle industry. Survey results for the period 1962-1963 to 1964-1965. Quarterly Review of Agricultural Economics, **20**:192-203.

Kernick, M.D. (1978). Indigenous arid and semi-arid forage plants of North Africa, the Near and Middle East. Vol. IV of Ecological Management of arid and semi-arid rangelands in Africa and the Near and Middle East, FAO, Rome.

Khan, S., Carter, E.D. Pattison, S. (1989). Production of oats, vetch and medic sown alone and in various combinations. Proc. 5th. Aust. Agron. Conf., Perth, p. 489.

Kirchner, R. and Andrew, W.D. (1971). Effects of various treatments on hardening and softening of seeds in pods of barrel medic. Aust. J. Exp. Agric. Anim. Husb. **11**:536-540.

Knight, W.E. and Hollowell, E.A. (1959). The effect of stand density on physiological and morphological characteristics of crimson clover. Agric. J. **51**:73.

Kumara, A. (1969). Studies on dry matter production in soybean plants. V photosynthetic system of soybean plant population. Proc. Crop Sci. Soc. Jpn. **38**:74-91.

Landsberg, H.E., Lippmann, H., Paffen, K.H. and Troll, C. (1963). World Maps of Climatology. Spring-Verlag, Berlin, 28 pages, plus 5 maps. (Includes map by Troll and Paffen - Seasonal Climates of the Earth).

Larson, A.H., Harvey, R.B. and Larson, J. (1936). Length of the dormant period in cereal seeds. Aust. J. Agric. Res. **52**:811-836.

Lawn, R.J. and Brun, W.A.(1974). Sybiotic nitrogen fixation in Soybeans. I. Effect of photosynthetic source/sink manipulations. Crop Sci. **14**:11-16.

Lawson, E.H. and Rossiter, R.D. (1958). The influence of seed size and seedling rate on the growth of two strains of subterranean clover. Aust. J. Agric. Res. **9**:286-298.

Lee, G.R. and Rothwell, W.E.M. (1966). Effects of grazing lucerne supplementation and stocking rate on sheep and native pasture productivity in the Queensland traprock region. Progress Report 1962-1965. Queensland Journal of Agricultural and Animal Science. **23**:287-297.

Leeper, G.W. (ed.) (1970). The Australian Environment. CSIRO/MUP, Melbourne. Fourth edit. 163 p.

Leeuwrick, D.M. (1974). Notes on the introduction of a ley-farming system for integrated cereal livestock production in rainfed areas of the Middle East. Arid lands Agricultural Development. Regional sheep and forage workshop. Beirut.

Leigh, J.H. and Mulham, W.E. (1966). Selection of diet by sheep grazing semi-arid pastures on the riverine plain. I. A bladder saltbush *(Attriplex vesicaria)* cotton bush *(kochia aphylla)* community. Aust. J. Exp. Agric. Anim. Husb. **6**:460.

Leigh, J.H. and Mulham, W.E. (1971). The effect of defoliation on the persistence of a bladder saltbush *(Atriplex visicaria)*. Aust. J. Agric. Res. **22**:239.

Leigh, J.H. and Noble, J.C. (1972). "Plants for sheep in Australia. A review of Pasture, Browse and Fodder Crop Research 1948-1970." (Angus and Robertson, Sydney).

Leonard, W.H. and Martin, J.H. (1963). Cereal Crops. New York : The Macmillan Company.

Lesins, K.A. and Lesins, I. (1979). Genus medicago (Leguminosae). A taxogentic study. uv. Junk, the hange.

Levy, E.B. and Madden, E.A. (1933). The point method of Pasture analysis. N.Z. J. Agric. **46**:267-279.

Litchfield, W.H. (1951). Soil survey of the Waite Agricultural Research Institute, Glen Osmond, South Australia. CSIRO Aust. Div. of Soils, Divisional Report No. 2/51, 37p.

Lloyd, D.L. and Hilder, T.B. (1985). Production by a subtropical grass *(Makarikari grass)* in association with a temperate annual legume (barrel medic) and nitrogen fertilizer in southern Queensland. Aust. J. of Exptl. Agric. and Ani. Husb. **25**:54-60.

