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AGRONOMIC STUDIES ON FABABEANS
(*VICIA FABA*. L)

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STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and that, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due to reference is made in the text of the thesis. I consent to the thesis being made available for photocopying and loan if accepted for the award of the degree.

 **Titis Adisarwanto**

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ABSTRACT

The effect of date of sowing and density, on yield of faba beans, was studied in the winter-rainfall environment of southern Australia, where the opportunity for a farmer to sow early in the autumn is determined by the first effective rain of the growing season.

During 1985 and 1986 field experiments were carried out on the cultivar Fiord, the only cultivar widely grown in this region. In both years, similar experiments were conducted at the Waite Institute and the Charlick Experiment Station with four sowings at approximately four-weekly intervals in 1985 and three weekly intervals in 1986. The sowings ranged from 30 April to 1 August in 1985 and 24 April to 14 July in 1986. Sowings were made at densities from 20 to 50 plant m^{-2} , in both years. In 1985 the experiments included three levels of N fertilizer as a starter application with the highest level being 20 kg N ha^{-1} . Measurements were made on the phenology of plants, yield and the yield components. The pattern of development of seeds in pods and on plants sown at the different times was also studied.

Once the effect on Fiord of sowing date and density were understood, a field experiment was conducted in 1987 on twelve accessions of faba beans, that differed greatly in seed size with the main treatment being two sowing dates, 1 May and 3 July.

In 1985 and 1986 the rapidity of emergence of Fiord seedlings varied from 10 to 20 days for different dates of sowing, an effect attributed mainly to temperature. Early sowing occurred during warmer temperatures and led to a more rapid emergence.

In general, the number of days to the commencement of flowering or podding in Fiord was less with later sowing. First flowering occurred 75 days after an early sowing, and 50 days after a late sowing. Similarly, first podding was at 100 and 60 days for early and late sowing, respectively. However, there was evidence that if very early sowing was feasible in mid to late April, flowering might be accelerated in some years by the favourable climatic conditions of early autumn.

The period from sowing to physiological maturity in Fiord ranged from 114 to 205 with the different sowing dates. Following early sowing it was observed ; maturity occurred at a time when environmental conditions appeared favourable for continued growth and plants in other treatments were still green. In 1986, when evaluations were made for each treatment, there was a 53 days difference between the plants of the first and last treatments to mature.

The response in yield, dry matter production and harvest index, to variation in sowing date and density, resembled the responses commonly observed in all crop plants. In 1985, yields rose to a plateau at the high densities following early sowing, whereas with late sowing, yield increased more linearly with density. In 1986, when very early sowing (April, 24) was feasible because of early rain, there was abundant plant growth, and yield fell with density. The highest yield was obtained for the lowest density (6.8 t ha⁻¹ at 20.0 plants m⁻²). With later sowing yields did not vary with density, and then with the latest sowing, yield increased with density to a plateau. The yield component most closely associated with variation in yield was pod number but weight per seed also declined with late sowing.

The study which related the yield components, to the nodes of the plants showed that, with early, sowing the pods were more evenly distributed over the many nodes of large plants. With late sowing, pods were concentrated on fewer nodes and there were more pods per node, on those nodes where this concentration occurred. The number of seeds per pod was constant over many nodes with early sowing ; with slightly lower numbers in the first and last formed pods. With late sowing, there was a fall in the number of seeds over many of the upper nodes. Weight per seed was constant over all nodes, of early sown plants, but declined on the upper nodes with late sowing. Of these yield components only pods per node was clearly affected by density. At low density many more pods set on the lower nodes of the plants whereas at high density pods were more evenly distributed.

Seeds formed in the first pods, following early sowing, developed over a longer period of time and their rate of development was slower than for later formed pods of that sowing, and pods formed from later sowings. It was suggested this was due to differences in temperature and other environmental condition during the periods of development.

The twelve accessions, arranged into groups with small, medium or large seeds were variable in their phenological development for the two different sowing dates in 1987. There were no differences among the accessions in the number of days to emergence for a particular sowing date, although there was a marked difference between sowing dates.

There was a strong interaction in the number of days to first flower for the sowing dates, some accessions took longer to flower and other less time to flower when sowing date was delayed from 1 May to 3 July. The period from first flower to first pod and the period to maturity decreased with delay in sowing and differed among the accessions.

As a group the large-seeded accessions were higher yielding for both sowing dates. However there was a strong interaction between sowing date and accessions for yield. The percentage yield reduction with late sowing was much greater in small-seeded accessions. It was evident the large-seeded accessions had greater yield stability over different sowing dates. Some had much higher yield than Fiord. It was suggested the yield stability of large-seeded accessions was a result of the manner in which they produced their yield ; a few pods and large seeds.

The results of applying N fertilizer as a starter application were inconclusive and further studied are needed.

The Discussion highlighted the advantages of early sowing and the potential merit of large-seeded fababeans.

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CHAPTER 1

INTRODUCTION

Fababeans (*Vicia faba* L) are a relatively new crop in southern Australia. The first cultivar bred in Australia was Fiord, which was released in 1980. The area devoted to fababean production has grown rapidly ever since. At present the two grain legumes that are grown, particularly in rotation with cereals, are peas and lupins. Fababeans offer the opportunity for an additional crop, able to yield well in environments where peas and lupins are not satisfactory because of diseases or unsuitable soils (Knight, 1982). They are more tolerant of wet soils than lupins, peas or cereals (Laurence, 1979).

Much of the published information about fababeans is the result of studies in northern Europe and is not relevant here because of climatic differences between Europe and southern Australia. The growing season in Australia begins with the autumn rains and later in the year the reproductive phase of the crop coincides with the coldest and wettest part of winter, unlike northern Europe where temperatures and radiation increase during the reproductive phase (Lim, 1978). When a new cultivar is developed or introduced into a region, appropriate agronomic practices must be developed, including the optimal sowing time and plant density to achieve high yield. So far, the research on fababeans in Australia has concentrated mainly on breeding and much less has been done on agronomic practice. The two factors that most easily and cheaply can be varied by farmers are sowing time and density.

Elsewhere it has been shown that sowing time affects the duration of the vegetative and reproductive stages and contributes to differences in yield (Ageeb, 1979 ; Krarup, 1984). There is some information on the effects of sowing time on yield of fababean in southern Australia. Sowing in late May (the earliest of his treatments) was the best according to Baldwin (1980), but yield losses from late sowing were not fully

quantified. Until now, there has not been enough evidence as to whether low yield from late sowing is caused only by a lower number of pods per plant or indirectly as a result of a shorter pod filling period, fewer flowers, a lesser number of seeds per pod or smaller seeds. If it were smaller seeds it would have consequence for marketing and possibly for resowing of the crop.

Fababeans are grown over a wide range of seeding rates and plant densities. But the optimal density is expected to vary with genotypes, edaphic and environmental conditions. It is already known from research elsewhere that as plant density increases above a certain level, yield per plant may decline as a result of decreases in the number of pods, the number of flowers, the number of branches and the number of seeds per-plant (Newton, 1977 ; Pandey, 1981a). The optimal plant density may be different for each time of sowing as a result of differences in the yield components.

The development of nodules in *Vicia faba* depends upon environmental conditions : soil type, pH, temperature, moisture, and fertility as well as cultural practices. It is well known that nitrogen fertilizer applied to legumes decreases nodulation and the nitrogen fixation rate (Mc Ewen, 1970 a ; Dean and Clark, 1980 ; Richard and Soper, 1982). But nitrogen fixation alone may not be sufficient to support maximal plant growth, especially in the first weeks after emergence. This study is mainly concerned with the effect of time of sowing and density on the yield of various genotypes of faba beans with some studies on the effects of a starter application of N fertilizer. The initial emphasis was on Fiord, but once the results for Fiord were obtained other studies were undertaken on a range of genotypes.

CHAPTER 2

LITERATURE REVIEW

This study was commenced early in 1985 and the literature review deals with research findings published to that date. Subsequent papers are considered in the final Discussion at the end of the thesis where they are related to the findings of this study.

Yield per unit area in faba beans can be considered in terms of the product of the density and the yield components, pods per plant, seeds per pod, and weight per seed. In addition to understanding yield components, information is needed on the indirect factors related to yield, such as the date of commencement of flowering and podding and the number of nodes bearing pods on the stem. All these factors are affected by genotypic variation and environmental conditions.

2. 1. Effect of sowing date on growth and development.

As faba beans are grown in many countries of the world, under very different environmental conditions, it is not possible to generalize about the effect of sowing dates except to say that sowing date has a large effect on yield of the crop and that usually a prolonged flowering period results in high yield. Optimal dates for spring or autumn sowing in various countries are presented in table 1.

The reduction in yield from late sowing is related to insufficient plant development before flowering, leading to pod abortion (Rowland, 1978). In western Canada, sowing date was found to be a more important factor than seeding rate in affecting yield (Mc Vetty *et al* , 1986).

In the Sudan, the earliest part of the potential growing season experiences high temperature and there is a likelihood of disease (Salih and Ageed, 1983). If sown too early there is a lower yield, due to a reduced stand of plants . The higher temperature not only made the plants more susceptible to wilt and root rot (Freigoun, 1980) but also

affected emergence and growth. When sowing was delayed from October 10 to October 20, grain yield was significantly increased, due partly to an improvement in plant establishment (Salih and Saxena, 1983 ; Mohamed, 1985). Salih (1982) and Mohamed (1986) found that the optimum sowing time was from 15 Oct to 12 Nov resulting in taller plants , more branches per plant , more pods per plant , heavier seeds, and higher yields than later sowing dates. The yield losses that occurred if sowing was delayed until late November was partly attributed to the incidence of powdery mildews (Last and Nour, 1961).

In France, early sowing in spring was recommended in order to reduce the chance of water stress and high temperatures during flowering and pod setting in summer (Berthelem, 1980). In southern Italy, which has an environment similar to South Australia, an autumn sowing was preferable to a spring sowing as it allowed the plants a longer growing season , a better utilization of water , and gave higher yields and increased protein (Zilotto and Tonioto, 1979, 1982). Similarly in Turkey, the yield of 25 genotypes sown in autumn had higher yields than when sown in spring (Tosun *et al*, 1984). The authors suggested that this was probably due to soil temperatures being higher than air temperatures during the winter. Soil conditions in the autumn were more favourable for root growth and penetration, and the crop was less affected by drought. The autumn-sown plants started to flower 20 - 25 days earlier than spring-sown plants, but reached maturity only 2 - 3 days earlier. Thus, the reproductive growth phase was longer following an autumn sowing.

In northern India, a delay in sowing was responsible for reducing the number of days to flowering and maturity , sharply reducing yield and this was associated with a reduced number of podding nodes and number of pods per plant (Pandey, 1981 b). In Chile, the growing period from planting to harvest was shortened from 146 days in an early sown crop to 89 days in a late sown crop and this had a strong effect on yield and plant growth (Krarup, 1984).

In southern Australia which has a Mediterranean type of climate, Baldwin (1980) found that sowing after the end of May resulted in a yield reduction of about 50 percent

for each week's further delay in sowing. In northern New South Wales Australia, if sowing is delayed after the end of April, grain yield is reduced, as is the plant dry matter and duration of pod filling. The later sowing also resulted in a reduction in the height above ground of the first pod and increased the likelihood of yield loss through foliar diseases (Marcellos and Constable, 1986). In Ireland, although the highest yields were recorded at the second sowing, which was about 10 days after soil conditions were first considered suitable, the yields were not significantly different from the first (Barry and Storey, 1979). They suggest that, it is better to wait until the weather and soil conditions improve. The results show that there were differences in the flowering and subsequent podding pattern as sowing date varied and the number of seeds per pod increased at the later sowings.

The number of pod-bearing nodes per plant and the number of pods per pod-bearing node together determine the number of pods per plant, and each of these components was markedly affected by sowing date (Thompson and Taylor, 1977). The relation between dry weight, leaf area index and sowing date in England was studied by Fasheun and Dennett (1982) who found that sowing in early July (mid summer) resulted in a faster growth rate and an eventual higher LAI than sowing in mid August. The August sown crop experienced a shorter daylength, less radiation, less frequent rainfall, but about the same mean temperature as the previous crops. The earlier sowing resulted in a larger seed size (Thompson and Taylor, 1977).

Other characteristics such as : seed protein concentration (Rowland, 1978 ; Mc Vetty et al, 1986), carbohydrate (El Rachman et al, 1980 ; Kodra, 1975), seed hull percentage and cookability (Ali and Ali, 1983), were not significantly affected by sowing date. But 1000 seed weight, the number of seeds per pod (Salih, 1983 ; Krarup, 1984 ; Tosun et al, 1984) and the number of flowers produced (Hanna and Lawes, 1967) all declined with later sowing.

As indicated above there is considerable information overseas about the effect of sowing time on plant development and the yield of fababeans in different regions. The optimum sowing time in a region depends on the agroclimatic conditions. Sowing

should take place when soil structure, temperature and rainfall are adequate to ensure good emergence and further growth. In South Australia, the ability of a farmer to sow early is determined by the incidence of rainfall necessary to prepare a seedbed and maintain early growth. Early sowing, in turn will influence the date of flowering and duration of the pod filling period.

Table 1. Optimum sowing dates for spring and autumn in various countries

Sowing	Country	Recommended sowing time	Reference
Spring	Canada	early to mid May	Kodra , 1975 Rowland, 1978
	China	March to April	Huan-xian, 1982
	United Kingdom	late February to mid March	Thompson and Taylor, 1977
	France	February to March	Plancquaert , 1978
	Northern Italy	mid February to early March	Ziliotto and Toniolio, 1979
	Southern Chile	end July to mid September	Krarup, 1984
	Turkey	early March	Tosun <i>et al</i> , 1984
	Mexico	February to end March	Osoria, 1983
Autumn	South Australia	end May	Baldwin, 1980
	New South Wales	end April	Marcellos and Constable, 1986
	New Zealand	March	Newton and Hill, 1977
	Sudan	mid to end October	Salih, 1982 Ageeb, 1979
	France	mid October to mid November	Plancquart, 1978
	Northern India	October	Pandey, 1981
	Northern Italy	mid to end October	Ziliotto and Olivieri, 1982
	Egypt	mid October to mid November	Ibrahim <i>et al</i> , 1982
	China	end October to early November	Huan-xian, 1982
	Spain	September to November	Moreno and Cubero, 1982

2. 2. Effect of photoperiod and temperature on flowering.

The faba bean (*Vicia faba* L) is widely grown in temperate and sub tropical regions from China to Brazil and from Oceania to Canada (Bond *et al*, 1985). It can be grown as a winter or spring season crop and as a summer crop at high elevations within the tropics (Hawtin and Hebblethwaite, 1985). The range of its cultivation extends from 0° to 60° latitude and from the sea level to more than 3000 m. The duration of the cropping season varies from three months in the Sudan and Canada to about 11 months for the winter crop in N.W. Europe (Bond *et al*, 1985). Crop development will vary according to the temperature and photoperiod, genotype and sowing date. Variations in photoperiod and temperature become increasingly important away from the equator and temperature effects on the crop change with altitude (Saxena, 1982).

Whether or not grain legumes make the most productive use of the growing season available depends to a large extent on when they come into flower, the number of nodes which become reproductive and whether their growth habit is determinate or indeterminate (Hadley *et al*, 1983). In the Mediteranean region, Moreno and Martinez (1980) found that the winter types of cultivars from more northern parts of Europe did not yield or even flower because of their requirement for low temperature and long photoperiod. Information on the effect of temperature and photoperiod on growth, development and yield of the crop is necessary to understand adaptation to various environments (Summerfield and Wien, 1980). In the present study of the agronomy of faba beans in southern Australia, with its Mediterannean type of environment, some consideration will be given these and other characters that determine yield of the crop. However studies conducted elsewhere, and mainly in controlled environments, that evaluate the effects of temperature and photoperiod have some relevance to the results obtained in my field experiment.

2.2.1. Photoperiod.

The effect of photoperiod on flower induction, and on the node of the first flower depends upon the cultivar, time of sowing, and location. Two major groups of response to photoperiod have been defined in plants : (1) flowering is hastened with increases in daylength longer than 12 hours and (2) the flowering occurred with decreases in daylength less than 12 hours (Summerfield and Wien, 1980). Many studies have shown that faba beans are quantitative long day plants (Evans, 1959 ; Moursi and El-Gawad, 1963 ; Pandey, 1981 a ; Skjelvag, 1981 a ; Hadley *et al*, 1983). In Europe the crop usually experiences lengthening days and increasing temperatures during the pre-flowering period (Hadley *et al*, 1983). In England, Evans (1959) when studying the response of four stocks (ranging for early Dutch Weir spring beans to the late flowering Bullock winter beans) to increasing photoperiod from 8 to 24 hours, observed that unvernallized plants showed a quantitative long day response in diurnal temperature regimes of 17°C or 23°C. The earliest flowering Dutch Weir showed a significant reduction in time to flowering with increase in photoperiod from 8 to 12 hours. In the latest flowering cultivar, Garton's giant winter beans, there was no flower initiation at either 8 or 16 hour- photoperiod at 17°C or 23°C, unless previously vernalized. This highlights the importance of both temperature and photoperiod in flower initiation , particularly in the late maturing types (Saxena, 1982).

