FINAL REPORT

TO

THE AUSTRALIAN WOOL CORPORATION

ADAPTATION AND PRODUCTIVITY OF ANNUAL MEDICS

Project number K/2/900(D)

(Previously part of K/2/900 (originally W.R.T.F. Project 6) - Pasture Improvement and Forage Cropping)

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ABSTRACT

The adaptation and productivity of annual medics (winter annual legumes in the Genus Medicago) in pasture-crop systems of southern inland Queensland were studied in two phases from 1969 to 1984. The potential area of adaptation of medics is 12 M ha in the pasture and croping lands. The adapted area lies between 24 and 29 S lat. with an annual rainfall from 500 to 800 mm. In the first phase (1969-76) the main environmental factors controlling the behaviour of annual medics were analysed at Warwick, while in the second phase (1977-84) field studies examined the role of medics in the nitrogen economy of pastures and pasture-crop rotations on two soils of high and low fertility at Warwick, Gayndah and Roma.

Growth potential and maturity characteristics: Measurements of yields under irrigation from serial plantings throughout the year showed that medics have a high potential for dry matter production (10 000 kg/ha), seed production (1 500 kg/ha) and protein content (20%). Germinations in June offer the highest yield potential at Warwick. Flowering times appear sufficiently early to ensure adequate seed set. Planting time is a dominant factor affecting responses to environment.

Laboratory studies showed how temperature and photoperiod interacted to determine flowering times, which could mostly be predicted using models driven by field climatic data. Other laboratory experiments under controlled temperatures were used to derive growth rate-temperature relationships which, although giving mixed results when used to predict growth in the field, were nevertheless able to explain how the seasonal pattern of growth rates and yield potential occurred. Glasshouse experiments showed that water stress, while restricting growth as expected, did not delay flowering or accelerate maturity until the stress was severe.

Pasture productivity: Annual medics made a major contribution to dry matter production and protein content of pastures during winter and spring when the grasses were dormant. Under adequate water supply, medic yields of 8 000 to 10 000 kg/ha were measured at each site. Under dryland conditions yields varied with winter rainfall, reaching half their apparent potential at Warwick and one third of their potential at Gayndah and Roma. Medics were adapted to all soils selected, except the infertile soil at Gayndah.

Pastures containing medics produced higher yields of grass with a higher nitrogen content than unfertilized grass pastures. The mean annual effect of medics was to increase grass yields under irrigation by approximately 110%. Comparable yields from pure grass pastures required application of nitrogen fertilizer at 100 kg/ha/year. Under dryland conditions medics increased associated grass yields by 25 to 100% at Warwick and Gayndah, equivalent to 50 kg N/ha/year on grass alone. Medics had no effect on grass yields at Roma, because of low summer rainfall. Total yields of grass-medic pastures were up to five times greater than those of unfertilized grass.

The results indicated that simple regression models could be constructed to predict medic yields retrospectively from rainfall records.

The importance of adequate plant densities (>100 plants/sq. m) in reaching attainable yields was emphasized in variety trials planted at low seeding rates. Using this approach with data from pot experiments it should be possible to estimate the productivity of medics on all major soils in the region.

Effect of medics on crops: Grain yields of wheat crops following ley pastures were higher than those of continuous wheat, and the presence of medics in the pasture enhanced the advantage obtained.

Under irrigation, the yield advantage of rotational wheat over unfertilized continuous wheat at Warwick (averaged over all crops) was 0.7 tonnes/ha for unfertilized grass, 0.8 t/ha for medic alone and 1.4 t/ha for grass/medic pastures. These compared with 0.9 and 1.6 t/ha responses in continuously grown wheat receiving fertilizer nitrogen at 100 and 200 kg/ha. The benefit from pastures at Gayndah was approximately two-thirds of that obtained at Warwick. There were no irrigated experiments at Roma.

Under dryland conditions, benefits from pastures at Warwick averaged 0.4 t/ha for unfertilized grass, 0.5 t/ha for medic alone and 0.6 t/ha for grass/medic pastures. Continuous wheat required nitrogen fertilizer at 100 kg/ha to equal the yields obtained after grass/medic pastures. At Gayndah and Roma, yield increases were smaller, partly because of greater water stress at anthesis.

The nitrogen concentration in grain was significantly higher in rotational crops following medics alone and grass/medic than in unfertilized continuous crops.

Using a crop growth model, three types of plant response to improved nitrogen supply were identified. Under adequate water supply, all differences in uptake of nitrogen were fully expressed in grain yields. When water stress occurred late in the season, increases in yield potential, which developed before anthesis through the effects of increased nitrogen supply on plant dry weight and leaf area, could not be fully expressed. This often increased the protein content of the grain. However, when a prolonged shortage of water occurred the growth of crops was limited regardless of differences in soil nitrogen supply which were therefore not expressed in higher grain yields.

Soil fertility changes: Pastures either increased soil total nitrogen or arrested the decline which occurred under continuous cropping. The greatest improvements occurred with grass/medic mixtures at all sites. Corresponding increases in grain yield were generally obtained in the following wheat crops with significant effects being observed for up to four years after the pasture phase. The most sensitive measure of improved soil fertility was nitrogen uptake in top growth, which integrated the effects of total nitrogen supply and different rates of mineralization following different pastures. These effects were associated with changes in the C:N ratio of the soil organic pool.

Strain testing: The highest yielding and most versatile medics from the material available in 1977, when protected from aphid attacks, were the cultivars Jemalong, Akbar and Cyprus in *Medicago truncatula* (barrel medic). Common burr medic (*M. polymorpha*) was a poor indicator of the suitability of soils for medic, yielding on average only half as much as the barrel medics, and being even more inferior on light soils.

This study has shown that annual medics are adapted and productive over a large area of southern Queensland. Use of medics in pastures can increase grass growth in summer through fixation of atmospheric nitrogen, extend the growing season into winter and spring when grasses are dormant, and improve the protein content of the pasture. When used in ley pastures, medics improve the yield of subsequent crops and counteract the decline in soil nitrogen which occurs under continuous cultivation.

Further work is needed on finding aphid-tolerant medics adapted to the region, agronomic aspects of medics in farming systems, management practices to ensure adequate seed reserves in the soil, effectiveness of fertilizers in the more arid areas, specialised genotypes for infertile acid soils and economics.

CONTENTS

SECTION I. PRECIS FOLLOWING A.W.C. SUGGESTED FORMAT

TERMINATED PROJECT K/2/900 (D)

Adaptation and Productivity of Annual Medics

(a) Definition of the Project

The project studied the adaptation and productivity of annual medics (winter annual legumes in the Genus Medicago) in pasture-crop systems of southern inland Queensland between lat. 24 and 29 S with annual rainfall of 500 to 800 mm. In this region of summer-dominant rainfall, the native pastures, on which most grazing enterprises are based, are deficient in protein and energy in winter when temperatures are low and frost injury occurs. As there is a shortage of adapted pasture legumes in the area, an investigation of the wider use of annual medics, which have been naturalized in parts of the region for many years and which make use of winter rain, was conceived. Since many farmers have a mixture of pastoral and cereal cropping enterprises, a study of the ability of ley pastures to counteract the decline in soil fertility under cropping was included.

(b) Objectives

This project was originally commenced in 1969 as part of the much larger W.R.T.F. Project 6 - Pasture Improvement and Forage Cropping. In the first phase (1969 to 1972), the objective was to record the growth potential and maturity characteristics of medics in field swards at Warwick to determine the general adaptation of medics to the environment. During 1973-76, these data were analysed with assistance from CSIRO in Brisbane, and additional laboratory experiments were conducted to assist in explaining and predicting medic behaviour in the field. Much of this work was prepared for publication.

In May 1977 K/2/900(D) was split from the larger K/2/900 project and a start made to assess the productivity of the medics as affected by rainfall and soil type using three localities, viz. Warwick, Gayndah and Roma. The objectives of this second phase (1977-84) were to test medics in three roles:

(i) as a winter grazed protein supplement,
(ii) as a source of symbiotic nitrogen for increased growth of companion grasses in mixed pastures, and
(iii) as a means of maintaining soil fertility and crop yields in crop-pasture rotations.

The work reported includes minor studies not previously covered in a final report to the A.W.C.

(c) Outcome

1969-76

(i) Measurement of yields under irrigation from serial planting throughout the year showed that medics have a high growth potential in winter and spring (10 000 kg/ha), seed yielding ability (1500 kg/ha) and protein content (20%). Germination in June and July offers the highest yield potential at Warwick. Frost injury can occur in cold winters.

(ii) Year-round measurements of flowering showed that medics are relatively early-flowering and become earlier-flowering as the season shortens to ensure adequate seed set. Planting time and medic strain are dominant factors in responses to environment.

(iii) Laboratory experiments showed that models could be derived under constant temperatures which would accurately predict plant development under field conditions using field temperature data. Flowering time could not be predicted until a glasshouse study showed how a vernalization requirement delayed flowering under some conditions.

(iv) The possible effect of water stress on changing maturity characteristics was examined in a glasshouse experiment. Flowering was delayed slightly under severe stress. Later stages of growth tended to be accelerated by stress, but overall the buffering capacity of plants was considerable.

(v) Laboratory and field studies were combined to develop a growth model for long-term assessment of medic productivity from climatic records. Despite some mixed results, the study explained how climatic factors determined growth rates, yield potential and timing of maximum yields. These studies demonstrated for the first time the potential value of medics in this subtropical environment.

<u>1977-84</u>

(vi) The three sites (Warwick, Gayndah and Roma) have equal dry matter production of 10 000 kg/ha under optimum conditions, but with different seasonal distributions.

(vii) Under raingrown conditions medic yields varied with winter rainfall, reaching half their apparent potential over four years at Warwick, and one third of their potential at Gayndah and Roma. Yields could be predicted from winter rainfalls using regression models.

(viii) Medics were adapted to all soils selected except the low fertility soil at Gayndah.

(ix) Grass competition had no effect on medic yields under optimum conditions, but reduced yields by 40% under conditions of severe water stress.

(x) The yield of grass in summer from irrigated pastures containing medics was more than double that from unfertilized grass and similar to that from grass fertilized with 100 kg N/ha/yr.

(xi) Under dryland conditions medics increased associated grass yields by 25 to 100% at Warwick and Gayndah, equating to 50 to 100 kg N/ha/yr on grass alone, but had no effect at Roma because of low summer rainfall.

(xii) Total yields of grass-medic pastures were up to five times greater than those from unfertilized grass. Medics increased the N concentration in summer grass growth and extended the growing season by producing high quality dry matter in winter and spring.

(xiii) Mixed pastures of grass and medic produced increases of up to 34% in soil total N in four years, while in the same period continuous cropping with wheat caused a fall of up to 19%. The supply of soil available N to crops was greatest following these pastures.

(xiv) Up to the third wheat crop after ploughing out the pastures, substantial responses in wheat yield were still being recorded to the previous growth of medics. Irrigation or favourable winter rainfalls for wheat increased the yield advantages.

(xv) The highest yielding and most versatile of the medics available in 1977, when protected from aphid attacks, were cultivars Jemalong, Akbar and Cyprus in Medicago truncatula (barrel medic). Common burr medic (M. polymorpha) was a poor indicator of the suitability of soils for medics, yielding on average only half as much material as the barrel medics and being even more inferior on light soils.

(d) Implementation/Extension

Medics at present are the sole major alternative legume to lucerne in the sheep areas of southern inland Queensland. In these areas they are adapted to most soils except the poorer solodic country with low pH, phosphorus and calcium status. This project has demonstrated that medics have considerable potential as sources of protein in winter, as a means of increasing total dry matter production and extending the pasture growing season, and for the maintenance and improvement of soil fertility.

The work on understanding how medics react to a sub-tropical climate, together with the later field studies, has contributed to assessing the potential value of medics. As pasture plants, the medics are capable of improving gross margins through improved carrying capacity, wool growth and reproductive rate, depending on location and winter rainfall. The likely impact is estimated as follows:

* In high rainfall areas (winter rain April to September > 230 mm) carrying capacity increases of two- to three-fold, a 10% increase in wool/head, and a 15% increase in lambing percentages are likely in two-thirds of years.

* In medium rainfall areas (winter rain 205 to 230 mm), a 50% increase in carrying capacity and a 5 to 10% increase in wool/head and lambing percentage appear attainable in half the years.

* Benefits in low rainfall areas (winter rain 180 to 205 mm) through increased carrying capacity are uncertain, but some improvements in wool/head and lambing percentage are likely in one-third of years.

In total these areas contain approximately 30% of Queensland's sheep.

Use of ley pastures containing grass/medic mixtures is clearly one way of either improving soil total nitrogen, or arresting the decline which occurs under continuous cropping. There is considerable scope for integrating pastures and cropping in mixed farming enterprises over much of the region under study. In high rainfall areas where the major limitation to long-term continuous cropping is the decline in soil mineral nitrogen supply, nitrogen fertilizer is likely to be used in the forseeable future. However on soils of lower fertility and in drier environments where nitrogen fertilizer may not be economic, and diversification of enterprises is necessary as a hedge against high seasonal variability, medic pastures have a more important role. On some light soils it has been found by other workers that serious degradation may occur after only one year of cropping, while on others such as the fertile brigalow soils, the period of cultivation has been too short for nitrogen deficiency in crops to require correction. These situations may be more clearly recognized and management advice given accordingly, using the results of the current studies.

Extension activities during the work have included farmer field days, numerous press articles, annual inspections by consultative committees (which include farmer representatives) at Hermitage and Brian Pastures Research Stations, annual visits by agriculture staff and students from the University of Queensland, and individual visits with farmers and extension officers. This process has already increased the confidence of both extension officers and farmers in the value of medics. As research publications arising from the project are completed, they will be made available to extension officers, and extension material written if required.

(e) Further Work

The project has indicated the need for further work on both the range of new medic cultivars now becoming available, where screening for aphid tolerance is a high priority, and the agronomic aspects of increasing the effectiveness of medics in farming systems of southern inland Queensland. Both these aspects are being tackled by other QDPI officers from Toowoomba.

To fully complete the past studies the following work is needed:

(i) Investigation of causes and remedies of high seed losses of medics in summer (often 80%) and the effects of grazing management on the promotion of high levels of seed reserves, are important in attaining high productivity of medics in these marginal environments.

(ii) Manipulation through grazing management of the grass-medic balance to advantage, which could not be included in this ungrazed project.

(iii) Measurements of animal production under the best system devised would also fill a gap in our knowledge since few studies of this type have been carried out in the area.

(iv) The improvement of medic productivity through correction of deficiencies of phosphorus and sulphur requires study in marginal rainfall areas where economic responses are uncertain because of frequent water stress.

(v) An alternative approach is to search for genera, species or cultivars which are better able to tolerate low pH, phosphorus and calcium supplies than the present commercial material.

(vi) Scope exists for economic analysis of the biological information gathered in this project and of improved systems emerging from further research, so that profitable strategies may be identified and implemented.

(f) Cost

Total costs to the Australian Wool Research Trust Fund and QDPI has been approximately $49 000 and $500 000 respectively. This project was initially part of W.R.T.F. Project 6 and as such was not costed separately until it became K/2/900(D).

(g) Publications Arising from the Project

1. Thesis

CLARKSON, N.M. (1982). Environmental control of development in annual medics (*Medicago* spp.). M.Agr.Sc. Thesis, University of Queensland.

2. Research Papers

CLARKSON, N.M. and ANDREW, C.S. (1979). Mineral nutrition and persistence of lucerne on the granite belt of south-east Queensland. *Trop. Grasslds* 13: 75-81.

CLARKSON, N.M. and RUSSELL, J.S. (1975). Flowering responses to vernalization and photoperiod in annual medics (*Medicago* spp). *Aust. J. agric. Res.* 26: 831-38.

CLARKSON, N.M. and RUSSELL, J.S. (1976). Effect of water stress on the phasic development of *Medicago* species. *Aust. J. agric. Res.* 27: 227-34.

CLARKSON, N.M. and RUSSELL, J.S. (1979). Effect of temperature on the development of two annual medics. *Aust. J. agric. Res.* 30: 909-16.

CLARKSON, N.M. (1986). Pasture species evaluation for the granite and traprock area of South-east Queensland. *Qd J. agric. and anim. Sci.* (in press).

CLARKSON, N.M., CHAPLAIN, N.P. and FAIRBAIRN, M.L. (Submitted). Dry matter production of annual medics (*Medicago* spp.) in southern inland Queensland. *Aust. J. exp. Agric.* (Submitted Feb. 1986).

3. Conference and Field Day Papers

CLARKSON, N.M. (1970). Pasture research in the granite and traprock areas of South-east Queensland. *Trop. Grasslds* 4: 171-74.

CLARKSON, N.M. (1978). Agronomic studies on annual medics. Trop. Grasslds 12: 214-5.

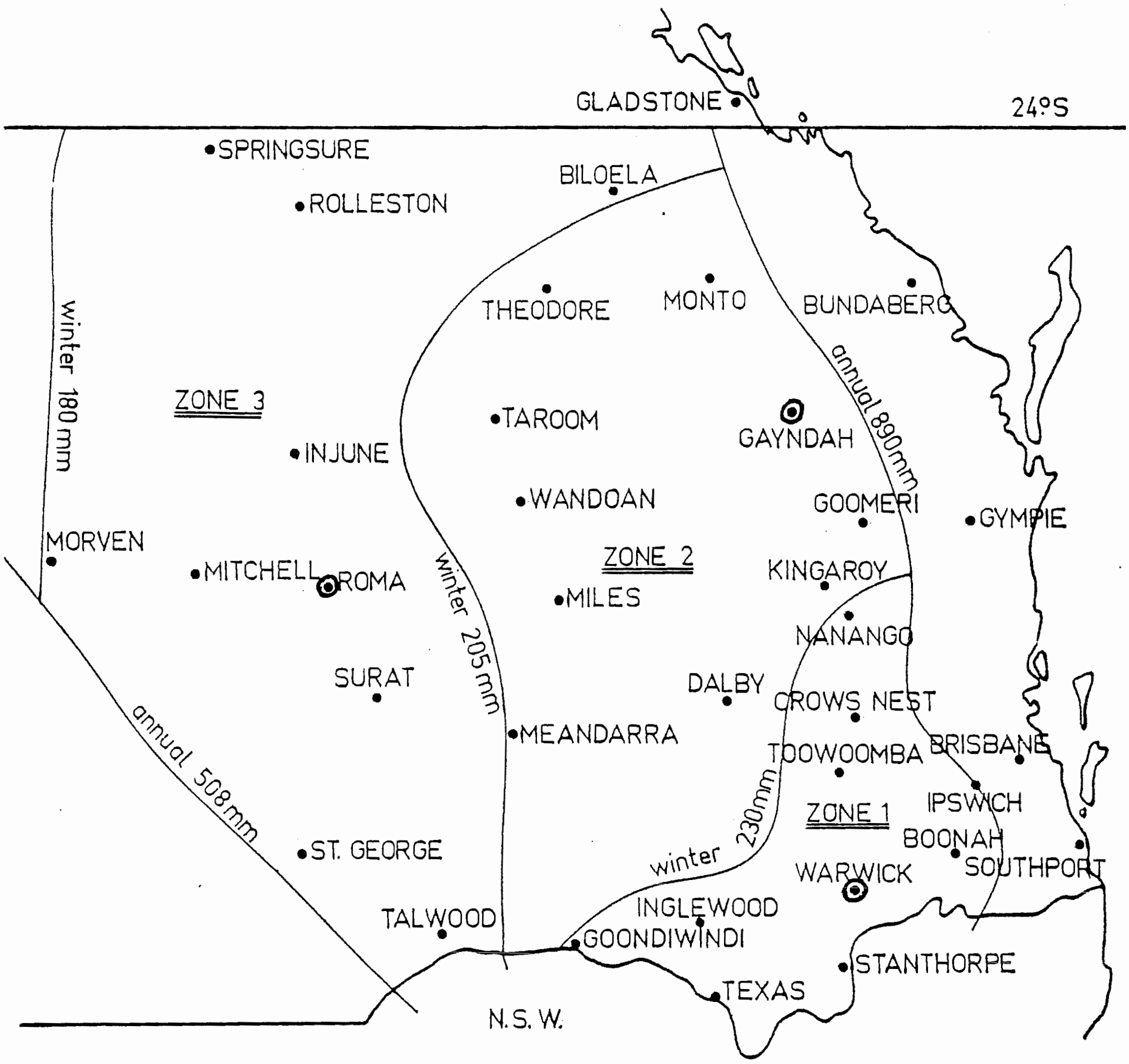
CLARKSON, N.M. (1980). Annual medic - A temperate pasture legume for the sub-tropics. In "Recent Advances in the Beef Industry". Proc. Meeting at Qd Agric. Coll. of Qd Branch Aust. Soc. Anim. Pdn pp.15-18.

RUSSELL, J.S. and CLARKSON, N.M. (1975). Estimation of temperature- and time-varying parameters of a differential equation plant growth model from experimental data using a least squares approach. Workshop on Modelling the Growth and Nutrition of Crops, CSIRO Division of Soils, Adelaide.

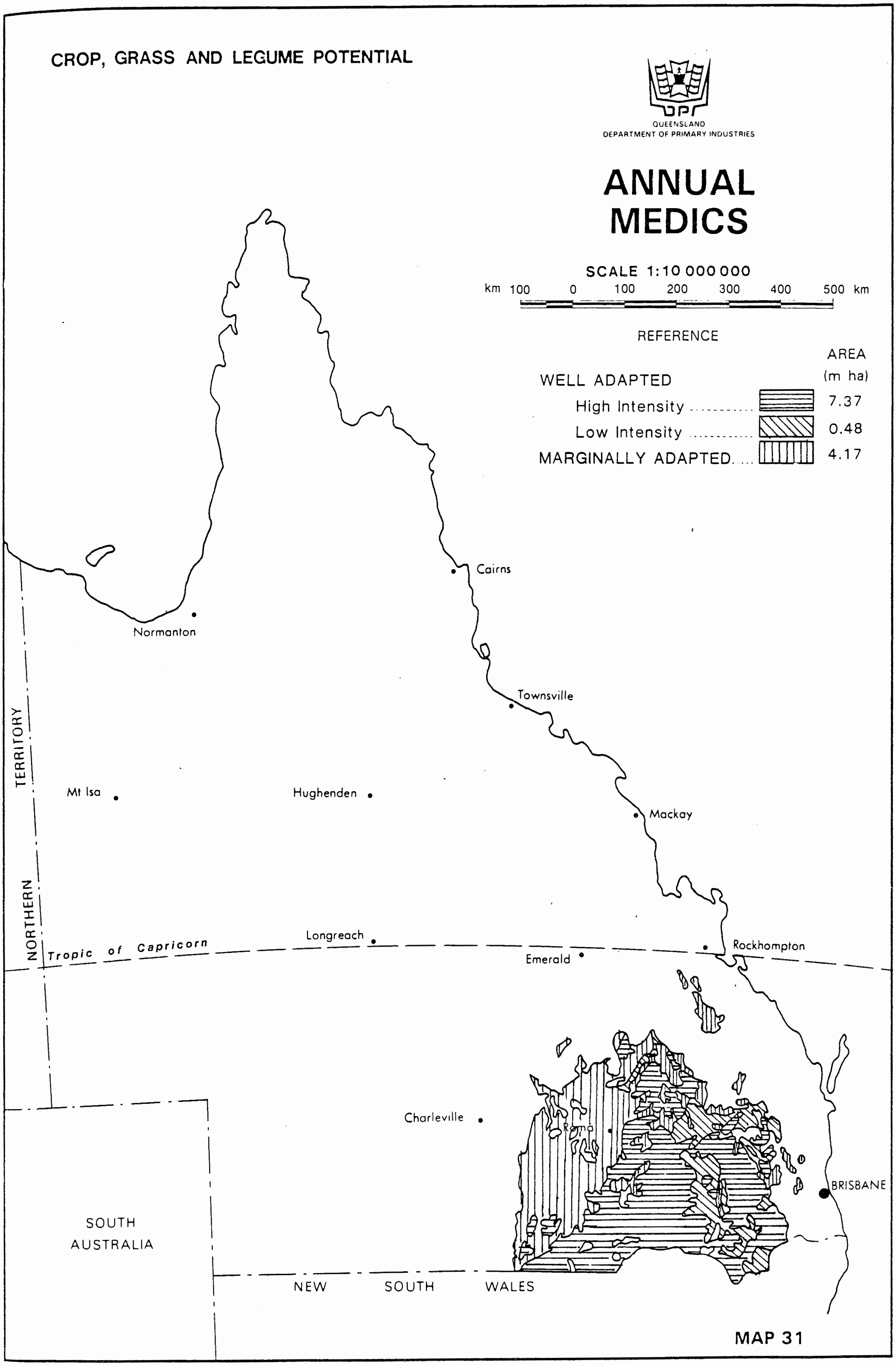
4. Extension Articles

CLARKSON, N.M. (1977). Annual medics in Queensland. Qd agric. J. 103: 39-48.