Lodge, G.M. and Greenup, L.R. (1980). Seedling survival, yield and seed production of three species of annual medics exposed to Lucerne aphids. Aust. J. Exp. Agric. Anim. Husb. **20**:457-462.

Loeppky, H., Lafond, G.P. and Fowler, D.B. (1989). Seedling depth in relation to plant development, winter survival and yield of no-till winter wheat. Agro. J. **81**:125-129.

Loftus Hills, K. (1942). Dormancy and hardseededness in *T. subterraneum*. I. The effect of time of harvest and of certain seed storage conditions. J. Coun. Sci. Ind. Res. (Aust.). **15**:275-284.

Loftus Hills, K. (1944). Dormancy and hard seededness in *T. subterraneum*. 4. Variation between varieties. J. Conn. Sci. Ind. Res. (Aust.) **17**:242-250.

Lorenzetti, F., Tyler, B.F., Cooper, J.P. and Breese, E.L. (1971). Cold tolerance and winter hardiness in (*Lolium perenne* L.). 1. Development of screening techniques for cold tolerance and survey of geographical variation. J. of Agric. Sci. Cambridge. **76**:199-209.

Lowe, K.F. and Bowdler, T.M. (1980). Effect of seeding rate and nitrogen on the herbage production of raingrown and irrigated oats in sub-coastal south-eastern Queensland. Queensland Journal of Agricultural and Animal Sciences. **37**:145-154.

Lowe, K.F. and Bowdler, T.M. (1988). Effects of height and frequency of defoliation on the productivity of irrigated oats (*Avena strigosa* cv. Saia) and perennial ryegrass (*Lolium perenne* cv. Kangaroo Valley), grown alone or with barrel medic (*Medicago truncatula* cv. Jemalong). Aust. J. Exp. Agric. **28**:57-67.

Lueck, A.G., Sprague, V.G. and Garber, R.J. (1949). The effect of a companion crop and depth of planting on the establishment of smooth bromegrass, *Bromus inermis* c.v. *Leyss*. Agron. J. **41**:137-140.

Mackay, J.H.E. (1975). Register of Austgralian herbage plant cultivars, B. Legumes, g. Annual medics, e *Medicago Polymorpha* L. (burr medic) cv. Serena. J. Aust. Inst. Agric. Sci. **41(1)**:78-79.

Mackay, J.H.E. (1976). Register of Australian herbage plant cultivars. B. Legumes. Annual medics. e *Medicago polymorpha* L. (burr medic) cv. serena. J. Aust. Inst. Agric. Sci. 1976, **42(4)**: 255-256.

Mackay, J.H.E. (1982). Register of Australian herbage plant cultivars: Supplement to the 1972 edition. Commonwealth Scientific and Industrial Organization, Melbourne.

Maguire, J.D. (1962). Speed of germination-aid in slection and evaluation for seedling emergence and vigour. Crop Sci. **8**:176-177.

Masterson, C.L. and Murphy, P.M. (1976). Application of the acetylene reduction technique to the study of nitrogen fixation by white clover in the field. In 'Symbiotic Nitrogen Fixation in Plants'. (Ed. P.S. Nutman). I.B.P. Programme 7, Cambridge University Press.

McAlister, D.F. and Krober, O.A. (1958). Response of soybeans to leaf and pod removal. Agric. J. **50**:674.

McComb, J.A. and Andrews, R. (1974). Sequential softening of hard seeds in burrs of annual medics. Aust. J. Exp. Agric. Anim. Husb. **66**:68-76.

McCree, K.J. and Throughton, 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.

McCree, K.J. and Silsbury, J.H. (1978). Growth and maintenance requirements of subterranean clover. Crop Sci. **18**:13-18.

McCree, K.J. and Amthor, M.E. (1982). Effects of diurnal variation in temperature on the carbon balances of white clover plants. Crop Sci. **22**:822-827.

McNeilly, T. (1968). Population dynamics of the grass *Anthoxanthum odoratum* on a zinc mine. J. Ecol. **60**:351-365.