A study of the interaction between vernalization and photoperiod confirmed that the flowering response to photoperiod was affected by temperature (Saxena, 1982). In Egypt, Moursi and El-Gawad (1963) indicated that increasing photoperiod accelerated flowering. Extending photoperiod from 6 to 16 hours reduced the number of days required for flowering from 105 days to 62 days. However, at ICARDA, Saxena (1982) found that extending the photoperiod to 16 hours from normal 9.5 to 10.5 hours did not change markedly the number of days to first flower in six European cultivars (4 spring and 2 winter types) and six diverse Mediterranean cultivars.

2.2.2. Temperature.

Temperatures prevailing during the pre-flowering period in faba beans affect not only the rate of vegetative growth but also the time of initiation of flower buds and their subsequent expansion as flowers. Flowering is usually recorded as the number of days from sowing until the appearance of the first flower or until 50% of the plants flower (Hadley *et al*, 1983). The flowering response to temperature is complex. At least three process, affected by temperature, appear to be involved in the initiation of flowering ; vernalization which is favoured by low temperature, dark inhibition, and a post vernalization process affected by high temperature.

Evans (1959) showed that vernalisation affected the flowering of Bullock winter beans. An increase in the length of exposure to low temperature from 1 to 4 weeks resulted in a linear acceleration of flowering, but further increases in the duration of vernalization delayed flower initiation. A similar effect was shown by Saxena (1982) with 12 different cultivars of European and Mediterranean origin. Under natural daylength (approximately 10 hours) in a heated plastic house in which the mean maximum and minimum was 24°C and 15 ° C, node to first flower decreased when vernalization at 5° was increased from 0 to 48 days. As well as inducing earlier flowering, vernalization caused the first flowers to be borne at a lower node of the plant and this effect was similar in both winter and spring types (Chakravarty *et al*, 1957). Similarly, Saxena and Wassimi (1979) reported that vernalization of seed hastened flowering while the node of the first flowers on the plant were slightly different.

Pandey (1981b) found that flower initiation, as indicated by the node number of the first inflorescence, was significantly promoted by low temperature during the early stages of development. On the other hand flowering was promoted by long days and warm temperature. It also has been shown that very high temperatures inhibit the flowering stage. Various studies have supported these general conclusions but have not given identical results. Skjelvag, (1981a) found that the period from flower initiation to the day of first flower anthesis was consistently shortened by temperatures rising above

18°C to 24°C . Hadley *et al* (1983) concluded that the onset of flowering in early maturing varieties was unaffected by photoperiod but strongly affected by mean temperature. The flowering of later maturing varieties was delayed by shorter days; warmer temperatures hastened flowering when combined with an appropriate photoperiod. High temperatures may have an inhibitory effect. For example, at temperatures above 14 °C, and particularly above 23° C, flower initiation was inhibited (Evans, 1959). In growth chambers with temperatures at 30°C during the day and 23° C at night, plants flowered late and produced fewer open flowers per node. (Abdalla and Fischbeck, 1978).

Schroder (1984) compared two minor (small-seeded) with one major (large-seeded) cultivar in growth chambers with combinations of 11000 and 21000 lux with 30/24° C and 22/16°C, he found that flowering differed widely between cultivars and that some cultivars had fewer flowers at high temperature. The rate of flowering, expressed as the number of podded nodes per day during this period, increased with temperature in the same way as the rate of leaf appearance during the flowering period.

Because temperature may influence the number of days to flowering and because it fluctuates daily in natural environments, the concept of growing degree days was developed (Arnold, 1959, Robinson,1971, Greenwood et al,1974, Davidson and Campbell, 1983, Rajput,Deshmukh and Paradhan, 1987). The equation used to calculate growing degree days is

$$\text{GDD} = \frac{(\text{max temp} + \text{min temp}) - (\text{base temp})}{2} \times \text{days. (Arnold, 1959)}$$

Basically, GDD is an accumulation of various daily temperatures during a growing period.

2.2.3. The joint effect of temperature and photoperiod on progress towards flowering.

Very many studies have been conducted at Reading University, U.K on the effects of temperature and photoperiod on flowering in the grain legumes. Much of this work was reviewed by Roberts and Summerfield (1987). They refer to a photothermal model proposed by Hadley, Summerfield and Roberts (1983) which relates days to flowering (f), to the mean diurnal preflowering temperature (T), and the mean diurnal preflowering photoperiod (P). They have found there is often a linear relationship such that

$$1/f = a + b T + c P$$

where a , b and c vary with genotype.

The lower limit, or base temperature at which no progress towards flowering occurs is the value of T when $1/f$ is zero. They state a linear regression is usually obtained on temperature up to an optimum in the absence of the complicating factors of vernalization and photoperiod. A negative linear regression is obtained for supraoptimal temperatures. In long-day plants, $1/f$ increases linearly with photoperiod. They also state that in most instances there is no interaction between the temperature and photoperiodic effects.

Most of their studies have been conducted in controlled environments. When vernalization is being assessed the vernalization is a clearly defined treatment of exposing seeds to continuous low temperatures for many days. Far fewer analyses have been conducted on results from natural environments where temperature and photoperiod fluctuate.

2. 3. Effect of environment on pod development.

Many studies have shown that yield in fababeans is largely determined by the number of mature pods per unit area (Seitzer and Evans, 1973 ; Kambal, 1969 a ; Ishag ,1973 a). There was a very close relation between the number of pods and number of seeds per plant (Lim, 1978). Thompson and Taylor (1977) concluded from an experiment on sowing date and plant density that the most stable component of yield was the number of seeds per pod and the least stable component was number of pod-bearing nodes per plant.

The number of pods harvested in leguminous crops is generally a small percentage of the number of flowers. A reduction in flower and pod abortion may increase yield (El-Fouly, 1982 ; Keller and Bellucci, 1983) and improve the stability of yield (Salem et al, 1983). In fababeans the number of flowers that set pods varies. Values have been found to be between ten to twenty percent (Soper, 1952 ; Hodgson and Blackman, 1956), five to fifty percent (Kambal, 1969 a) and thirteen to twenty percent. (El-Antably, 1976). A low percentage and variation between location may be due to a lack of pollinating agents (Rowland, 1961 ; Free, 1966), self incompatibility, unfavorable conditions, drought, waterlogging, mineral nutrition or soil physical factors (El-Fouly, 1982 ; Thompson, 1983), or other physiological and genetic factors in the plant (Newaz and Lawes, 1980). For example, Kellerhals and Keller (1984) by using plant regulator combinations of GA₃, GA_{4/7}, BA, NAA, ABA, Atrinal and Alar concluded that BA and NAA seem to play important roles in the abscission of flowers and pods. In England, Smith (1982) found that abscission was affected by shading during late flowering and early pod set. Most abscission was due to bud abortion on the upper positions of each raceme. However, it is also known that an inadequate water supply particularly at the end of the flowering period, favours pod abscission (Kambal, 1969 a).

The number of flowers that produce pods is affected by both drought and waterlogging (El Nadi, 1969 ; Jones, 1963 ; Tamaki and Naka, 1971), but the number

of seeds per pod is relatively insensitive to these conditions (El Nadi, 1970 ; Tamaki and Naka, 1971). Jones (1963) found that the number of pods was less when plants were grown in soil with a water table at 0.05 m or 0.56 m depth compared with 0.25 or 0.35 m. Thus if the water table was too high or too low there were fewer pods. It has been suggested that the high levels of ABA associated with water stress may be a factor in flower abscission (El-Beltagy and Hall, 1975). The conclusion must be that drought can affect all the components of yield, and that the timing of the drought determines which components are affected. However, the crop is able to compensate to some extent for loss of pods by increasing the mean seed weight if more water is available later (Day and Legget , 1983). El-Antably (1976) found that a CCC application at 250 mg l⁻¹ given a week before and at flowering resulted in a decrease in shedding of pods by 3.25% .

It has been suggested that an increase in pod number on the main stem should be an objective in cultural practice. Yield per main stem reproductive node was most closely associated with the number of pods (Newton, 1979). Intra - plant competition for nutrient supply and growth regulators between ovaries and between young pods could be important in reducing pod set (Kambal, 1969 a). There is strong competition among pods and seeds on the stem of a plant. The establishment of competing ability seems to depend on the order of pollination of the pods and Kogure (1981) found that the stems of plants behave essentially independently, and make a source-sink unit within one stem. Some authors have found that over 80 percent of the flowers and pods were on the middle to lower part of the main stem (Zeng, 1982 ; Ishag, 1973 a ; Adcock and Lawes, 1976). However, compensation for number of pod bearing nodes by number of pods per node has been shown to result from competition for light at different times during development of the plant (Thompson and Taylor, 1982). Shading during early pod set at lower nodes of the crop reduced the number of flowering nodes by inducing bud abortion, probably as a results of enhanced competition for assimilates between pods and developing buds (Gates *et al*, 1983).

Physiological maturity denotes the time when the seeds reach maximum dry weight. The weight of the seed remained constant when seed moisture content fell to 15 percent (Davies and Williams, 1986). Stulpnagel (1984) proposed a key for growth stages of faba beans in which maturity was the stage when all pods were darkly colored (seed in the last developed pod could still be cut with fingernail), and a stage of drying off, with complete straws ripeness and the seeds hard. The change in colour of the maturing cotyledon from a deep green to a pale buff is probably due to the loss of chlorophyll and breaking down of amyloplast grana since these two processes appear to run in parallel (Briarty *et al*, 1969). This stage occurred at about four weeks (Dantuma *et al*, 1983), 65 days (Davies and Williams, 1985) or 60 days after first flowering (Boulter and Davies, 1968 ; Barratt, 1982). The period of constant growth rate, associated with cell expansion and cell division (Millerd and Whitfeld, 1973), varied depending on the cultivar and temperature from 25 to 90 days after flowering (Briarty *et al*, 1969 ; Millerd and Whitfeld, 1973 ; Dekhuijzen and Verkerke, 1986). Final seed weight was related both to pod size (length and width) and seed number. The rapid drying out of pods associated with physiological maturity was under internal control and partly independent of the environment (Davies and Williams, 1985).

The process of development of the seed starts at day 11 when the cotyledon is 1mm in width (Davies and Williams, 1985). The cotyledon was completely formed by 85 to 90 days, following which there was water lost until the seed became hard and ripe by 110 days after flowering (Briarty *et al*, 1969).

Growth, dry matter production and maturation of pods depend on the cultivar and environmental conditions such as a temperature and water supply (Dekhuijzen and Verkerke, 1986). An increase in temperature, accelerated pod and seed development, and stimulated dry matter accumulation, starch and protein synthesis. However, the time to maturation of seed was shortened, resulting in lower weight per seed (Dekhuijzen and Verkerke, 1986).

It appears that the time taken by a seed to attain maturity depends (a) on genotype, (b) on its position on the plant, (c) on the time of flowering and (d) on climatic conditions during its growth.

Effect of plant density on plant development.

In a crop, a main determinant of plant development and yield per unit area is plant density. Some generalisations about the relation between plant development, yield and density were reviewed by Donald (1963). It is common to find that early in the life of the crop, biological yield per unit-area (biomass, or dry matter production) increases linearly with density but later, and beginning with the highest densities, biological yield shows a plateau in regard to density. Progressively with time, the lower densities reach the same plateau. In contrast, grain yield per unit area increases with density, to an optimum and falls at very high densities. The optimum density for grain yield is usually the minimal density that results in the plateau of biological yield. Because grain yield falls at very high density, when biological yield has plateaued, harvest index will also fall with these high densities. At present there is no evidence to suggest that the biological yield, grain yield or harvest index of faba beans will not conform to these generalised findings on the effects of density on crops. The only additional factor in the response of faba beans might be that density could affect the activity of bees, where this is important for pod set.

Many authors have found that yield, and its components, in faba beans were affected by plant density and that the optimum plant density for yield varied with genotypes and environments (e.g. Ishag, 1973 a). As this is to be expected there is little merit in reviewing in detail all the instances of yield/density relations, instead some indications of the range in optima will be considered. Pandey (1981 a) working in India with densities ranging from 11 to 133 plant m^{-2} found that dry matter production (ie biomass) was linearly related to plant density 85 days after sowing but, by 115 days the total dry matter weight was the same for all densities above 66 plant m^{-2} . During early growth, relative growth rate was the same for all densities. In England, Hodgson and

Blackman (1956) found that the optimum density was 35 - 45 plant m^{-2} for winter-types and 67 plant m^{-2} for spring-types.

Ingram and Hebblethwaite (1976) summarised the relationship between yield, density and sowing time in England. Most of the 41 experiments on spring beans were within the population range of 37.0 to 49.0 plant m^{-2} . Only nine experiments with small-seeded beans and two experiments with large seeded beans had treatments exceeding 74.0 and 49.0 plant m^{-2} respectively. With both types of beans a diminishing yield response to increasing plant population up to 86.0 plant m^{-2} was obtained. This effect was more marked with large-seeded types (ie. Horse beans). In both types the response changed very little at the highest densities and density may have approximated the optimum .

Ingram's (1976) results for the yield response of cultivars to density (Figure 1) showed the cultivars differed in the two years. These curves also indicate the highest density was not sufficient to define the optimum and highest possible yield.

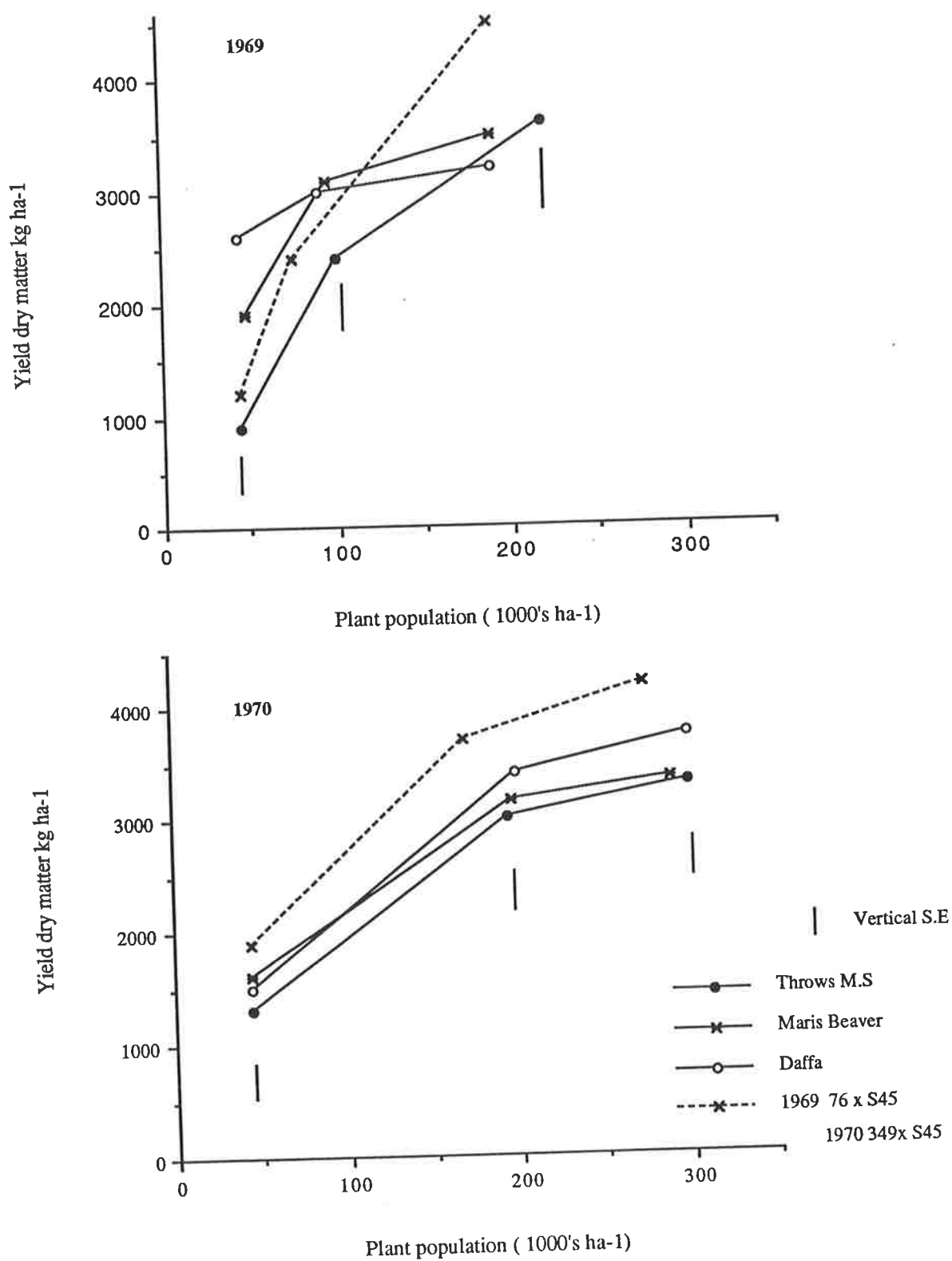


Fig 1. The response of yield to plant population for individual varieties in two years (from Ingram's 1976)

With winter sown beans, when disease did not occur, the yield response was similar to that for spring beans. But, when the disease chocolate spot was severe, yield decreased as plant population increased. The growing season of winter beans is three months longer than for spring sown beans and this affected their yield/density relations. The crops sown at a low density in spring probably did not have sufficient time to reach their full yield potential. Ingram and Hebblethwaite (1976) concluded that there are three factors which reduce yields of dense crops : diseases, a reduction in insect pollination and lodging. Stringi *et al* (1986) found 30% of plants lodged at 30 plant m^{-2} and about 90% at 100 plants m^{-2} .