FIGURE 1



Map showing the region in Queensland which is climatically suitable for medics. The zones are based on winter rainfall with Zone 1 being the most favourable for medics.


CROP, GRASS AND LEGUME POTENTIAL
QUEENSLAND
DEPARTMENT OF PRIMARY INDUSTRIES
ANNUAL MEDICS
SCALE 1:10 000 000
km 100 0 100 200 300 400 500 km
REFERENCE
AREA (m ha)
WELL ADAPTED
High Intensity 7.37
Low Intensity 0.48
MARGINALLY ADAPTED 4.17
Cairns
Normanton
Townsville
Mt Isa
Hughenden
Mackay
NORTHERN TERRITORY
Tropic of Capricorn
Longreach
Emerald
Rockhampton
Charleville
Roma
BRISBANE
SOUTH AUSTRALIA
NEW SOUTH WALES
MAP 31

SECTION II DETAILED PROJECT REPORT

ACKNOWLEDGEMENTS

Since this project was commenced in 1969 by Agriculture Branch of the Queensland Department of Primary Industries, a considerable number of research centres, farmers, graduates, technical and field staff have contributed to it in some way. The idea to investigate the potential for greater exploitation of naturalized annual medic (a temperate annual legume) in this subtropical region came from Dr J.P. Ebersohn.

The project was made possible by financial support of the Australian Wool Corporation and the Queensland Department of Primary Industries through its senior administrators. The co-operation of Agricultural Chemistry and Biometry Branches in Q.D.P.I. is also acknowledged.

Colleagues who worked in partnership on aspects of the study were Dr J.S. Russell (CSIRO) and Mr D.R. Woodruff (Qld Wheat Research Institute). Provision of facilities and technical support by the CSIRO Cunningham Laboratory and Dept of Agriculture, University of Queensland is also gratefully acknowledged.

Farmers who played a vital role in providing and cultivating experimental sites were Mr P. Bondfield, "Palgrove"; Mr N. Bridle, "Ballandean Station"; Mr W. Raff, "Warahgai"; Mr I. Murray, "Kelso"; Mr L. O'Dea, "Baramulla"; Mr G. Maunder, "Sans Pariel"; Mr C. O'Donnell, "Mountain Park"; Mr G. Leahy, "North Springdale"; and Mr D. Hamlin at Leyburn.

Major assistance in the work was provided by the management and farm staff of the Hermitage and Brian Pastures Research Stations, Mr E. Wickham, Mr J. Fletcher, Mr P. Chaplain and Miss M. Fairbairn. Other technical staff who contributed included Messrs C. Ladewig, R. Neilsen, R. Marr, R. Henderson, G. Robinson, C. Mackay, G. Stirling and J. Prinsen. Any other contributing staff who have not been named are included in these acknowledgements.

HISTORY OF K/2/900(D)

ADAPTATION AND PRODUCTIVITY OF ANNUAL MEDICS

Project Commenced: 1969 Terminated: June 1985

NOTE: This project began as part of a large ongoing project (W.R.T.F. Project 6 - Pasture Improvement and Forage Cropping). In 1973 the project number became K/2/900 and in 1978 this blanket project was subdivided into several component parts with separate titles and suffix letters.

Locations: The base for these studies was the QDPI office at Warwick and all work in the early stages was carried out on the Hermitage Research Station out of Warwick and in the surrounding districts. From 1977 sites were also located at "Brian Pastures" Pasture Research Station, Gayndah and Roma. In each district two soil types were utilized, one each of high and low fertility. These sites were from 25° to 28°S latitude and from 600 to 800 mm mean annual rainfall.

Staff involved in Project K/2/900(D):

Officer in Charge: Mr N.M. Clarkson 1969-1985

Technicians: Mr N.P. Chaplain and Miss M.L. Fairbairn

Allocation from W.R.T.F.: Approximately $49 000 (Not costed separately prior to 1978).

Allocation from Q.D.P.I.: Approximately $500 000 (Most of this for salaries, transport and support staff and facilities, chemists, biometricians, etc.)

A. INTRODUCTION

This project arose from the need to improve the productivity of summer-growing grass pastures which are the basis of pastoral enterprises over large areas of southern inland Queensland. The productivity of these pastures is declining, mainly because of a declining nitrogen supply from the soil. Poor pasture quality in winter also restricts animal production. As the use of nitrogen fertilizer is uneconomic and few pasture legumes are adapted to the area, an investigation of the wider use of annual medics (*Medicago* spp.), which have been naturalized in parts of the region for many years, was conceived.

When the work began there was almost no information available on the adaptation and productivity of medics in southern inland Queensland. The approach to medic research in the mediterranean environments of southern Australia was not suited to Queensland although useful contact was made with researchers in the South Australian Department of Agriculture where a large collection of medics is maintained. The subtropical environment has major differences in its seasonal pattern of temperature and rainfall which create different opportunities for the exploitation of winter annual legumes.

Accordingly the first phase of the research was to establish the potential productivity, seasonal growth pattern, maturity characteristics, and response to temperature and water stress of the full range of medics commercially available at the time. In the second phase, the medics were tested under field conditions, attempting to cover the whole area where they are potentially adapted. Three widely spaced sites were chosen with two soils of high and low fertility at each site, representing an area from lat. 25° to 28° S with annual rainfall from 500 to 800 mm (Figure 1) and a potential area of medic adaptation of 12 m ha (Weston *et al* 1984) (Figure 2).

Since many farmers in the region have a mixture of pastoral, fodder cropping and cereal cropping enterprises as a means of diversifying income in a variable environment, an evaluation of the benefits from ley pastures using medics was included. There are long-term problems of declining soil fertility on arable soils which may be alleviated by the integrated use of pastures and crops in rotations.

Throughout, the problems of the highly variable environment and the difficulty of sampling it adequately in a short time were major influences on the approach used. The possible use of modelling techniques to extend the findings as widely as possible to other sites and other years was borne in mind, and influenced the measurements of soil and plant parameters.

The report is written in sections covering pasture and cropping aspects separately. Each section is self-contained and is prefaced by a summary. Most results from the first phase of the programme on potential productivity and seasonal growth patterns have been published whilst the material on the second phase is in preparation for publication. Results of minor supplementary or unrelated experiments conducted during this period, and receiving minor financial support under this project, are summarized in a separate section.

B. GROWTH POTENTIAL AND MATURITY CHARACTERISTICS 1969-76

Summary

The growth potential, maturity characteristics, nitrogen content and seed dormancy of a range of medics was measured from monthly plantings over two years, grown under irrigation on a fertile black earth at Warwick. In conjunction with the analysis of the results, other experiments were conducted under controlled conditions in the glasshouse and growth rooms so that fundamental relationships between plant behaviour and the environment could be derived. These results were used to interpret the field data and build mathematical models of the main processes, with a view to predicting plant behaviour directly from climatic records.

The results showed that the yield potential of medics is approximately 10 000 kg/ha of dry matter containing up to 20% protein and 1500 kg/ha of seed from the optimum planting time in June. Low temperatures retarded growth and caused frost injury in cold winters. Differences in growth rhythm between early and late-flowering cultivars became obvious only at planting times out of season which produced extreme differences in maturity. All medics flowered earlier in late winter plantings than in autumn plantings, thereby adapting to the shorter growing season. Their relatively early maturity overall was suited to seed set for survival. Planting time was a dominant factor in responses to environment.

Laboratory experiments showed that models could be derived under constant temperatures which would predict plant development under field conditions using field temperature data. Flowering time could not be predicted until a glasshouse study showed how a vernalization requirement delayed flowering under some conditions. The effect of water stress on development was to delay flowering slightly under severe stress. Later stages of growth tended to be accelerated by stress, but overall the buffering capacity of the plants was considerable.

To develop a growth model for long-term assessment of productivity from climatic records, field studies and laboratory experiments were combined. Several approaches were investigated including multiple regression analysis between plant growth and climatic factors, use of a modified empirical growth equation to describe the growth curves, a detailed examination of the physiology of leaf production by computer simulation, and the use of relationships between relative growth rate and temperature. The last method, when based on growth room data, was the most useful for predicting medic growth in the field. Despite some mixed results, the experiments were able to explain how climatic factors determined growth rates, yield potential and timing of maximum yield.

This work provided a basic understanding of medic growth in the subtropics as a foundation for more specific applied studies which followed.

Introduction

In the first phase, the approach used was as follows:

(1) record growth potential and maturity characteristics of medics in this environment by growing them under irrigation on a fertile soil with planting times throughout the year,

(2) analyse and interpret these data as far as possible using weather records collected during the experiment,

(3) conduct supporting experiments under controlled laboratory conditions so that fundamental relationships between the plants' behaviour and the environment (eg. temperature) could be derived,

(4) analyse and interpret these data in their own right,

(5) use these experiments to interpret the field data, and

(6) build mathematical models of the main processes discovered, with a view to predicting plant behaviour directly from climatic records.

This work was designed to lay a foundation for understanding the growth of medics in relation to environment, which was not previously available and which was needed to make sense of a large number of scattered and at times erroneous observations and theories about the behaviour and value of medics in the sub-tropics.

<u>Growth potential and maturity characteristics in the field</u>

The aims of this work were to:

(1) record the potential of the environment for medic growth throughout the year,

(2) measure the degree to which low temperatures in winter retarded the growth of medics, since one potential use was to produce high quality feed in winter when summer grasses are dormant and of low quality,

(3) record the maturity characteristics (eg. flowering time) of early and late-flowering cultivars of medics as a guide to their chances of setting seed from various germination times which in practice depend on the timing of highly variable winter rains,

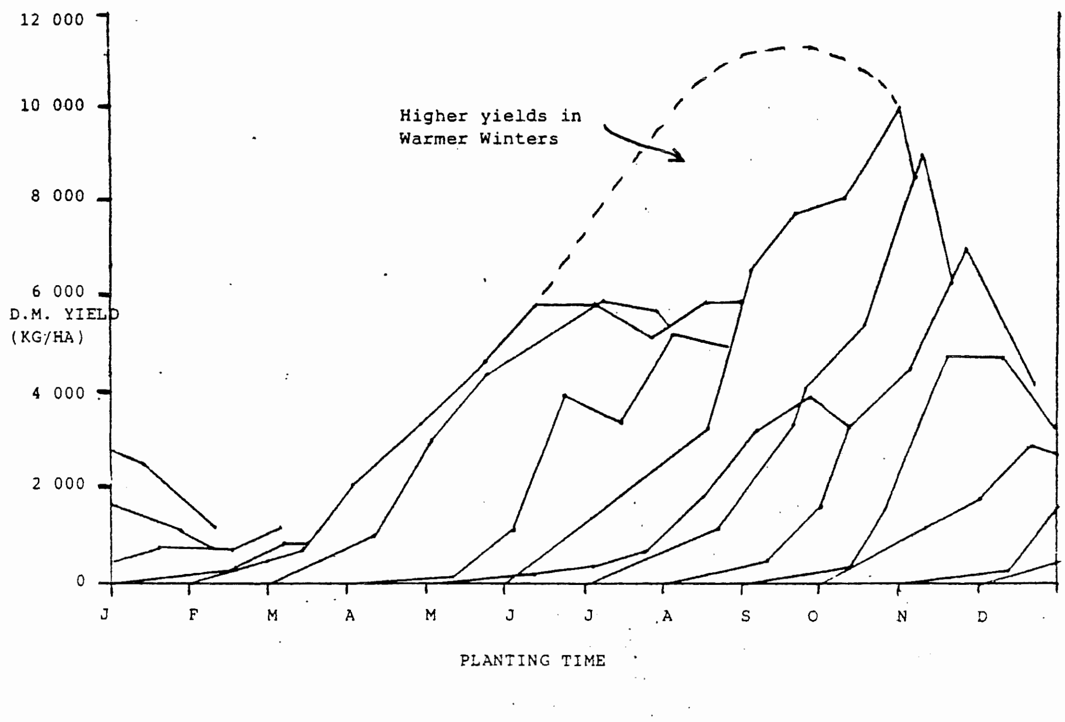
(4) test opinions prevalent in more Mediterranean areas of southern Australia that: (i) early-flowering cultivars had higher growth rates in winter than late-flowering cultivars, but a lower maximum yield, (ii) late-flowering cultivars could recover and extend their growing season if late spring rains fell when the plants were nearly mature, and (iii) medic productivity could be maximised by using mixtures of early and late-flowering cultivars,

(5) measure the level of hardseedness in mature seed pods (which must be high to prevent "false breaks" and loss of seed in summer, while still supplying sufficient soft seed for natural regeneration). It was known that in South Australia some medic cultivars regenerate poorly because of excessive hardseededness,

(6) derive fundamental plant-environment relationships from the data wherever possible.

All the cultivars of annual medics which were commercially available in 1969 were grown under irrigation in small sward plots at high planting rates on a fertile black soil at Warwick. Twenty-four plantings were made at monthly intervals over two years to obtain the widest possible experience of the environment. Measurements were made of cumulative dry matter yields every three weeks, nitrogen content, seed yields at maturity, and the time taken to reach various stages of growth eg. first stem branching, first flower, first mature pod, and death. Measurements were also made of hardseedness at maturity and the rate of breakdown of hard seed for later germination, a process which is promoted by high temperatures in summer.

FIG 3 Effect of time of planting on potential yield of Jemalong barrel medic under irrigation on a black earth at Warwick. There were 110 frosts in winter, with grass minimum down to - 13.4°C.



The results showed that yield potential of medics is approximately 10 000 kg/ha of dry matter from plantings in winter, falling to 1 000 to 2 000 kg/ha for plantings in summer (Figure 3). Low temperatures in mid-winter may greatly retard the growth of medics in winter at Warwick, and extensive frost injury occurred in the two very cold winters encountered. Later experience in other years and at other sites has shown a considerable variation from year to year in the size of this effect. In mild winters, plantings in April and May have occasionally produced nearly 12 000 kg/ha as shown in Figure 3. The highest yielding cultivars were M. truncatula cv. Jemalong (very frost resistant) and M. scutellata cv. Robinson.

The pattern of flowering was very different in early and late-flowering cultivars and changed with time of planting (Table 1). In an early cultivar (eg. Robinson), flowering was rapid in summer and slow in winter, while in a late cultivar (eg. Jemalong) flowering was very late in summer and autumn, but became progressively earlier in plantings between April and September.

Table 1. Effect of time of planting on days to flowering at Warwick of an early flowering medic (M. scutellata cv. Robinson) and a late flowering medic (M. truncatula cv. Jemalong) in 1969-71.

		Planting Time											
Cultivar	Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Robinson	1969-70	35	35	40	63	81	69	61	59	42	32	32	31
	1970-71	31	34	41	63	78	82	60	46	41	36	31	32
Jemalong	1969-70	138	116	111	126	105	74	75	69	58	92	99	135
	1970-71	115	103	134	118	109	93	67	64	65	76	104	109

There are several important points arising from these data:

(1) The relative maturity of early and late cultivars depends on when they are planted (germinate). Differences are greatest in early autumn plantings and least in early spring plantings.

(2) All medics flowered earlier in late winter plantings than in normal autumn plantings. This is a valuable adaptation to environment which shortens their maturity as the winter growing season shortens due to a late germination.

(3) This knowledge is useful in advising farmers who wish to plant mixtures of summer and winter pasture plants at a time when they have reasonable prospects of setting seed. Late winter plantings of medics have good prospects due to early maturity. The data can also be used to estimate the time of germination of plants observed in the field.

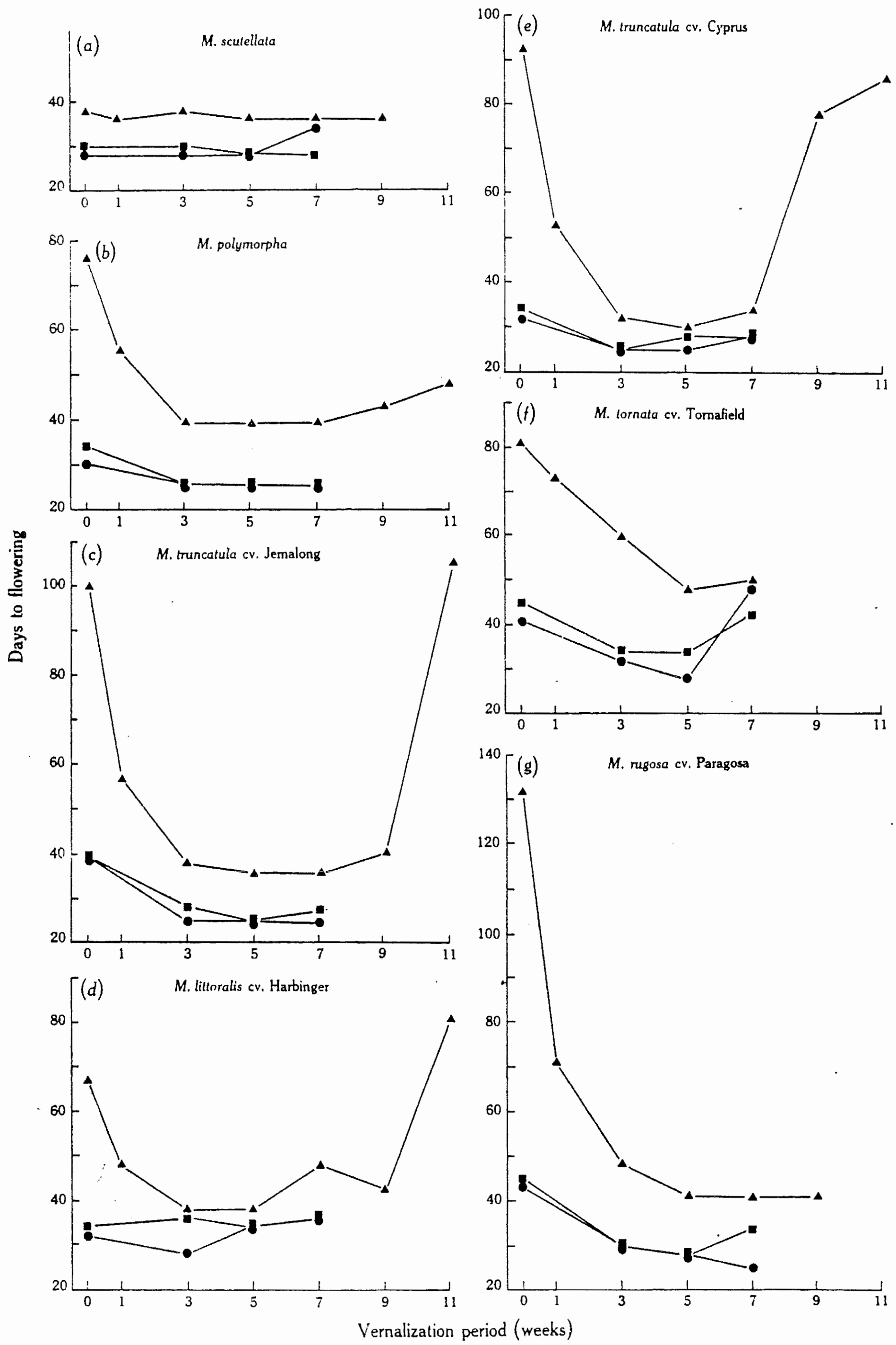


Fig. 4 Effect of different periods of vernalization of germinated seed on time to flowering of seven annual medics grown under three photoperiods, viz. natural (P12, ▲), 18-hr (P18, ●) and continuous light (P24, ■).

photoperiods in the glasshouse. To study the third process, the time to flowering of selected treatments from this experiment was compared with flowering data from plants grown in the field at a range of temperatures lower than in the glasshouse.

Vernalization and photoperiod caused large shifts in flowering time but the effects varied widely among species (Figure 4). Vernalization and short dark periods were additive in accelerating flowering and largely able to substitute for each other. Species flowered almost simultaneously when given their most favourable conditions for flowering (Table 2).

Table 2. Ranking of species in order of increasing flowering response to photoperiod (P24 *v.* P12) in unvernalized plants and to vernalization under natural photoperiod.

Rank	Species	Acceleration of flowering (days) by: Photoperiod	Vernalization	Time to flowering (days) Longest	Shortest
1	*M. scutellata*	8	2	38	28
2	*M. littoralis* cv. Harbinger	33	29	67	28
3	*M. tornata* cv. Tornafield	36	33	81	28
4	*M. polymorpha*	42	37	76	25
5	*M. truncatula* cv. Cyprus	58	62	92	25
6	*M. truncatula* cv. Jemalong	61	64	100	25
7	*M. rugosa* cv. Paragosa	87	91	132	25

High temperatures accelerated flowering in all species studied. However in species other than *M. scutellata* it was necessary for a vernalization requirement to be met before this effect was observed. A simple exponential equation was able to describe the response (Figure 5).

A new finding was that the vernalization response in *M. truncatula* and *M. littoralis* was largely reversed after more than seven weeks of vernalization. This suggests a previously undetected flowering mechanism in these species.

These results explain the reasons why flowering in some cultivars in the field is not simply related to temperature, while in others it is. The results above were published by Clarkson and Russell (1975). The vernalization process was used to improve the prediction of flowering times in the next experiment.

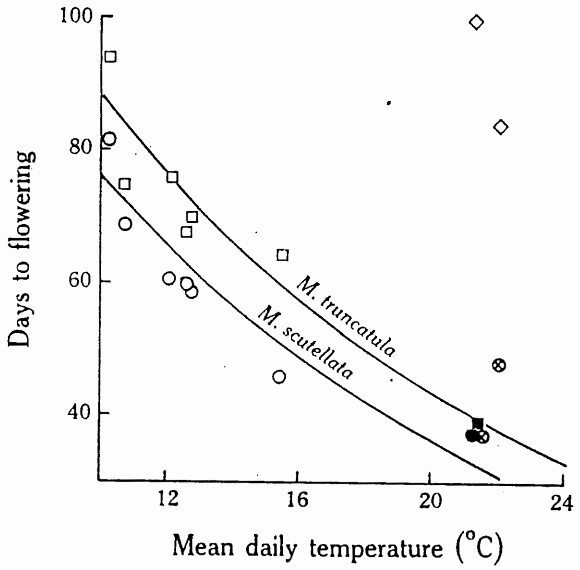


Fig. 5 Effect of daily temperature after germination on time to flowering of *M. scutellata* and *M. truncatula* cv. Jemalong. Equations for the curves fitted to the data from the glasshouse (vernalized only) and field are given in the text. *M scutellata*: field, ○; glasshouse (vernalized 3 weeks), ●; glasshouse (not vernalized), ⊗. *M. truncatula*: field, □; glasshouse (vernalized 3 weeks), ■; glasshouse (not vernalized), ◇.

Studies of temperature effects on development

The aims were to measure development of annual medics under controlled temperatures, to derive relationships for predicting development in the field, and to test these relationships using field temperature data.

Development of two annual medics (M. scutellata cv. Robinson and M. truncatula cv. Jemalong) was recorded under four controlled day/night temperature regimes of 12/5°, 18/11°, 24/17° and 30/23 C. Increasing temperature accelerated the rate of development to all stages recorded. Jemalong flowered early at high temperatures, apparently due to vernalization while the seedlings were established at a low temperature.

In order to consider development under field conditions in daily increments, mathematical representation of development under controlled conditions was carried out using the approach of Robertson (1968), where rate of development was considered to be a function of daily temperature when daylength was constant. Rate of development was integrated between two development stages. To permit calculations using a daily time interval and different daily temperatures, a quadratic function was used and fitted to the experimental values using a suitable computer program. The value of the function for a given temperature and development stage is the daily fractional increment of development. The effect of temperature on this increment is shown in Figure 6.