McWilliam, J. (1978). Response of pasture plants to temperature. In "Plant relation in pastures". (Ed. J.R. Wilson). pp. 17-34. (CSIRO Aust.. Melbourne).

Metcalfe, D S and Nelson, C.J. (1985). The botany of grasses and legumes, pp 52-63. In M.E. Heath *et al* (ed.) Forages 4th ed. Iowa State Univ. Press, Ames.

Metcalfe, D.S. and Nelson, C.J. (1985). The botany of grasses and legumes. pp. 52-63, 4th ed. Iowa State University.

Milford, R. (1964). The nutritive value of pasture plants. In "Some concepts and methods in sub-tropical pasture research". CAB Bulletin, **47**:144-153. (Commonwealth Agricultural Bureaux : Farnham Royal, G.B.).

Miller, H.W. Hakenrichter, A.L. and Hoglund, O.K. (1957). The influence of management methods on seeding perennials in the annual range area. J. Range Manage. **10**:62-66.

Mitchell, K.J. (1956). Growth of pasture species under controlled environment. 1. Growth of various levels of constant temperature. N.Z. Jl. Sci. Technol. A. **38**:203.

Mitchell, K.J. (1956a). Growth of pasture species. III. White clover (T. repens) subterranean clover (T. subterraneaum) and Lotus major (L. uliginosus). N.Z. J. Sci. Technol. A. **37**:395-413.

Mitchell, K.J. (1956b). Growth of pasture species under controlled environment. I. Growth at various levels of constant temperature. N.Z. J. Sci. Technol. A. **38**:203-216.Metcalfe, D.S. and Nelson, C.J. (1985). The botany of grasses and legumes. pp. 52-63. In M.E. Health *et al* (ed.) Forages 4th ed. Iowa State Univ. Press, Ames.

Mitchell, K.J. and Lucanus, R. (1960). Growth of Pasture Species under Controlled Environment II. Growth at low temperatures. N.Z. Agric. Res. **3**:647-655.

Mitchell, K.J. and Lucanus, R. (1962). Growth of pasture species under controlled environment III. Growth of various levels of constant temperature, with 8 and 16 hours of uniform light per day. N.Z. Jl. Agric. Res. **5**:135-144.

Millikan, C. (1957). Effects of environmental factors on the growth of two varieties of subterranean clover (T. Subterraneaum L.). Aust. J. Agric. Res. **8**:225-245.

Monsi, M. and Soeki, T. (1953). The light factor in plant associations and its importance for assimilation. Jpn. J. Bot. **14**:22-25.

Moore, R.M. (1970). Chapter 12: "Australian Grasslands" South eastern temperature woodlands and grasslands. (Editor: R.M. Moore.) (Australian National University Press: Canberra.)

Morley, F.H.W. and Davern, C.I. (1956). Flowering time in subterranean clover. Aust. J. Agric. Res. **7**:388-400.

Morley, F.H.W. (1958). Effects of strain and temperature on the growth of subterranean clover. Aust. J. Agric. Res. **9**:745-753.

Morley, F.H.W. and Evans, L.T. (1959). Flowering time in *I. subterraneum* L. II. Limitation by vermilization, low temperatures and photoperiod in the field at Canberra. Aust. J. Agric. Res. **10**:17-26.

Morley, F.H.W. (1961). Subterranean Clover Advan. Agron. **13**:57-123.

Moustafa, E., Ball, R. and Field, T.R.O. (1969). The use of acetylene reduction to study the effects of nitrogen fertilizer and defoliation on nitrogen fixation by field grown white clover. N.Z. J. Agric. Res. **12**:691-696.

Muller, S., Glatzle, A. and Cocks, P.S. (1989). Performance and yield of self-regenerating medic (*Medicago* spp.) in short rotation with cereals in northern Syria. Herba (in press).

Munns, D.N. (1977). Mineral nutritional and legume symbiosis.. In 'A Treatise on Dinitrogen Fixation'. (Eds. R.W.F. Hardy and A.H. Gibson). Section 4: Agron and Ecology, pp. 353-391. (John Wiley and Sons: New York).