The effect of density on yield has been mainly attributed to changes in number of pods per plant (Soper, 1952 ; Hodgson and Blackman, 1956 ; Last and Nour, 1961 ; El-Saeed, 1968). In New Zealand , increasing plant density from 20 - 65 plant m^{-2} reduced the number of pods per node (Newton, 1979). Plant density had little affect upon the number of seeds per pod or the mean seed weight (Hodgson and Blackman, 1956 ; Ishag, 1973 a ; Switzer and Evans, 1973 ; Sprent *et al*, 1977 ; Pandey, 1981a ; Salih, 1985). Thompson and Taylor (1977) found that number of seeds per pod from two genotypes, one *Vicia faba equina* and the other *Vicia faba minor* were stable in different densities. However, Day *et al* (1979) found that weight per seed increased as density increased from 9 to 13 plant m^{-2} and then remained constant between 13 and 98 plant m^{-2} .

Poulain (1984) found that increasing density resulted in increases in plant height, and leaf area index but decreases in the number of branches. The number of nodes did not change, and the number of leaves per stem was constant. Therefore, variation in stem number per plant, or per square metre, explained the differences in leaf area index among densities (Poulain *et al*, 1986). Similarly, Hodgson and Blackman (1956) reported that plants at the highest densities were tallest due to an increase in mean internode length and not to a change in internode number on the main stem. High density also increased flower abscission, especially in the middle and distal

position on each raceme (Smith, 1982). On low fertility soils, the increase in the number of branches with increasing plant densities is less than for high fertility soils and because of this variation. Soper (1952) found there was no direct correlation between plant density and the number of branches per plant or yield.

El- Zahab *et al* (1981b) found an increase in LAI and CGR at high densities. Ishag (1973 a) found LAIs varying from 4.9 to 6.4 for various cultivars while Fasheun and Dennett (1982) reported a maximum LAI of 8.5.

Competition for light is often a significant factor with variation in density and can affect the number of pods as well as delaying pod maturity. Hodgson and Blackman (1957) found that at high densities (55 to 65 plants/m⁻²), during the early ripening phase, about 60 percent of the light may be intercepted by the upper leaves of the canopy and less than 10 percent may reach the lower leaves. In low densities (11 to 12), 30 percent reached the lower leaves or the soil surface. Their results indicated that by the time of full flower there was no difference in light intensity at ground level between the low, medium and high densities. They also concluded the pattern of water use was affected by plant density. At high density, evapotranspiration was greater than at low density, early in the life cycle, so that it was more likely to deplete soil moisture and suffer water stress at the time of pod filling when rainfall was limited at the end of the growing season. Greater competition for light as population density increased reduced assimilation per plant and resulted in a reduced numbers and weight of seeds per plant (Dantuma and Thompson, 1983). Sprent *et al*, (1977) found that normal variation in soil moisture was a more important factor affecting yield than solar radiation.

Density affected the amount of carbon assimilated by leaves in different positions on the stems (Crompton *et al*, 1984). Poulain *et al*, (1986) found that for high densities the environmental conditions in which the plants grew may increase the rate of photosynthesis or reduce respiration and photorespiration resulting in a better net photosynthesis. Plant density also affects the length of the growth cycle. Ripening

occurred 5 to 7 days earlier at the highest density (100 plants m^{-2}) compared with the lowest density of 5 plant m^{-2} (Stringi *et al* , 1986).

Besides the many direct characters related to plant habit affected by plant density, Thompson and Taylor (1977) found that density affected harvest index and protein. However, Stringi *et al* , (1986) concluded there was no effect on protein or ash contents of the seed .

2. 6. Effect of bee activity on pollination.

Fababeans (*Vicia faba* L) are entomophilous. Both self and cross pollination occur as a result of insect-tripping of the flowers. It is only when collecting pollen that the bee enters the flower and acts as a pollinator (a) in setting off the tripping mechanism, thus releasing pollen, and (b) in carrying on its body pollen from other flowers (Scriven *et al*, 1961).

In England, cross pollination is affected by bumble bees (*Bombus spp*) and honey bees (*Apis mellifera*) (Soper, 1952 ; Williams, 1986). The amount of crossing in a crop was associated with suitability of the locality for these bees (Bond and Pope, 1974). Free and Williams (1974) found that when colonies of honey bees are placed short distances away from crops rather than beside them, the proportion of bees that visit the crop is diminished. In France, the most efficient pollinators are the long tongued bumble bees (*Bombus hortorum*) and solitary bees (*Eucera* and *Anthophora*) (Berthelem, 1980). In fababeans visited by honey bees and long tongued bumble bees 66 to 70 percent pod set occurred. In contrast, the short tongued bumble bees produced only about 37 to 45 percent pod set (Kendall and Smith, 1975). The insect responsible for pollination in southern Australia is under investigation and to date, feral honey bees are the only pollen vectors seen working the flowers (Stoddart and Bond, 1987).

Honey bees make three types of visit : to the extrafloral nectaries only, to obtain nectar through holes at the flower bases, and by entering the flower to collect pollen (Free, 1962). The proportions of these different types of visits varies from day to day and at

different times of day. Some bees visit one crop for nectar and another for pollen at different times (Ribbands, 1949). Usually, bees bring pollen in contact with the stigma and rupture the stigmatic surface, releasing an exudate (Pace *et al*, 1985). The estimate of natural cross pollination ranges from 2 to 84 percent, indicating bees do not lead to complete self or cross pollination (Bond and Poulsen, 1983). However, the number of seeds per pod produced depends upon the tripping of flowers by bees (Poulsen, 1977). Sometimes, insect pollination is inadequate (Free, 1966 ; Free and Williams, 1976), because there are too few bees or too many flowers (Hanna and Lawes, 1967). A survey of commercial crops of winter beans in England found that as few as 17% of the flowers may be fertilized, particularly in the first three weeks of flowering, and the distribution of pods on the plant suffered as a result (Stoddard, 1985). On the other hand, Reidel and Wort (1960) concluded plants could not produce mature pods in more than about one-third of their flowers although more than one-third were pollinated. Such a low level of fertility, therefore, does not necessarily indicate insufficient pollination. Scriven *et al* (1961) found there was a higher incidence of pod drop in self-pollinated plants.

The success of cross pollination by bees depends on the openness of the flower, the number of flowers, and the time the flowers are open. The percentage of flowers pollinated by bees is constant regardless of flower colour, plant density, plant morphology or flower size (Stoddard, 1985). The major factors determining the efficiency of pollination are whether there is a uniform daily distribution of flowers that are open, the duration of their open time, as well as the intensity of bee activity in a crop. The opening of new flowers showed a peak between 1500 and 1700 h, but the number of flowers opening increased from 0900 to 1500 h and then decreased (Synge, 1947 ; Percival, 1955 ; Pace *et al*, 1985). Bee visitation declines late in the flowering season as the number of flowers is reduced (Stoddard and Bond, 1987).

The efficiency of pollinating agents is affected by climate and other environmental conditions (Kendall and Smith, 1975 ; Free and William, 1976). More bees foraged on the sunny side of trees than on the shady sides (Free, 1960). In view

of the dependence of faba beans on bees, weather factors that affect bee activity might also affect the amount of cross pollination and pod set. Windy conditions, approaching storms, and wet conditions following rain are all unfavorable for bee activity (Eckett and Shaw, 1960). Burrill and Dietz (1981) concluded that temperature and radiation are the major factors in the weather influencing honey bee activity. The optimum temperature was about 33 °C (Grout, 1949). Bee flight activity was low when temperature fell below 13 °C (Langridge and Jenkins, 1970).

Scriven *et al* (1981) indicated that cross pollination is to some extent associated with plant density. Plants grown in wider rows obtained more light, tended to flower better and were more accessible to honey and bumble bees. Stoddard (1985) however, showed that plant density had no effect on pollination.

2. 5. Effect of nitrogen fertilizer on growth.

Fababeans, have the potential to produce large quantities of protein about 23 to 39 % of the weight of grain (Evans *et al*, 1972 ; Barratt, 1982 ; Simpson, 1983). In England, seed yields of 4820 kg ha⁻¹ contained 229 kg N ha⁻¹ as protein in the seed (Mc Ewen, 1970 b).

For growth and development, the plant has symbiotic nodules and the development of individual nodules on a plant is influenced by root temperature (Gibson, 1971) and moisture (Masefield, 1961). In controlled environment cabinets Fyson and Sprent (1982) found that nodule infection, initiation, differentiation, and rate of growth of nodule occurred more slowly at low temperature (10°C) than at high temperature (18°C). The period from nodule initiation to the commencement of fixation was 18 days at 10°C but only 5 days at 18°C. At 6° C in the laboratory, Andrews *et al* (1985) found that fully functional nodules will not form and previously formed nodules show a low rate of fixation. In contrast, at high temperature in a green house, additional nitrate increased the growth rate of nodulated plants (Hill-Cottingham and Lloyd-Jones, 1980).

The sensitivity of nodules and fixation to water availability has been demonstrated clearly by Gallacher and Sprent (1978) who found that cultivars responded differently to an excessive water regime, but Sprent (1972) showed that, in the field, fixation was greatest when the soil was at field capacity.

Nitrate is the form of nitrogen most commonly taken up by plants. In Syria, on a clay-loam soil with pH 8.5, the yield of fababeans increased with an application of 20 kg ha⁻¹ as starter nitrogen (Saxena, 1982). In the same region, a dose of 20 kg ha⁻¹ nitrogen had a small effect on yield when applied 30 or 60 days after sowing (Saxena and Wassimi, 1980).

In Canada, forage and seed yields of nodulated fababeans were not increased by applied nitrogen at seeding whether it was broadcast up to 300 kg nitrogen ha⁻¹, or placed at 67.0 kg nitrogen ha⁻¹ (Richard and Soper, 1982). However, there was an effect from 300 kg nitrogen ha⁻¹ on seed protein content. In the same region, 20 kg nitrogen ha⁻¹ placed near the seed at sowing did not affect nitrogen fixation (Clark, 1980). On a very sandy loam, the addition of 20 kg ha⁻¹ nitrogen applied with the seed at sowing depressed nodulation (Dean and Clark, 1980). Fertilizer appeared to delay fixation (Dean and Clark, 1980). Mc Ewen (1970 b) found that various forms of nitrogen fertilizer inhibited nodulation by up to 50 percent.

On saline and alkaline soils in the Sudan, Yousif (1983) found that yields were not affected by nitrogen fertilizer of 46.5 kg nitrogen ha⁻¹ when applied after sowing, but were increased significantly by chicken manure, alone or mixed with nitrogen, which suggested some other elements were deficient.

Last and Nour (1961) found that the response to nitrogen fertilizer was influenced by fungicide application and sowing date. Nitrogen had its least effect on crops sown at the optimum sowing date (5 November) and greater effect on crops sown before or after that date.

Application of 90 kg nitrogen ha⁻¹ at full bloom or the early pod filling stage in which N uptake and growth were at a maximum had no effect upon seed yield (Richards and Soper, 1982). Andrews (1986 a) concluded that the differences in

response to nitrogen application depend on such factors as soil nitrogen level before application, and the time of application .

In Spain, Olivares *et al* (1982) showed that 40 kg ha⁻¹ applied as calcium ammonium nitrate (26 % N) when the first flower appeared had a significant effect on yield. In Egypt, nitrogen application of 18 and 36 kg ha⁻¹ increased yield from 9.4 to 10.5 percent above the controls (Hamissa, 1980). In the field and using 15 Nitrogen , Dekhuijzen and Verkerke (1984) reported that over 50 percent of the applied nitrate was recovered in plants when treatments were given at early flowering and early pod fill. When soil nitrogen levels were low before application, Andrews (1986) found that added nitrate gave greater yields. Nitrogen increased yield either by increasing the number of stems or the number of pods per unit area. (Mc Even, 1970 a ; Saxena and Wassimi, 1980 ; Hamissa, 1981 ; Clark, 1981). The root length of the plants were also increased with increasing nitrogen level (Geisler and Krutzfeldt, 1984)

In the field, Andrews *et al* (1986) found that application of ammonium and urea can give a greater yield than the application of nitrate. Similarly, in the laboratory , at 6° C, urea resulted in more growth than nitrate at comparable applied nitrogen concentrations , but at 15° C the opposite was the case (Andrews *et al*, 1985).

Sprent *et al* (1977) reported that faba beans are capable of fixing N₂ during the later growth stages. About 28 percent of the seasons total nitrogen was fixed after the early to mid pod filling stages according to Richard and Soper, (1979) and was proportional to the nitrate concentration in the pod (Hill-Cottingham and Jones, 1980). On low nitrate soils, symbiotic fixation accounted for a maximum of 67.5 - 70.0 kg nitrogen ha⁻¹ in 1975 and 146.0 kg ha⁻¹ in 1976 (Dean and Clark, 1977). Richards and Soper (1979), using the 15 N technique reported that fababeans grown in a nitrogen deficient soil in a growth chamber experiment did not respond to fertilizer nitrogen. The plants fixed 83 percent of their requirement, with the soil supplying the remainder. The addition of fertilizer nitrogen decreased symbiotic N₂ fixation proportionally to the amount of nitrogen added (Richard and Soper, 1982).

It may be concluded that in the field, fababeans seldom respond to nitrogen fertilizer possibly because of mineralized nitrogen in the soil (Yousif and Sprent, 1983). Nevertheless, the effect of nitrogen fertilizer is still controversial as results depend upon soil conditions, time and dosage of application and the types of fertilizer used.

2.7. Present investigations.

A basic conclusion arising from the literature review is that the yield of faba beans is strongly influenced by sowing date with early sowing being advantageous in most instances. A second conclusion is that biomass, yield and harvest index in faba beans in general respond in the same way to density and sowing date as most other crops. The present investigation was designed to study the relation between yield and sowing date for the cultivar Fiord, the only cultivar grown extensively in southern Australia and to provide precise information on the interaction of sowing date with density in this cultivar. The earliest possible date of sowing is determined in southern Australia by the onset of effective rain and the time necessary to prepare a seed bed. There is much variation from year to year in the date this occurs. Frequently it is not possible for a farmer to sow on the date he chooses because of insufficient rain, and later because of excessive rain, and it might be necessary to vary density accordingly.

The review of literature also indicated that instability in the yield of fababeans depended on the relation between growth phases of the crop such as flowering and podding with environmental factors such as temperature, radiation, water supply and pollinating insects. Seed set in fababean in this environment may be favoured by bee visitation, and the setting of pods by Fiord may depend on the relation between the date of flower development and pollinating insect activity. An approach to evaluating this question of the influence of weather on seed set and yield is to vary sowing time.

When grown as a winter crop, nodule development in fababeans may be delayed as a result of low soil temperatures. The time to first nodule development needs to be determined and the affect of various factors including N application needs to be studied under field conditions.

Experiments in the first two years of this study concentrated on resolving the effects of sowing date and density on the cultivar Fiord. In the third year several different accessions of faba beans and FIORD were compared to determine their response and to evaluate the chances of breeding cultivars superior in yield and stability to Fiord.

CHAPTER 3

MATERIALS AND METHODS

The Experiments

3.1 Introduction

In 1985 and 1986 experiments were conducted to determine the effect of sowing date, density and fertilizer on yield and its components in the cultivar FIORD. FIORD was bred and released for its small seed, averaging 0.4 g a seed, that enabled sowing and harvesting with conventional cereal machines (Knight-personal communication). However many accessions of fababeans have large seeds, and have considerable marketing potential, but would require specialized machines for sowing and harvesting.

The term accession as used in the thesis needs to be defined. An accession is a population received from elsewhere that will contain some genetic variation as a result of the partial cross-pollinated breeding behaviour of faba beans. In general such variation within an accession is far less than the variation that occurs between accessions. Some accessions are cultivars while others are land races.

In 1987 experiments were conducted comparing the growth and yield of FIORD with other accessions varying in seed size. Besides the immediate practical significance of evaluating in detail the yield of various accessions differing in seed size, the aim of the 1987 experiments was to determine the influence of growth characters such as the duration of flowering and podding on yield of the different accessions.

3.2 Sites of Experiments

The experiments were conducted at the Waite Institute and at the Charlick experiment station (about 60 km from the Waite). The soil at the Waite is a red brown earth, usually with 25 cm or more of top soil of fine sandy loam texture, a prismatic

structured clay sub soil and a calcareous deep sub soil with variable waterworn gravel or stone (Litchfield , 1951). An analysis of the soil indicated that the available amount of NH_4 and NO_3 was 47.0 and 11.9 mg N.g⁻¹ soil respectively. The soil pH for the 0-10 cm depth was 5.9. The particular sites at the Waite were sown to wheat, barley and oats the previous three years before the bean experiment in 1985, and to clover as a pasture for three years before the bean experiments in 1986 and 1987. The site at Charlick used for the bean experiment, had been sown to barley for the previous three years. The soil at Charlick is a solonized brown soil and consists of 17.9% sand, 30.6% silt and 24.7% clay. It is a textured loam with 0.17% total N and a pH 8.1 (Muneer, 1987)

3.3. Climate

The total monthly rainfall, hours of bright sunshine, solar radiation and air temperature for each month of 1985, 1986, 1987 at the Waite are shown in figure 2. Average values for 58 years of records (from 1925 to 1983) are given in table 1 of the appendix. A detailed listing of meteorological data for the three years is given in tables 2, 3 and 4 of the appendix. Rain that leads to the commencement of the growing season starts usually in April or May and ends between October and November. For Charlick the 1985 and 1986 values are given in tables 4 and 5 of the appendix.