Prediction of field development was carried out using this model and the mean daily temperatures from the field study at Warwick (1969-71), for which development data were available. For each stage of development in each planting, the daily increment was calculated and accumulated until a value of 1.0 on the predicted day was reached. The comparison between predicted and observed field development of cv. Robinson is shown in

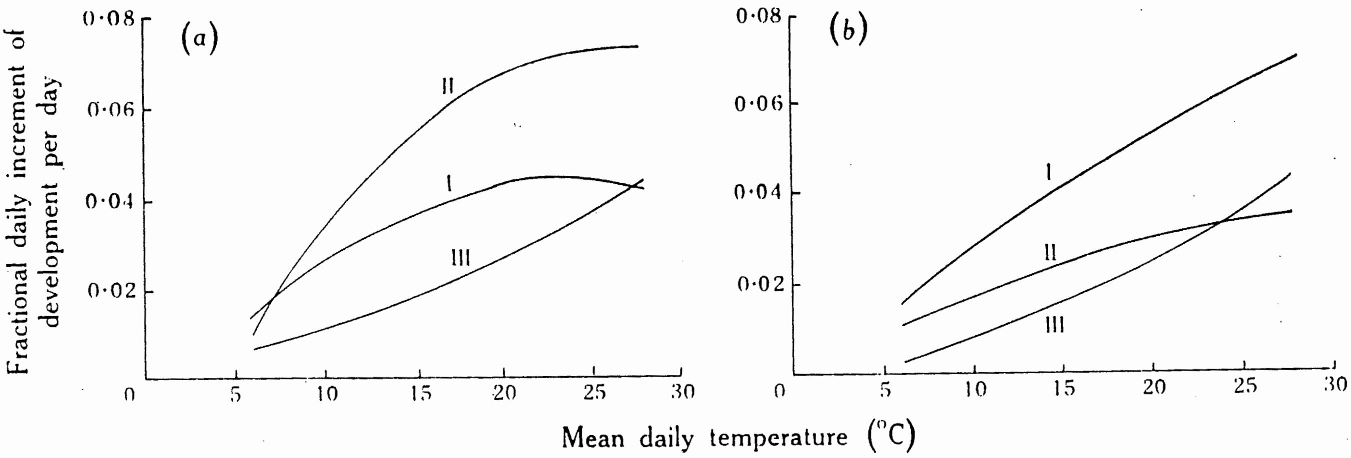


Fig. 6. Effect of daily temperature on fractional daily increments of development of medics to first lateral, first flower and first mature pod. (*a*) *M. scutellata.* (*b*) *M. truncatula.* I, Planting to first lateral; II, first lateral to first flower; III, first flower to first mature pod.

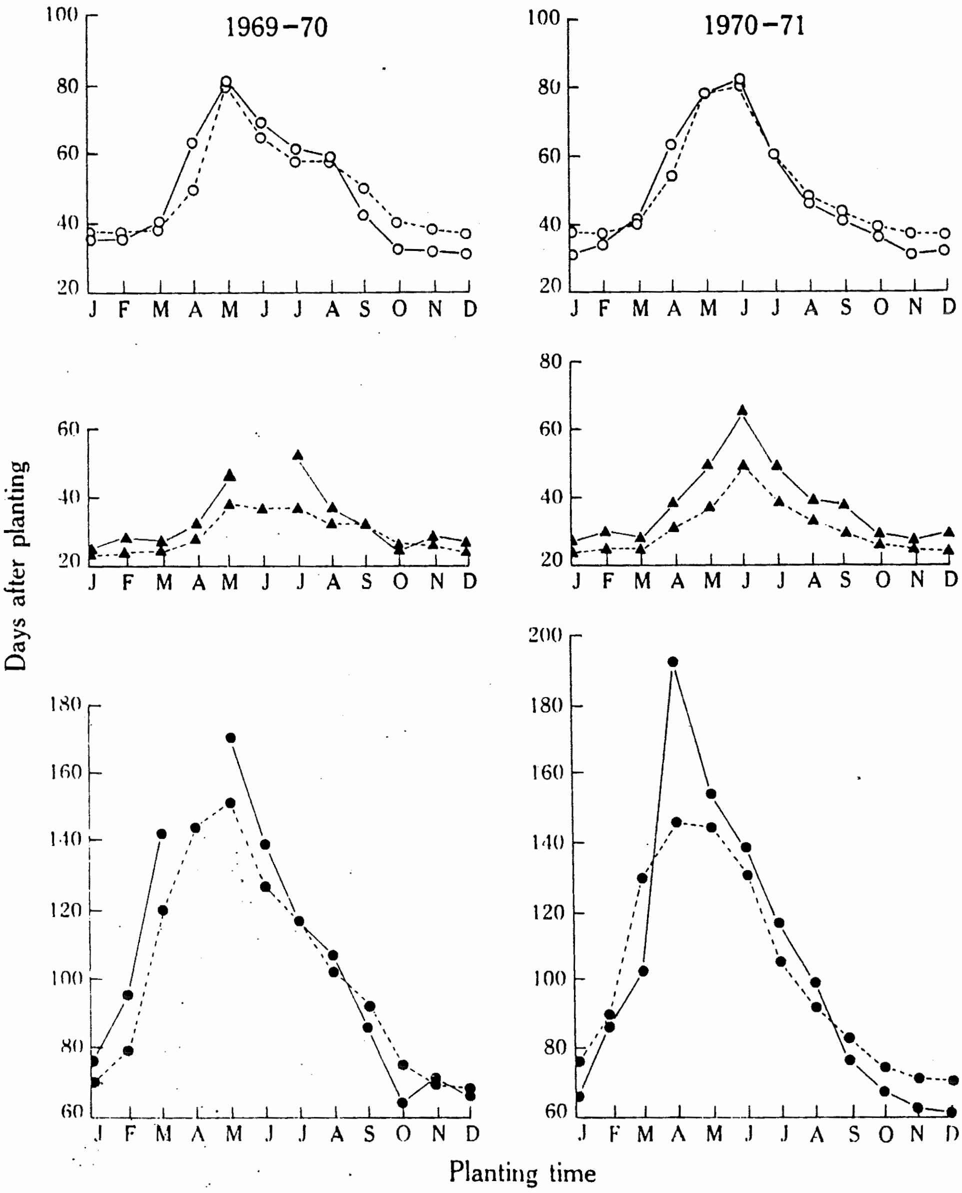


Fig. 7 Comparison between predicted and observed development of *M. scutellata* cv. Robinson at Warwick. Predictions use temperature equations derived from the controlled environment rooms and mean daily temperatures from the Warwick field site.

—— Observed.
– – – Predicted.
▲ First stem branching.
○ First flower.
● First mature pod.

C. ADAPTATION AND PASTURE PRODUCTIVITY 1977-83

Summary

A comparison was made between the winter annual legumes *Medicago scutellata* cv. Robinson (snail medic) and *M. truncatula* cv. Jemalong (barrel medic) and nitrogen (N) fertilizer as a means of increasing dry matter yields and N content, and extending the growing season, of introduced winter-dormant tropical grass pastures in southern inland Queensland. Pastures were grown in cutting experiments under dryland conditions on high and low fertility soils at three sites (Warwick, Gayndah and Roma) with decreasing winter rainfall respectively, and under irrigation on the high fertility soils at Warwick and Gayndah.

Medics were adapted to all soils selected except the low fertility soil at Gayndah. Under irrigation or adequate rainfall, medic yields of 8000 to 10 000 kg/ha were measured at each site. Under dryland conditions yields varied with winter rainfall, reaching half of their apparent potential over four years at Warwick and one third of their potential at Gayndah and Roma (four years and six years respectively). The yield of grass in summer from irrigated pastures containing medics was more than double that from unfertilized grass and similar to that from grass fertilized with 100 kg N/ha/yr. Under dryland conditions medics increased associated grass yields by 25 to 100% at Warwick and Gayndah, equating to N fertilizer at 50 kg/ha/yr on grass alone, but had no effect at Roma because of low summer rainfall. Total yields of grass-medic pastures were up to five times greater than those of unfertilized grass. Medics increased the N concentration in summer grass growth and extended the growing season by producing high quality dry matter in winter and spring.

The results indicate there is considerable potential for expanding the use of annual medics in dryland pastures.

Introduction

In southern inland Queensland (lat. 24° to 29°S, mean annual rainfall 500 to 800 mm), native pastures are the major source of feed for sheep and beef cattle (Weston *et al* 1975; Keating 1967). Although these pastures are of adequate quality from late spring to early autumn, animal production in the cooler months is poor and stock frequently lose weight (Lee and Rothwell 1966; Alexander and Beatie 1968; Russell 1985). This is due to protein shortages in the feed (Milford 1964; Addison *et al* 1984a) which may also impair reproductive efficiency. Nitrogen deficiency also limits pasture growth (Henzell 1963).

As hand feeding of protein-rich supplements is expensive and not readily accepted by graziers, other approaches are to 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 in the region, the most adapted species being the annual medics (*Medicago* spp.) (Russell 1969; Clarkson 1970; Jones and Rees 1972).

Although the contribution of medics in mixed farming areas of temperate Australia is well known (Amor 1965), there is a need to study medics in more detail in this sub-tropical environment (Weston et al 1975). Out of 5.8 m ha where medics are adapted in Queensland (Weston et al 1981), only 1.5 m ha contain naturalized medics (Weston, unpublished data). This indicates considerable potential for expanding the use of annual medics in dryland pastures.

In our study, medics were sown alone and with an introduced tropical grass on two contrasting soils at three sites spanning the climatic range of medic adaptation in Queensland (Clarkson 1977). The aim was to measure: a. dry matter production of annual medics, b. the effect of medics on grass production in summer compared with the use of N fertilizer, and c. the effect of medics on the seasonal growth pattern of grass/medic pastures.

Methods

Sites

The experimental sites were located at Warwick, Gayndah and Roma (Table 3). At each site dryland experiments were conducted on a high fertility uniform clay and a duplex soil of lower fertility (Table 4). The experiments at Warwick were located on Hermitage Research Station (high fertility) and "Baramulla", 30 km south-east of Warwick (low fertility). At Gayndah both sites were situated on Brian Pastures Research Station, and the Roma sites were both located on "Sans Pariel", 40 km east of Roma. An irrigated experiment was also included on the high fertility soils at Warwick and Gayndah to compare pasture growth with and without water stress.

Treatments

The seven treatments sown in four randomized blocks in each dryland experiment were:

1. Grass alone
2. Grass + N at 50 kg/ha/yr as urea
3. Grass + N at 100 kg/ha/yr as urea
4. Grass + *M. scutella* (snail medic) cv. Robinson
5. Grass + *M. truncatula* (barrel medic) cv. Jemalong
6. Robinson alone
7. Jemalong alone

The irrigated experiments were watered throughout the year to prevent water stress. Rates of N were doubled but otherwise treatments were identical to those above.

The grass was a forage sorghum hybrid (*Sorghum* spp.) cv. Silk at Warwick and Gayndah, while at Roma buffel grass (*Cenchrus ciliaris*) cv. Gayndah was sown on the more fertile soil and green panic (*Panicum maximum* var. trichoglume) cv. Petrie was used on the less fertile soil.

TABLE 3 Location and climatic data for the experimental sites.

	WARWICK	GAYNDAH	ROMA
Latitude	28° 10'S	25° 38'S	26° 36'S
Longitude	152° 4'E	151° 37'E	148° 42'E
Annual rainfall (mm)	702	786	595
Summer Rainfall (Oct-Mar)	459	559	397
Winter rainfall (Apr-Sept)	243	227	198
Annual evaporation (mm)	1464	1677	1737
Mean temp (°C)- January	23.4	26.0	27.3
Mean temp(°C)- July	10.2	13.8	11.8
Altitude (m)	455	104	300

TABLE 4 Analytical data for the surface layer (0-10cm) of soils in the experiments.

Site	Common Name	Classification[A]	pH	Exc. Ca (me/100g)	Avail P(ppm) Acid	Avail P(ppm) Bicarb	Total N%	Bulk Density	% Clay	Grav. Moisture% F.C.	Grav. Moisture% W.P.
WARWICK	Black earth	Ug 5	8.4	30	31	15	.14	0.91	61	48	26
	Sandstone	Dy 2	6.8	7	11	12	.08	1.32	23	23	7
GAYNDAH	Basalt	Ug 5	6.6	30	73	63	.07	1.14	67	39	18
	Box	Dy 2	6.1	2	5	8	.07	1.61	17	10	6
ROMA	Brigalow	Ug 5	8.2	17	20	14	.07	1.39	41	25	10
	Box	Dr 2	6.3	4	22	15	.05	1.55	7	12	6

[A] Northcote (1965).

The medics were established at Warwick and Gayndah in May 1977 and at Roma in May 1978 in plots 4.5 m x 4.5 m. The experiments continued until March 1981 at Warwick and Gayndah and until November 1983 at Roma. Lime-pelleted inoculated seed was broadcast at 50 kg/ha and harrowed into a clean fallowed seedbed treated with trifluralin for pre-emergent weed control. In the following summer, the soils were disc harrowed once and seed in grass treatments was broadcast at 20 kg/ha and harrowed. All the sites received Mo-400 superphosphate at 500 kg/ha in the first autumn and superphosphate at 250 kg/ha in each subsequent autumn. Fertilizer treatments received N in three equal 6-weekly applications between September and January each year.

Management

The experiments were ungrazed. In summer the grass growth above c. 5 cm was mown with an autoscythe and removed every six weeks from September to March at Warwick, and from September to April at Gayndah and Roma where plots were sometimes not mown if growth was very poor. The last mowing in each autumn was at a height of c. 15 cm. In winter when the grass was dormant the plots were not mown and the medics were sprayed with dimethoate every six weeks to prevent damage from lucerne aphids.

Measurements of pasture yield and quality

Dry matter yields of grasses, and annual medics when present, were measured every six weeks. In summer the yield of mown grass was first estimated by cutting an area of 1.84 m^2 from each grass plot with the mower. The remainder was then mown and raked. The yield of stubble remaining was then estimated with samples of 0.2 m^2 hand-cut at ground level. This enabled determination of the total above-ground yield at that time and the starting yield for the next regrowth period. In winter the cumulative yield of annual medic and dormant grass components was sampled at ground level, using a different position on each occasion, as for the grass stubble. Litter from each component was included in the sample. All samples were analysed for N concentration. Measurement of medic yields commenced two weeks after germinating rains fell in autumn, when seedling densities were also measured using nine 0.2 m^2 quadrats per plot.

Results

Rainfall

Winter rainfall during the experiments varied widely about the mean, ranging from 126 to 351 mm at Warwick (coefficient of variation 43%), from 117 to 363 mm at Gayndah (c.v. 63%), and from 68 to 565 mm at Roma (c.v. 83%). Summer rainfall was nearly all below average, ranging from 270 to 477 mm at Warwick, from 347 to 596 mm at Gayndah, and from 187 to 379 mm at Roma.

Medic populations

Medic seedling densities ranged from a mean annual value of 280 plants/m^2 on the Gayndah box site to 660 plants/m^2, on the Warwick sandstone. Densities rarely fell below 100 plants/m^2, the exceptions being Robinson on the Gayndah box soil in 1977 (60 plants/m^2) and 1980 (10 plants/m^2), and Robinson and Jemalong on the Roma box soil in 1983 (40 and 80 plants/m^2) respectively).

Apparent yield potential of medics

Annual medics produced 8000 to 10 000 kg/ha of dry matter on most sites when moisture was not limiting (Table 5). Growth under irrigation at Warwick in 1978 and 1980 was attenuated by severe frosts in August but these had less effect on the adjacent dryland experiment. At Gayndah in 1980, medic yields under irrigation were low because of shading by unseasonal growth of Silk sorghum in a mild winter. Growth of Robinson medic was also reduced by a black stem fungus.

TABLE 5 Highest cumulative yield of medics (kg/ha, mean of Robinson and Jemalong) in the presence of grass.

YEAR	WARWICK			GAYNDAH			ROMA	
	Irrigated Black earth	Dryland Black earth	Dryland Sandstone	Irrigated Basalt	Dryland Basalt	Dryland Box	Dryland Brigalow	Dryland Box
1977	8188	5433	3990	8252	2089	639		
1978	4128	7942	8670	8920	5848	2015	9203	9510
1979	7703	2387	1807	8443	2899	568	55	298
1980	5790	3278	1880	4665	433	68	1303	1238
1981							3313	3295
1982							218	450
1983							8628	4957
MEAN	6452	4760	4087	7570	2817	823	3786	3291
C.V.%[A]	29	52	79	26	80	101	109	108

[A] Coefficient of variation

Effect of rainfall on medic yields

Medics grown under dryland conditions at Warwick yielded on average 50% of the apparent potential under irrigation (taken to be 10 000 kg/ha) while at Gayndah and Roma only 30% of this potential was achieved. Not surprisingly, yields under irrigation were much less variable (c.v. 27%)

than those achieved under dryland conditions at Warwick (c.v. 66%), Gayndah (c.v. 91%) and Roma (c.v. 109%). On any one soil type this variation was closely associated with winter rainfall. e.g. on the brigalow soil at Roma, the lowest yield of 55 kg/ha in 1979 was obtained from 68 mm of rain, an intermediate yield of 3313 kg/ha in 1981 was from 190 mm, while the highest yield of 9203 kg/ha in 1978 was from 360 mm.

Effect of soil type on medic yields

At Warwick, dryland medics on the black earth and sandstone soils yielded similarly in the wet 1978 winter. Frost injury hindered growth on the black earth which was a colder site. In drier years yields were higher on the black earth, partly because of slightly higher winter rainfall. However in 1980 when winter rainfall was similar, medics produced 3278 kg/ha on the black earth but only 1880 kg/ha on the sandstone. Yields on the sandstone were more variable than on the black earth (c.v. 79% vs. 52%) even though the sites had similar variation in winter rainfall.

At Gayndah, medic yields were much higher on the basalt (average 2800 kg/ha) than on the box soil (average 800 kg/ha) where medics grew poorly even in the wet 1978 winter. Yields on the box soil were also more variable than on the basalt (c.v. 101% vs. 80%) which received the same winter rainfall.

At Roma, medic growth was very similar on the brigalow and box soils except in 1983. In that year yields were lower on the box soil because of low medic populations. In the very dry 1979 and 1982 winters, medics were more productive on the box soil, probably because of better availability of soil water (Table 4). Variation in yields was similar on the two soils (c.v. 109%).

Effect of medics on yields of summer grass

Under irrigation, medics doubled the yields of grass at Warwick and Gayndah ($P < 0.01$) (Table 6a). The effect of medics was equivalent to application of fertilizer at 100 kg N/ha/yr. Yields at Gayndah were much higher than at Warwick with an average across all treatments of 8700 kg/ha compared with 5600 kg/ha.

The most responsive dryland site was the Warwick sandstone where grass yields were doubled from 1300 to 2500 kg/ha by the inclusion of medics. Yields were equivalent to those obtained with N applied between 50 and 100 kg/ha/yr. On the high fertility soils at Warwick and Gayndah, yields were increased by 25%, equivalent to application of less than 50 kg N/ha/yr. Yields on these soils were similar, with site means of 3700 kg/ha. No responses to medics were obtained on the Gayndah box soil where medics were not adapted. The grass however responded to N fertilizer, and yields were similar to those obtained on the Warwick sandstone soil. At Roma yields of grass were very low, averaging only 550 kg/ha because of low summer rainfall. There were no significant treatment effects.

Under irrigation, medics at Warwick increased total pasture yields five- fold to almost 12 000 kg/ha, while application of 200 kg N/ha/yr increased yields to only 10 000 kg/ha (Table 6b). At Gayndah the

Increases in grass yields from associated medics at Warwick were much smaller than the average increases from 2900 kg/ha without medics to 5500 kg/ha with medics reported by Lloyd and Hilder (1985), despite similar medic yields. This is probably because our pastures received on average about half the summer rainfall of theirs (390 mm vs. 730 mm), and frequently experienced water stress. Thus we conclude that moisture, rather than N released from medics, limited the grass response during dry periods. The responses to N fertilizer at Warwick and Gayndah were approximately linear as typically reported (eg. Henzell 1963). However yield increases per kg of applied N were also lower than those reported by Lloyd and Hilder (1985) because of lower summer rainfall and perhaps greater cutting frequency (6-weekly vs. 2-monthly).

The lack of response to medics and N fertilizer at Roma was attributed to the very low summer rainfall (average 297 mm over five seasons). The grass pastures at Roma, even after successful emergence of seedlings, remained shallow-rooted and vulnerable to severe water stress. Plant mortalities were high and the pastures were frequently invaded by weeds.

The improved supply of N to the grass at the more favoured sites, either from medics or N fertilizer, failed to produce any significant improvement in winter growth. This highlights the limitations to grass growth caused by low winter temperatures (Ivory and Whiteman 1978) and the importance of a winter-growing legume in providing high quality dry matter and protein for grazing animals. Winter legumes also enhance the utilization of poor quality standover grass which is the main source of forage in winter. The contribution of medics, with N content ranging from 3.7% in seedlings to 2% at peak yield is thus of major importance to pasture growth and quality in winter and spring, thereby enhancing animal production (Howard 1961, Coaldrake et al. 1969, Russell 1985).

Our results have implications for grazing enterprises in the region where the safe stocking rate is frequently determined by shortages of forage in winter. In higher rainfall areas, higher year-round stocking rates are likely where medics are well established in grass pastures.

The year-to-year variability in the growth of medics is buffered to some extent by their ability to supply accumulated N to grass in years of little or no medic growth. In marginal environments, high variability in medic production is likely to prevent higher stocking rates. In this area, the role of medics will be mainly as a protein supplement in wet winters when they may also enhance the utilization of poor standover grass.

D. EFFECT ON MEDICS ON CROPS. (I) RAW DATA

Summary

Ley pastures were examined as a means of improving soil fertility and crop yields of winter cereals in southern inland Queensland. The pastures based on introduced tropical grasses and winter-growing annual medics (*Medicago* spp.) were grown in cutting trials on two soils of contrasting fertility at three climatic sites (Warwick, Gayndah and Roma) with decreasing winter rainfall. Similar irrigated pastures were grown on the fertile soils at Warwick and Gayndah.

After four years of pasture the sites were cropped with wheat for three years to determine the effect of changes in soil fertility on the yields and protein content of grain. Yields were compared with continuous wheat grown with three rates of nitrogen fertilizer. Crops following irrigated pastures were also irrigated.

Ley pastures generally increased grain yields and protein content of subsequent crops. Under irrigation the beneficial effects of pure grass and pure medic pastures were additive, with average yields after grass/medic mixtures at Warwick being increased by 1400 kg/ha or 58%. An equivalent yield in the continuous crop required almost 200 kg/ha of fertilizer nitrogen. Part of the benefit of ley pastures at this site derived from a reduced burden of root lesion nematodes (*Pratylenchus thornei*). At Gayndah the grass/medic ley increased yields by 40%, equivalent to a continuous crop receiving nearly 100 kg/ha of fertilizer nitrogen.

Under some dryland conditions grain yields were enhanced by grass leys, with small additional benefits from annual medics at some sites. At Warwick the yield increases of 1000 kg/ha on the more fertile soil and 800 kg/ha on the less fertile soil were above those obtained from continuous crops receiving 100 kg/ha of fertilizer nitrogen. Ley pastures at Gayndah did not improve crop yields but medic pastures improved the protein content of grain in the first crop. At Roma the only crop grown showed marked responses in growth up to anthesis but subsequent water stress negated this benefit. However the protein content of grain was higher after grass/medic leys than after grass alone.

The best indicators of improved soil fertility appeared to be nitrogen uptake of crops and leaf area index at anthesis. Treatment differences in these attributes were sometimes not expressed in grain yields because of water stress, particularly near anthesis.

Introduction

Continued intensive cropping of arable soils causes a gradual decline in soil fertility. This decline must eventually be halted or reversed to maintain crop yields. This has been demonstrated in southern Australia for a long time, and more recently in Queensland. Some light textured soils in southern Queensland suffer rapid loss of chemical and physical fertility after only a few years of cropping.