Murata, Y., Iyama, J. and Honma, T. (1965). Studies on the photosynthesis of forage crops. 4. Influence of air temperature upon the photosynthesis and respiration of alfalfa and several southern-type forage crops. Proc. Crop Sci. Soc. Jap. **34**:154-158.

Murphy, A.H., Jones, M.B., Clawson, J.W. and Street, J.E. (1973). Management of Clovers on California annual grasslands. Calif. Agr. Exp. Sta. Circ. 564.19p.

Nishuimura, S. and Arata, H. (1957). Studies on the soiling of winter cereal crops. Bull. Shikoku Agric. Exp. Sta. **3**:1.

Nuttonson, M.Y. (1958). The Physical Environment and Agriculture of Australia with Special Reference to its Winter Rainfall Regions and to Climatic and Latitudinal Areas Analogous to Israel. American Institute of Crop Ecology, Washington D.C., U.S.A., 1958. 1124 p.

Nuttonson, M.Y. (1961a). An Introduction to Northern Africa and a Survey of the Physical Environment and Agriculture of Morocco, Algeria, and Tunisia with Special Reference to their Regions containing Areas Climatically and Latitudinally Analogous to Israel. American Institute of Crop Ecology, Washington D.C., U.S.A., 1961. 600 p.

Nuttonson, M.Y. (1961b). The Physical Environment and Agriculture of Libya and Egypt with Special Reference to their Regions containing Areas Climatically and Latitudinally Analogous to Israel. American Institute of Crop Ecology, Washington, D.C., U.S.A. 1961. 452 p.

Ozanne, R.G., Asher, C.J. and Kirton, D.J. (1965). "Root distribution in a deep sand and its relationship to the uptake of added potassium by pasture plants". Aust. J. of Agric. Res. **16**:785-800.

Pearce, R.B., Carlson, G.E., Barnes, D.K., Hart, R.H. and Hanson, C.H. (1969). Specific leaf weight and photosynthesis in alfalfa (*Medicago sativa* L.), ???? **9**:423-426.

Pearson, C.J. and Hunt, I.A. (1972). Effects of pretreatment temperature on carbon dioxide exchange in alfalfa. Can. J. Bot. **50**:1925-1930.

Peters, D.C. and Painter, R.H. (1957). A general classification of available small seeded legumes as host for three aphids of the "yellow clover aphid" Complex. J. of Economic Entomology. **50**:231-235.

Piper, C.S. (1938). The red-brown earths of South AustralianTrans. Roy. Soc. S. Aust. **62**:53-100.

Poole, M.L. (1970). An agronomic evaluation of *Medicago tornata* cv. Tornafield, a new medic cultivar. Aust. J. Exp. Agric. Ani.-Husb. **10**:405-409.

Porter, N.G. (1982). Interaction between lateral growth and pod set in primary inflorescences of lupin. Aust. J. Agric. Res. **33**:957 -

Possingham, J.V. Moye, D.V. and Anderson, A.J. (1964). Influence of elevated shoot and root temperature on nitrogen fixation. Plant Physiol. Suppl. **39**:561-563.

Prioul, J.L. and Silsbury, J.H. (1982). A physiological anlaysis of the effect of sowing density on the growth rate of subterranean clover. Aust. J. Agric. Res. **33**:213-222.

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.

Quigley, P.E. and Carter, E.D. (1985). The effects of cereal straw on productivity of annual medic pastures. Proc. Aust. Agron. Cong. Hobart, Tasmania, p 205.

Quigley, P.E., Carter, E.D. and Knowles, R.C. (1987). Medic seed distribution in soil profiles. Waite Agricultural Research Institute Biennial Report 1987, p.53.

Quigley, P.E., Carter, E.D. and Knowles, R.C. (1987). Medic seed distribution in soil profiles. Proc. 4th Aust. Agron. Conf., Melbourne. p. 193.

Quinlivan, B.J. (1961). "The effect of constant and fluctuating temperature on the permeability of the hard seeds of some legume species". Aust. J. of Agric. Res. **12**:1009-1022.

Quinlivan, B.J. and Millington, A.J. (1962). The effect of a Mediterranean summer environment on the permeability of hard seeds of subterranean clover. Aust. J. Agric. Res. **13**:377-387.