3.4. General Materials and Methods

In general, the materials and the cultural practices used were similar in the three years of the study. They are described first and any other details, specific to each experiment, are given later.

From a seed stock of the cultivar Fiord any seeds that were shrunken , deformed or broken were discarded before sowing the experiments. Tests indicated the seeds had a 98 percent germination capacity.

At sowing, the areas were cultivated twice. After sowing, the plots were handraked to give an even soil surface. A basal fertilizer application was applied at the rate of 16 kg ha⁻¹ of P for the experiment at the Waite in 1985. The seeds were sown at depth of 6 cm using a Wintersteiger precision seeder (Plate 1). No inoculum was applied to the seed. Previous studies had shown this had not been necessary at the Waite or Charlick sites. In some years the plots were treated with the pre-emergence herbicide Simazine at 2 litre ha⁻¹ five days after sowing. The post emergence herbicide Fusilade 212 at 500 ml ha⁻¹ combined with the spreader Agral 60 at 3.5 ml ha⁻¹ was also used to control grass weeds. When necessary, weeds were also removed by hand.

To protect the plants from *Aschochyta fabae*, applications were made of the fungicide Bavistin at 500 g ha⁻¹ combined with Bravo at 1.7 l ha⁻¹ and the wetting agent Agral 60 at 12 ml l⁻¹. The fungicide Bayleton 50 wettable powder at 1 g l⁻¹ was used to control chocolate spot (*Botrytis fabae*).

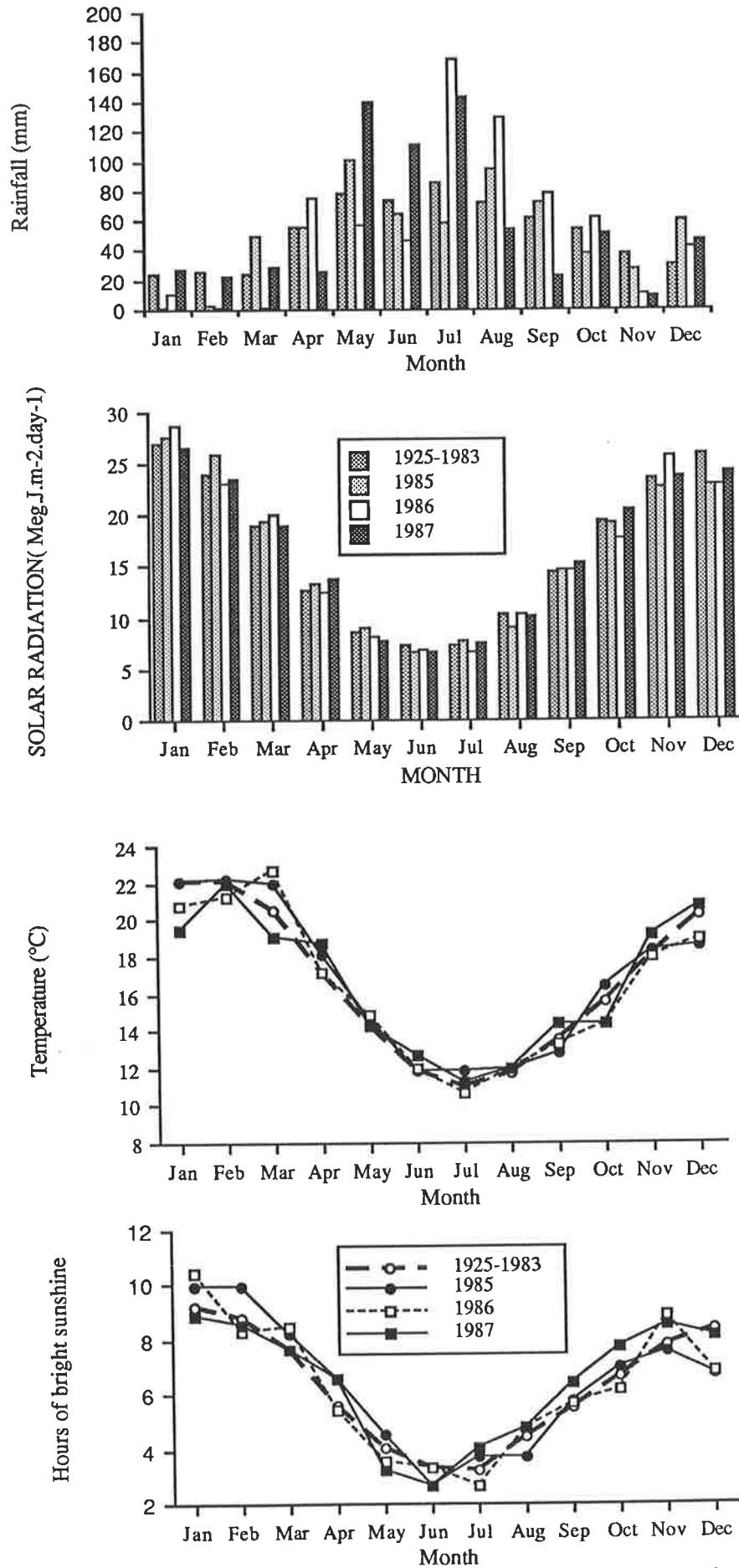


Fig 2. Climatic value of rainfall, temperature, bright sunshine and solar radiation for 58 years. and for 1985, 1986, and 1987.



Plate 1. The Wintersteiger precision seeder

3.4.1. The Assessment of plant characters

A. Plant growth :

Samples of plants, varying between experiments in number, from 10 to 25 plants, and from the second and third row of the eight row plots, were scored for the following characters :

- (1) emergence - when the shoot first became visible above the soil
 - (2) first flowering - when a fully opened flower was first evident on the main stem of the plant .
 - (3) flower bearing node - the number of the node bearing the first flower on the main stem of the plant.
 - (4) end of flowering - the date when flowering ceased on the main stem of the plant .
 - (5) first pod development - when the first pod reached 2 cm in length at any node on the main stem of the plant.
 - (6) pod bearing node - the number of the node bearing the first pod on the main stem of the plant
 - (7) end of pod development - the date when the last pod developed on the main stem of the plant .
 - (8) maturity, recorded when 95 % pods had turned black .
- All of the observation involving time were recorded as the number of days from sowing.

B. Harvest :

At final harvest , the sampled plants in each plot were harvested individually by cutting at ground level. Measurement were made on :

- (1) Grain yield
- (2) Number of pods.
- (3) Number of seeds.
- (4) Number of seeds per pod.
- (5) Number of stems .

(6) Seed size (calculated from grain yield and the number of seeds).

In addition a 1 x 1m area in the middle of the plot was used to sample for the following measurements :

(7) Grain yield

(8) Dry matter of shoot without roots.

(9) Number of pods.

(10) Harvest index.

The results were analysed on the University of Adelaides VAX computer using GENSTAT programs.

3.5. Details of experiments.

3.5.1. Experiment 1 1985

Effect of sowing date, plant density and nitrogen fertilizer on the growth and yield of the cultivar Fiord.

Design of experiment

A split plot design with four replications was used, with date of sowing as main plots and combinations of five plant densities and three N fertilizer rates as sub plots. Within each replicate and date of sowing therefore, there were 15 plots. The sowing dates, densities and fertilizer applications are designated T, D and F respectively.

The treatments were:

Sowing Date		Density	N-fertilizer
Waite	Charlick	plants m ⁻²	kg ha ⁻¹
T1 April, 30	May, 13	D1. 20.0	F1. 0
T2 June, 7	June, 13	D2. 27.6	F2. 10
T3 July, 2	July, 10	D3. 34.4	F3. 20
T4 July, 31	August, 1	D4. 42.4	
		D5. 50.0	

Each sub plot was 2 x 4 m , with rows 25 cm apart and there was a pathway of 0.50 m between plots. The field layout is given in figure 3. Four rows were sown around the block to act as a border.

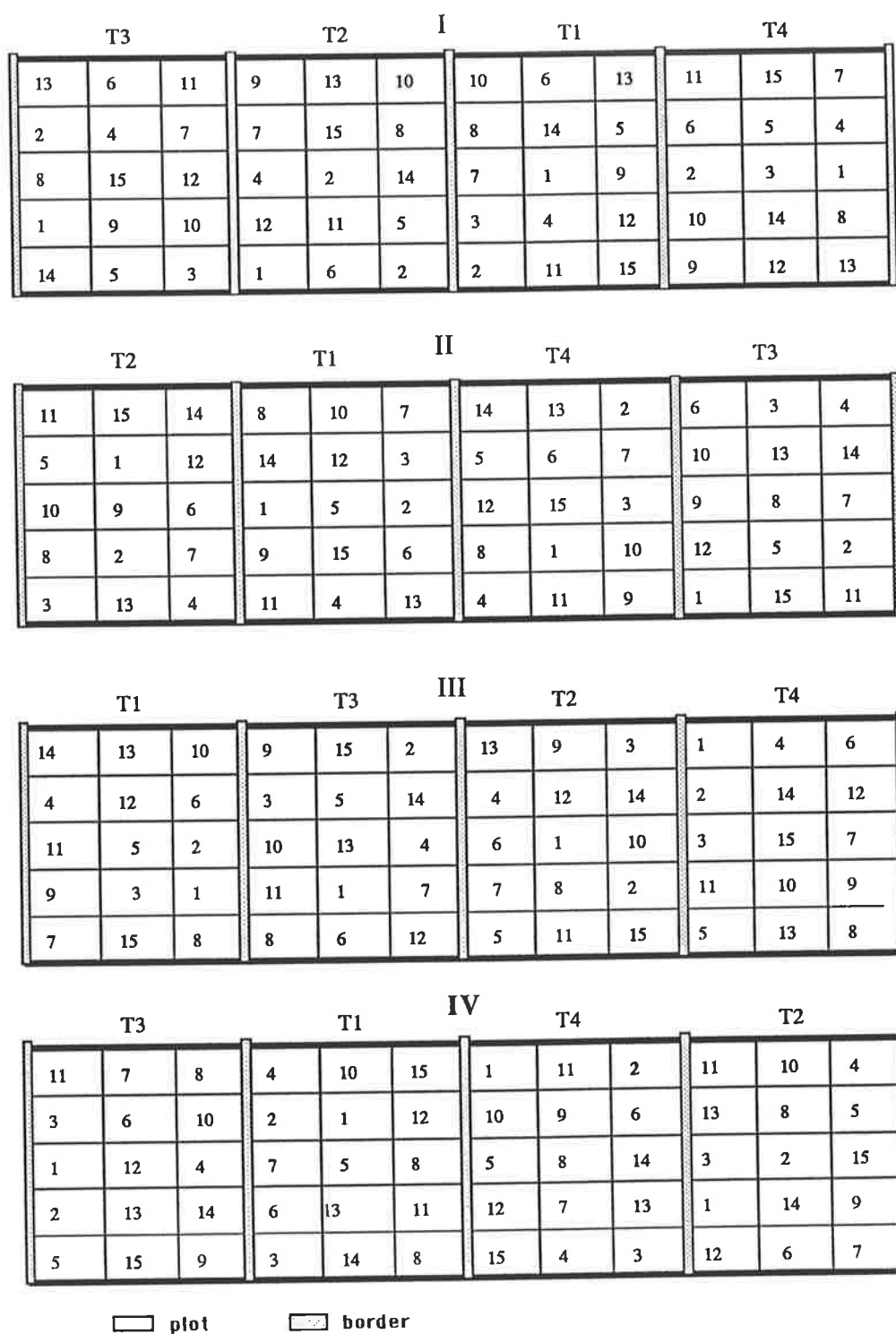


Fig 3. Layout of experiment 1, 1985

3.5.2. Experiment 2 1986

Effect of sowing date and plant density on the growth and yield of the cultivar Fiord.

Design of experiment

The aims of the 1986 experiment were similar to those of the 1985 experiment, however a more comprehensive set of results were obtained. At the end of 1985 it was evident that the date of maturity had been influenced by the date of sowing. Early sown plants were black and ripe while late sown plants were still green. In 1986 the date of maturity was carefully monitored. A Randomized complete block design with four replications was used, with four sowing dates and six plant densities. The treatments were

Sowing date			Density
	Waite	Charlick	plant m ⁻²
T1	April, 24	April, 29	D1: 20.0
T2	May, 14	May, 20	D2: 27.0
T3	June, 5	June, 10	D3: 35.0
T4	June, 26	July, 14	D4: 42.0
			D5: 49.0

Each plot was 2 x 5 m, with row 25 cm apart. Border plots were sown which were treated similarly to the experimental plots (figure 4). The crop development at low and high density at 20 and 50 days after sowing is shown in Plates 2 and 3.

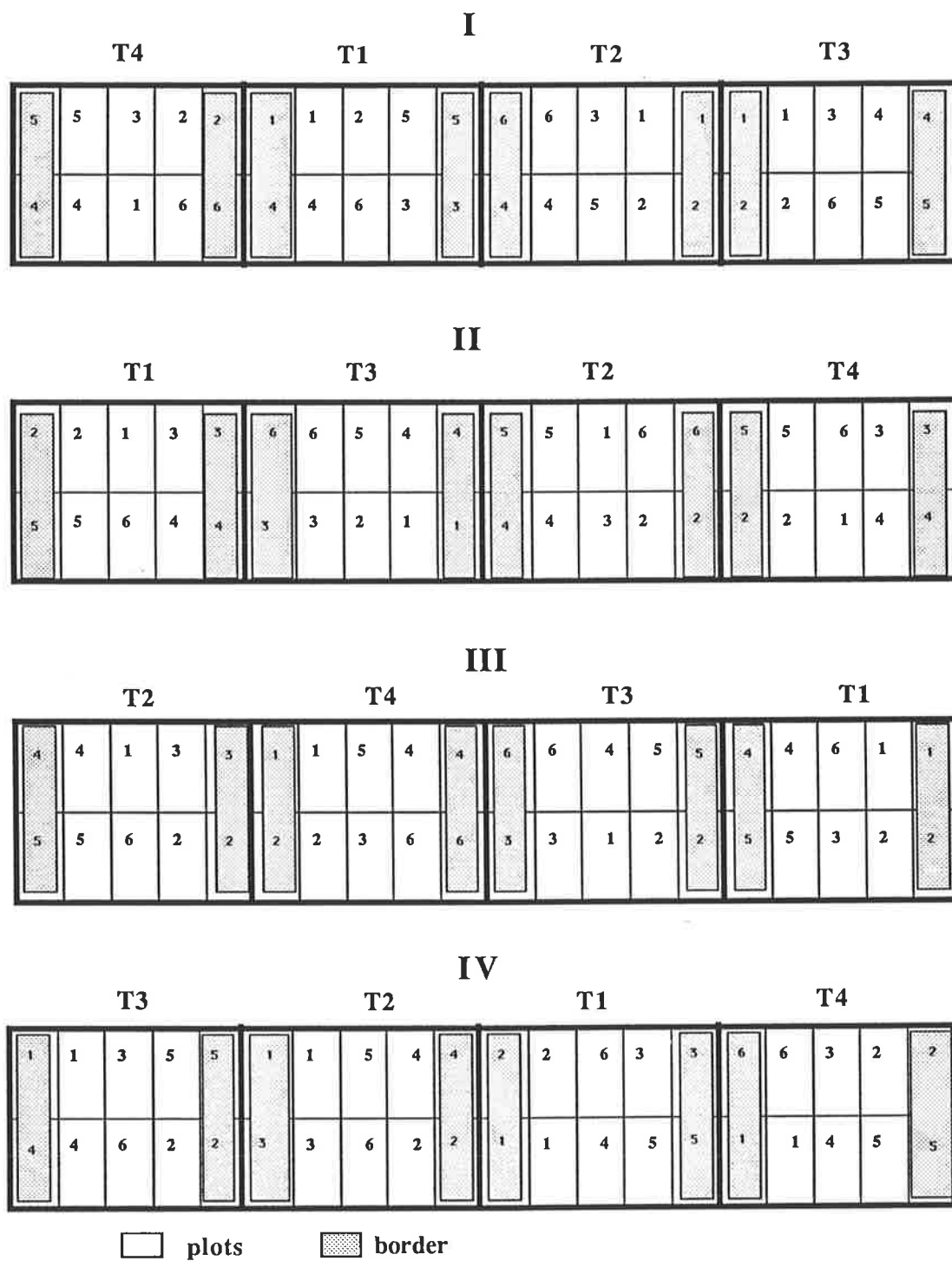


Fig 4. Layout of experiment 2, 1986



Plate 2. The lower density (20 plant m⁻²) of experiment 2 at 20 days and 50 days after sowing at the Waite Institute in 1986.



Plate 3. The highest density (56 plant m⁻²) of experiment 2 at 20 days and 50 days after sowing at the Waite Institute in 1986.

Characters measured.

In addition to characters measured in 1985, in 1986 pod and seed development were monitored.

At the beginning of pod development, between 60 to 80 pods, each approximately 2 cm in length were tagged in the border plots. The tagged pods were usually in the middle rows of each plot. Pods were sampled (10 pods each) at 15 day intervals from the beginning of pod development to maturity, for the first and second sowing, and at 10 day intervals for the third and fourth sowing. After the samples were collected, seeds were dried (85°C) for 24 hour and the individual seed weight obtained.

3. 5. 3. Experiment 3 1987

Effect of sowing date on yield and its components for various accessions of fababeans.