One strategy to maintain soil fertility is to use legume-based ley pastures in rotations with crops. While this practice is not common in

TABLE 8 Site characteristics and rainfall for soils in the experiments

(a) Site characteristics

Site	Acronym	Northcote Classification	Surface pH	Surface % clay	Rooting depth (cm)	Available water (mm)	Average rainfall (mm, May-Oct)
WARWICK	Black earth	Ug 5	8.4	61	90	214	267
(Lat. 28°12'S, Long. 152°4'E)	Sandstone	Dy 2	6.8	23	90	141	267
GAYNDAH	Basalt	Ug 5	6.6	67	60	114	254
(Lat. 25°38'S, Long. 151°37'E)	Box	Dy 2	6.1	17	60	70	254
ROMA	Brigalow	Ug 5	8.2	41	90	150	214
(Lat. 26°36'S), Long. 148°42'E)	Box	Dr 2	6.3	7	90	109	214

(b) Rainfall and crop parameters

Site		Year	Planting Date	Anthesis Date	Avail water at planting(mm)	Rain + irrigation in growing season*	Total avail. water
WARWICK	Irrigated	1981	30/6	12/10	197	320	517
		1982	29/7	1/11	205	267	472
		1983	26/7	24/10	206	285	491
		1984	10/7	10/10	203	187	390
	Black earth	1981	30/6	12/10	188	133	321
		1982	29/7	2/11	158	204	362
		1983	26/7	25/10	195	285	480
		1984	10/7	10/10	192	187	379
	Sandstone	1981	9/6	1/10	66	80	146
		1982	21/7	25/10	83	151	234
		1983	7/6	21/9	119	192	311
GAYNDAH	Irrigated	1981	18/6	14/9	96	359	455
		1982	19/7	27/9	98	247	345
		1983	18/5	15/8	102	360	462
	Basalt	1981	18/6	14/9	96	73	169
		1982	19/7	27/9	103	34	137
		1983	18/5	15/8	103	186	289
	Box	1981	18/6	15/9	65	73	138
ROMA	Brigalow	1984	4/7	2/10	103	259	362
	Box	1984	4/7	1/10	54	259	313

* Planting to 10 days after anthesis.

Table 8(b) outlines the times of planting and anthesis for each crop together with available water. The total available water for irrigated crops was generally above 400 mm but under dryland conditions fell as low as 137 mm. Under dryland conditions soil water holding capacity as well as rainfall greatly affected the available water supply. The black earth at Warwick had superior water storage capacity.

Grain yields

Grain yields for the main treatment groups are shown in Figure 14. As the yields following unfertilized and fertilized grass were not significantly different, only the former are presented. Treatments 5(a) and (b) and treatments 6(a) and (b) were regarded as duplicate sets and were not statistically different unless stated. Results will be considered under (a) responses to N fertilizer in continuous crop,(b) responses to medics in rotational treatments and (c) comparison between continuous and rotational treatments.

(a) Warwick black earth (irrigated)

The continuous crop showed large yield increases with N fertilizer but only in 1981 did N200 significantly out-yield N100. In the rotational crops the medic alone did not significantly increase yields above those of the grass alone, but the grass/medic mixture gave significant increases in all years except 1983 when yields in all treatments were low. The rotational crops outyielded the unfertilized continuous crop, with the grass/medic treatment being equal to N200 in all years except 1981 when the adjusted yield was equivalent to N100. The 1983 crop was found to be heavily infested with root lesion nematode (Pratylenchus thornei) which together with waterlogging in the young crop, caused low yields.

(b) Gayndah basalt (irrigated)

The continuous crop showed large yield increases with N fertilizer. The highest yield was from N100, while N200 produced significantly lower yields than N100 in 1981 and 1982. In the rotational treatments the medic alone significantly outyielded grass alone in 1982. The grass/medic mixture gave the highest yields, reaching significance over grass alone in 1981 and 1982. In those years rotational crops following medics outyielded unfertilized continuous crops and were equivalent to N100. In 1981 wheat after Robinson medic alone outyielded wheat after Jemalong.

(c) Warwick black earth

In the continuous crop N100 increased grain yields significantly in 1981 and 1983. Continuous wheat yielded poorly in 1983 following early waterlogging and infestation with nematodes.

The rotational crops showed no benefits of medic treatments over grass alone. In 1981 the yields of rotational treatments were reduced by inferior seedbed preparation. However in the years 1982 to 1984 all rotational crops significantly outyielded continuous crops receiving N100.

was equivalent to N0 while treatments containing medics fell between N0 and N50.

Table 9 compares the average grain yields and % N of unfertilized continuous crop and other treatments. Under irrigation the beneficial effects of grass and medic pastures on subsequent grain yields were additive, with yields after grass/medic improved by 1400 kg/ha or 58% at Warwick. An equivalent yield in the continuous crop required almost 200 kg/ha of fertilizer N.

TABLE 9 Comparison between unfertilized continuous crop and other treatments in average grain yield and % N in grain.

(a) Grain yield (kg/ha)

	WARWICK			GAYNDAH		ROMA	
	Irrigated	Black earth	Sandstone	Irrigated	Basalt	Brigalow	Box
Treatment \ Years	4	3**	3	3	3	1	1
1 Continuous crop + N0*	2346	2265	2404	2215	1362	2046	1392
2 " " + N1*	+914	+226	+630	+1873	+528	-200	+807
3 " " + N2*	+1557	+449	+776	+1170	+529	-308	+624
4 Grass alone	+684	+1129	+645	+180	+340	-24	+560
5 Medic alone	+833	+1065	+858	+563	+321	-65	+648
6 Grass + medic	+1418	+1050	+864	+876	+294	-17	+796

** Excluding 1981 when poor seedbed retarded rotational treatments
* N rates 0, 100, 200 kg/ha irrigated and 0, 50, 100 dryland

(b) % N in grain

Treatment	WARWICK			GAYNDAH		ROMA	
	Irrigated	Black earth	Sandstone	Irrigated	Basalt	Brigalow	Box
1 Continuous crop + N0	1.95	2.37	2.56	1.94	2.23	3.06	1.92
2 " " + N1	+.15	+.22	+.03	+.30	+.33	-.01	+.55
3 " " + N2	+.46	+.27	+.22	+.70	+.52	-.02	+.83
4 Grass alone	-.09	-.25	-.09	-.04	.00	-.61	-.06
5 Medic alone	+.09	+.26	+.08	+.05	-.02	-.09	+.22
6 Grass + medic	+.13	+.24	+.04	+.12	+.05	-.12	+.18

At Gayndah a yield increase of 40% in continuous crop, comparable to the grass/medic treatment, would require less than 100 kg/ha of fertilizer N. Under dryland conditions average grain yields were enhanced by grass leys, with small additional benefits from medics at some sites. At the Warwick sites the yield increases of 1000 kg/ha on the black earth and 800 kg/ha on the sandstone were both above those obtained with N fertilizer at 100 kg/ha. At the Roma box site the trend was similar.

The % N in grain was increased by N fertilizer at all sites except the Roma brigalow where the supply of soil mineral N was high. The increases were greater under dryland than under irrigated conditions, eg. Warwick black earth where N100 produced +.27% vs. +.15%. This was probably because water stress restricted grain yield responses under dryland conditions. Following grass pastures, the % N was slightly lower at most sites and substantially lower on the Roma brigalow site. However pastures based on medics or grass/medic caused moderate increases at most sites.

Analysis of grain yield

The data in Table 10 indicate how the higher grain yields recorded were achieved at Warwick under irrigation. Similar details are available for all other centres. These data indicate the stage in the plant's growth when nitrogen supply became important. In the following comparisons, summarising results at all centres, responses to N fertilizer were in relation to unfertilized continuous crop, while responses to grass/medic or medic alone were by comparison with grass alone. Only responses significant at the $P<0.05$ level are reported.

(a) Warwick black earth (irrigated)

The number of tillers (reflecting early crop growth and development) was almost unaffected by treatments, but grass/medic increased tiller numbers in 1981. The number of heads (reflecting the degree of tiller development) was increased by N fertilizer in 1981 and 1982, and by grass/medic in 1981. Only in 1981 did N fertilizer increase the percentage of tillers producing a head.

The number of spikelets per head (reflecting growing conditions at the time of head initiation) was increased by N fertilizer in 1981 and 1983, and by grass/medic in 1981. The grains per head (reflecting growing conditions at anthesis and shortly after) proved sensitive to N-supply, being increased by both N fertilizer and medics on all occasions when grain yield was increased. The result of these two factors was for grains per spikelet to also be increased by N fertilizer and medics in 1982.

No effects of treatments on 1000-grain weights (reflecting growing conditions during grain filling) occurred. Harvest index based on maturity could not be statistically analysed, however analysis based on yield of top growth at maturity showed increases in 1982 in N fertilized and grass/medic treatments.

TABLE 10. Growth analysis of grain yields. (G = grass, N = nitrogen fertilizer, M1 = Robinson medic, M2 = Jemalong medic, CW = continuous wheat)

LSD (1) For comparing all treatments. (2) For comparing means of (4-5) and (6+7) with other treatments.

(a) Warwick black earth (irrigated)

Treatment	Tillers/ m^2	Heads/ m^2	% Tillers in head	Spikelets/ head	Grains/ head	Grains/ spikelet	1000-grain wt (g)	Harvest Index	
								Maturity	Anthesis
1981									
1 G+N0	202	149	74	7.3	14.3	2.0	37.4	0.49	1.09
2 G+N100	435	241	55	9.7	16.4	1.7	36.4	0.46	0.38
3 G+N200	560	316	56	10.9	18.6	1.7	37.6	0.46	0.43
4 G+M1	660	339	51	10.5	20.2	1.9	38.8	0.52	0.53
5 G+M2	643	298	46	10.2	15.8	1.5	38.1	0.45	0.74
6 M1	686	386	56	12.2	24.6	2.0	37.3	0.45	0.84
7 M2	717	415	58	10.8	16.2	1.5	34.1	0.34	0.73
8 CW+N0	809	453	56	12.1	17.3	1.5	32.8	0.35	0.50
9 CW+N100	694	614	88	14.8	20.3	1.4	34.3	0.38	0.77
10 CW+N200	744	621	83	14.9	24.7	1.7	34.3	0.42	0.91
LSD (5%)	(1) (2) 239/200	134/113	36/30	2.1/1.8	4.6/5.1	N.S.	2.4/2.2	Not available	N.S.
1982									
1 G+N0	630	558	89	13.4	18.7	1.4	38.1	0.41	0.46
2 G+N100	731	497	68	13.4	18.7	1.4	38.3	0.42	0.43
3 G+N200	842	580	69	13.8	22.3	1.6	36.9	0.44	0.42
4 G+M1	617	579	94	14.5	24.3	1.7	36.3	0.47	0.73
5 G+M2	721	615	85	13.9	22.4	1.6	37.5	0.43	0.54
6 M1	695	640	92	13.2	22.6	1.7	34.7	0.42	0.51
7 M2	734	612	83	14.4	21.3	1.5	36.4	0.42	0.52
8 CW+N0	556	444	81	12.8	17.8	1.4	34.7	0.40	0.50
9 CW+N100	694	582	84	13.9	21.3	1.5	34.3	0.44	0.53
10 CW+N200	602	565	94	14.4	25.9	1.8	32.8	0.45	0.69
LSD (5%)	147/128	117/99	23/19	N.S.	3.6/3.1	0.2/0.2	2.3/2.0		0.14/0.13
1983									
1 G+N0	547	403	74	11.7	21.1	1.8	29.2	Not measured	0.67
2 G+N100	566	326	58	12.7	24.8	2.0	26.2		0.52
3 G+N200	531	289	54	13.1	27.9	2.1	28.0		0.70
4 G+M1	615	441	72	13.1	20.6	1.6	29.8		0.66
5 G+M2	573	413	72	12.6	23.9	1.9	23.6		0.53
6 M1	638	314	49	11.3	18.7	1.7	25.0		0.46
7 M2	578	360	62	12.4	22.9	1.8	26.0		0.48
8 CW+N0	588	305	52	12.3	19.0	1.6	27.1		0.55
9 CW+N100	690	253	34	12.7	20.8	1.6	25.9		0.44
10 CW+N200	561	442	79	14.6	27.0	1.8	23.0		0.55
LSD (5%)	N.S.	N.S./ 117	N.S./26	1.6/1.4	4.9/4.4	0.3/0.3	N.S.		N.S.

and 1983. The only effect of medics was for Robinson alone to decrease area/weight at Warwick (irrigated) in 1981 and for all medic treatments on the Warwick black earth in 1981 to show strong reductions in area/weight. In both cases these reductions were associated with lower grain yields but the causes for these treatment effects are unknown.

In most years values were highest at six weeks and declined markedly by anthesis. However in 1981 values were low at six weeks and were higher at anthesis. The lowest values by far were recorded on the Warwick black earth in 1981 in treatments receiving a short fallow.

Overall these analyses identified N-uptake and LAI at anthesis as the most sensitive indicators of improved soil N supply and potential yield responses to treatments.

Conclusion

Ley pastures were able to significantly improve grain yields and protein content of subsequent wheat and barley crops. The biggest and most durable improvements occurred under irrigation. This was expected since the irrigated sites had the highest legume yields and the crops were able to fully express differences in soil N under adequate water supply. At Warwick the benefits extended at least to the fourth crop after pasture, even allowing for the adverse effects of nematodes on the continuous crop in the third year. Yield responses related quite well to changes in soil total N which occurred under pasture.

The best pasture overall was a grass-medic mixture, although some useful benefits accrued even from pure grass pastures. This seemed to be mainly because they did not suffer the decline in soil total N which occurred under continuous cropping.

The benefits in grain yield from dryland leys were sometimes restricted by water stress. However this was partly offset by increased protein content which in practical terms increased the quality and monetary value of the grain. The duration of benefits from these leys was more difficult to assess because of water stress, but responses were still evident in the fourth year on the Warwick black earth and in the third year on the sandstone soil. Responses at Gayndah were less likely because the shallow soil as well as climatic factors increased the likelihood of water stress. The % N in grain also indicated that responses beyond the first year were unlikely. At Roma the improvements in soil N after medics would probably benefit two or three crops if sufficient water were to be available. Thus the duration of the benefits from leys would depend not only on the amount of improvement in soil fertility under pasture but on the incidence of subsequent wet years.

The interactions between nitrogen and water supply were important in determining whether or not a yield response occurred. Under irrigation the N-effects were evident right through the crop, through increased tillering, production of heads, spikelets/head and grains/head. By contrast under dryland conditions the first responses often occurred at spikelet initiation. The main indicators of enhanced N supply were N-uptake and LAI at anthesis which were correlated with yield potential.

However the water supply at the time of anthesis and grain filling was critical to the realization of that potential. Evidence of this could be found firstly in the 1000-grain weights which were often lower in high-N treatments under dryland conditions, but rarely lower under irrigation. Secondly, the failure of the crop at the Roma box site to realize potential yield differences developing at anthesis could be attributed to the very dry finish to the season. Grain yields on the brigalow site at Roma were also less than half of the expected yield based on measurements up to anthesis when the water supply was adequate.

The next part of this report (Section E) will examine N-uptake, LAI and water stress in more detail using the published growth model of Woodruff and Tonks (1983). This approach aims to improve the understanding of how available soil N and water supply interact to influence grain yield. This is important in assessing the benefits to crops of using ley pastures to improve soil fertility.

E. EFFECT OF MEDICS ON CROPS. II. MODEL INTERPRETATION

Summary

The effect of ley pastures based on annual medics on subsequent wheat yields in southern Queensland was examined using the wheat growth model of Woodruff and Tonks (1983). The model provided a means of interpreting the interactive effects of N x water supply on grain yields by using measured total dry weight (TDW), leaf area index (LAI) and soil water status to predict transpiration at anthesis. This was integrated with the effects of growth duration, anthesis date, environment and N supply into a yield index.

Three types of plant response to improved N supply were identified. In the first, water supply was adequate and all differences in N uptake were fully expressed in grain yields. In the second case, increases in yield potential which developed before anthesis through the effects of increased N supply on TDW and LAI could not be sustained by the soil water supply and potential differences were not fully expressed. This often caused increases in protein content of the grain. In the third case a prolonged shortage of water limited the N uptake and growth of the crop regardless of N supply, so that potential differences in N uptake were not expressed in higher grain yields. The model was also used to estimate the loss of yield due to water stress at anthesis under various conditions of N and water supply. The pastures which improved the N supply the most contained an introduced tropical grass and annual medics.

The probabilities of rainfall and crop yields exceeding those in the experiments were also calculated. The results were very dependent on time of planting, with the yields occurring much more frequently from the optimum planting time than from the later times used in the experiments. The increased demand for N from planting at the optimum time also increased the likelihood of yields being limited by soil N. The results recorded were considered to be a conservative measure of the benefits from ley pastures on the soils examined, all of which except one were quite deficient in mineral N.

The duration of yield responses following ley pastures was estimated from N uptake in grain, grain yields and soil total N. At Warwick responses extended for at least four years under irrigation and on a black earth, and three years on a sandstone soil. At Gayndah responses were small by the third year but excessive rain in the third fallow distorted the results. Soil N data indicated that responses should occur beyond the third crop under irrigation. At Roma where only one crop was grown the brigalow soil was too fertile to show responses to medic pastures. However on the box soil substantial increases in yield potential following medics were obtained by anthesis but dry conditions thereafter prevented yield increases. Soil N data indicated a capacity to increase yields in approximately three crops provided soil water supply was not a major limitation.

Introduction

This is the second of two reports examining ley pastures based on annual medics as a means of improving soil fertility and wheat yields in southern Queensland. The first report (Section D) presented the responses in grain yield and % N which occurred in wheat following ley pastures in our experiments. It also suggested that interactions between nitrogen and water supply were important in determining whether or not a yield response to additional nitrogen occurred. The second report attempts to interpret the results further using the published growth model of Woodruff and Tonks (1983) as an aid to defining the conditions under which useful responses to medic pastures might occur.

Methods

Pasture leys using annual medics (Medicago spp.) with and without an introduced tropical grass were grown on a fertile uniform clay and a less fertile duplex soil for four years at Warwick and Gayndah, and 5.5 years at Roma. An irrigated experiment was also included on the fertile soils at Warwick and Gayndah. The pasture plots were then cropped with Cook wheat for three years at Warwick and Gayndah, and Grimmett barley for the fourth year at Warwick and one year at Roma. These crops were compared with continuous crops receiving rates of nitrogen fertilizer.

Measurements of soil and plant parameters were first used to validate the model of Woodruff and Tonks. Although it was derived from experiments examining the effects of time of planting, genotype and water supply on wheat, it appeared to be suitable for studying nitrogen supply as well. After minor tuning on our data, the model was used to interpret the grain yields obtained in our experiments. These results were then examined in the wider context of variations in soil fertility, climate and time of planting in the region. The experimental data were also used to estimate the duration of benefits from ley pastures.

The model of Woodruff and Tonks is a development of a general model of deWit and others who showed that dry matter (DM) was related to transpiration thus:

$$DM = m\ T/Eo$$

where T is transpiration (mm), Eo is average free water evaporation (mm/day) and m is a crop factor with similar dimensions to DM. Rasmussen and Hanks used this approach for the relative grain yield of wheat with a fixed potential transpiration function for each stage of development. Woodruff and Tonks introduced more flexibility by using the concept of water use or transpiration over the period around anthesis. This was predicted from measured total dry weight (TDW) and/or leaf area index (LAI) together with the soil water status around anthesis. This provided an integrated measure of prior environmental conditions. Their yield index constructed from plant and environmental variables was highly correlated with the growth potential which was highly buffered against sudden changes due to the control of transpiration by either soil water or leaf area, whichever was the most limiting at a given time.

The effects of growth duration, anthesis date and environment were integrated into a grain yield index (YI) of the form

$$YI = a + b(T/Eo) \times (1/Tm), \qquad (1)$$

where a and b are constants, T, Eo and Tm are transpiration (mm), pan evaporation (mm) and mean daily temperature (^{o}C) respectively, all estimated or measured within $\pm$ 10 days of anthesis. The LAI and soil water status measured at anthesis (A) were combined to provide an estimated transpiration (T) over the period A $\pm$ 10 days from whichever of the following equations gave the lower value:

$$T \text{ (mm)} = 16W^2 \text{ ,} \tag{2}$$
(with a minimum of 0.8 mm/day if available)

$$T = Eo\ (1-\exp\ (-0.5\ LAI)), \tag{3}$$
where W is fractional available water in the rooting zone and Eo is mean daily 'A' class pan evaporation.

Using multiple regression on a wide range of field experimental data, they derived a quadratic relationship between grain yield and yield index thus:

$$\text{Grain yield} = a + b(YI) + c\ (YI)^2, \tag{4}$$
where a , b and c are coefficients. For semi-dwarf wheats the values were a = 112, b = 3962 and c = 68432. To take account of low yield values, the a was later changed to equal 0.2 (TDW), the value used initially to evaluate our data.

In our experiments we measured Eo, Tm, LAI, W and grain yield. T was calculated from equations (2) and (3). YI calculated from equation (2) was denoted YI (H_2O) and YI from equation (3) as YI (LAI). The minimum of these two values was YI (minimum).

Results

Dates of planting and anthesis, with measurements of mean daily class 'A' pan evaporation and mean daily temperature for the sites and years of the experiments are shown in Table 13. Earlier plantings experienced lower evaporation and lower temperatures around anthesis than later plantings. Cook wheat was earlier maturing at Gayndah than at Warwick. No data are presented for the less fertile soil at Gayndah where growth was very poor and the crops were destroyed by native birds and mammals.

Relationships between environment, plant growth and grain yields

The correlation coefficients between plant and environmental factors are presented for Cook wheat in Table 14 and include variation due to site, year, irrigation and nitrogen supply. Variation in grain yield was mainly associated with variation in grain number which was positively correlated with total dry weight, LAI, yield index and N uptake of tops (closely related to N supply in the soil).

Multiple linear regression analysis by progressive deletion of best predictors (Table 15) was used to examine variables associated with LAI and TDW. LAI was most strongly dependent on TDW under dryland conditions but on N uptake under irrigation. TDW was strongly dependent on N uptake regardless of irrigation. These relationships provide a link between the soil N supply and grain yield. The link between N supply and LAI affects transpiration through equation (3), yield index in equation (1), and thence to grain yield in equation (4). If water becomes limiting because improved N supply increases the transpiration demand, this is catered for automatically by equation (2). The influence of N supply on TDW directly affects yield through the intercept in equation (4) and is particularly important when TDW is low.

TABLE 13 Planting dates and anthesis dates, with pan evaporation and mean daily temperature estimated over the period anthesis ± 10 days.

Site		Year	Planting date	Anthesis date	Anthesis day no.	Pan evaporation (mm/day)	Mean daily temperature (°C)
WARWICK	Black earth	1981	30/6	12/10	285	5.6	15.7
	(irrigated and	1982	29/7	1/11	305	6.5	19.9
	dryland)	1983	26/7	24/10	297	4.5	19.0
		1984	10/7	10/10	283	-	-
	Sandstone	1981	9/6	1/10	274	5.7	16.3
		1982	21/7	25/10	298	6.4	17.9
		1983	7/6	21/9	265	3.8	16.9
GAYNDAH	Basalt (irrigated	1981	18/6	14/9	257	5.1	19.7
	and dryland)	1982	19/7	27/9	270	6.2	19.2
		1983	18/5	15/8	227	3.5	16.6
ROMA	Brigalow and box	1984	4/7	2/10	274	5.3	16.9

The updated model of Woodruff and Tonks explained a high proportion ($r2 = 0.78$) of the variation in grain yield, but tended to over-estimate the low yields. To test the assumptions of the model, regression analysis was carried out on our data to select the best predictors with no presumed model. The result was:

$$\text{Grain yield} = -301.6 + 0.316\ (\text{TDW}) + 53092\ (\text{YI}\ (\text{min})), \text{ with } r^2 = 0.82.$$

However by taking the published yield index to be accurate, the residuals after allowing for the yield index terms in equation (4) were correlated only with TDW. The best value for a was found by regression to be

$$a = -146 + 0.237\ (\text{TDW}).$$

The final model was then:

TABLE 14 Correlation matrix for selected plant and environmental variables at anthesis in the semi-dwarf wheat variety Cook (n = 150).

	Grain yield (kg/ha)	Total dry wt (kg/ha)	Yield index (minimum)	N uptake of tops (kg/ha)	LAI	Yield index (LAI)	Yield index (H_2O)
Total dry wt (kg/ha)	0.783	-					
Yield index (minimum)	0.807	0.547	-				
N uptake of tops (kg/ha)	0.631	0.840	0.393	-			
LAI	0.837	0.703	0.894	0.639			
Yield index (LAI)	0.836	0.673	0.941	0.566	0.949	-	
Yield index (H_2O)	0.311	0.005	0.641	-0.219	0.362	0.440	-
No. of grains (/ha)	0.950	0.801	0.748	0.679	0.809	0.795	0.253

TABLE 15 Regression analyses showing variables associated with leaf area index and total dry weight at anthesis.