Quinlivan, B.J. (1965). The naturalized and cultivated annual medics of Western Australia. J. of the Dep. of Agric, W.A. 4th series. **6**:532.

Quinlivan, B.J. (1966). The relationship between temperature fluctuations and the softening of hard seeds of some legume species. Aust. J. Agric. Res. **17**:625-631.

Quinlivan, B.J. (1971). Seed coat impermeability in legumes. J. Aust. Inst. Agric. Sci. **37**:283-295.

Raynal, D.J. and Bazzaz, F.A. (1975). The contrasting life-cycle strategies of three annuals pasture. J. Ecol. **63**:587-596.

Robson, A.D. (1969). Soil factors affecting the distribution of annual *Medicago* species. Journal of the Australian Institute of Agricultural Science. **35**:155-162.

Rook, D.A. (1969). The influence of growing temperature on photosynthesis and respiration of pinus radiata seedlings. N.Z. J. Bot. **7**:43-45.

Rossiter, R.C. (1959). The influence of maturity grading on total yield and seed production in strains of *Trifolium-subterraneum* L. grown as single plants and in swards. Aust. J. Agric. Res. **10**:305-321.

Rossiter, R.C. (1961). The influence of defoliatiion on the components of seed yield in swards of subterranean clover (T. subterraneaum L.). Aust. J. Agric. Res. **12**:821-833.

Rossitor, R.C. (1966). Ecology of the Mediterranean annual type pasture. Adv. Agron. **18**:1-56.

Rossiter, A.D. and Lonergan, J.F. (1970). "Nodulation and growth of *Medicago truncatula* on acid soils. II Colinisation and acid soils by *Rhizobium meliloti*". Aust. J. Agric. Res. **21**:435-445.

Rossiter, R.C. (1972). The effect of defoliation on flower production in subterranean clover (T. subterraneum L.). Aust. J. Agric. Res. **23**:427-435.

Rossiter, R.C. (1976). The influence of defoliation on vegetative growth in swards of three strains of subterranean clover. Aust. J. Agric. Res. **27**:197-206.

Rossiter, R.C. (1978). The ecology of subterranean clover-based pastures. In "plant relations in pastures", ed. J.R. Wilson, pp.325-339.

Rossiter, R.C. and Palmer, M.J. (1981). An analysis of seed yield in some strains of subterranean clover *(T. subterraneum L.)* when grown in binary mixtures. Aust. J. Agric. Res. **32**:445-452.

Rumbough, M.D. and Johnson, D.A. (1986). Annual medics and related species as reseeding legumes for Northern Utah Pastures. J. Range Manage. **39**(1):52-58.

Russell, J.S. (1969). Evaluation of temperate legumes on a solodic soil and a gilgaied clay soil in the southern brigalow region. Tropica,l Grasslands. **3**:123-135.

Russell, J.S. (1977). Modelling of plant growth. In. "Applications in Agricultural Modelling", ed. A.J. de Boer and C.W. Rose, pp.113-130. (Aust. Inst. Agric. Sci. Brisbane.)

Russell, J.S. (1985). Soil treatment, plant species and management effects on improved pastures on a solodic soil in the semi-arid sub-tropics. 2. Cattle liveweight gains. Aust. J. of Expt. Agric. **25**:380-391.

Sacki, T. (1960). Interrelationships between leaf amount, light distribution and total photosynthesis in a plant community. Bot. Mag. (Tokyo). **73**:55-63.

Sackston, W.E. (1959). Effect of artificial defoliation on sunflowers. Canad. J. Plant Sci. **39**:108.

Sakamoto, C.M. and Shaw, R.H. (1967). Light distribution in field soybean canopies. Agron. J. **59**:7-9.

Sakamoto, C.M. and Shaw R.H. (1967). Apparent photosynthesis in field soybean communities. Agron. J. **59**:73-75.

Sato, K. (1979). The growth responses of Soybean plant to photoperiod and temperature. III. The effects of photoperiod and temperature on the development and anatomy of photosynthetic organs. Jpn. J. Crop Sci. **48**:66-74

Sawado, S. (1970). An ecophysical analysis of the difference between the growth rates of young wheat seedlings grown in various seasons. J. Fac. Sci. Uni. Tokyo Sci. III. **10**:233-263.