Design of experiment

The experiments conducted in 1985 and 1986 on cv Fiord showed that early sowing gave the highest yield. The yield losses that occurred with later sowing were due to a reduced duration of flowering and pod filling and a smaller seed size. In view of the potential farming significance of accessions with an average seed size greater than FIORD, the 1987 experiment compared the growth and yield of FIORD with eleven accessions. The eleven accessions were chosen on a basis of seed size, seed availability and origin. Two accessions, Acc 286 and Acc 758 have the potential of being released as new cultivars (Knight personal communications). The twelve entries in this experiment form three broad groups, differing in seed size, with Fiord belonging to the small-seeded group.

The following table gives details of the 12 entries in the trial. The accessions are arranged in order of increasing seed weight at harvest. Seed weight at harvest was

considered a more precise attribute of an accession, as it was a measure obtained under conditions of an experiment, whereas the seed that was sown had been produced in different years and environments.

Seed size	Accessions	Weight of seed(g of 100 seed)		Origin
		(at sowing)	(at harvest)	
Small	Acc 754	42	39	Ethiopia
	Fiord	45	45	Naxos, Greece.
	Acc 792	29	52	Afghanistan.
	Acc 801	65	53	Italy.
Medium	Acc 176	53	56	France.
	Acc 863	94	67	Colombia.
	Acc 12	87	74	Morocco.
	Acc 231	87	81	France.
Large	Acc 506	144	106	Spain.
	Acc 286	156	111	Crete.
	Acc 873	181	111	Morocco.
	Acc 758	194	129	Ethiopia.

Sowing dates : There were two sowing dates T1 (1 May 1987) and T2 (3 July 1987).

A split plot design was used with four replicates. The different sowing dates were arranged as main plots while the sub plots were the eleven accessions and FIORD. Each sub plot was 2 x 4 m and contained eight rows. Spacing within and between rows was 20 cm and 25 cm respectively. The layout is presented in figure 5.

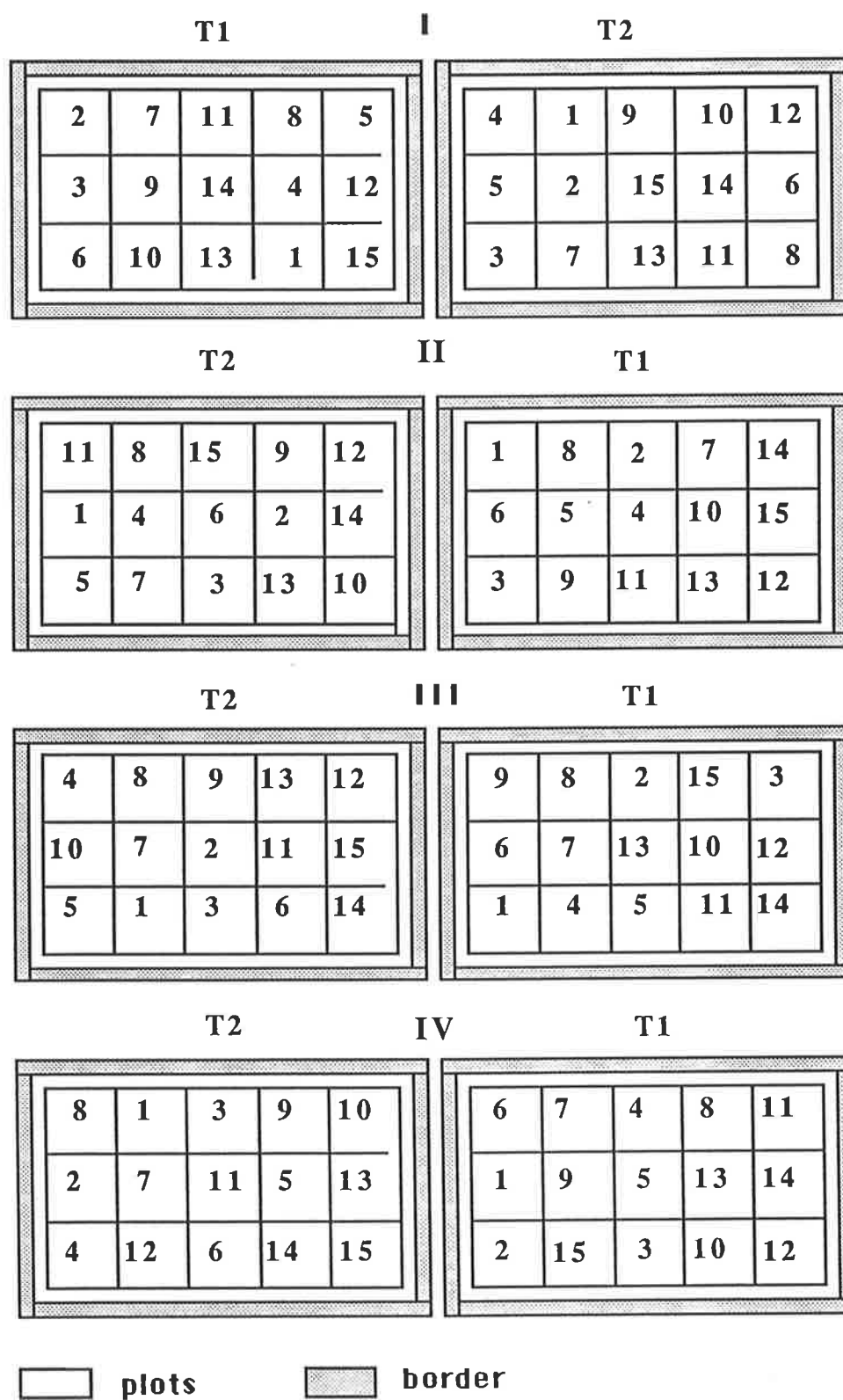


Fig 5. Layout of experiment 3, 1987

3. 5. 4. *Experiment 4 1987*

The effect of time of nitrogen application on the growth and yield of Fiord

Design of experiment.

The objective of this experiment was determine the response of Fiord to different times of application of nitrogen fertiliser.

A randomized block design with four replications was used with seven different times of nitrogen fertilizer application. The nitrogen fertilizer was applied as Urea.

The treatments were :

1. no nitrogen .
2. 90 kg N ha⁻¹ at emergence .
3. 90 kg N ha⁻¹ at flowering .
4. 90 kg N ha⁻¹ at podding .
5. 45 kg N ha⁻¹ at emergence and 45 kg N ha⁻¹ at flowering.
6. 45 kg N ha⁻¹ at emergence and 45 kg N ha⁻¹ at podding.
7. 30 kg N ha⁻¹ at emergence , 30 kg N ha⁻¹ at flowering and 30 kg N ha⁻¹ at podding.

Each plot was 2 x 5 m with plants 20 cm apart in rows 25 cm apart and 25 cm pathways, between plots. The Nitrogen fertilizer was applied by broadcasting.

CHAPTER 4 A

PHENOLOGICAL RESPONSE OF FIORD TO VARIATION IN SOWING DATE

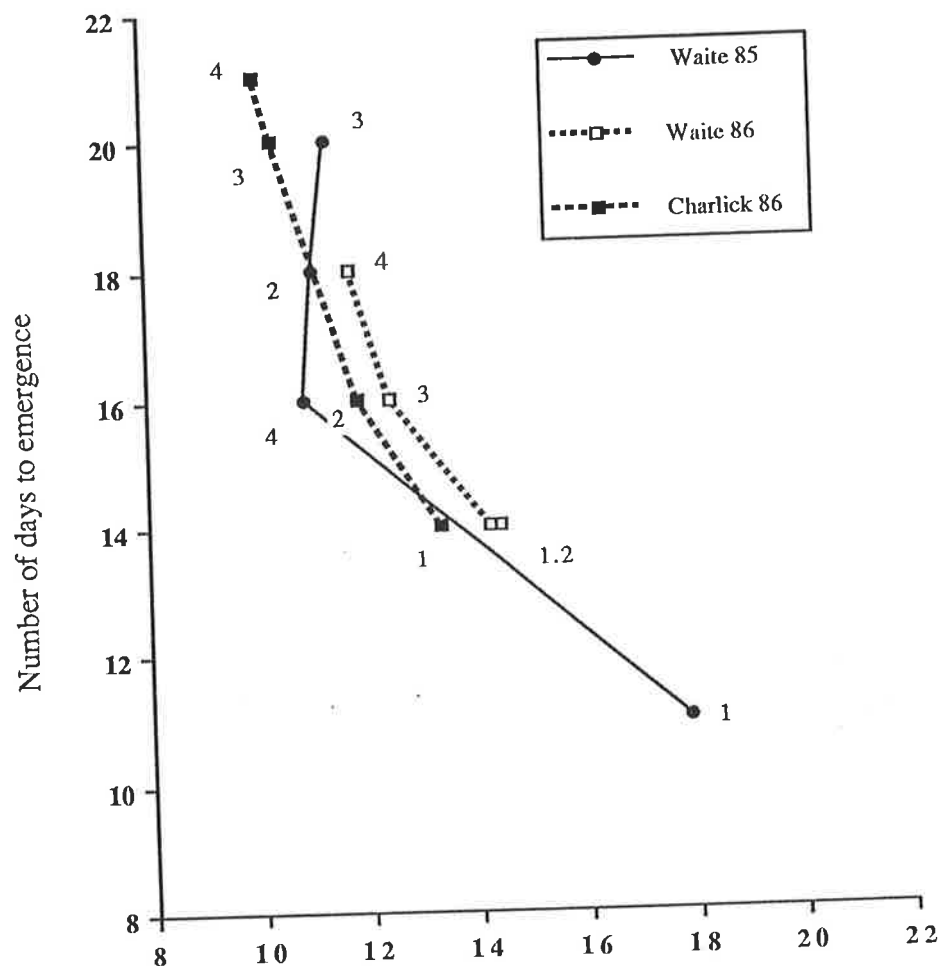
RESULTS

1. Sowing to emergence

The number of days to the emergence of the shoot ranged from 11 to 21 days and varied with sowing date and location. Days to emergence increased as sowing was delayed into the winter. As temperature was the main environmental factor that could have influenced germination, and as it varied with sowing date, a regression of days to emergence on average temperature was plotted (Figure 6). The regression was significant and negative. Neither plant density nor nitrogen fertilizer level had any significant effect on rapidity of emergence.

The results of the experiment at the Waite Inst in 1985 showed that the number of days from start to the completion of emergence was 6 days for the first, second and third sowing, and 4 days for the last sowing. The percentage emergence differed with sowing dates (Tables 2 and 3). The reason for the poor establishment in June is unclear. Some plants were damaged by birds just before emergence, but this could not have been entirely responsible. It was possibly an effect of the particular site, heavy rain and low temperatures.

The percentage emergence was not recorded at the other sites and years as observation suggested it was very high and consistent.



Mean temperature from sowing to emergence (°C)

When the results are combined the curvilinear regression is

$$y = 51.409 - 4.168 x + 0.107 x^2 \quad R^2 = 0.843$$

Fig 6. The effect of temperature on emergence.
The numbers on the regression line designate the times of sowing.

Table 2. The percentage of plants that emerged in the different densities the Waite 1985.

Sowing dates Densities	Emergence (%)					mean
	15	21	27	33	39	
30 April	83	83	88	87	88	86
7 June	58	70	63	72	72	67
2 July	78	75	83	74	72	76
31 July	88	87	84	80	77	83
mean	77	79	80	78	77	

Table 3. The percentage of plants that emerged in the different levels of nitrogen fertilizer the Waite 1985.

Sowing dates	Nitrogen fertilizer levels (kg N ha ⁻¹)		
	0	10	20
30 April	86	83	87
7 June	63	68	66
2 July	73	78	78
31 July	82	82	85

2. Emergence to flowering.

Waite Institute 1985 (Exp 1).

The date of flowering is given in table 4. The mean number of days from emergence to the first flower, for the four sowing dates was 65, 47, 36, and 34 respectively indicating that later sowing shortened the time to the first flower.

The date of flowering was estimated from a sample of 1500 plants for each time of sowing and there was variation within the samples. For the four sowing dates the range between the first and last plant to flower was 14, 8, 6, and 5 days respectively (Figure 7).

Waite Inst 1986 (Exp 2)

In 1986 the experimental design was modified so that the interval between the sowings was shortened to three weeks instead of the four weeks that had been the practice in the first year. As a result, the last sowing was on 26 June in contrast to 31 July of the previous year. The first flower development is given in figure 8. For the four dates of sowing, the number of days from emergence to the first flower were 63, 65, 65, and 63 respectively indicating a very small difference. There was variation within the samples of plants sown on any one day. This variation expressed as a range was 12, 12, 9, and 6 days respectively for the four sowing dates.

Charlick 1986 (Exp 2)

The number of days from emergence to flowering for the four dates of sowing were 71, 78, 67 and 57 respectively. After the second sowing (May 5) any later sowing resulted in a shortened time to flower development. In the Discussion the variation in flowering will be considered in relation to the environmental conditions of temperature, daylength and solar radiation.

Table 4. Effect of sowing date on the date of emergence, flowering and podding of 50% of the plants.

a. Waite 1985.

Sowing date	Emergence	Flowers	Pods
30 April	11 May(-1)	15 July(-9)	8 August(-4)
7 June	25 June(-1)	11 August(-3)	26 August(-4)
2 July	22 July(-1)	27 August(-1)9	September(-2)
31 July	16 August(0)	19 September(-6)	29 September(5)

b. Waite 1986.

Sowing date	Emergence	Flowers	Pods
24 April	8 May(*)	10 July(-8)	8 August (-18)
14 May	28 May(*)	1 August((-5)	26 August(-5)
5 June	21 June(*)	25 August(-5)	9 September(-5)
26 June	14 July(*)	15 September(-6)	25 September(-5)

c. Charlick 1986.

Sowing date	Emergence	Flowers	Pods
29 April	13 May(*)	23 July(-11)	18 August(-14)
20 May	5 June(*)	22 August(-4)	20 September(15)
10 June	30 June(*)	5 September(-6)	27 September(-8)
14 July	4 August(*)	30 September(-4)	14 October(-7)

Indicated in parentheses are the number of days before each date at which the first emergence, flower or pods were recorded. (*) not recorded

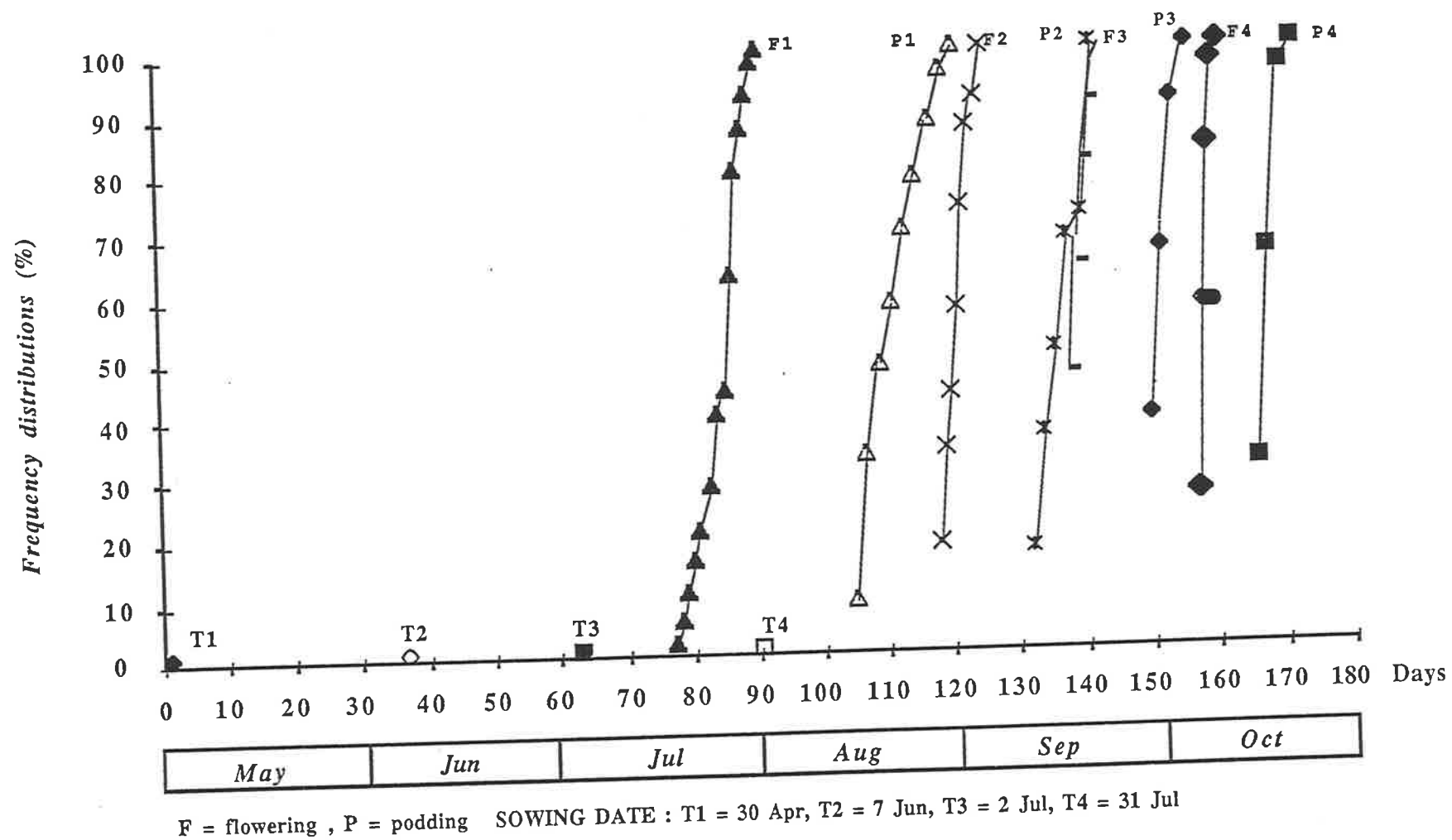


Fig 7. Effect of sowing date on the first flower and pod development for samples of plants at the Waite Institute in 1985