Dependent variable	No. of cases	Data sets	Variables entered	Progressive r^2
LAI	150	All data	1 Total dry wt	0.49
			2 Yield index (H_2O)	0.62
			3 N uptake	0.69
	67	Dryland	1 Total dry wt	0.74
			2 Yield index (H_2O)	0.76
			3 N uptake	0.78
	83	Irrigated	1 N uptake	0.66
			2 Temperature	0.74
			3 Yield index (H_2O)	0.82
			4 Total dry wt	0.83
Total dry wt	67	Dryland	1 N uptake	0.81
			2 LAI	0.86
			3 Temperature	0.87
	83	Irrigated	1 N uptake	0.69

Grain yield = -146 + 0.237 (TDW) + 3962 (YI) + 68432 $(YI)^2$, with $r^2 = 0.80$.

Interpretation of yield data using the model

Yield predictions for the major treatments at the Warwick irrigated site are shown in Table 16, together with various plant and environmental parameters. Similar calculations have been prepared for all other sites. Variations in soil nitrogen supply were evident from soil nitrate analyses at planting time and the N uptake in tops at anthesis. These effects were expressed in LAI, T/Eo and TDW. 1000-grain weights gave an indication of the degree of water stress during grain filling. Where grain yields were limited by soil water supply around anthesis, a "potential" yield was also calculated using YI (LAI) to show the size of this limitation.

At Warwick the irrigated site (Table 16) was free of water stress and the grain yield potential indicated by LAI and TDW values was expressed. However in 1983 early growth was reduced by waterlogging and later growth was affected by root lesion nematodes (*Pratylenchus thornei*). This explains the very low 1000-grain weights in that year.

On the Warwick black earth (data not presented) in 1981 the yield of continuous wheat was reduced by up to 1.3 t/ha by water stress at anthesis. The rotational treatments produced low yields due to a combination of rough seedbed tilth at planting and a shorter fallow which increased the N deficiency. In 1982 the rotational treatments, having the highest LAI, experienced water stress sufficient to restrict grain yields by 0.8 t/ha. In 1983 waterlogging and nematodes influenced the results as for the irrigated site.

On the Warwick sandstone site the growth of wheat in 1981 was generally restricted by water stress which was severe in most treatments by anthesis, reducing yields by 0.8 to 1.2 t/ha. However treatments 4 and 6 were so N-deficient because of a short fallow that even the limited water available was reasonably adequate for this N supply. 1982 was characterised by a general early water limitation on LAI and TDW, affecting treatments almost equally. When water stress was removed around anthesis, treatments were unable to express their potential differences beyond 0.8 t/ha. 1983 was almost an ideal wet year with very high LAI and TDW in relation to the modest N supply, and very high grain yields. No stress was detected but the yields of continuous wheat + N100 and grass + medic were 0.6 to 0.7 t/ha below the values predicted by the model. This indicates a probable water stress in these treatments.

At Gayndah under irrigation, water stress occurrred in N-fertilized treatments with a yield potential above 3.5 t/ha. The yield reduction was highest in 1983, reaching 2.5 t/ha in continuous wheat + N200, of which 1 t/ha was attributable to a reduction in 1000-grain weight. Although not all the water stress was detected through fractional available water, a small error in calculation could lead to under-estimation of stress between irrigations on such a shallow soil. Alternatively, temporary wilting at mid-day may have caused sufficient stress to reduce yields.

The Gayndah basalt site in 1981 experienced a general effect of severe water stress around anthesis after good early rains. Grain yields were up

TABLE 16

Plant and environmental factors around anthesis, prediction of grain yields, and potential yields assuming no water stress after anthesis.

Treatment code:

1 Continuous wheat (CW) + NO
2 Continuous wheat + N at 100 kg/ha (irrig) or 50 kg/ha (dryland)
3 Continuous wheat + N at 200 kg/ha (irrig) or 100 kg/ha (dryland)
4 Rotational wheat after grass alone (G)
5 Rotational wheat after medics alone (M)
6 Rotational wheat after grass/medic mixture (G+M)

Warwick black earth (irrigated)

Year	Treat. No.	Soil Nitrate (p.p.m. N)	N uptake (kg/ha)	LAI at anthesis	T/Eo	Dry wt at anthesis (kg/ha)	1000-grain wt (g)	Fractional available water[A]	Grain yield (kg/ha)	Predicted yield	Potential yield
1981	1 CW+NO	3.2	63	1.87	.67	5277	32.8	1.0	2605	3659	Same
	2 CW+N100	19.4	73	2.37	.69	4696	34.3	1.0	3620	4029	Same
	3 CW+N200	35.6	105	3.04	.78	5259	34.3	1.0	4787	4757	Same
	4 G	1.0	10	0.31	.14	780	37.4	1.0	851	446	Same
	5 M	5.2	50	1.37	.50	4208	35.7	1.0	3281	2781	Same
	6 G + M	1.2	33	1.02	.40	2830	38.5	1.0	1773	1985	Same
1982	1	4.4	49	0.92	.37	4897	34.7	1.0	2468	1987	Same
	2	20.6	100	1.54	.54	7383	34.3	1.0	3898	3182	Same
	3	36.8	122	1.81	.59	6574	32.8	1.0	4506	3187	Same
	4	5.5	71	1.81	.59	7292	38.1	1.0	3340	3358	Same
	5	6.3	102	2.04	.64	7873	35.6	1.0	3792	3687	Same
	6	7.2	95	2.01	.63	7439	36.9	1.0	4631	3542	Same
1983	1	4.3	37	1.09	.42	2991	27.1	1.0	1616	1773	Same
	2	20.5	65	1.58	.54	4785	25.9	1.0	2092	2666	Same
	3	36.7	85	1.79	.59	4475	23.0	1.0	2472	2804	Same
	4	4.5	44	1.27	.47	3367	29.2	1.0	2245	2050	Same
	5	5.7	55	1.50	.53	3970	25.5	1.0	1877	2412	Same
	6	5.9	57	1.49	.53	4232	26.7	1.0	2520	2475	Same

[A] Lowest value calculated between anthesis (A) and A+10 days.

to 1 t/ha below the potential yields at anthesis. Fertilizer treatments recorded the greatest water stress and the lowest 1000-grain weights. In 1982 N uptake was affected by lack of water throughout a very dry winter, as shown by the very small additional N uptake in fertilized treatments. The plants regulated their water consumption so that water stress at anthesis caused only a minor reduction in grain yield across all treatments. In 1983 rainfall of 280 mm in the fallow shortly before planting left the soil severely deficient in nitrogen. Very large responses to N fertilizer were indicated by anthesis. However 100 kg/ha of N produced water stress which reduced the yield of that treatment by 2.2 t/ha to the level achieved with N50. 1000-grain weights were also reduced.

At Roma the barley on the brigalow soil was well supplied with N in all treatments except following grass alone. Despite a very wet winter, the crop experienced severe water stress at anthesis. Soil moisture measurements showed that early waterlogging had restricted rooting depth,and subsoil moisture below 75 cm was beyond reach. The very low 1000-grain weights confirm the severity of the stress. The model of Woodruff and Tonks, although untested on barley, indicated yield reductions of half to two-thirds below the potential yield at anthesis. It also showed that presence of medics in a grass pasture supplied sufficient N to compensate for the poor mineralization of N in the first fallow. This compensation could improve grain yields by up to 1 t/ha under favourable moisture conditions.

The box soil at Roma grew barley showing a lower N supply, LAI, TDW and yield potential at anthesis than on the brigalow soil. Combined with freedom from waterlogging, this led to reduced water stress. Treatments realized approximately 60% of their yield potential, with only minor effects on 1000-grain weights. However the water stress prevented treatment differences from exceeding 0.8 t/ha, whereas the model indicated potential responses of 1.8 t/ha from N100 and 1.4 t/ha from grass/medic pastures.

Probability of these conditions being repeated

Table 17 attempts to place our results in context by considering how often the experimental conditions occur. On the Warwick black earth, rainfall during the crop (planting to anthesis plus five weeks) from the given planting time in 1981 would be exceeded in 60% of years. The yield obtained for the given soil type, planting moisture and N supply (assumed to be 70 kg/ha N) has been shown by research and wheat industry records to be exceeded in 40% of years. Thus 1981 was an "average" year at this site. The wet 1983 winter was much less common, while at Roma the very wet 1984 winter produced yields which occur in less than 5% of years from the stated planting times.

It is important however to note that the planting times were mostly late according to Woodruff and Tonks (1983), causing a major reduction in yield potential. Thus a yield which occurs with 15% frequency at Warwick from a July planting will occur with 80% frequency from a May planting with the same N supply. The yield responses obtained at Warwick are therefore conservative and very likely to occur on the given soil type. Furthermore if it is assumed that planting at the optimum time does not

TABLE 17 Probabilities of rainfall and grain yields (unfertilized continuous crop) exceeding those in the dryland experiments.

Site		Year	Grain yield (kg/ha)	Rain during crop (mm)	% Probability of greater rain[A]	% Probability of higher yield[B] (This planting time)	(Optimum planting time[C])
WARWICK	Black earth	81	2511	219	60	40	80
		82	2491	266	65	15	80
		83	979	378	15	>95	100
		84	3326	268	45	< 5	55
	Sandstone	81	639	180	70	85	
		82	2571	162	85	5	
		83	4001	300	35	< 5	
GAYNDAH	Basalt	81	1565	86	90	20	
		82	1201	79	90	30	
		83	1321	212	40	80	
ROMA	Brigalow	84	2406	309	15	< 5	
	Box	84	1392	309	15	< 5	

[A] Based on rainfall records.

[B] Based on unpublished data collected by D. Woodruff.

[C] At Warwick, plant early May, anthesis late August (Woodruff and Tonks 1983).

substantially change the N supply in the soil, the extra demand for N from the higher yielding crop is likely to transform a mild N deficiency into a more severe one. Depending on the mineralizing capacity of the soil, the responses to medics may well increase in crops planted at the optimum time, providing the water supply is sufficient for the extra transpirational demand. This should tend to occur because the optimum planting times suggested by Woodruff and Tonks produce peak demands for water during late winter when rainfall is relatively reliable and evaporative demand is low. Judged in this context, all the soils studied except the brigalow clay at Roma exhibited a level of N deficiency likely to be increased in crops planted at the optimum time.

Duration of improved N supply and grain yields following ley pastures

Using N uptake in grain as an index of N supply, Table 18 presents the treatment effects for each year so that the trend through time may be studied. The results show major benefits from irrigated medic pastures at Warwick with little downward trend after four years of cropping. Benefits were also still significant on the black earth (4 years) and the sandstone

TABLE 18

Time trends in treatment effects on N uptake in grain and average yields (kg/ha) compared with unfertilized continuous crop.

Site		Treatment	N uptake in grain 81	82	83	84	Average N uptake[A]	Average grain yield	Extra grain÷extra N in grain
WARWICK	Irrigated	1 CW+N0	49	44	36	54	46	2346	51.0
		2 CW+N100	+25	+34	+12	+18	+22	+914	40.8
		3 CW+N200	+58	+58	+29	+34	+45	+1557	34.1
		4 G	+6	+13	+13	+13	+11	+684	57.7
		5 M	+16	+34	+8	+22	+20	+833	38.9
		6 G + M	+25	+45	+22	+27	+30	+1418	46.3
	Black earth	1 CW+N0	60	56	23	67	52	2327	44.8
		2 CW+N50	+0	+9	+9	+11	+7	+112	23.4
		3 CW+N100	+18	+19	+22	+16	+19	+470	26.6
		4 G	-19	+13	+37	+13	+11	+594	58.8
		5 M	-14	+44	+34	+16	+20	+559	44.0
		6 G + M	-11	+39	+35	+15	+20	+585	46.4
	Sandstone	1	19	65	84		56	2404	42.9
		2	+11	+0	+42		+18	+630	35.7
		3	+31	+15	+39		+28	+776	29.9
		4	+42	+13	-6		+16	+645	39.5
		5	+38	+16	+24		+26	+858	34.5
		6	+47	+15	+12		+25	+864	36.2
GAYNDAH	Irrigated	1 CW+N0	34	57	35		42	2215	52.7
		2 CW+N100	+57	+41	+49		+49	+1873	37.2
		3 CW+N200	+52	+41	+50		+48	+1170	23.8
		4 G	+15	-6	+0		+3	+180	52.0
		5 M	+25	+9	+4		+13	+563	40.4
		6 G + M	+30	+23	+8		+20	+876	42.7
	Basalt	1 CW+N0	37	31	24		31	1362	43.9
		2 CW+N50	+5	+13	+31		+16	+528	37.2
		3 CW+N100	+7	+14	+34		+18	+529	23.8
		4 G	+8	+11	+4		+8	+340	52.0
		5 M	+14	+12	+3		+10	+321	40.4
		6 G + M	+17	+10	+4		+10	+297	42.7
ROMA	Brigalow	1				63	63	2046	32.5
		2				-7	-7	-200	-
		3				-10	-10	-308	-
		4				-14	-14	-24	-
		5				-4	-4	-65	-
		6				-3	-3	-17	-
	Box	1				27	27	1392	51.6
		2				+27	+27	+807	29.9
		3				+28	+28	+624	22.3
		4				+9	+9	+560	62.2
		5				+17	+17	+648	38.1
		6				+19	+19	+796	41.9

[A] Approximately equal to 85% of N uptake in tops.

(3 years). At Gayndah the responses lasted two years under irrigation and one to two years under dryland conditions. The Roma brigalow showed some benefit of medics compared with grass alone and the box site exhibited moderate responses.

Ignoring the trends through time, Table 18 also shows the average increase in N uptake and the corresponding increases in grain yield for each treatment. The highest value for N uptake was 30 kg under irrigation at Warwick, producing an extra 1.4 t/ha of grain. The average effect over all sites of grass/medic leys was to increase the grain yield by 43 kg for every kg of extra N in the grain, at an N content of 2.3%. The efficiency of uptake of N fertilizer in grain varied considerably from year to year but was generally higher under irrigation.

Similar data for grain yields of pasture leys only are presented in Figure 16, illustrating the trends through time. By allowing for water stress at anthesis on the Warwick black earth site, the downward trend in response to ley pastures is more clearly seen. On the sandstone soil, the benefits from medic and grass/ medic pastures appeared to last longer than those from grass alone.

Discussion

Our results show substantial benefits from ley pastures based on annual medics under the arbitrary conditions of our experiments. They must be viewed in a broad context where many factors may influence the response obtained.

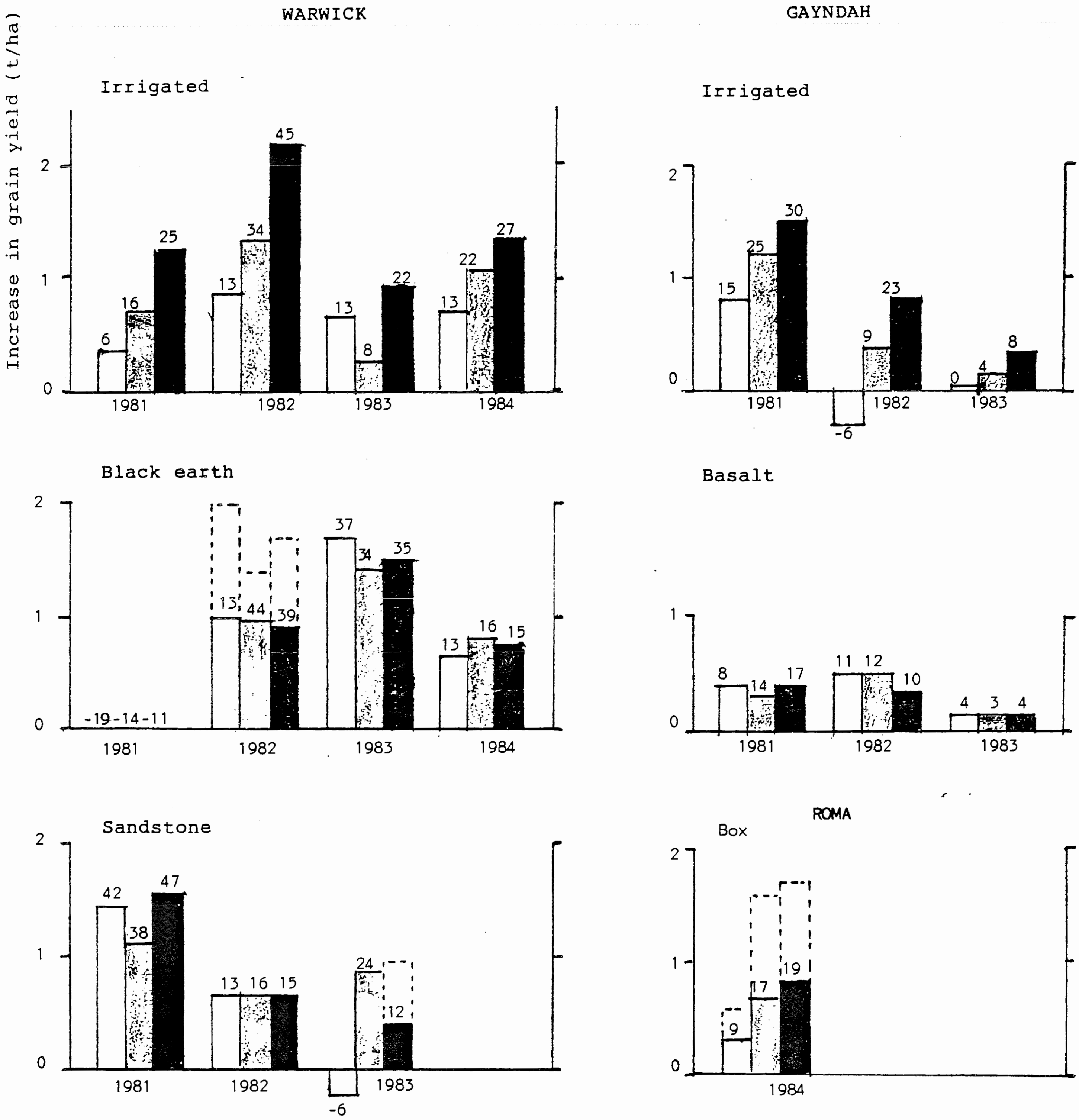
The first condition for obtaining a nitrogen response from a ley pasture is that the ley improved the nitrogen mineralizing capacity of the soil. This could occur either by increasing the total N in the soil or by changing the proportion of readily mineralizable N in the organic pool through changes in the C:N ratio. Both mechanisms were apparent in our experiments.

A positive response to improved soil N supply then depends on there being an N-deficiency, ie. the soil cannot satisfy the demand of the crop. This raises questions firstly of the fertility of the soil in the experiment, which is governed not only by soil type but also cropping history, degree of erosion, etc. Our soils varied widely in fertility and cropping history. At Warwick the black earth had been cultivated for around 50 years and its ability to mineralize N was probably well below that in its virgin state. The soil was very responsive to N but was otherwise an excellent cropping soil. The lighter textured sandstone soil, while having been cultivated intermittently for 15 years, was still mineralizing N at a rate which was close to that in its virgin state but inadequate for most crops. At Gayndah the basaltic soil had been cultivated intermittently for many years and had suffered considerable soil erosion in the past. Its mineralizing ability was less than at Warwick, partly because it was shallow. The box soil, although previously cleared virgin grassland, showed very low mineralizing ability due to inherent lack of nitrogen. At Roma the brigalow soil showed high mineralizing ability after 15 years of intermittent cultivation following clearing, and it had little need for ley pastures to restore N fertility at present. The box soil had been cropped for a longer period and having

FIGURE 16

Time trends in pasture effects on grain yields (kg/ha) compared with unfertilized continuous crop. Numbers above graphs are increases in N uptake in grain.

Key: Grass
Medic
Grass + Medic
Adequate water after anthesis



also a lower fertility in its virgin state, was likely to be responsive to N in years of sufficient rainfall.

The second question involves the demand for N made by the crop, which is influenced by the type of crop, variety, planting time and environmental stresses such as water supply. The model of Woodruff and Tonks proved well suited to handling variations in N supply. It provided a means of understanding how the opposing effects of N on increasing leaf area development and increasing the demand for water interacted to influence yield. We encountered various situations which were more readily understood and weighted using the model. Under irrigation at Warwick, adequate water supply enabled the full expression of potential yield differences due to differing N supply. Under some dryland and irrigated conditions, improving the N supply created an increased demand for water which could not be satisfied by the soil. This led to a reduction in yield responses, with the model being able to show the size of this reduction. These limitations imposed by water stress were estimated conservatively by the model, since it did not take account of water stress before anthesis. In other years, eg. Gayndah basalt in 1982, shortage of water limited the rates of N uptake and growth in all treatments, thereby preventing the expression of potential yield differences related to N supply. A further example of this is the Roma box site where extra N supplied from medic pastures did not produce higher grain yields in 1984 because of water stress. The model again showed the potential response obtainable using measurements made at anthesis.

A further aspect of this question is the time of planting which changes the demand for N in the crop. Our results were obtained from planting times which by being late (Woodruff and Tonks 1983), limited the demand for N. Since all but one of our soils showed crop yield responses to N, it may be deduced that our responses to ley pastures were conservative. We have quoted survey data showing that the frequency of years at Warwick when N supply will limit yield is much higher for the optimum planting time than for the times used in our experiments. The same principle applies to Gayndah and Roma, although data are not available at present to quantify the effect.

Changes in pest and disease problems following ley pastures may also influence the response obtained in subsequent crops. The severe nematode infestation on the Warwick black earth in 1983 was probably more damaging to the seventh continuous wheat crop than to the third rotational crop. The effect was to reduce average yields while still allowing treatment differences to develop, eg. responses to N fertilizer. No other sites were infected. Disease did not appear to influence our results since periodic checks by a plant pathologist showed that it was negligible.

Changes in soil physical fertility caused by ley pastures were not measured. However as no effects eg. on soil structure in the surface soil were observed, these changes were thought to be minor. This does not however preclude the occurrence of useful benefits from leys on the lighter and more unstable soils of the region.

Another important consideration with ley pastures is the duration of benefits in subsequent crops. Information on this aspect in our experiments comes from crop responses in N uptake and yield and from changes in soil total N. At Warwick the trends presented from the irrigated site do not define the number of responsive crops which appears to be at least five. However the response in the dryland experiments appears to be small by the fifth crop on the black earth and the fourth crop on the sandstone soil. These estimates agree quite well with total N data. At Gayndah the downward trend towards no response in the third crop is complicated by the fallow in 1983. The extremely wet conditions shortly before planting were followed by severe N-deficiency as the N previously accumulated in the fallow was apparently removed by leaching or denitrification. The total N values after three crops were still well above the starting values and indicated by inference from the Warwick sites that further responses could be obtained in later years, particularly on the irrigated site. At Roma the increases in total N on the brigalow may take some years to decline since they did not increase the uptake of N in the barley. In practical terms the medics were beneficial only in compensating for a shortage of mineral N in the first crop following grass. This effect would probably disappear in the second year. On the box soil the changes in total N, if applied to wetter sites, would cause increased yields in at least three crops. Rainfall would be an important determinant of the duration of responses at this site. Aspects of soil nitrogen will be examined in more detail in a separate section.

F. SOIL FERTILITY CHANGES

Summary

Ley pastures containing a sub-tropical grass with and without annual medics (Medicago spp) were examined as a means of maintaining soil fertility in continuously cropped soils in southern inland Queensland. Comparisons were made between a rotation of 4 years' pasture followed by three years of wheat as against seven years of continuous wheat grown with rates of nitrogen (N) fertilizer. The dryland experiments were located on a fertile clay soil and a less fertile duplex soil at Warwick, Gayndah and Roma with decreasing winter rainfall. Irrigated experiments were also carried out on the fertile clay soils at Warwick and Gayndah.

Grass/medic mixtures produced the greatest improvement in soil total N at all sites, reaching 34% under irrigation at Warwick, while in the same period continuous cropping caused a 5% decline. After three subsequent crops, N levels following ley pastures were still significantly above those of the continuous crop and above the initial values. Under dryland conditions, ley pastures at Warwick maintained soil total N on the fertile clay soil against a decline of 19% under continuous crop, while on the duplex soil the pastures showed a decline of 8% compared with 20% under continuous crop. Ley pastures had no effect at Gayndah, but at Roma total N following grass/medic leys was increased by 25% on the fertile clay soil and 44% on the duplex soil.