Scott, D. (1970). Relative growth rates under controlled temperatures of some New Zealand indigenous and introduced grasses. N.Z. Jl. Bot. **8**:76-

Scott, D. (1971). An agronomic evaluation of subterranean clover cultivars. Proc. N.Z. Grassl. Ass. **33**:134-140.

Sheridan, K.P. (1973). Productivity of a grazed natural pasture on the North-west slopes. Agricultural Gazette of NSW. **84**:46-47.

Shibles, R.M. and Weber, C.R. (1965). Leaf area, solar radiation interception and dry matter production by soybean. Crop Sci. **5**:575-577.

Shibles, R.M. and Weber, C.R. (1966). Interception of solar radiation and dry matter production by various soybean planting patterns. Crop. Sci. **6**:55-59.

Silsbury, J.H. (1968). Variation among ryegrasses in rates of apparent photosynthesis. Carnegie Inst. Yearb. **67**:491-493.

Silsbury, J.H. (1969). Seedling growth of summer-dormant and non-dormant ryegrass in relation to temperature. Aust. J. Agric. Res. **20**:417-423.

Silsbury, J.H. (1976). Growth and respiration of communities of subterranean clover. Australian Society of Plant Physiologists 17th General Meeting, New England.

Silsbury, J.H. and Fukai, S. (1977). Effects of sowing time and sowing density on the growth of subterranean clover at Adelaide. Aust. J. Plant Physiol. **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.

Silsbury, J.H. (1981). Co_2 exchange and dinitrogen fixation of subterranean clover in response to light level. Plant Physiol. **67**:599-602.

Silsbury, J.H., Zuill, D. and Brown, P.H. (1984). Effects of temperature on germination, emergence and early seedling growth of swards of Mt. Barker Subterranean clover plants grown with and without nitrate. Aust. J. Agric. Res. **35**:539-549.

Silsbury, J.H. and Hancock, T.W. (1990). Growth responses of cultivars of subterranean clover to temperature, plant density and nitrate supply. Aust. J. Agric. Res. **41**:101-114.

Sinclair, A.G. (1975). Measurement of atmospheric nitrogen fixation in legume-based pasture turfs using the acetylene reduction assay. N.Z. J. Agric. Res. **18**:189-195.

Sinclair, A.G. and Hannagan, R.C. (1976). Evaluation of the acetylene-reduction assay of nitrogen fixation in pastures using small soil core samples. N.Z. J. Agric. Res. **19**:451-458.

Sironval, C., Bonnier, C.H. and Verlinden, J.P. (1957). Action of day-length on nodule formation and chlorophyll-content in soybean. Physiol. Plantarium **10**:697-707.

Smith, M.A. and Baltensperger, A.A. (1983). Agronomic and acetylene reduction evaluation of three annual medics. J. Ranage. Manage. **36**:55-57.

Snaydon, R.W. and Davies, M.S. (1976). Rapid population differentiation in a mosaic environment. IV. Populations of Anthoxanthum odoratum at sharp boundaries. Heredity, **37**:9-25.

Stephens, C.G. (1957). The soils of South Australia, from South Australian Forestry Handbook, 1957, pp. 21-28.

Stephens, C.G. (1962). A Manual of Australian Soils. Third Edition, 1962. 61 p. (plus plates). CSIRO, Melbourne, Australia.

Stern, W.R. (1960). The light factor in grass and clover swards. Ph.D. Thesis. The University of Adelaide. p. 384.

Stern, W.R. and Donald, C.M. (1962). The influence of leaf area and radiation on the growth of clover and swards. Aust. J. Agric. Res. **13**:615-623.

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.

Strain, B.R. (1969). Seasonal adaptations in photosynthesis and respiration in four desert shrubs growing in situ. Ecology **50**:511-513.

Sunderman, D.W. (1964). Seedling emergence of winter wheat and its association with depth of sowing. Coleoptile length under various conditions, and plant height. Agron. J. **56**:23-25.