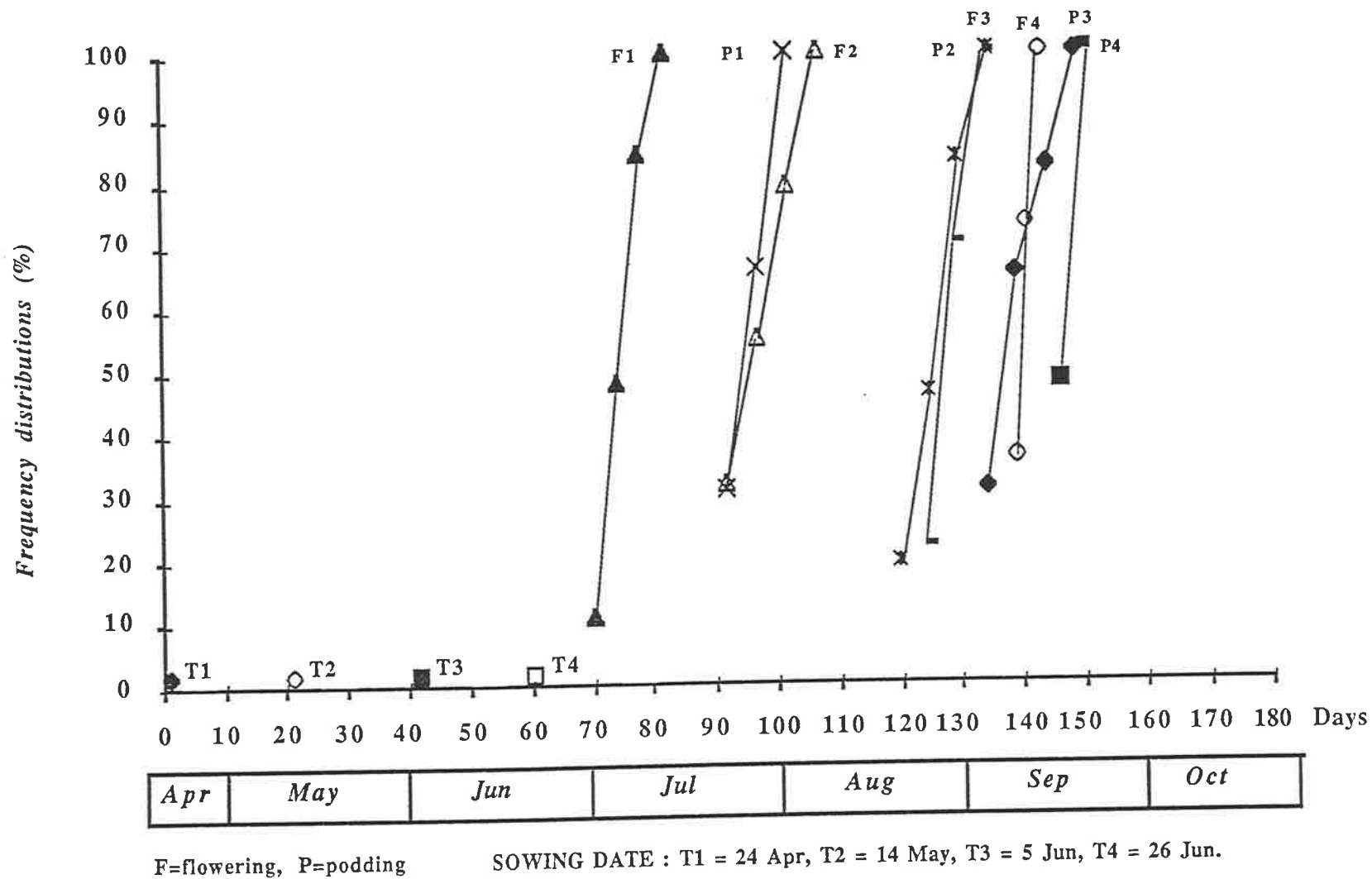


Fig 8. Effect of sowing date on the first flower and pod development for samples of plants at the Waite Institute in 1986

The node bearing the first flower.

Frequency diagrams show that the lowest node bearing the first flower was generally the fourth node for all sowing dates at the Waite in 1985, but the highest node to bear the first flower on a plant differed considerably (Figure 9 a). For the first or early sowing there were plants that did not bear the first flower until the twelfth node whereas for the other sowing dates the highest number was the ninth node

Somewhat similar results were obtained at the Waite in 1986 and usually the lowest node at which the first flower opened was generally the fourth node for all dates of sowing, but the highest node of the first flower differed considerably (Figure 9 b). For the early sowing there were plants that did not bear the first flower until the eleventh node whereas for the other dates of sowing it was the 10th node. For those sowing date which approximately correspond in the two years, there are marked similarities in the frequency diagrams. In general the results show that with early sowing more nodes were formed before the first flower appeared.

3. Sowing to podding

Waite Inst 1985 (Exp 1).

The dates on which 50% of the plants bore their first pods is indicated in table 4. The period from emergence to first pod development for each sowing date decreased from a value of 100 days for the first sowing to 80, 69, and 60 days respectively for the later sowings (Figure 10). Although there was a shortening of the period with later sowing, this was not of the same magnitude as the difference between dates of sowing and podding occurred sequentially. Podding from the first sowing commenced soon after the emergence of seedlings of the last sowing.

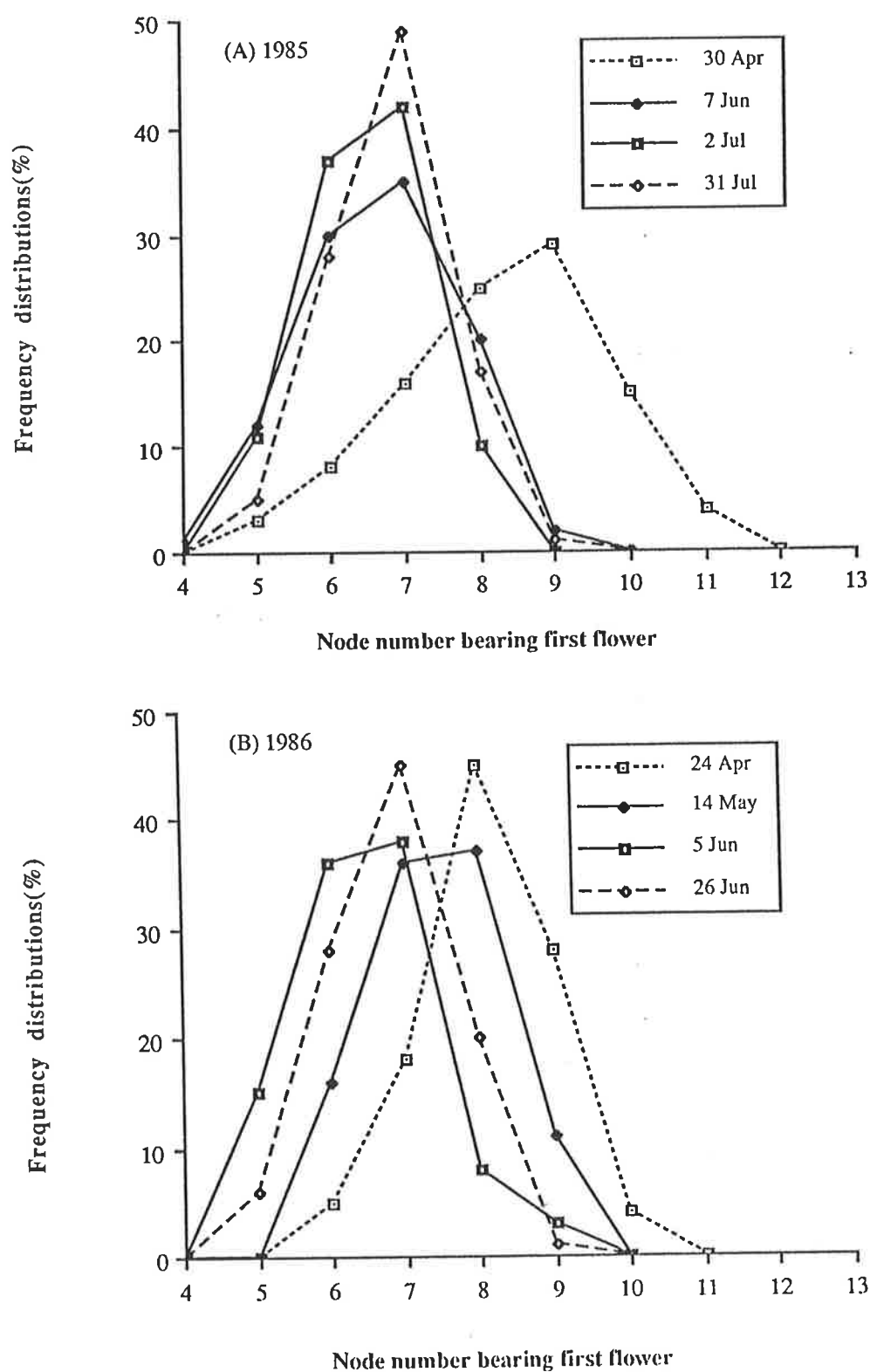


Fig 9. Effect of sowing date on the number of the node bearing the first flower at the Waite Institute in (a) 1985 and (b) 1986

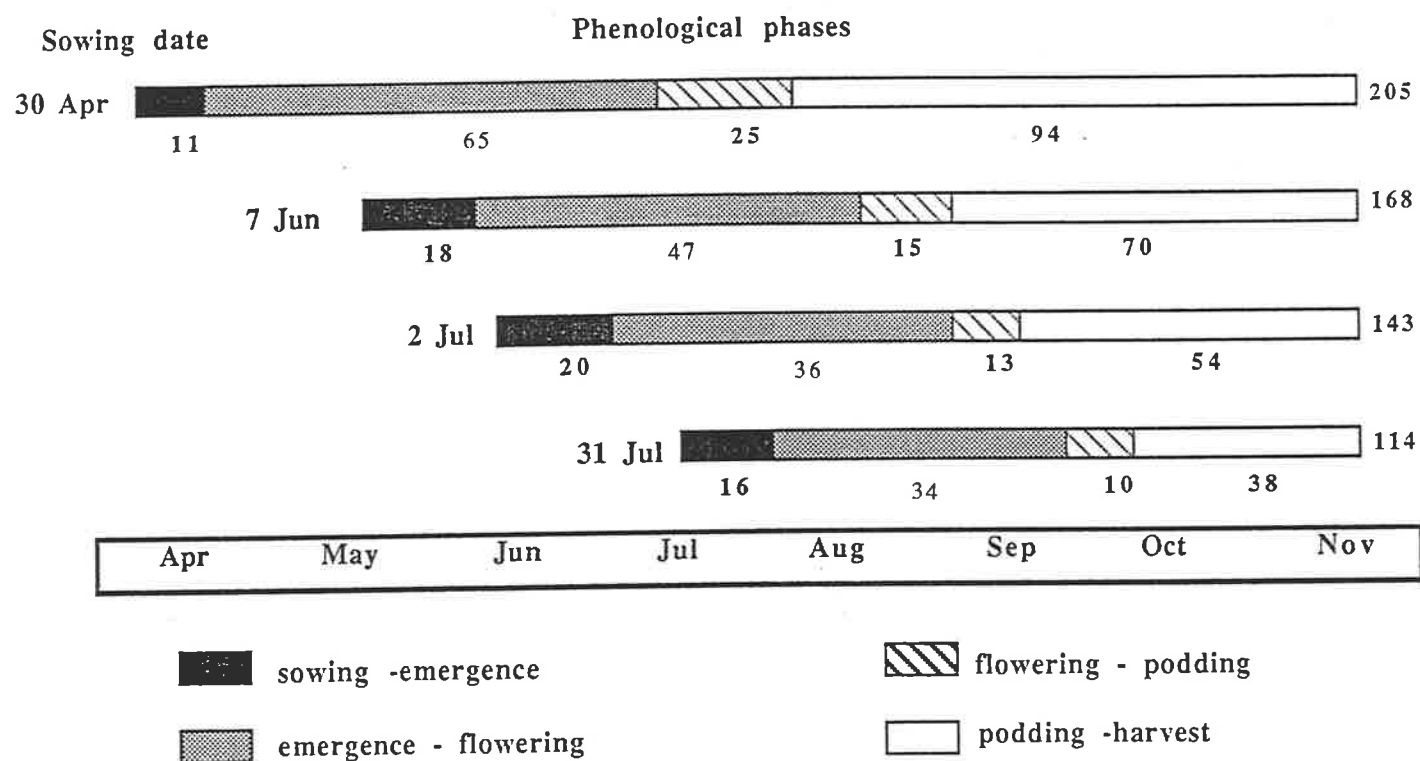


Fig 10. Effect of sowing date on phenological development at the Waite Institute in 1985. For each phase emergence, flowering, podding the number of days value for 50% of plants to reach that phase. To the right of the diagram are days to harvest.

Waite Inst 1986 (Exp 2).

The period from emergence to the first pod development for each date of sowing is presented in figure 11. As had occurred in 1985 the number of days to the first pod development declined with sowing from 92 to 90, 80, and 73 days respectively.

Charlick 1986 (Exp 2).

The number of days from emergence to the first pod increased at the second sowing and then decreased with further delay in sowing (Figure 12). The periods were 97, 107, 89 and 71 days respectively.

4. Podding to maturity.

Waite Inst 1985 (Exp 1).

The period from the first pod development for each date of sowing is given in figure 10. The date of plant maturity was not recorded in 1985 ; only the date of harvest, which was when all plants were mature. Using this date, the maximum duration of the pod filling period was 94 days for the early sowing and 38 days for the last sowing. Also using this date the growing period for the crop ranged from 205 days to 114 days for the first and last sowing

Waite Inst 1986 (Exp 2).

In 1986 the date of maturity for each treatment was recorded separately. Again it was found that the pod filling period decreased with delayed sowing (Figure 11). The pods of plants sown on 24 April were mature by 14 November, a period of 98 days from the start of pod filling to maturity. For the other sowing dates it ranged from 80, 71 and 60 days. For the last sowing date the pods were not mature until 24 November. The growing period for the crop ranged from 204 days for the early sowing to 151 days at the last sowing.

Charlick 1986 (Exp 2).

The number of days from the first pod development to maturity declined with later sowing (Figure 12). For the early sowing, the pods were mature in 86 days after the first pod development and this period for the other sowing dates were 62, 65 and 48 days.

The node bearing the first pod.

Frequency diagrams for the various samples of plants grown at the Waite in 1985 show that the lowest node bearing the first pod was generally the fourth node for all sowing dates (Figure 13 a) but the highest node differed considerably being the twelfth node for the early sowing and ninth node for the other sowing dates. Thus the results for the first pods correspond with the first flowers.

Similar results were obtained at the Waite in 1986 and usually the lowest node bearing the first pod development was the fourth node for the four sowing dates but the highest was the 11 th node for the early sowing and the 10 th node for later sowing (Figure 13 b)

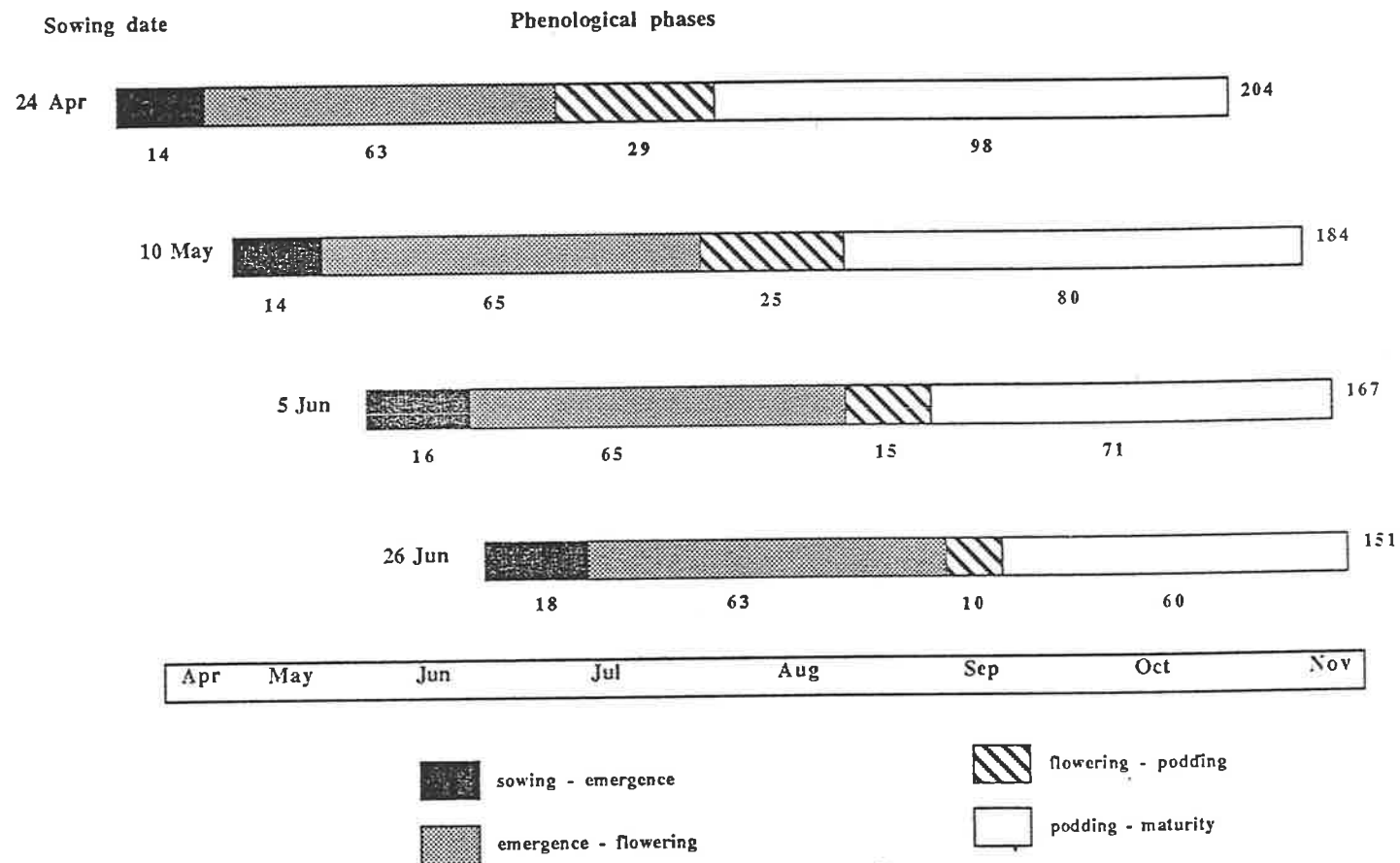


Fig 11. Effect of sowing date on phenological development at the Waite Institute in 1986. For each phase emergence, flowering, podding the number of days value for 50% of plants to reach that phase. To the right of the diagram are days to maturity.