Organic carbon (C) levels generally rose rapidly under pastures, particularly grass/medic mixtures, and fell almost as rapidly under cropping. C:N ratios followed a similar trend at Warwick and Gayndah, but at Roma ley pastures caused a moderate decline on the fertile clay and a large decline on the duplex soil. The lowest C:N ratios at all sites occurred in grass/medic mixtures.

Soil nitrate levels under pasture were very low, but at planting time of wheat crops they were consistently highest following pastures containing medics.

The benefits from medics in ley pastures were also evident in N-uptake of pastures and of the grain of subsequent wheat crops.

Introduction

In Sections C, D and E the role of annual medics in improving subtropical grass pastures in southern inland Queensland and in ley pastures in pasture-wheat rotations, was examined. Evidence was presented of how pasture yields and growth rates were improved by the inclusion of medics, and how the grain yields of subsequent crops were affected by ley pastures containing medics.

This Section examines the changes in soil fertility which occurred during the pasture and cropping phases, by direct measurements on the soil and by using N-uptake data from the pastures and crops.

Methods

Pasture leys using annual medics (Medicago spp.) with and without an introduced tropical grass were grown on a fertile uniform clay and a less fertile duplex soil for four years at Warwick and Gayndah and 5.5 years at Roma. The grass alone was either unfertilized or received nitrogen (N) fertilizer at two rates. An irrigated experiment was also included on the fertile soils at Warwick and Gayndah. The pasture plots were then cropped with Cook wheat for three years at Warwick and Gayndah, and Grimmett barley for one year at Roma. These crops were compared with continuous crops receiving rates of N fertilizer. At Warwick the continuous crop was grown annually without N fertilizer during the pasture phase but received rates of N thereafter. At other sites the continuous crop commenced with the first crop after pasture. The treatments in the dryland experiments, arranged in four randomized blocks, were:

Continuous crop treatments

1. Wheat unfertilized (duplicate sets)
2. Wheat + N at 50 kg/ha/yr.
3. Wheat + N at 100 kg/ha/yr.

Pasture treatments in the rotation

4. (a) Grass alone
   (b) Grass + N at 50 kg/ha/yr.
   (c) Grass + N at 100 kg/ha/yr.
5. (a) *M. scutellata* cv. Robinson alone
   (b) *M. truncatula* cv. Jemalong alone
6. (a) Grass + Robinson
   (b) Grass + Jemalong

The grass was a forage sorghum hybrid (*Sorghum* spp.) cv. Silk at Warwick and Gayndah. At Roma the grasses were buffel (*Cenchrus ciliaris*) cv. Gayndah on the fertile clay and green panic (*Panicum maximum* var. *trichoglume*) cv. Petrie on the duplex soil. Rates of N fertilizer were doubled in the irrigated experiments.

Total N and organic carbon (C) levels in the surface (0-10 cm) soil were measured initially, at the end of the pasture phase, and at the end of the cropping phase, using ten bulked 50 mm diameter cylindrical core samples per plot. Plant available N as soil nitrate was estimated in the 0-60 cm surface layer with one core per plot. In the pasture phase, samples were taken quarterly in winter, spring, summer and autumn on the fertile soil at Warwick, and half-yearly in spring and autumn elsewhere except at Roma which was not sampled. Samples in the cropping phase were taken immediately before planting and at grain harvest, using one core per plot and depths of 0-60 and 60-120 cm in the first four years, and 0-60 cm thereafter. No soil samples were taken from continuous wheat receiving N fertilizer. Spot checks on soil ammonium indicated that levels were negligible. All soil samples were finely broken up and immediately air dried at 40°C for 24 hours in a forced draft dehydrator before being ground (particle size <2mm) in preparation for chemical analysis.

Samples for pasture and grain yield determinations were analysed for N content so that the mineralizing ability of the soil could also be assessed through N uptake by the plants.

Results

Effects of pastures and crops on soil total N

On the Warwick irrigated site, ley pastures containing medics or fertilized grass significantly increased soil total N (Table 19), with the greatest increase being 34% under grass/medic pastures. During this period, total N declined significantly by 5% under continuous wheat. After cropping the ley pastures for three years, the only significant decline in total N occurred in the grass/medic treatment. However during this period a significant recovery occurred in total N under continuous wheat. At the end of the experiment, total N in all treatments was significantly higher than initially.

On the Warwick black earth, all ley pastures maintained total N near the initial value while a decline of 19% occurred under continuous wheat. After the cropping phase, significant increases were recorded, so that final N levels were above the initial value in all treatments except continuous wheat.

The Warwick sandstone site showed a strong downward trend overall. The only ley pasture not to register a significant fall in total N during the pasture phase was grass receiving 50 or 100 kg N/ha/yr. Grass/medic pastures showed the smallest fall, while a decline of 20% occurred under continuous wheat and 26% under medic alone. Three subsequent wheat crops continued the decline in all treatments except medic alone. The overall decline in total N was highly significant in all treatments.

At Gayndah all irrigated ley pastures significantly raised total N, with the greatest increase of 31% occurring under grass/medic pastures. Three wheat crops reduced total N in grass/medic pastures but the downward trend in other treatments was not significant. Final levels were well above the initial value in all treatments.

On the Gayndah basalt and box sites no consistent changes were detected in total N under pasture, but increases occurred under cropping on the basalt following pastures with medics or N100. Final levels were 11% higher than initially in all treatments except grass alone.

At Roma ley pastures on the brigalow site containing either medics or N fertilizer caused highly significant increases (averaging 25%) in total N, with no detectable differences between pasture types. The effect of one subsequent crop on N levels was not measured. A similar result occurred on the Roma box soil where increases averaged 44%.

Effects of pastures and crops on soil organic C

At Warwick on both the irrigated and black earth sites, large increases in organic C occurred in the first four years under pasture particularly in grass/medic mixtures, with lesser increases under continuous wheat during the same time (Table 20). In the subsequent cropping phase, values in all treatments fell significantly, but in most treatments they were still above the initial value. The continuous crop recorded one of the

TABLE 19 Effect of pasture/crop rotations compared with continuous crop on soil total N% (0-10cm) over time. (CW = continuous wheat, G = grass, M = mean of two medics).

	Site	Treatment	I Initial	II End Pasture	III End Crop	Significance over time I to II	II to III	I to III
WARWICK	Irrigated	1 CW	.119[A]	.113a	.125a[B]	*↓[C]	**	*
		2 G+N0		.126b	.133bc	N.S.	N.S.	**
		3 G+N100		.146d	.146de	**	N.S.	**
		4 G+N200		.144cd	.138cd	**	N.S.	**
		5 M		.135be	.139cd	**	N.S.	**
		6 G+M		.160e	.149e	**	*↓	**
	Black earth	1 CW	.135	.110a	.131a	**↓	**	N.S.
		2 G+N0		.128b	.145b	N.S.	**	**
		3 G+N50		.131b	.141b	N.S.	N.S.	*
		4 G+N100		.128b	.141b	N.S.	*	*
		5 M		.129b	.140b	N.S.	**	**
		6 G+M		.136b	.145b	N.S.	*	**
	Sandstone	1 CW	.114	.091ab	.065a	**↓	**↓	**↓
		2 G+N0		.101bc	.077a	**↓	*↓	**↓
		3 G+N50		.105c	.079a	N.S.	**↓	**↓
		4 G+N100		.105c	.070a	N.S.	**↓	**↓
		5 M		.084a	.072a	**↓	N.S.	**↓
		6 G+M		.105c	.075a	*↓	**↓	**↓
GAYNDAH	Irrigated	1 CW	-	-	-	-	-	-
		2 G+N0	.134	.161a	.154a	**	N.S.	**
		3 G+N100		.160a	.156a	**	N.S.	**
		4 G+N200		.161a	.155a	**	N.S.	**
		5 M		.158a	.154a	**	N.S.	**
		6 G+M		.175b	.159a	**	**↓	**
	Basalt	1 CW	-	-	-	-	-	-
		2 G+N0	.139	.145a	.145a	N.S.	N.S.	N.S.
		3 G+N50		.151a	.154a	**	N.S.	**
		4 G+N100		.139a	.153a	N.S.	*	**
		5 M		.139a	.154a	N.S.	*	**
		6 G+M		.145a	.155a	N.S.	**	**
	Box	1 CW	-	-		-		
		2 G+N0	.049	.054a		N.S.		
		3 G+N50		.057a		N.S.		
		4 G+N100		.053a		N.S.		
		5 M		.045a		N.S.		
		6 G+M		.059a		**		

[A] Initial value for all treatments.
[B] Values followed by the same letter within a column are not significantly different (P>0.05).
[C] ↓Indicates reduction in value. * = P<0.05, ** = P<0.01, N.S. = not significantly different (P>0.05).

TABLE 19(Continued)

	Site	Treatment	I Initial	II End Pasture	Significance I to II
ROMA	brigalow	1 CW	-	-	-
		2 G+N0	.109	.119a	N.S.
		3 G+N50		.134a	**
		4 G+N100		.131a	**
		5 M		.143a	**
		6 G+M		.139a	**
	box	1 CW	-	-	-
		2 G+N0	.058	.066a	N.S.
		3 G+N50		.079ab	**
		4 G+N100		.083b	**
		5 M		.082b	**
		6 G+M		.090b	**

lowest final organic C levels.

On the Warwick sandstone site, organic C levels were maintained in most treatments during the pasture phase, but fell in all instances during the subsequent cropping years. The overall result was a fall of 12% with no significant differences between treatments in final values.

At Gayndah all ley pastures caused similar large increases in organic C under irrigation and on the basalt site. Three years of cropping then reduced values to the initial level. On the box site ley pastures had practically no effect and the effect of subsequent cropping was not measured due to poor growth of crops.

At Roma the pasture phase produced no significant change in most treatments on the brigalow soil. However on the box site organic C increased significantly under grass fertilized with 100 kg N/ha/yr and grass/medic mixtures. The effects of one subsequent crop were not measured.

Effects of treatments on C:N ratios in soil organic matter

C:N ratios were examined as an indicator of the ease of mineralization of soil organic N, with 10:1 or less being preferred. At Warwick ley pastures caused a big increase in C:N ratios from 11:1 to 14:1 under irrigation and to 15:1 on the black earth site (Table 21). The smallest increase occurred in grass/medic pastures, while the biggest increase occurred in the continuous crop during that time. The subsequent cropping phase caused an equally large decrease to the initial values. On the sandstone soil the ratio rose from approximately 14:1 to 17:1 under ley

TABLE 20 Effect of pasture/crop rotations compared with continuous crop on soil organic carbon % (0-10 cm)

	SITE	Treatment	I Initial	II End pasture	III End crop	Significance over time I to II	II to III	I to III
WARWICK	Irrigated	1 CW	1.33	1.69a	1.34a	**	**↓	N.S.
		2 G+N0		1.84b	1.44b	**	**↓	**
		3 G+N100		2.04c	1.33a	**	**↓	N.S.
		4 G+N200		1.94bc	1.45b	**	**↓	**
		5 M		1.86b	1.41ab	**	**↓	**
		6 G+M		2.05c	1.53c	**	**↓	**
	Black earth	1 CW	1.44	1.84a	1.48a	**	**↓	*
		2 G+N0		1.91ab	1.55b	**	**↓	**
		3 G+N50		1.99c	1.55b	**	**↓	**
		4 G+N100		1.92b	1.47a	**	**↓	N.S.
		5 M		1.97bc	1.61c	**	**↓	**
		6 G+M		2.00c	1.54b	**	**↓	**
	Sandstone	1 CW	1.61	1.54a	1.35a	N.S.	**↓	** ↓
		2 G+N0		1.67ab	1.43a	N.S.	**↓	** ↓
		3 G+N50		1.67ab	1.36a	N.S.	**↓	** ↓
		4 G+N100		1.76b	1.35a	*	**↓	** ↓
		5 M		1.48a	1.37a	*↓	* ↓	** ↓
		6 G+M		1.64ab	1.42a	N.S.	**↓	** ↓
GAYNDAH	Irrigated	1 CW	-	-	-	-	-	-
		2 G+N0	1.63	2.06a	1.61a	**	** ↓	N.S.
		3 G+N100		2.20a	1.64a	**	** ↓	N.S.
		4 G+N200		2.21a	1.59a	**	** ↓	N.S.
		5 M		2.09a	1.68a	**	** ↓	N.S.
		6 G+M		2.22a	1.74a	**	** ↓	**
	Basalt	1 CW	-	-	-	-	-	-
		2 G+N0	1.63	2.26a	1.72a	**	** ↓	N.S.
		3 G+N50		2.37a	1.64a	**	** ↓	N.S.
		4 G+N100		2.16a	1.66a	**	** ↓	N.S.
		5 M		2.23a	1.64a	**	** ↓	N.S.
		6 G+M		2.19a	1.58a	**	** ↓	N.S.
	Box	1 CW	-	-	-	-	-	-
		2 G+N0	1.11	1.08a		N.S.		
		3 G+N50		1.09a		N.S.		
		4 G+N100		1.16a		N.S.		
		5 M		1.01a		*↓		
		6 G+M		1.12a		N.S.		

TABLE 20 (Continued)

	Site	Treatment	I Initial	II End pasture	Significance I to II
ROMA	brigalow	1 CW	-	-	-
		2 G+N0	1.21	1.12a	*↓
		3 G+N50		1.22ab	N.S.
		4 G+N100		1.27b	N.S.
		5 M		1.18a	N.S.
		6 G+M		1.26b	N.S.
	box	1 CW	-	-	-
		2 G+N0	1.03	1.01ab	N.S.
		3 G+N50		0.98a	*↓
		4 G+N100		1.12d	**
		5 M		1.04bc	N.S.
		6 G+M		1.08cd	**

pastures and continued to rise to 19:1 during the subsequent cropping. The smallest rises occurred in grass/medic treatments.

At Gayndah ley pastures increased C:N ratios slightly from 12:1 to 13:1 under irrigation and to nearly 16:1 on the basalt, with grass/medic mixtures again registering the smallest rises. Three years of subsequent cropping caused decreases to levels a little below the initial value. Ley pastures on the box site had little effect. The effects of cropping were not measured on this site.

At the Roma brigalow site, C:N ratios were the lowest of all, indicating a soil with excellent mineralizing capacity. Values fell from 11:1 to 9:1, with pastures containing medics registering the lowest ratio. On the box soil the initial high ratio of 18:1 fell to an average of 13:1 after 5.5 years of pasture. Grass/medic pastures showed the lowest ratio of 12:1. The effects of one subsequent crop were not measured.

Soil nitrate levels during the pasture phase

Nitrate levels were very low, averaging 1 p.p.m. (Table 22a) under grass pastures regardless of N fertilizer received. Values were slightly (<0.5 p.p.m.) higher in grass/medic pastures. Pure medic pastures accumulated nitrogen under summer fallow except under irrigation at Gayndah where liverseed grass (Urochloa panicoides) was difficult to control.

TABLE 21 Effect of pasture/crop rotations compared with continuous crop on soil C:N ratios (0-10cm)

	Site	Treatment	Initial	End of Pasture	End of Crop
WARWICK	Irrigated	1 CW	11.2	15.0	10.7
		2 G+N0		14.8	10.8
		3 G+N100		14.0	9.1
		4 G+N200		13.5	10.5
		5 M		13.8	10.2
		6 G+M		12.7	10.3
	Black earth	1 CW	10.7	16.6	11.3
		2 G+N0		14.9	10.7
		3 G+N100		15.2	11.0
		4 G+N200		15.0	10.4
		5 M		15.0	11.5
		6 G+M		14.8	10.7
	Sandstone	1 CW	14.1	16.9	20.8
		2 G+N0		16.5	18.6
		3 G+N50		15.9	17.2
		4 G+N100		16.8	19.3
		5 M		17.6	19.0
		6 G+M		15.7	18.9
GAYNDAH	Irrigated	1 CW	-	-	-
		2 G+N0	12.2	12.8	10.5
		3 G+N100		13.8	10.5
		4 G+N200		13.7	10.3
		5 M		13.2	10.9
		6 G+M		12.8	11.0
	Basalt	1 CW	-	-	-
		2 G+N0	11.7	15.6	11.9
		3 G+N50		15.7	10.6
		4 G+N100		15.5	10.8
		5 M		16.0	10.6
		6 G+M		15.1	10.3
	Box	1 CW	-	-	
		2 G+N0	22.7	20.0	
		3 G+N50		19.1	
		4 G+N100		21.9	
		5 M		22.4	
		6 G+M		19.0	

TABLE 21 (Continued)

	Site	Treatment	Initial	End of Pasture
ROMA	brigalow	1 CW	-	-
		2 G+N0	11.1	9.4
		3 G+N50		9.1
		4 G+N100		9.7
		5 M		8.3
		6 G+M		9.1
	box	1 CW	-	-
		2 G+N0	17.8	15.3
		3 G+N50		12.4
		4 G+N100		13.5
		5 M		12.7
		6 G+M		12.0

The seasonal pattern of soil nitrate levels on the black earth at Warwick (Table 22b) showed a small autumn peak under irrigation and a slight peak in summer under dryland conditions when water stress frequently restricted pasture growth. There was no accumulation of nitrate under growing medics, but values rose progressively between November and May under summer fallow. Rates of mineralization were higher on the dryland site.

The mineralizing ability of soils, judged by nitrate levels in autumn in pure medic treatments (Table 22c), ranged from very high on the Roma brigalow to very low on the Gayndah box soil.

Soil nitrate levels during the cropping phase

Nitrate levels at planting time were consistently highest following pastures containing medics (Table 23a). Their superiority over unfertilized grass leys averaged 3 p.p.m. or approximately 20 kg N/ha, and ranged from 0.2 p.p.m. on the Gayndah box site to 7.5 p.p.m. on the Roma brigalow. Most nitrate levels equated to half the N required to grow a typical wheat crop taking up 70 kg N/ha in top growth. N fertilizer on grass increased fallow nitrate levels by 1 to 2 p.p.m. at Warwick. The relatively low reading in the unfertilized grass treatments at the Roma brigalow site is a characteristic of the first fallow and would be expected to increase in subsequent fallows. Addition of medics to grass pastures overcame this deficit.

Deeper sampling to 120 cm at Warwick showed that little nitrate was supplied from the subsoil (Table 23b), with values not exceeding 2 p.p.m. There was considerable year-to-year variation in the amount of nitrate accumulated in the surface soil under fallow, eg. levels were high at all sites in the dry 1982 year which contrasted with low values in the much wetter 1983 season when leaching and denitrification probably occurred.

TABLE 22 Soil nitrate levels (ppm, 0-60cm) during the pasture phase at Warwick and Gayndah. (G = grass, N1 = low N, N2 = high N, M1 = Robinson medic, M2 = Jemalong medic).

(a) Treatment comparisons at each sampling

	Site	Date	Treatment No. 1 G+N0	2 G+N1	3 G+N2	4 G+M1	5 G+M2	6 M1	7 M2
WARWICK	Irrigated	12/12/77	2.8					3.5	2.8
		17/4/78	1.0	<1.0	<1.1	1.3	2.3	6.8	6.5
		7/8/78	1.3	<1.1	<0.6	1.0	2.3	2.0	1.0
		30/10/78	<0.8	<0.9	<0.8	1.8	1.0	<0.9	<0.8
		22/1/79	<1.0	1.0	2.5	1.3	1.5	6.3	4.3
		17/4/79	<1.5	<1.5	<2.3	<1.3	<1.5	5.3	<5.0
		6/8/79	<1.0	<1.0	<1.0	<1.0	<1.0	<1.5	<1.3
		29/10/79	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		11/2/80	<1.0	<1.0	<1.0	<1.0	<1.0	<1.3	<1.5
		14/5/80	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	1.0
		4/8/80	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		17/11/80	<1.0	<1.5	<1.0	<1.0	<1.0	<1.0	<1.0
		30/3/81	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		Mean 1978-81	1.1	1.1	1.2	1.1	1.3	2.5	2.1
	Black earth	12/12/77	10.0					3.3	4.5
		17/4/78	7.5			6.8	10.0	10.8	8.3
		7/8/78	4.3			2.5	2.0	2.8	1.8
		30/10/78	1.5			1.0	1.0	2.5	1.3
		22/1/79	<1.0	<2.0	<2.3	<1.0	<1.8	5.5	5.5
		17/4/79	<1.0	<1.0	<1.0	<1.0	<1.0	<7.0	<6.0
		6/8/79	<1.0	<1.0	<1.0	<1.0	<1.3	<1.0	<1.5
		29/10/79	<1.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.5
		11/2/80	<1.0	<1.0	<1.0	1.8	1.8	9.8	8.5
		14/5/80	<1.0	<1.0	1.0	1.3	<3.5	10.3	8.0
		4/8/80	<1.0	<1.0	<1.0	<1.0	<1.0	<1.5	<1.0
		17/11/80	1.0	<1.3	1.5	2.8	3.3	3.5	3.5
		30/3/81	<1.0	<1.8	<1.0	<1.0	<1.3	<4.5	5.3
		Mean 1979-81	1.0	1.2	1.2	1.3	1.8	4.9	4.5
	Sandstone	12/12/77	<2.0					2.3	2.8
		18/4/78	<1.0	<1.0	<1.0	<1.0	<1.0	2.5	3.8
		1/11/78	<1.0	<1.0	<1.3	<1.0	<1.0	<1.5	<1.0
		18/4/79	<1.0	<1.0	<1.0	<1.8	<1.8	8.3	8.0
		30/10/79	<1.0	<1.0	<1.0	<1.0	<1.0	1.3	<1.0
		13/5/80	<1.3	<1.0	<1.0	<1.0	<1.0	5.5	<1.5
		31/3/81	<1.0	<1.0	<1.0	<1.0	<1.0	9.3	6.0
		Mean 1978-81	1.1	1.0	1.1	1.1	1.1	4.7	3.6

TABLE 22 (a) (Continued)

	Site	Date	Treatment No. 1	2	3	4	5	6	7
GAYNDAH	Irrigated	22/4/80	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		4/11/80	<1.0	<1.0	<1.0	<1.0	<1.0	<1.3	<1.0
		11/3/81	<1.0	<1.0	<1.0	<1.7	<2.7	<1.0	<1.0
		Mean 1980-81	1.0	1.0	1.0	1.2	1.6	1.1	1.0
	Basalt	23/5/77	7.8	7.8	7.8	7.8	7.8	7.8	7.8
		20/12/77	5.0					4.3	3.3
		26/4/78	<1.0			2.0	2.8	5.8	6.0
		7/11/78	1.0			3.3	4.3	3.3	4.0
		23/4/79	<1.0	<1.0	<1.3	<1.0	1.5	2.3	1.5
		6/11/79	<1.0	<1.0	<1.0	<1.0	<1.0	1.3	1.5
		22/4/80	<1.0	<1.0	<1.0	1.0	1.0	<1.3	1.7
		4/11/80	<1.0	<1.0	<1.0	1.0	1.0	1.7	2.3
		11/3/81	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	2.3
		Mean 1979-81	1.0	1.0	1.1	1.0	1.1	1.7	1.9
	Box	7/11/78	<1.5			<1.0	<1.0	<1.0	<1.0
		23/4/79	<1.8	<1.8	<1.0	<1.0	<1.0	2.5	2.8
		6/11/79	<1.0	<1.0	<1.0	<1.0	<1.0	<2.5	<3.5
		22/4/80	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	<1.7
		4/11/80	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		11/3/81	<1.0	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0
		Mean 1979-81	1.2	1.2	1.0	1.0	1.2	1.6	2.0

(b) Seasonal pattern on the black earth at Warwick.

Site	Years	Month	Treatment No. 1	2	3	4	5	6	7
Irrigated	3	August	1.1	1.0	0.9	1.0	1.4	1.5	1.1
	3	November	0.9	1.1	0.9	1.3	1.0	1.0	0.9
	3	February	1.0	1.0	1.5	1.1	1.2	2.9	2.3
	3	May	1.2	1.2	1.5	1.2	1.6	4.7	4.2
Dryland	2	August	1.0	1.0	1.0	1.0	1.2	1.3	1.3
	2	November	1.2	1.2	1.3	1.9	2.2	2.3	2.5
	3	February	1.0	1.6	1.4	1.3	1.6	6.6	6.4
	2	May	1.0	1.0	1.0	1.2	2.3	8.7	7.0

(c) Comparison between soils in autumn after a summer fallow following pure medic swards.