Tadmor, N.H. and Cohen, Y. (1968). Root elongation in the pre-emergence stage of Mediterranean grasses and legumes. Crop Science. **8**:416-419.

Tamimi, S.A. (1976). Technical report on initiation of a research programme in general agronomy, United Nation Development Programme/FAO. YEM 73010 Rome.

Taylor, G.B. and Rossiter, R.C. (1967). Seed production and persistence of Carnamah and other early strains of (*Trifolium subterraneum* L.) in the wheat belt of Western Australia. Aust. J. Exp. Agric. Ani. Husb. **7**:25-32.

Taylor, G.B. (1972). The effect of seed size on seedling growth in subterranean-clover (*Trifolium-subterraneum* L.). Aust. J. Agric. Res. **23**:595-603.

Taylor, G.B. and Rossiter, R.C. (1974). Persistence of several annual legumes in mixtures under continuous grazing in the south west of Western Australia. Aust. J. Exp. Agric. Anim. Husb. **14**:632-639.

Taylor, G.D., Rossiter, R.C. and Palmer, M.J. (1984). Long term patterns of seed softening and seedling establishment from single seed crops of subterranean clover. Aust. J. Exp. Agric. Anim. Husb. **24**:200-212.

Taylor, G.B. (1984). Effect of burial on the softening of hard seeds of subterranean clover. Aust. J. Agric. Res. **35**:201-210.

Taylor, G.B. (1985). Effect of tillage practices on the fate of hard seeds of subterranean clover in a ley farming system. Aust. J. Exp. Agric. **25**:568-73.

Taylor, J.W. and McCall, M.A. (1936). Influence of temperature and other factors on the morphology of the wheat seedling. J. of Agric. Res. (Washington DC). **52**:557-568.

Tischer, C.R. and Voigt, P.W. (1984). Screening and selection to improve establishment of warm-season forage grasses in arid regions. p. 115-119. Proc. forage and Grassland Conf., Houston

Tow, P.G. and Hodgkins, D. (1982). Factors affecting seed production in Jemalong Barrel Medic based pastures at Roseworthy Agricultural College. 2nd. Aust. Agron. Cong. Wagga Wagga, p. 179.

Tow, P.G. (1982b). Plant-environment studies in regional evaluation of pasture species. 2nd. Aust. Agron. Cong. Wagga Wagga. pp. 178.

Trumble, H.C. (1937). Some factors affecting the germination and growth of herbage plants in South Australia. J. Dep. Agric. S. Aust. **40**:779-786.

Trumble, H.C. and Donald, C.M. (1938). Soil factors in relation to the distribution of subterranean clover and some alternative legumes. J. Aust. Inst. AGric. Sci. **14**:206-208.

Trumble, H.C. (1939). Barrel medic (Medicago tribuloides, Desr.) as a pasture legume. J. Dept. Agric. S. Aust. **42**:953-958.

Trumble, H.C. (1949). The ecological relations of pastures in South Australia. J. Brit. Grassland Soc. **4**:135-160.

Unesco-Fao (1963). Bioclimatic Map of the Mediterranean Zone. Arid Zone Research XXI UNESCO-FAO. 58 p. plus maps.

Van der Veen, J.P.H. (1967). Report to the Government of Syria on range management and fodder development. FAO. TA No. 2351, Rome.

Vickery, P.J. Brink, V.C. and Ormrod, D.P. (1971). Net photosynthesis and leaf area index relationships in swards of *Dactylis glomerata* under contrasting defoliation regimes. J. Br. Grassld. Soc. **26**:85-90.

Vince-Prue, D. (1975). Photoperiodism in plants. McGraw Hill Book Company (U.K.).

Walton, G.H. (1975). Response of burr barial in subterranean clover (T. subterraneum L.) to defoliation. Aust. J. Exp. Agric. Anim. Husb. **15**:69-73.

Walton, G.H. (1982). Lupins : Better practices for higher production. J. Agric. West Aust. (4th series). **23**:77.

Walton G.H. (1984). Lupin plant densities. West Aust. Dep. Agric. Technote **7**:84.