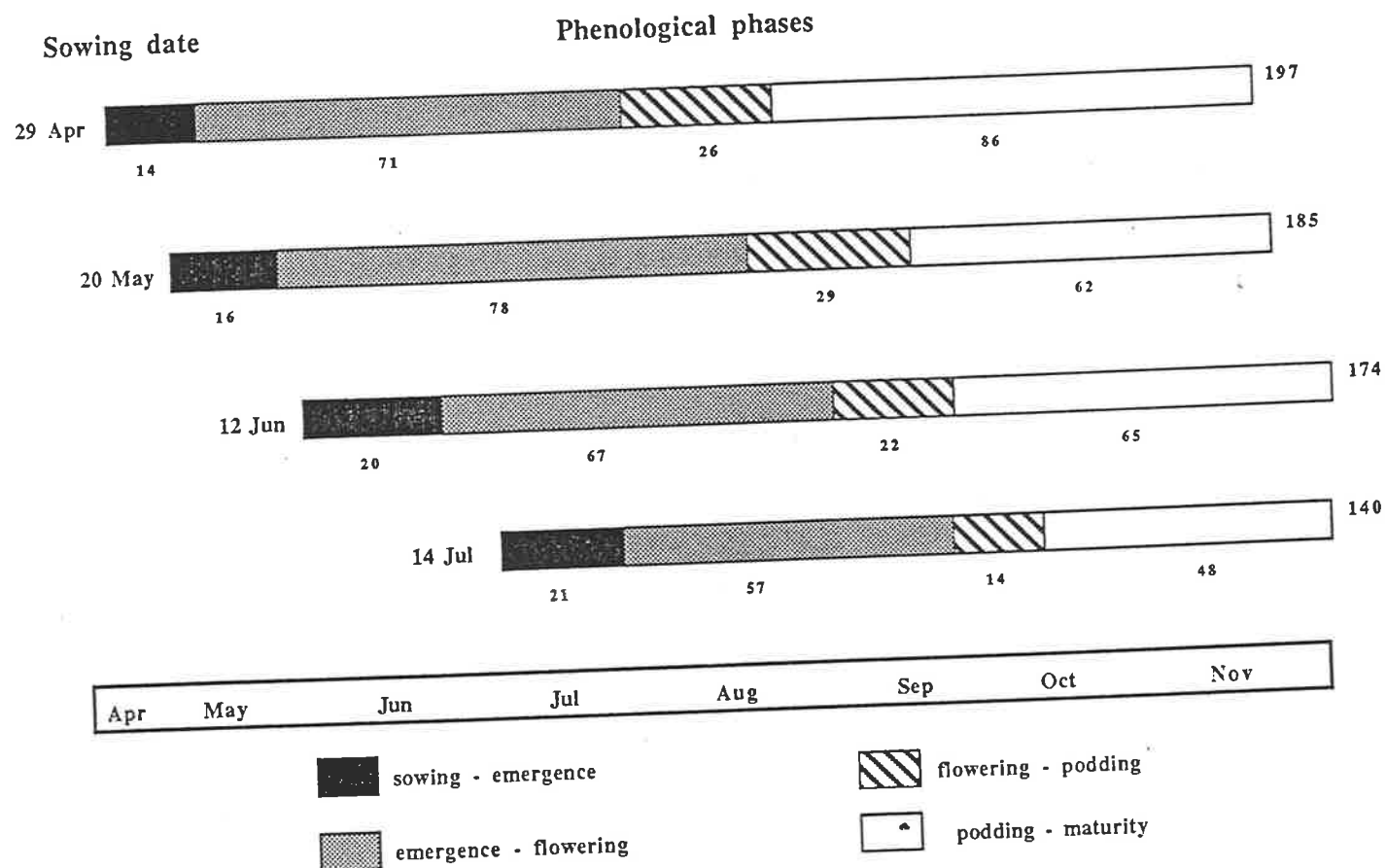


Fig 12. Effect of sowing date on phenological development at the Charlick in 1986. For each phase emergence, flowering, podding the number of days value for 50% of plants to reach that phase. To the right of the diagram are days to maturity.

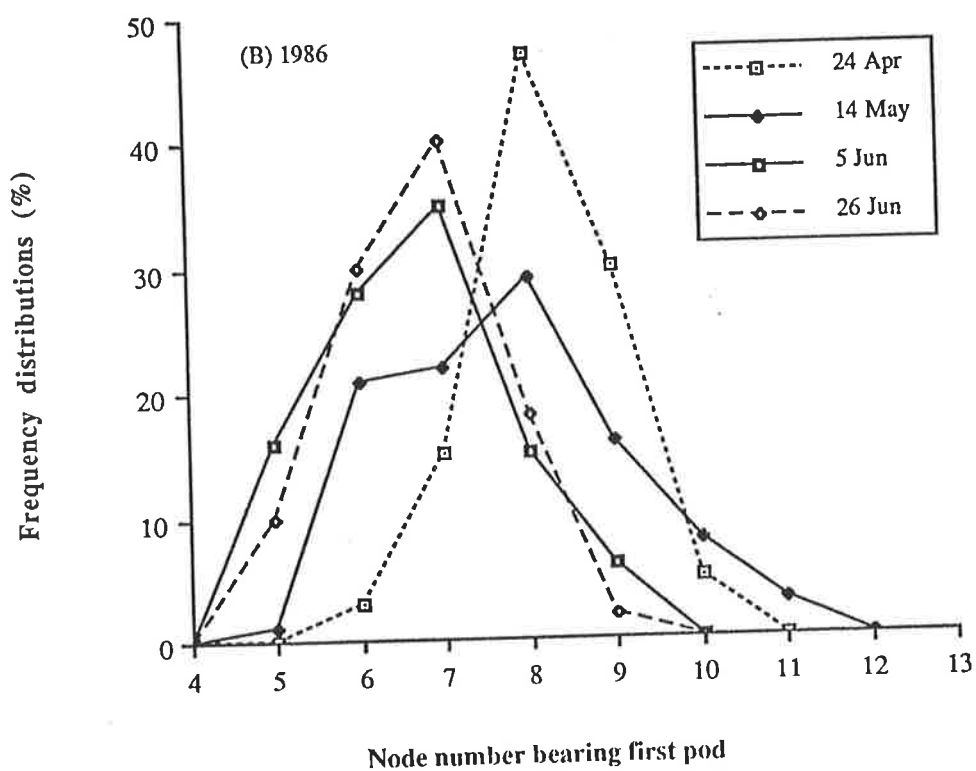
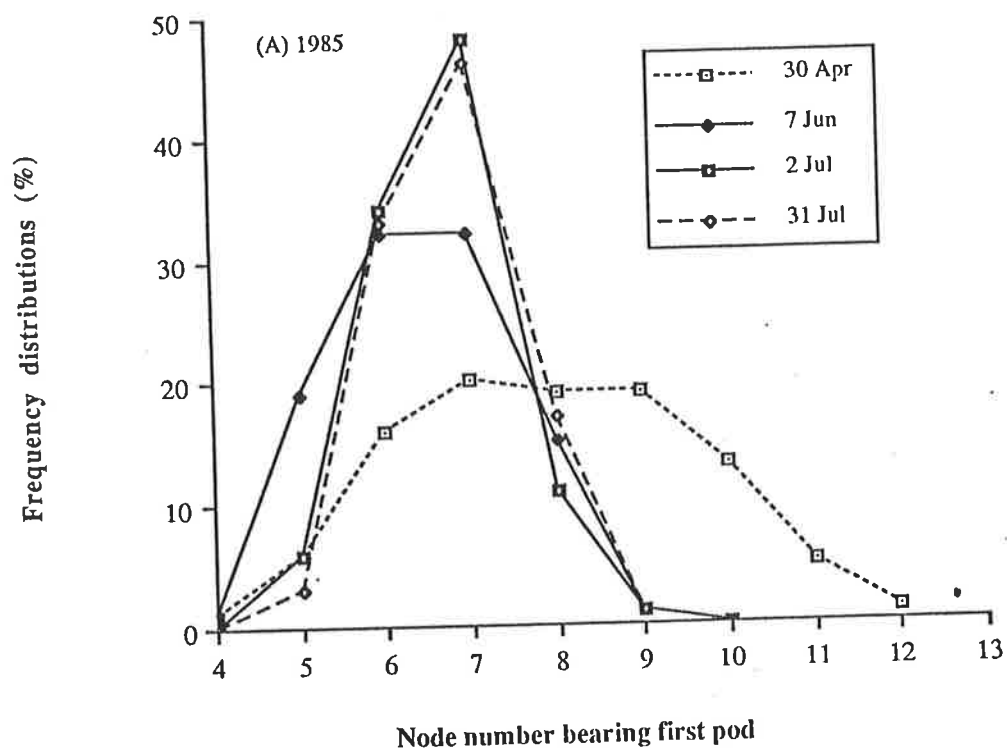


Fig 13. Effect of sowing date on the number of the node bearing the first pod at the Waite Institute in (a) 1985 and (b) 1986

DISCUSSION

This study has investigated the effect of sowing date on the phenology and related characters in FIORD and the discussion will be concerned with the phases of growth of the crop.

Emergence.

It was apparent that the period from sowing to emergence could vary considerably from 10 to 21 days and the regression on temperature (Figure 6) suggest this environmental factor was the cause of the variation. The response to temperature appears to be curvilinear and simple reasoning suggests this must be the case. There was variation around the regression, an effect which may have been induced by several factors. Although attempts, were made to keep soil compaction, and hence seeding depth, the same for the all sowing dates there may have been some variation as a result of environmental conditions. It was noted that the wheels of the tractor sank to a greater depth after periods of heavy rain. The observed result of the effect of temperature on emergence is similar to one obtained by Sjelkag (1981) who found that the germination rate was increased with rising temperature over the range 6 to 24° C. Saxena (1982) also showed that temperatures below 10° C resulted in an increase in the number of days from sowing to emergence.

In each instance the highest temperatures and therefore the most rapid emergence occurred with early sowing. In 1985, when for reasons unknown, the percentage emergence in general was not good, the highest emergence occurred with early sowing. It can be concluded that there would be a considerable advantage if farmers sowed their crops as early as possible after the commencement of autumn rain.

Phasic developments

Emergence to flowering

Summaries of the duration of the development phases of plants at the Waite Inst in 1985, 1986 and at the Charlick 1986 are presented in table 4, and figures 10, 11, and 12. The periods from sowing to first flower, first pod development and harvest or maturity were generally shortened by later sowing. In most instances late sowing led to these phases taking place during improving environmental conditions of temperature, solar radiation and bright sunshine which led to the more rapid completion of these phases (Table 1, 2, 3, and 4 in Appendix). There was also less plant-to-plant variation in the time to arrive at each of these phases as is evident from figures 7 and 8.

The number of days to flower in relation to sowing date for FIORD.

It is convenient to consider here the relation between emergence to flowering in Fiord and the environmental factors in the preflowering period, although the results for two sowing dates in 1987 are not presented until later in the thesis. Fiord was grown in 1987 as one of the 12 accessions studied in that year.

Fig 14 illustrates the large variation of 34 to 78 days that can occur in the number of days from emergence to flowering in FIORD when grown at different sites and sowing dates. This cultivar was sown on 14 dates in four site/year environments. There were considerable differences between years, for example between 1985 and 1986, at the Waite site. When all the sowing dates are considered together, the response in days to flower appears to be curvilinear with sowing date. This is most clearly illustrated when sowings were at intervals of only three weeks (the Waite 86 and Charlick 86). From the curve it can be estimated the longest time to flowering for FIORD, would occur from a sowing 50 to 60 days after Apr 1, that is from the 20 to 30 May. As the relationship is curvilinear it is difficult to believe FIORD has an obligate requirement for vernalization as the earliest sowing in late April or early May were followed by relatively high temperatures and it was not until late June or early July that cold temperatures were experienced. FIORD was flowering by early July from the early sowings.

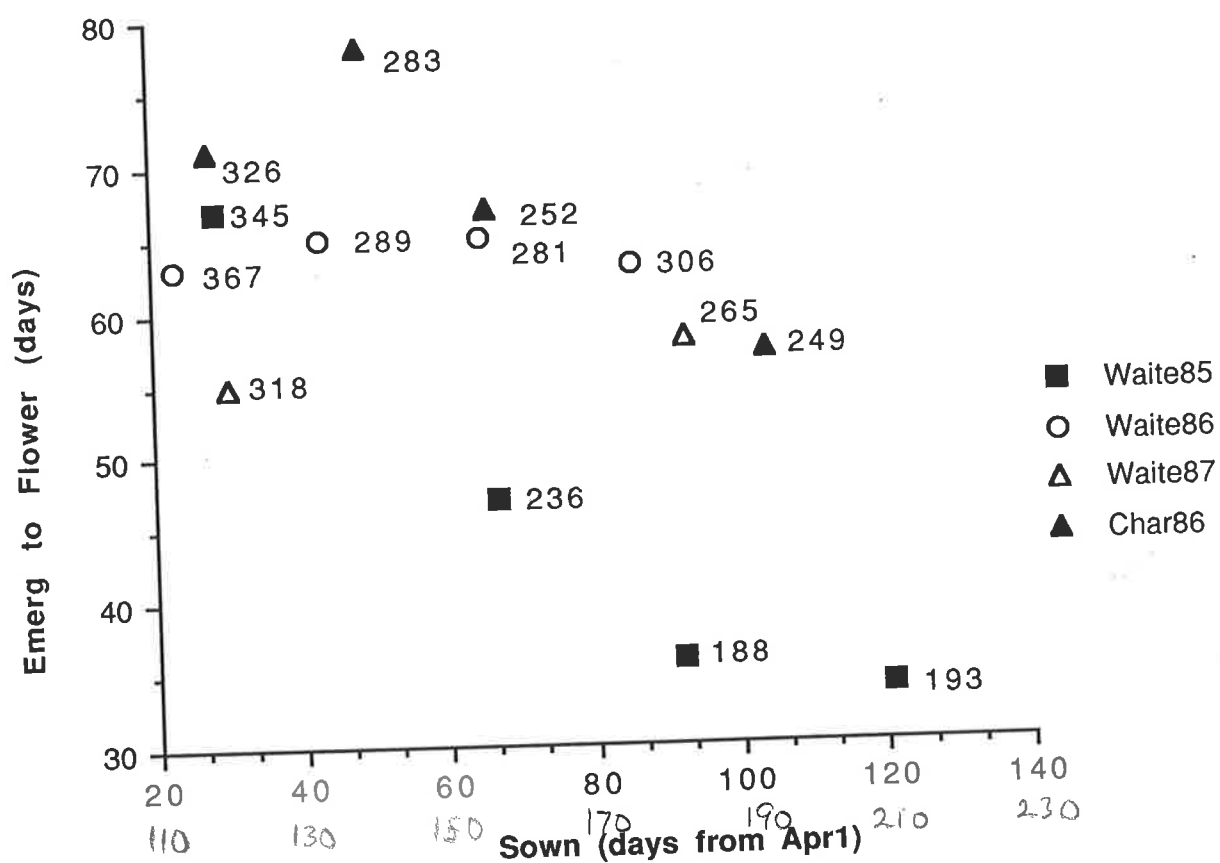


Fig. 14 The relation between sowing date and the number of days to flowering in FIORD. The values on the graph are the respective GDD.