Site		Years of data	Nitrate
Roma	brigalow	1	14.3
Warwick	black earth	4	9.3
Warwick	sandstone	4	6.7
Roma	box	1	4.9
Warwick	irrigated	4	4.6
Gayndah	basalt	4	3.9
Gayndah	irrigated	2	2.2
Gayndah	box	3	2.0

TABLE 23 (a) Mean annual pre-planting soil nitrate (p.p.m., 0-60 cm) in the cropping phase. (M = mean of two medics)

Site		Treatment G+N0	G+N1	G+N2	G+M	M	CW
WARWICK	Irrigated	3.7	4.0	5.9	4.8	5.7	4.0
	Black earth	5.7	6.1	6.8	8.8	13.0	7.9
	Sandstone	4.5	5.5	5.8	6.9	9.5	6.5
GAYNDAH	Irrigated	3.5	3.5	3.6	4.5	5.2	-
	Basalt	3.9	3.5	4.4	4.6	4.7	-
	Box	1.6	2.2	1.8	1.8	2.9	-
ROMA	Brigalow	6.8	12.3	13.0	13.1	14.3	-
	Box	2.8	5.8	3.3	4.6	4.9	-

TABLE 23(b) Soil nitrate levels (ppm, 0-60 cm) measured at pre-planting (Pre) and post-harvest (Post) for each wheat crop.

Site		Date	Stage	Depth	Treatment No. 1 G+N0	2 G+N1	3 G+N2	4 G+M1	5 G+M2	6 M1	7 M2	8 CW+N0
WARWICK	Irrigated	7/6/78	Pre	0- 60cm								6.8
				60-120								1.3
		21/12/78	Post	0- 60								1.0
				60-120								<0.5
		10/5/79	Pre	0- 60								<3.5
				60-120								<2.0
		12/12/79	Post	0- 60								<1.0
				60-120								<1.0
		2/6/80	Pre	0- 60								3.5
				60-120								1.8
		10/12/80	Post	0- 60								<1.0
				60-120								<2.0
		22/6/81	Pre	0- 60	<1.0	<1.0	<1.0	<1.3	<1.0	3.5	6.8	3.2
		25/11/81	Post	0- 60	<1.0	<1.0	1.0	<1.0	<1.0	<1.0	<1.0	1.0
		28/7/82	Pre	0- 60	5.5	5.3	6.8	7.3	7.0	6.0	6.5	4.4
		9/12/82	Post	0- 60	1.7	2.3	2.3	2.0	2.0	2.3	3.0	2.3
		14/6/83	Pre	0- 60	4.5	5.8	5.5	5.8	6.0	4.5	6.8	4.3
		14/12/83	Post	0- 60	3.3	3.3	2.7	3.3	4.0	4.3	4.0	2.5
	Black earth	7/6/78	Pre	0- 60								13.0
				60-120								1.8
		21/12/78	Post	0- 60								2.0
				60-120								2.3
		10/5/79	Pre	0- 60								5.0
				60-120								2.0
		12/12/79	Post	0- 60								<3.0
				60-120								2.0
		2/6/80	Pre	0- 60								2.8
				60-120								<1.3
		10/12/80	Post	0- 60								3.5
				60-120								1.3
		22/6/81	Pre	0- 60	1.8	2.5	2.8	3.8	5.3	12.8	10.8	7.4
		8/12/81	Post	0- 60	1.7	1.7	3.0	3.3	4.7	5.7	6.0	4.2
		28/7/82	Pre	0- 60	11.0	11.8	13.3	17.3	16.5	19.5	24.0	11.1
		9/12/82	Post	0- 60	2.3	3.0	2.7	5.0	6.7	8.3	8.3	3.9
		14/6/83	Pre	0- 60	4.3	4.0	4.3	5.8	4.0	4.5	6.0	5.1
		14/12/83	Post	0- 60	4.0	2.0	3.0	2.7	3.3	3.3	4.7	1.3

TABLE 23b (Continued)

Site		Date	Stage	Depth	Treatment No. 1	2	3	4	5	6	7	8
	Sandstone	6/6/78	Pre	0- 60								3.0
				60-120								<1.0
		21/12/78	Post	0- 60								<1.0
				60-120								<1.0
		10/5/79	Pre	0- 60								1.0
				60-120								<1.0
		12/12/79	Post	0- 60								<1.0
				60-120								<1.0
		2/6/80	Pre	0- 60								<1.0
				60-120								<1.0
		10/12/80	Post	0- 60								<1.0
				60-120								<1.0
		5/6/81	Pre	0- 60	2.3	3.3	4.0	5.3	4.8	9.0	15.0	6.0
		2/12/81	Post	0- 60	<1.0	1.0	1.0	1.7	1.3	4.0	2.0	1.0
		21/7/82	Pre	0- 60	7.3	8.8	9.5	11.8	10.8	12.5	13.3	8.8
		7/12/82	Post	0- 60	4.3	5.0	7.0	6.7	9.7	9.0	7.0	4.7
		6/6/83	Pre	0- 60	3.8	4.3	3.8	4.5	4.0	3.5	3.8	4.8
		6/12/83	Post	0- 60	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
GAYNDAH	Irrigated	1/6/81	Pre	0- 60	<1.0	<1.3	<1.0	1.3	2.0	3.3	3.3	
		25/11/81	Post	0- 60	<1.0	<1.0	<1.0	1.3	1.0	1.3	1.3	
		13/7/82	Pre	0- 60	7.0	6.3	6.5	8.8	8.5	7.8	8.5	
		11/11/82	Post	0- 60	2.0	2.0	2.0	1.7	<1.3	1.7	1.7	
		17/5/83	Pre	0- 60	2.5	3.0	3.3	3.3	3.0	4.0	4.3	
		19/10/83	Post	0- 60	1.3	1.3	1.7	2.0	2.0	1.7	2.0	
	Basalt	1/6/81	Pre	0- 60	2.5	3.5	4.3	4.0	4.0	4.8	7.5	
		25/11/81	Post	0- 60	1.0	1.0	1.3	1.0	1.3	1.3	1.0	
		13/7/82	Pre	0- 60	6.3	5.5	6.3	6.8	7.8	6.3	4.3	
		11/11/82	Post	0- 60	2.3	3.7	3.0	3.3	3.3	4.0	2.7	
		17/5/83	Pre	0- 60	2.8	1.5	2.5	2.3	2.3	3.0	2.3	
		19/10/83	Post	0- 60	1.0	1.3	1.3	1.0	1.0	1.3	1.3	
	Box	1/6/81	Pre	0- 60	1.3	2.0	1.0	1.8	1.3	3.5	2.5	
		2/12/81	Post	0- 60	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	
		13/7/82	Pre	0- 60	2.5	3.0	2.8	2.5	2.3	3.5	4.3	
		11/11/82	Post	0- 60	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	
		17/5/83	Pre	0- 60	1.0	1.5	1.5	1.3	1.3	1.3	1.8	
		19/10/83	Post	0- 60	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	
ROMA	Brigalow	2/7/84	Pre	0- 60	6.8	12.3	13.0	12.8	13.3	15.3	13.3	
		20/11/84	Post	0- 60	1.3	2.7	4.3	3.3	4.0	4.7	3.7	
	Box	25/6/84	Pre	0- 60	2.8	5.8	3.3	4.8	4.3	5.3	4.5	
		19/11/84	Post	0- 60	<1.0	<1.0	1.3	1.0	2.0	1.3	1.0	

Uptake of N by plants as an indicator of soil N supply

Since direct measurement of soil N changes is inaccurate because of sampling variation and the complexity of the N-cycle, and because mineralization continues under growing crops, plant uptake is a second and potentially more sensitive index of the capacity of the soil to mineralize N.

TABLE 24 Effect of medics and N fertilizer on the mean annual uptake of N (kg/ha) in the pasture phase.

Site		Grass + N fertilizer				Grass + Medic			Medic alone
		No	N50	N100	N200	Grass	Medic	Total	
WARWICK	Irrigated	38		86	141	99	161	260	173
	Black earth	42	69	77		69	118	187	132
	Sandstone	36	64	95		77	98	175	127
GAYNDAH	Irrigated	92		126	152	139	191	330	209
	Basalt	30	48	65		50	79	129	92
	Box	20	35	49		22	19	41	46
ROMA	Brigalow	36	40	46		33	81	114	87
	Box	26	32	50		33	69	102	79

In the pasture phase, grass/medic pastures took up four to seven times more N than grass alone under irrigation, and two to five times more under dryland conditions (Table 24). The effect under irrigation was double that obtained with fertilizer at 200 kg N/ha/yr. This benefit was made up of extra N supplied to the grass in summer, together with the direct contribution from medics in winter and spring. Obviously the N came from both the soil mineral pool and symbiosis by the medics. On the Gayndah box and Roma sites, uptake of N by grass was not enhanced by medics in the pasture, because of poor medic growth and dry summers respectively.

In the subsequent cropping phase, N uptake by wheat continued to be higher after pastures containing medics than after grass alone, with the highest average benefit across years being 19 kg/ha on the Warwick irrigated site (Table 25).

The uptake in these treatments exceeded that of continuous wheat receiving 100 kg N/ha/yr. Details of individual years are contained in another report. Ley pastures even using grass alone were beneficial at Warwick, improving N uptake by 11 to 16 kg/ha/yr. The benefits of ley pastures were generally associated with higher total N levels in the soil (Table 25).

Estimated N-fixation by annual medics

N-fixation was estimated by comparing unfertilized grass with and without medics with respect to the N contained in grass removed by mowing plus the N accumulated in the soil at the end of the pasture phase. The difference was attributed to symbiotic N-fixation by the medics. The resulting estimates (Table 26) ranged from 113 kg/ha/yr at Warwick under irrigation to 10 kg/ha/yr at Gayndah on the basalt soil. Whereas at Warwick the benefits were almost equally distributed between pasture growth and soil accumulation, at Roma with dry summer conditions inhibiting pasture growth, all the symbiotic N accumulated in the soil.

TABLE 25 Effect of ley pastures and N fertilizer on the mean annual uptake of N (kg/ha) in grain in the cropping phase.

Site		Continuous wheat+N fertilizer				Rotational wheat		
		N0	N50	N100	N200	Grass	Medic	Grass+Medic
WARWICK	Irrigated	46		68	91	57	66	76
	Black earth	52	59	71		63	72	72
	Sandstone	56	74	84		72	82	81
GAYNDAH	Irrigated	42		91	90	45	55	62
	Basalt	31	47	49		39	41	41
	Box	NA[A]	NA	NA		NA	NA	NA
ROMA	Brigalow	63	56	53		49	59	60
	Box	27	54	55		36	44	46

[A] Not available

TABLE 26 Estimated mean annual N fixation (kg/ha) of annual medics over four years at Warwick and Gayndah and six years at Roma.

Site		Treatment	Extra N from medics		Total
			In mown grass	In soil	
WARWICK	Irrigated	Grass/medic	36	77	113
		Medic	-	21	21
	Black earth	Grass/medic	17	18	35
		Medic	-	2	2
	Sandstone	Grass/medic	14	13	27
		Medic	-	0	0
GAYNDAH	Irrigated	Grass/medic	28	40	68
		Medic	-	0	0
	Basalt	Grass/medic	10	0	10
		Medic	-	0	0
	Box	Grass/medic	0	20	20
		Medic	-	0	0
ROMA	Brigalow	Grass/medic	0	46	46
		Medic	-	56	56
	Box	Grass/medic	2	83	85
		Medic	-	62	62

The estimated N-fixation did not appear to relate very well to medic yields presented elsewhere. N-fixation by pure medic pastures appeared to be much lower than grass/medic pastures except at Roma where grass growth was weak. This emphasizes the way in which medics alone improved the soil N supply to subsequent crops by increasing the proportion of readily mineralizable N in the soil.

Discussion

The results showed that ley pastures using grass/medic mixtures are able to improve soil fertility in many instances either by increasing total N or reducing the decline occurring under continuous cropping. Both soil type and rainfall affected the benefit obtained. While the greatest benefits occurred under irrigation at Warwick and Gayndah, the range of increases recorded did not relate simply to medic yields. One possible explanation of the superiority of the irrigated leys is that in addition to producing high medic yields, the adequate water supply enables the grass to deplete the soil mineral N, thereby encouraging greater symbiotic N-fixation. This is supported by the superiority of grass/medic pastures over medics alone which apparently obtained most of their N requirement from mineral N accumulated during the summer fallows. However it does not explain the surprisingly large increases in total N at Roma on the brigalow soil which had been farmed for only a short time and had a high capacity to mineralize N when cultivated. This may indicate that the harsh summer environment inhibited the micro-organisms responsible during the pasture phase. It is significant that all the N fixed at the Roma sites was stored in the soil, apparently because water stress prevented its exploitation by grass in summer.

The importance of soil type is also illustrated by the results on the Warwick sandstone soil where total N declined even under ley pastures. This soil was also not intensively cultivated previously and was probably in the phase of rapid decline characteristic of newly cultivated soils. This would partly explain the contrast with the black earth at Warwick which had been cultivated for at least 60 years.

Cropping after ley pastures produced the expected decline in soil total N, with the greatest reduction in grass/medic treatments which had the highest accumulation. This was consistent with the greater use of N by crops in these treatments. However the highly significant increases in total N under the continuous crop on the black earth at Warwick during the latter years was unexpected and no explanation is offered. The only possibilities appear to be that the crops brought up subsoil N to the surface or that non-symbiotic N-fixation occurred under the crops. The significant elevation in total N remaining on the black earth sites at Warwick and the irrigated site at Gayndah following three wheat crops appears sufficient to sustain improved crop growth for at least one or two more years.

Organic carbon proved more volatile, with the overwhelming finding being that levels rose rapidly during the pasture phase and fell equally rapidly during the cropping phase. Although grass/medic pastures consistently registered the highest organic carbon levels, treatment differences were generally small compared with the effects of pastures *vs* crops. A large seasonal effect appeared to be present since levels rose rapidly under continuous wheat during the pasture years and fell rapidly in later years. This phenomenon is unexplained. The different pattern recorded on the Warwick sandstone again emphasized the differences between soil types, while the lack of change under pasture at Roma was probably attributable to the low dry matter production of the grass.

C:N ratios reflected the tendency of organic carbon to rise faster than total N under ley pastures, so that C:N ratios generally widened. The exception was at Roma where a large part of the dry matter in the pasture came from N-rich legume growth. Thus the pastures usually produced conditions unfavourable for mineralization of organic N, since a ratio of 10:1 or less is regarded as ideal. It is significant that the tendency for C:N ratios to widen under pastures was minimised by the inclusion of medics. These findings may not be valid under grazing, since much of the dry matter is then returned via excreta, instead of dying *in situ* or being cut and removed. Repeated cropping narrowed the C:N ratio at all sites measured except the Warwick sandstone where it continued to widen. The values approaching 20:1 indicate a very unfavourable environment for further mineralization of organic N. The cause of this atypical behaviour is not apparent and the problem was only slightly alleviated by use of N fertilizer.

Soil nitrate levels were predictably very low under the pastures, although the effect of medics in raising levels was just detectable, particularly in the late autumn. Significant findings were that soil nitrate does not accumulate appreciably even under high-yielding medic swards, and that death of medics in early summer causes only a gradual release of N which is immediately taken up by the companion grass. The accumulation of nitrate during summer fallowing of pure medic treatments followed the usual pattern and highlighted the high nitrogen fertility of the brigalow soil.

In the cropping fallows, the ability of medics to improve soil nitrate was very valuable. Although levels at planting were consistently higher after pure medics than after grass/medic leys, the N uptake by crops tended to be the opposite. This is explained by the higher total N in the grass/medic treatment, enabling higher rates of mineralization during the growing crop. It was common for half the N required by the crop to be supplied in this way.

The N uptake data from both the pasture and cropping phases illustrate the major contribution of medics as opposed to N fertilizer as a supplement to inadequate soil mineral N. Medics contained half to two-thirds of the N in grass/medic mixtures and the extra N in grass growth was often equivalent to that obtained with fertilizer at 100 kg N/ha/yr. These averages do not take account of year-to-year variability in medic growth which has been discussed elsewhere.

The continuation of these benefits in crops for some years after the ley pastures were ploughed out is of long-term practical importance in southern inland Queensland where continuous cereal cropping is gradually depleting soil N.

G. STRAIN TESTING OF ANNUAL MEDICS

Summary

This trial tested the growth, seed set and regeneration of winter annual legumes under dryland conditions on two contrasting soils at three climatic sites. The sites were Warwick, Gayndah and Roma. The trial was an 18 x 4 R.B. with species: Medicago scutellata (snail medic) cv. Robinson, M. polymorpha (burr medic), M. littoralis (strand medic) cv. Harbinger, M. truncatula (barrel medic) cvv. Jemalong, Cyprus, Hannaford, Borung, Akbar, Cyfield and Ghor, M. tornata (disc medic) cvv. Tornafield and Murrayland, M. rugosa (gama medic), cv. Paragosa, Vicia villosa (woolly pod vetch) cv. Namoi, Astragalus hamosus cv. Ioman, and three spare plots.

After seven years the mean annual dry matter yields (kg/ha) averaged over all cultivars for each site were 1400 (Warwick black earth), 1100 (Warwick clay loam), 2000 (Gayndah basalt), 100 (Gayndah box), 2200 (Roma brigalow) and 1900 (Roma box). The Gayndah box site was unsuitable for medics. The best three cultivars were Jemalong, Akbar and Cyprus.

Introduction

There is a need for legumes for southern inland Queensland to overcome shortages of protein and energy in pastures during winter. The best species to supplement lucerne have so far been the annual medics, with one or two other genera showing some promise.

A major evaluation of annual medics began in 1977 to measure their contribution to dry matter and protein production of grass pastures and their effect on soil N fertility expressed either in extra grass growth or in crop yields in a pasture-crop rotation.

This trial formed part of that evaluation and measured the growth and persistence of registered medic cultivars under dryland conditions on two contrasting soils at three climatic sites. The cultivars are shown in Table 28. The sites were Warwick (black earth at Hermitage Research Station [HRS] and clay loam based on Marburg sandstone at L. O'Dea, Elbow Valley [EV]), Gayndah (basaltic clay and poplar box solodic soil at Brian Pastures R.S. [BRP]) and Roma [RMA](brigalow clay and poplar box solodic soil at G. Maunder, Wallumbilla).

Materials and Methods

Design: 18 x 4 Randomized Block with fifteen legume plots and 3 spare plots. Plot size was 3 x 3 m.

The sites were fallowed and treated with Treflan for preemergent weed control. The Treflan was applied at HRS, E.V. and BRP box at 1400 ml/ha and at BRP basalt and Roma at 1050 ml/ha.

The legumes were established by hand broadcasting and harrowing lime-pelleted inoculated seed at 2 kg/ha into a clean seedbed in the autumn of 1977 followed by 2 kg/ha sown on the surface in 1978. Due to dry conditions in 1977 the Roma site required sowing in 1978 and 1979. Sowing dates were 13/5/77 and 20/4/78 (HRS); 25/5/77 and 20/4/78 (EV); 25/5/77 and 26/4/78 (Gayndah); 9/7/77, 9/5/78 and 19/2/79 (Roma). The fifteenth legume, Astragalus hamosus (milk vetch) cv. Ioman, was sown in 1978.

The initial grass planting was of Panicum maximum var. trichoglume (green panic) cv. Petrie established by the same method at all sites using 1 kg/ha germinable seed. However poor establishment and persistence at HRS forced a change to Sorghum spp. hybrid (perennial forage sorghum) cv. Silk which was sown at all sites. This species did not persist at Roma due to drought and a further change to Cenchrus ciliaris (buffel grass) cv. Gayndah was made at the Roma sites. Thus at HRS plantings were on 14/12/77 and 6/4/78 (Petrie); 21/1/79 and 11/11/80 (Silk at 5 kg/ha); at EV on 14/12/77 (Petrie) and 21/2/79 (Silk); at Gayndah on 20/12/77 and 16/3/78 (Petrie), 14/3/79 and 2/4/79 (Silk); at Roma on 9/11/78 (Petrie at 5 kg/ha), and 19/2/79 (Silk). Roma brigalow then received buffel on 4/12/80 (10 kg/ha) and 27/10/81 (20 kg/ha) while Roma box received Petrie on 20/12/81 (10 kg/ha failing to establish) and buffel on 28/10/82 (20 kg/ha failing to establish). The frequent failures at Roma were caused by droughts which did not allow seedlings to consolidate.

Mo-24 super was applied at planting in the first year at a rate of 500 kg/ha and then at 250 kg/ha annually in autumn thereafter. The summer grass growth was cut to a height of 15 cm with a jari mower and removed.

Spraying for blue-green aphids was done at approximateky 6-weekly intervals during the winter growing season using dimethoate. Spraying for weed control using 2,4, D-B was carried out at HRS (21/6/77) and RMA brigalow (13/7/78). Hand weeding was also done at HRS while the trial was establishing.

Measurements were taken on the ungrazed, undisturbed growth once yearly to measure plant density (autumn), peak dry matter yield (spring) and seed set (summer). Quadrat size was 0.2 m^2 with four per plot for measurements of seedling density and one each for d.m. yields and seed yields.

Results

Rainfall See Table 27. With the exception of 1978 the winter rainfall totals were below the long term average in the first 6 years of the trial 1977-82. The 1983 rainfall was well above average.

Plant Densities (Table 28). In the initial planting the Warwick sites germinated and established well with a plant density of 16 to 136 plants/m^2, Gayndah sites were fair with 2 to 61 plantings/m^2 and Roma very poor with densities of 0.4 plants/m^2. Gayndah received only marginal germinating rains whilst the Roma sites received only a minimal fall of 1.3 mm.

The wet winter of 1978 boosted the population densities with all values being generally quite good; however the dry winters of 1979-82 resulted in small germinations or caused seedlings and young plants to perish

27 Rainfall (mm) received in winter (April-Sept) and summer (Oct-March) compared with the long-term average at each site.

R	WARWICK HERMITAGE R.S.		WARWICK L.O'DEA, ELBOW VALLEY		GAYNDAH BRIAN PASTURES R.S.		ROMA G.MAUNDER, WALLUMBILLA	
	Rainfall	Deviation	Rainfall	Deviation	Rainfall	Deviation	Rainfall	Deviatio
	147	-40%	126	-48%	177	-48%	106	-47%
	351	+44%	292	+20%	363	+60%	360	+82%
	177	-27%	145	-40%	139	-39%	68	-66%
	189	-22%	190	-22%	121	-47%	118	-30%
	225	- 7%	176	-28%	246	+ 9%	190	- 4%
	120	-50%	96	-61%	88	-61%	96	-51%
	574	+137%	491	+102%	488	+116%	565	+185%
e of s *	202	-17%	171	-27%	179	-21%	156	-19%
erm average	243		243		227		198	
/78	316	-31%	397	-14%	347	-38%	404	+2%
/79	477	+4%	465	+1 %	425	-24%	375	-5%
/80	336	-27%	400	-13%	514	- 8%	299	-25%
/81	429	- 7%	270	-41%	596	+ 6%	245	-38%
/82	500	+ 8%	487	+ 5%	532	- 4%	379	- 4%
/83	358	-22%	347	-25%	273	-51%	187	-53%
e of rs	403	-13%	394	-15%	448	-20%	315	-21%
erm average	459		459		559		397	

not included in average as winter was extremely wet.

through water stress. In 1981 good autumn rains produced quite high populations, particularly at Roma, which indicates the very small amount of seed set in 1979 and 1980 had little or no effect on ability to regenerate.

Good germinating rains at all sites in 1983 produced very high densities with the exception of BRP box where continuous low seed set had drastically depleted seed reserves, resulting in very patchy stands.

The best species over six sites in seven years were Jemalong, burr medic and Harbinger. The worst species were Ioman vetch, Paragosa and Namoi vetch.

The best site over seven years was Roma brigalow with an average of all cultivars of 465 plants/m^2, followed by Roma box 274 plants/m^2, Elbow Valley 178 plants/m^2, BRP basalt 160 plants/m^2, HRS 156 plants/m^2 and BRP box 37 plants/m^2.

Legume Yields (Table 29). In 1977 measurements were not made on dry matter yield or seed set as plant densities varied greatly and comparative yield data would not be valid at low densities. In the wet 1978 winter, however, the top yields were extremely high considering the low commercial planting rates which were used. The best sites were RMA brigalow and BRP basalt. Hermitage growth was restricted by the low populations and severe weed competition and Elbow Valley was also restricted by extreme competition from the naturalized woolly burr medic, *M. minima*. The worst site was BRP box.