Watanabe, I. and Tabuchi, K. (1972). Mechanism of varietal differences in photosynthetic rate of soybean leaves III. Relationship between photosynthetic rate and some leaf characters such as fresh weight, dry weight or mesophyll volume per unit leaf area. Proc. Crop Sci. Soc. **42**:437-441.

Watson, D.J. (1952). The physiological basis of variation in yield. Advance Agron. **4**:101-145.

Webb, R.B. and Stephens, D.E. (1936). Crown and root development in wheat varieties. J. of Agric. Res. (Washington, D.C.) **52**:569-583.

Webber, G.D. (1965). Agriculture in South Australia. The Lower North. J. Dept. Agric. South Australia. **68**:282-299.

Webber, G.D. (1973). Agron. Branch Rep. Dep. Agric. S. Aust. pp. 1-7.

Webber, G.D. (1975). Ley farming. Dept. Agric. Fish. S. Aust. Sept. Bull. No. **20**:75.

Webber, G. Matz, N. and William, G. (1977). Ley farming in South Australia, Dep. of Agric. S.A. Bull. No. 15.

Wesselmann, A. and Caesar, K. (1989). The influence of day length on plant and nodule development of Faba beans (*Vicia faba* L.) and Grasspeas (*Lathyrus sativus* L.). J. Agron. and Crop Sci. **162**:157-165.

Westoby, M. and Howell, J. (1982). Self-thinning in *Trifolium subterraneum* populations transferred between full daylight and shade. J. Ecol. **70**:615-621.

Weston, E.J., Nason, C.N. and Armstrong, T.D.H. (1975). Resources study and problem analysis for primary industries in the Condamine-Maronoa basin of southern Queensland. Queensland Journal of Agricultural and Animal Science. **32**:1-92.

Wheeler, W.A. (1950). Forage and pasture crops. D. Van Nostrand Co., New York.

White, J and Harper, J.L. (1970). Correlated changes in plant size and number in plant populations. J. Ecol. **58**:467.

Whyte, R.O., Nilsson-Leissner, G. and Trumble, H.C. (1953). Legume in AGriculture. FAO Agricultural Studies. No. 21.

Williams, W.A. (1963). The emergence force of forage legume seedings and their response to temperature. Crop Sci. **3**:472-474.

Willoughby, W.M. (1959). Limitations to animal production imposed by seasonal fluctations in pasture and by management procedures. Aust. J. Agric. Res. **10**:248-268.

Wilman, D., Koocheki, A., Lwoga, A.B. and Samaan, S.F. (1976b). Digestion in vitro of Italian and perennial ryegrass, red clover, white clover and lucerne. Journal of the British Grassland Society. **32**:13-24.

Winch, J.E.E. (1959). Development, crop management and harvest of birdsfoot trefoil (*Lotus corniculatus*, L.). Seed. Herb. Abstr. **29**:116.

Withers, N.J. (1975). A spacing and defoliation study with Unicrop lupins. Proc. Agron. Soc. N.Z. **5**:13.

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 Scherb)*. Ann. Bot. (Lond.) **33**:896-914.

Woodward, R.G. and Morley, F.H.W. (1974). Variation in Australian and European collections of Trifolium glomeratum L. and the provisional distribution of the species in southern Australia. Aust. J. of Agric. Res. **25**:73-88.

Xenophontos, E. (1975). Germination and growth potential of cereal seeds. M.Sc. dissertation. The University College of Wales, Aberystwyth.

Yates, J.J. (1957). Seed setting in subterranean clover (*T. Sub*. L.). I. The importance of the microenvironment. Aust. J. Agric. Res. **8**:433-443.

Yates, J.J. (1958). Seed setting in subterranean clover (*T. subterraneum* L.) II. Strain environment interactions in single plants. Aust. J. Agric. Res. **9**:754-766.

Yates, J.J. (1961). Seed-setting in subterranean clover (*T. subterraneum* L.) 3. The effect of plant density. Aust. J. Agric. Res. **12**:10-26.

Zarrough, K.M. and Nelson, C.J. (1980). Regrowth of genotypes of tall fescue differing in yield per tiller. Crop Sci. **20**:540-544.

Zelitch, I. (1982). The close relationship between net photosynthesis and crop yield. Bio Science **32**:796-802.