Yields in 1979 reflected the dry conditions with water stress at Warwick sites being moderate but quite severe everywhere else. Most species had slightly higher production in 1980 but once again showed no real potential due to the dry.1981 looked hopeful but finished very badly when growth was curtailed by a severe dry spell in spring causing extensive death of leaves and preventing further growth.

In 1982 HRS and RMA box were the only two sites with measurable legume yields. At the other sites medic plants died prematurely due to severe drought. This was the worst year of medic growth since the trial began in 1977.

Table 28 Plant density (plants/m^2) for each cultivar at six sites, averaged over seven years.

Treatment	Warwick		Gayndah		Roma			
	Hermitage black earth	Elbow Valley Sandstone	BRP basalt	BRP box	Brigalow	Box	Cultivar Mean	Rank
1. M.scutellata (snail medic) cv. Robinson	179	162	41	4	159	169	119	12
2. M.polymorpha (burr medic)	339	472	120	8	1497	224	443	2
3. M.littoralis (strand medic) cv. Harbinger	171	237	357	46	781	733	388	3
4. M.truncatula (barrel medic) cv. Jemalong	268	284	221	97	497	347	633	1
5. M.truncatula cv. Cyprus	156	166	281	80	681	399	294	5
6. M.truncatula cv. Hannaford	313	166	202	51	557	373	277	7
7. M.truncatula cv. Borung	193	285	186	39	577	390	278	6
8. M.truncatula cv. Akbar	103	174	201	56	452	319	218	9
9. M.truncatula cv. Cyfield	302	176	168	41	539	333	260	8
10. M.truncatula cv. Ghor	28	46	194	42	431	320	177	11
11. M.tornata (disc medic) cv. Tornafield	110	254	214	47	388	238	319	4
12. M.tornata cv. Murrayland	60	88	181	32	327	227	213	10
13. M.rugosa (gama medic) cv. Paragosa	15	77	3	4	43	2	24	14
14. Vicia villosa (woolly pod vetch) cv. Namoi	93	79	18	2	21	19	39	13
15. Astragalus hamosus (milk vetch) cv. Ioman	13	5	6	5	30	14	12	15
SITE MEAN	156	178	160	37	465	274		

Table 29 Dry matter yields (kg/ha) of each cultivar at six sites, averaged over six years.

Treatment	Warwick		Gayndah		Roma			
	Hermitage black earch	Elbow Valley Sandstone	BRP Basalt	BRP Box	Brigalow	Box	Cultivar Mean	Rank
1. Robinson medic	2463	1008	1494	66	2185	1739	1493	9
2. Burr medic	1751	1012	748	39	2539	283	1062	11
3. Harbinger medic	1234	1885	2476	134	2591	3455	1963	4
4. Jemalong medic	2053	2255	3400	229	3660	3494	2515	1
5. Cyprus medic	1800	1309	2567	263	3572	2546	2010	3
6. Hannaford medic	1966	1206	2627	322	2373	2942	1906	6
7. Borung medic	1828	1401	2261	43	3050	2904	1915	5
8. Akbar medic	1688	1738	2951	114	3523	2803	2316	2
9. Cyfield medic	2481	1037	2423	183	1817	2798	1790	7
10. Ghor medic	273	741	2595	88	3326	3220	1707	0
11. Tornafield medic	1437	1554	2448	122	1226	894	1280	10
12. Murrayland medic	646	301	2527	112	1188	1038	969	12
13. Paragosa medic	65	8	533	7	975	100	188	14
14. Namoi vetch	1186	1158	1062	13	413	264	683	13
15. Ioman vetch	49	118	181	3	106	127	97	15
SITE MEAN	1395	1115	2020	116	2170	1907		

Naturally the good season in 1983 allowed all sites to do well. RMA box and BRP basalt were able to show their full medic potential with RMA box producing the top yield during the 7 years of the trial. Jemalong at this site produced 11635 kg/ha.

The best cultivars over six sites in seven years were Jemalong, Akbar, Cyprus and Harbinger. Worst species were Ioman vetch, Paragosa and Namoi vetch.

Best site over six years was RMA brigalow with average of all cultivars of 2170 kg/ha compared with BRP basalt 2020 kg/ha, RMA box 1907 kg/ha, HRS 1395 kg/ha, Elbow Valley 1115 kg/ha and BRP box 116 kg/ha. Site averages were lowered considerably by the inclusion of the worst three cultivars in the data.

Seed yields (Table 30). The seed yields in 1978 were very good under the good conditions, but in 1979 and 1980 medics were extremely water stressed with the yields being very low. In 1979 three sites recorded zero.

In 1981 water stress interacted with maturity thereby affecting the seed yields. The winter conditions were generally good from May-July but turned very dry during the August-October period.

Up until September the medics grew well but then became extremely water-stressed at all sites. This resulted in the early flowering cultivars, Robinson and Ghor, having high seed yields while later-flowering cultivars which experienced water-stress at flowering produced seed yields much lower than usual. Most yields were satisfactory.
In 1982 plants were so severely water-stressed that only the HRS site set seed. As the HRS medics germinated in September, once again the late flowering cultivars ran into heat stress. Robinson, being an early flowering cultivar, produced the best seed yield at 37 kg/ha.

With the exception of the BRP box site the 1983 seed yields were very good. BRP box set little seed due to its patchy establishment caused by depleted seed reserves. The best cultivars in 1983 were Cyprus, Akbar and Ghor. The worst were Ioman vetch, Paragosa and Namoi vetch. The highest seed yield was measured at Elbow Valley with Hannaford measuring 1165 kg/ha.

Over all sites in six years the best cultivars were Ghor, Robinson and Cyprus. Worst cultivars were Paragosa, Ioman vetch, Murrayland and Namoi vetch. The best site overall was Elbow Valley with the average of all cultivars over six years being 166 kg/ha compared with RMA box 134 kg/ha, BRP basalt 128 kg/ha, RMA brigalow 120 kg/ha, HRS 102 kg/ha and BRP box 9 kg/ha.

Discussion

In a comparison of species it appears the barrel medics were far superior with Jemalong showing strong potential as a very adaptable medic in the three climatic regions and differing soil types. In 1983 at the RMA box site it produced the highest D.M. yield during the entire trial phase with a yield of 11635 kg/ha, produced under the excellent

Table 30. Clean seed yield (kg/ha) for each cultivar at six sites, averaged over six years.

Treatment	Warwick		Gayndah		Roma			
	Hermi-tage black	Elbow Valley Sand-	BRP Basalt	BRP Box	Briga-low	Box	Cultivar Mean	Rank
1. Robinson medic	348	233	114	7	224	240	194	2
2. Burr medic	102	59	37	10	155	27	65	11
3. Harbinger medic	46	116	330	3	130	256	147	5
4. Jemalong medic	138	219	157	24	86	186	135	6
5. Cyprus medic	98	217	199	23	223	194	159	3
6. Hannaford medic	154	256	74	21	85	136	121	7
7. Borung medic	100	267	89	4	104	139	117	9
8. Akbar medic	137	282	152	14	123	212	153	4
9. Cyfield medic	139	241	101	2	110	117	118	8
10. Ghor medic	53	476	358	15	224	264	232	1
11. Tornafield medic	83	53	125	1	33	129	71	10
12. Murrayland medic	4	6	108	4	77	39	40	13
13. Paragosa medic	10	1	1	0	47	12	12	15
14. Namoi vetch	107	56	32	0	73	49	53	12
15. Ioman vetch	3	0	45	0	89	8	24	14
SITE MEAN	102	166	128	9	120	134		

conditions of a mild, wet winter. The species also showed it could do reasonably well even under stress during particularly dry years.

In ranked order of dry matter yields over six years (Table 27) the other barrel medics ranked between second and eighth behind Jemalong with Akbar being second best and Ghor eighth. At all sites the barrel medics did well but at the difficult BRP box site they were clearly superior, illustrating their adaptability and versatility.

Harbinger performed consistently well on all sites despite its reputation for special adaptation to light soils. Ghor and Robinson showed their potential in dry seasons by setting seed due to early flowering. In 1979 Ghor was the only cultivar to set seed on BRP basalt as all other medics were dead from water stress by September. This was shown again in 1981 when Ghor and Robinson both showed higher clean seed yields as their flowering was not hindered by the dry spring.

Robinson (ranking 9th in Table 29) proved to be a very productive species and would have ranked much higher only its average was pulled down by its poor germination at Elbow Valley in 1983. It did well on the heavier soils especially the black earth at HRS.

The better of the two disc medics was Tornafield with its dry matter production and seed yield occasionally equalling or bettering some of the barrel medics. Murrayland grew normally at all sites but even when soil fertility was high and water adequate it appeared to lack production.

Burr medic displayed good regeneration but very average growth. In 1978 when most medics grew well, burr medic was yellow and lacking vigour on most soils. It was not a good indicator of the suitability of soils for medics in general yielding only half as much as the barrel medics on average, and being inferior on lighter soils.

Namoi woolly pod vetch persisted well only at Warwick sites where yields mostly were bolstered by the native vetch which could not be weeded out. In 1978 it displayed N-deficiency possibly associated with the wet conditions but recovered at the Gayndah and Roma sites by mid-August.

Paragosa did not set seed at any site in 1977 and even at the beginning appeared to be a doubtful species. It was very late flowering which was one factor contributing to its poor seed set. It also showed nodulation problems in 1978 but showed some recovery in mid-August. However, by 1980, yields were zero at most sites and by 1983 it had obviously died out.

Ioman milk vetch was very disappointing having very poor nodulation and an obvious lack of seed reserves. By 1983 Ioman appeared to have died out at all sites.

Considering the climatic factors it would seem that HRS would favour medic growth in comparison to other sites and this was so in adjacent experiments. However in this experiment the medic establishment at the HRS site was set back by its short fallow and severe competition from weeds. Hand-weeding in 1978 removed many seedlings thereby limiting the site's dry matter potential in suppressed growth. However, in the dry years of 1980 and 1982 HRS was the most productive site due to its higher rainfall and water-holding capacity.

Elbow Valley experienced considerable competition from the naturalized woolly burr medic (M. minima) which responded well to the superphosphate applications causing yield data from this site to be reasonably disappointing. However, in 1983 with the good rainfall the sown cultivars were strong and Elbow Valley displayed good medic growth with correspondingly high yields.

BRP basalt's ability to do well was associated with the rainfall as occurred with the RMA sites, but during the seasons where medics did not run into severe water stress the basalt site was extremely productive. This was not so however with the light soil on the BRP box site where regeneration was very poor. The barrel medics persisted at this site but the low plant densities reduced their yields. As well as being the poorest soil chemically, this site also suffered from low water holding capacity, a dense impervious subsoil, waterlogging and poor nodulation.

The RMA sites established well after the dry weather setback they suffered in 1977. The brigalow site proved to be the more productive site of the two. Once again the ability of these sites to set seed and regenerate depended on the reliability and regularity of the winter rainfall.

In an overall site comparison it would be difficult to select a number one site considering the undetermined variants, such as weed competition, were not equal at all sites. However, it seems fair to say that during the trial RMA brigalow and BRP basalt would have been the most productive and well-established sites, while HRS did not express its full potential indicated in adjacent experiments. The BRP box site was the only one unsuitable for medics.

Conclusion:

Although four years of the trial phase were very dry this may not have been a disadvantage as it provided a view of the medics potential in varying seasons. The last year, 1983, of the trial illustrated the potential of medics to regenerate after a succession of dry years and limited seed set.

Jemalong was the number one medic showing its ability to adapt to varying site conditions and to survive and produce top yields under heat and water stress.

All sites showed similar yield potential but their reliability of production was related to the mean annual rainfall which was highest at Warwick, intermediate at Gayndah and lowest at Roma.

H. MISCELLANEOUS EXPERIMENTS

Headings indicate QDPI project number, title and location.

WRK P56 WR Lucerne fertilizer trial on granite (Dalveen)

This experiment investigated the fertilizer requirements of lucerne on a "wet" granite soil with annual rainfall of 860mm. Lucerne is the main pasture legume for improvement of native grasslands in the area but requires correct fertilizing for successful results.

In addition to superphosphate, the application of lime raised lucerne yields by 31%, copper raised yields by 15%, and both together increased growth by 51% to mean annual yields of 5000 kg/ha. Corresponding increases in plant density were slightly smaller but highly significant.

WRK P72 WR Pasture nursery on traprock (Karara)

Native pastures on the shallow stony traprock soils near Warwick produce high quality wool but pastures are low-yielding throughout the year and protein deficient in winter. A range of introduced temperate and tropical pasture species was evaluated under periodic grazing on a typical traprock soil with annual rainfall of 650 mm.

The outstanding perennial legume was lucerne. Siratro and lotononis were sporadically productive but other tropical legumes failed to persist due to inadequate summer rainfall and winter frost. The best temperate annual legumes were clovers (seven accessions of *Trifolium*), medics (two accessions of *Medicago*), vetch (*Vicia*) and serradella (two accessions of *Ornithopus*), which were productive in wet winters but suffered at times from slow seedling growth and poor nodulation. The best tropical grasses were rhodes (*Chloris*) and woolly finger grass (*Digitaria*). Temperate grasses died out in dry summers. The best approach was to introduce lucerne and winter annual legumes into native grassland with adequate superphosphate.

WRK P73 WR Effect of two management treatments on the regeneration and yield of barrel medic (Texas)

Annual medics (*Medicago* spp.) have shown promise as a pasture legume for improvement of native pastures used for wool production on the drier traprock soils with annual rainfall of 630 mm. The experiment tested management practices applied annually to increase medic production by renovation of grassland in autumn to conserve moisture for medic seedlings, and in spring to bury medic pods, thereby reducing consumption of seed reserves by sheep. Chemical desiccant was also applied in some treatments to increase the severity of the autumn renovation.

Autumn renovation successfully increased the mean annual yield of medics over four years from 1700 kg/ha (untreated) to 2800 kg/ha (tillage alone), 2400 kg/ha (desiccant alone), and 3000 kg/ha (tillage and desiccant together). Renovation reduced the yield of poor quality stand-over grass in winter but had only a minor effect in summer.

Renovation in spring did not increase the regeneration of medics because favourable growing conditions ensured adequate seed reserves.

WRK P76 WR Lucerne fertilizer trials on granite (Ballandean, Dalveen)

This experiment extended the work reported in a previous study (WRK-P56) to drier areas and in more detail with rates of nutrients included. The effects of phosphorus, sulphur, copper, boron, molybdenum and various calcium carbonate treatments on the yield and persistence of lucerne were measured at two sites on the granite belt of south-east Queensland.

Phosphorus and calcium carbonate increased the dry matter yield of lucerne, the effects being additive. When both nutrients were applied, annual lucerne yields increased from 1500 to 5200 kg/ha at Ballandean and from 3500 to 7700 kg/ha at Dalveen. Lime at 250 kg/ha, drilled with the seed, produced a yield equal to that from 2500 kg/ha broadcast. Small sporadic yield responses to copper and boron occurred but there was no response to sulphur or molybdenum.

The phosphorus content of plant tops increased linearly with increasing rates of application of phosphorus but the critical levels varied considerably among harvests.

Initial lucerne density was highest in treatments receiving phosphorus, calcium carbonate (lime pelleting or broadcast lime) or boron, but differences in density were small compared to the decline in density over three years. The stands were productive for at least six years.

WRK P78 WR Seasonal production and growth rhythm of a range of legumes (Leyburn)

In a continuation of the search for legumes to improve native grasslands on lighter soils used for grazing in the Warwick district, some of the more promising winter annual legumes and lucerne were tested with adequate fertilizer on a Marburg sandstone (solodic) soil with annual rainfall of 635 mm. The annual legumes were serradella (two species of *Ornithopus*), rose clover (two cultivars of *Trifolium*) and medics (three cultivars of *Medicago*). Half of each plot was defoliated at flowering to simulate grazing.

Over seven seasons most species persisted well, with productivity determined mainly by winter rainfall. Lucerne was productive in summer and persisted for 4.5 years. Peak yields of annual legumes were around 6000 kg/ha, with a seven-year average of 1100 to 1700 kg/ha in winter and spring, compared with 2400 kg/ha for lucerne in summer. Defoliation in the first three years reduced seed set which led to lower plant populations and yields in later years.

WRK P82 WR Flowering time in annual medics (Warwick, Roma, Biloela, Gayndah)

In an earlier study (WRK-P77) investigating the maturity characteristics of annual medics in the sub-tropical environment of southern inland Queensland, time of planting studies showed that at

Warwick (a favourable environment with relatively high and reliable winter rainfall), the flowering times of commercial medics varied considerably but were suited to the production of adequate seed for regeneration in subsequent years. However it was not known how the higher winter temperatures in drier parts of the region would affect maturity and the prospects of setting seed in a shorter growing season. This experiment studied a wider range of winter annual legumes planted in March, May, July and September for two years in outdoor pots under field conditions at four widely spaced sites. Sixteen annual medics (*Medicago*), two accessions of milk vetch (*Astragalus*) and one of woolly pod vetch (*Vicia*) were grown at all sites. Additional sowings were made at Warwick of two serradellas (*Ornithopus*) and seven clovers (*Trifolium*).

Flowering responses to time of planting were of three types, viz. species in which low temperature accelerated flowering, eg. *M. truncatula* cv. Jemalong, species in which high temperature accelerated flowering, eg. *M. scutellata* cv. Robinson, and those with intermediate responses, eg. *M. polymorpha*. At Warwick the clovers as a group were later flowering than the medics, with the earliest of the clovers being similar to the latest flowering medic. Warmer sites tended to produce earlier flowering, with ranking from earliest to latest being Biloela < Roma < Gayndah < Warwick. The time to flowering in a species was shortened by up to 25 days at the warmest site (Biloela) compared with the coldest site (Warwick). This tended to assist the plants to set seed in marginal rainfall environments.

WRK P83 WR Fertilizers on medics on traprock (Stanthorpe)

The trial investigated the need for fertilizers for surface establishment of Jemalong barrel medic (*M. truncatula*) into native pasture on a shallow stony clay loam traprock soil. The treatments consisted of three P levels (0, 10, 40 kg/ha) x three S levels (0, 10, 40 kg/ha) x three S sources ('super and sulphur', bulk gypsum, 'Crop King' sulphur) and agricultural lime at 2500 kg/ha either alone or with P and S at 40 kg/ha. The medic was surface sown with the fertilizer.

Yield responses to P and S occurred with a positive interaction showing no response to P alone (420 kg/ha), large responses to S alone (1350 kg/ha) and largest responses to P and S together (2700 kg/ha). Maximum growth required P10 and S40. Crop King sulphur was inferior due to slow mineralization in cold weather. The % N in *M. truncatula* was not affected by application of P alone, raised by S alone, and raised from 2.12% to 2.98% by adequate P and S together. The % P was raised considerably by application of P alone, lowered considerably by S alone, and raised slightly from 0.19% to 0.22% by adequate P and S together. The % S was raised by super and sulphur which was enhanced by application of P, raised considerably by bulk gypsum from 0.10% to 0.23% regardless of P supply, and raised only slightly by Crop King sulphur regardless of P supply. Crop King sulphur was inferior when applied in June.

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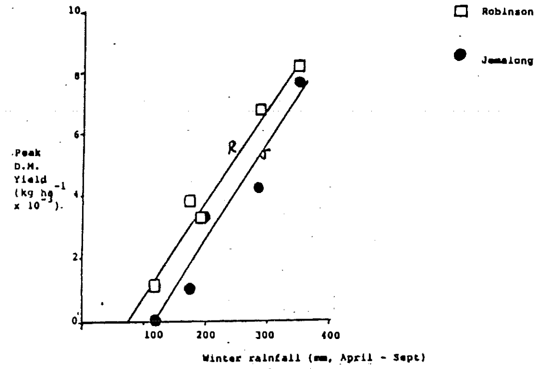
APPENDIX I

Relative importance of winter rainfall and soil-type in determining peak dry matter yields (kg ha^{-1}) of medics grown with grass. Equations show linear regression models, regression coefficients and statistical significance.

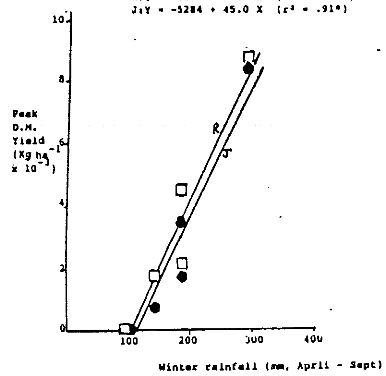
(a) Warwick black earth

R: Y = –2240 + 30.6 X (r^2 = .98 **)
J: Y = –3764 + 31.3 X (r^2 = .91 *)



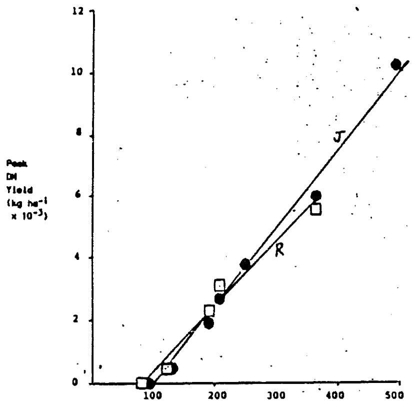
(b) Warwick sandstone

R: Y = –4677 + 44.7 X (r^2 = .91 *)
J: Y = –5284 + 45.0 X (r^2 = .91*)



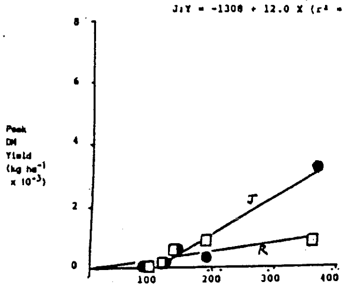
(c) Gayndah basalt

R: Y = –1802 + 21.2 X (r^2 = .98 **)
J: Y = –2591 + 25.5 X (r^2 = .99 **)



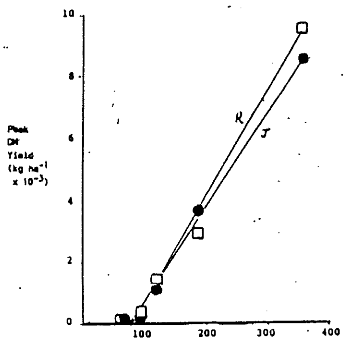
(d) Gayndah box solodic

R: Y = –21.2 + 2.7 X (r^2 = .52 N.S.)
J: Y = –1308 + 12.0 X (r^2 = .94 **)



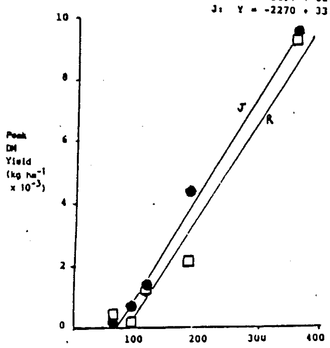
(e) Roma brigalow clay

R: Y = –2747 + 33.8X (r^2 = .98**)
J: Y = –2366 + 30.8X (r^2 = .99**)



(f) Roma box solodic

R: Y = –2697 + 32.3X (r^2 = .96**)
J: Y = –2270 + 33.1X (r^2 = .99**)



APPENDIX 2

List of QDPI projects receiving financial support from the A.W.C. at Warwick since 1969.

WRK-P56-WR	Lucerne fertilizer trial (Dalveen)
WRK-P72-WR	Pasture nursery on traprock (Karara)
WRK-P73-WR	Effect of two management treatments on the regeneration and yield of barrel medic (Texas)
WRK-P76-WR	Lucerne fertilizer trials on granite (Ballandean, Dalveen)
WRK-P77-WR	Studies of annual mediterranean legumes in relation to environment. I. Effect of time of planting on growth rhythm, morphology and seed production of annual medics (Warwick).
WRK-P78-WR	Seasonal production and growth rhythm of a range of legumes (Leyburn).
WRK-P82-WR	Flowering time in annual medics (Warwick, Roma, Biloela, Gayndah).
WRK-P83-WR	Fertilizers on medics on traprock (Stanthorpe).
WRK-P84-WR	Regional medic trials. I. Irrigated (Warwick, Gayndah).
WRK-P85-WR	Regional medic trials. II. Dryland (Warwick, Gayndah, Roma).
WRK-P86-WR	Regional medic trials. III. Dryland cultivar testing (Warwick, Gayndah, Roma).