On the graph, besides each value of days to flower, is the respective growing degree days (GDD) calculated from a base temperature of 7° C. The method used to determine this base temperature is described below. Temperature, when it is represented as GDD, does not seem to be the major determinant of days to flowering. If the GDD were of major importance, the values would have some similarity especially for any sowing date. Neither does photoperiod appear to be of overriding significance. For any one date, photoperiod is identical for the Waite and very similar for Charlick and photoperiod therefore could not be the sole explanation for the variation.

The relation between enviromental factors and progress towards flowering in FIORD.

Many studies have been conducted on annual crops relating the rate of progress towards flowering ($1/f$), calculated as the inverse of the number of days to flowering, and mean preflowering diurnal temperature (T) and mean preflowering photoperiod (P) (Roberts and Summerfield 1987). This approach was applied to FIORD for the 14 environments provided by the various times of sowing and the different sites. The analysis was modified subsequently to include the factor radiation, but as radiation was not recorded at the Charlick Meteorological Station the analysis was restricted to the 10 sowings made at the Waite Institute.

For the 14 environments, there was an apparent effect of temperature as the regression $1/f = -2.916 + 0.395 T$ was significant (prob .0295) (Fig 15). This equation was also used to calculate the base temperature; the temperature at which no development towards flowering would occur. The value of $1/f$ was zero when $T = 7.38^\circ \text{C}$. It is evident from the figure that this regression may be made up of several different regressions, each one being a site/year environment and that the estimate of the base temperature was strongly dependent on the sample of site/years in the analysis. If, for example, the four results from the Waite Institute in 1985 had not been obtained,

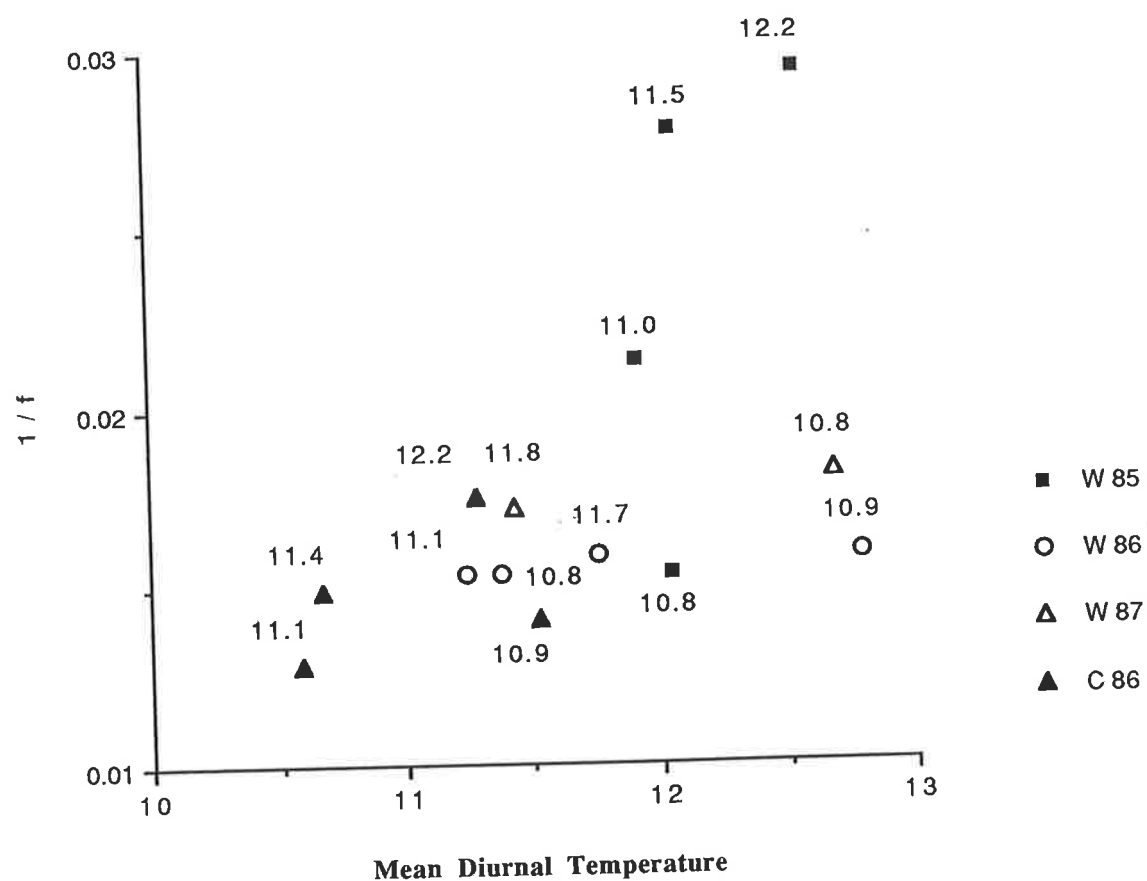


Fig.15 The relation between progress towards flowering($1/f$) and mean diurnal temperature. The values on the graph are the respective photoperiods.

the estimate of the base temperature would have been close to 0°C. It will be suggested in the final Discussion, that there are other possible criticisms of a combined regression and analyses base on data derived from field experiments. Also indicated on the diagram, adjacent to each coordinate, are the respective values of the mean photoperiod. They suggest, that for any one temperature, progress towards flowering was more rapid in a longer photoperiod.

However photoperiod on its own was not a significant factor. A graph of this relation is given in Fig16. The regression was not statistically significant with a probability of .071. Again there is evidence that the site/years represent different environments for flowering not accounted for by photoperiod.

To determine whether including both temperature(T) and photoperiod (P) could explain more of the variation in flowering than the simple regressions, a multiple regression on these two factors was calculated and gave $1/f = -8.717 + .402 T + .505 P$ with an R^2 value of .595. Both partial regression coefficients were significant at the 5% level of probability, with temperature accounting for more of the variation in the dependent variable than photoperiod. There was no correlation between temperature and photoperiod for the values used in this multiple regression.

If the mean photoperiod of 11.327 hr is entered in this equation the base temperature is estimated as 7.46° C.

When the analysis was undertaken on only the 10 Waite sowings and the Charlick results were excluded, none of the simple regressions on temperature, photoperiod or radiation were significant nor was the multiple regression on these combined factors. With only 10 sets of values, and the lower range in temperatures, this lack of significance was perhaps not surprising.

Some of the alternative methods, used by other workers, to estimate the base temperature were also applied. One was to calculate for the 14 environments, the growing degree days (GDD) required to reach flowering, using a range of base temperatures. With this method it is considered the base temperature resulting in the lowest coefficient of variation across the environments is the appropriate temperature for that accession.

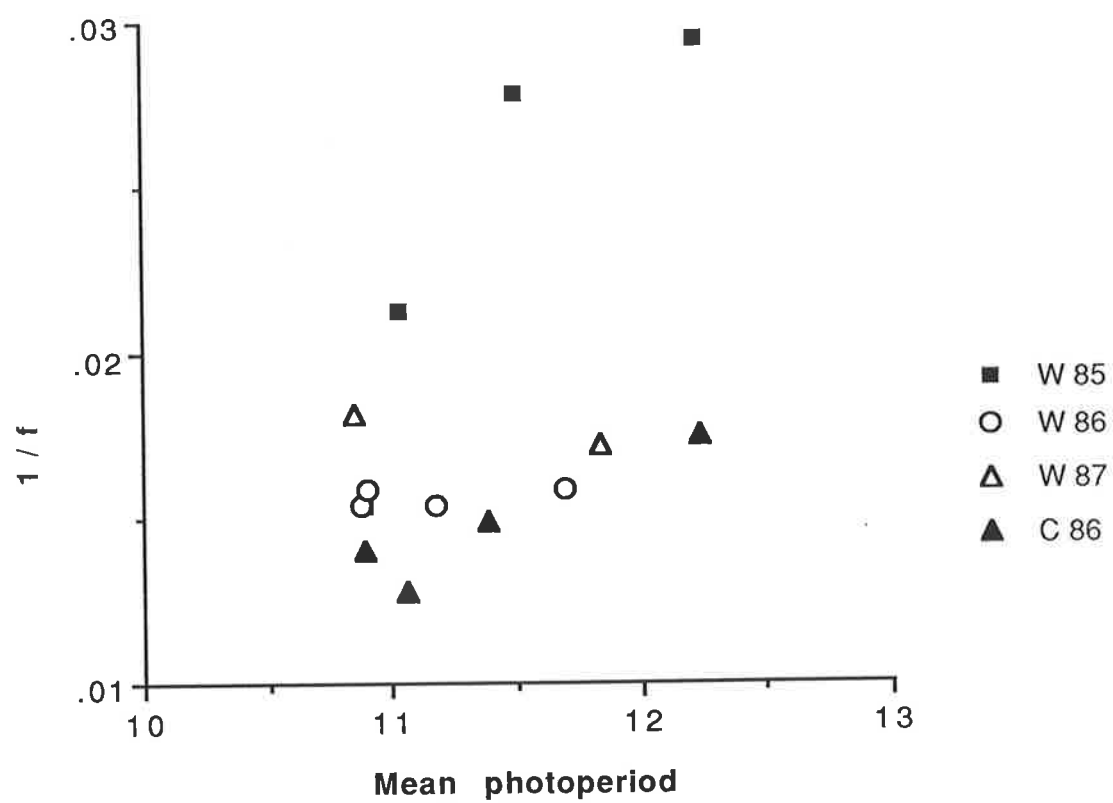


Fig. 16. The relation between progress towards flowering ($1/f$) and mean photoperiod.

The results are given in Table 5 from which it was estimated the base temperature for FIORD was 4.5° C

A third method used to estimate the base temperature was to calculate regressions, with the mean preflowering diurnal temperature as the independent variable and the GDD, derived from a range of base temperatures, as the dependent variable. With this technique the regressions are negative when the base temperatures are too low and positive when they are too high. When applied to the present results the appropriate base temperature (ie the regression slope was zero) was estimated to be 6.47° C. Thus the various methods for estimating base temperature have given the values 4.50°, 6.47°, 7.38° and 7.46° C. It will be shown subsequently, using results for the 12 accessions grown in 1987, that the most suitable common base temperature to apply to these accessions was 7.4° C. In view of these various results and because using different base temperatures, within the range estimated by these techniques, did not influence the biological conclusions drawn from the study, a single base temperature of 7° C was used in all subsequent analyses.

It could be concluded from the results for FIORD that progress towards flowering apparently was mainly influenced by temperature, but that photoperiod was also a statistically significant factor when temperature was held constant, as in the multiple regression. It might also be concluded that as the multiple regression on temperature and photoperiod accounted for only 60 % approximately of the variation in flowering, there remain other important factors which are unknown. However, as will be explained in the Discussion, the bases of these analyses are open to criticism.

The node number bearing the first flower.

The number of the node bearing the first flower and first pod was relatively constant (Figures 9 and 13); a result which differs from one obtained by Pandey (1981b) who found that the first flowering node was lower in late-planted crops. In my results the earliest node to develop a flower was the fourth for all sowing dates and the latest the 12th node for the early sowing. For the other sowing dates it was the 9th node. These

findings indicate that the positions of first flowers and pods were relatively unaffected by sowing dates. In the U.K, different results were obtained by Rowland (1955) who found that , in most instances, both first flowers and first pods were at 6th node. Jones (1963) found that the peak of mature pods occurred between 11 th and 13 th node and above the 13 th node there was an increasing tendency for pods to abort. Oliphant (1973) found differences between cultivars ; for the large-seeded cultivar Strubes, the lowest pod bearing node was the 4 th with a peak at the 7 th and the highest node was the 14 th but in the small-seeded cultivar Minor the lowest was the 7 th with a peak at the 10 th and the highest node was the 16 th.

Flowering to podding

For the two years, the period from flowering to podding decreased with delay in sowing. The explanation might be that, following early sowing, the first flower opened when temperatures were low and limiting to bee activity. For the first period of flowering the average temperature was 10 to 11 °C, while for last sowing it was up to 14°C.

However it is also known that autofertility increases with time and with higher temperatures (Poulsen, 1975) and this might have accounted for the shorter period between flowering and podding.

Podding to maturity

The period from podding to maturity also decreased as sowing dates were delayed. All of the environmental factors of temperatures, daylength and radiation were increasing rapidly during September and October and temperature rose from an average of 13°C to 19 °C. In 1986 when precise records were kept of the date of maturity of the plants, a 14 day difference was recorded between the date of maturity of the first sown and last sown plants. Various factors could have been involved but it will be suggested as a result of additional evidence in 1987 that maturity was determined largely by internal factors of the plants rather than environmental conditions. Other studies have suggested internal factors determine maturity in faba beans (Davies and Williams, 1986).

Table. 5. Growing Degree Days 2 - 8 Degrees C for flowering of Fiord.

Emergence to flowering (days)	Growing Degree Days (GDD)						
	GDD2	GDD3	GDD4	GDD5	GDD6	GDD7	GDD8
65	670	605	540	475	410	345	280
47	471	424	377	330	283	236	189
36	368	332	296	260	224	188	152
34	363	329	295	261	227	193	159
63	682	619	556	493	430	367	304
65	614	549	484	419	354	289	224
65	606	541	476	411	346	281	216
63	621	558	495	432	369	306	243
55	593	538	483	428	373	318	263
58	555	497	439	381	323	265	207
71	682	611	540	469	398	327	256
78	673	595	517	439	361	283	205
67	587	520	453	386	319	252	185
57	534	477	420	363	306	249	192
Average	572.8	513.9	455.1	396.2	337.4	278.5	219.6
STDEV	106.4	94.82	83.49	72.53	62.16	52.71	44.78
CV	0.186	0.185	0.183	0.183	0.184	0.189	0.204

CHAPTER 4 B

THE RESPONSE IN YIELD AND OTHER CHARACTERS TO VARIATION IN SOWING DATE AND DENSITY

RESULTS

The Waite Institute and Charlick 1985.

Yield, Dry matter, Pod number and Harvest index

The results, already presented for emergence at the Waite in 1985 indicated that the percentage emergence was less than that expected. Account has been taken of this, and the densities referred to in the following are observed mean densities.

Sowing date and density affected yield, with the highest yield being obtained from the earliest sowing (Figure 17). The interaction of sowing date and density was highly significant ($P < 0.01$) at the Waite but not at Charlick. At both locations, yield increased with density, however at the Waite only with the early sowing there was evidence that an optimum yield was obtained at 27 plant m^{-2} .

At the Waite, total dry matter production and the number of pods per unit area showed a similar response to yield (Figure 18); both decreased with delay in sowing. The relation between yield and total dry matter was not constant with sowing date. This was reflected in variation in the harvest index (Table 6 a). For the first sowing, when environmental conditions were favourable for growth there was a high dry matter production and a lower HI. For the next two sowings HI rose, and the lowest HI was found for the last sowing. This was due probably to an insufficient time for pods to develop and a shorter pod filling period. Harvest index was relatively constant across density at the Waite in 1985.

At Charlick, yield for the first and second sowings increased with increasing density while for the third and last sowing the response was almost flat across various densities. Dry matter production and the number of pods were not measured at Charlick in 1985.

b.Yield and its components per plant

Measurements of yield components on a per-plant basis were made on samples of 10 plants per plot and the mean values given in table 7, and later tables, are derived therefore, from 40 plants. It was found that these mean values, if multiplied by the respective densities, gave higher yields than were actually obtained from the bulk harvesting of a plot. It is believed that plants in the samples benefited occasionally if plants were missing from neighbouring rows. This effect might be greater in a crop, such as faba beans, in which the plants are more squarely planted, than in cereals where there is a large distance between rows. Although this occurred, it is not thought to have influenced the general conclusions about the effect of sowing date and density on yield components.

In general yield per plant declined with increasing density and delay in sowing (table 7) however, there was a significant interaction and at the last sowing there was no trend with density.

The total dry matter and the number of pods declined with later sowing and increased density. For the number of seeds per pod and seed weight there were no interactions between sowing date and density. The number of seeds was very constant for any one sowing date but declined with later sowing.

Mean weight per-seed was similar for the first two times of sowing but decreased with the later sowings. Again density had no effect.

Table 6 a. Effect of sowing date and density on harvest index at the Waite Institute in 1985.

Sowing date	Plant m ⁻²					mean
	15	21.0	27.0	33.0	39.0	
30 April	0.52	0.59	0.55	0.56	0.54	0.55
7 June	0.62	0.61	0.59	0.59	0.63	0.61
2 July	0.64	0.56	0.56	0.58	0.58	0.58
31 July	0.48	0.47	0.45	0.44	0.46	0.46
mean	0.56	0.56	0.54	0.54	0.55	0.55

Table 6 b. Effect of sowing date and density on harvest index at the Waite and Charlick 1986.

Sowing date	Plants m ⁻²						mean
	20.0	27.0	35.0	42.0	49.0	56.0.	
Waite.							
24 April	0.48	0.45	0.41	0.40	0.40	0.40.	0.42
14 May	0.46	0.48	0.44	0.45	0.45	0.42.	0.45
5 June	0.54	0.49	0.48	0.47	0.47	0.47.	0.48
26 June	0.52	0.50	0.51	0.48	0.45	0.44.	0.48
mean	0.50	0.48	0.46	0.45	0.44	0.43	0.46
Charlick.							
29 April	0.42	0.41	0.42	0.41	0.40	0.39.	0.41
20 May	0.66	0.62	0.52	0.57	0.56	0.58.	0.59
10 June	0.51	0.52	0.58	0.54	0.59	0.52.	0.54
14 July	0.59	0.54	0.57	0.55	0.40	0.49.	0.52
mean	0.55	0.52	0.52	0.52	0.49	0.49	0.52

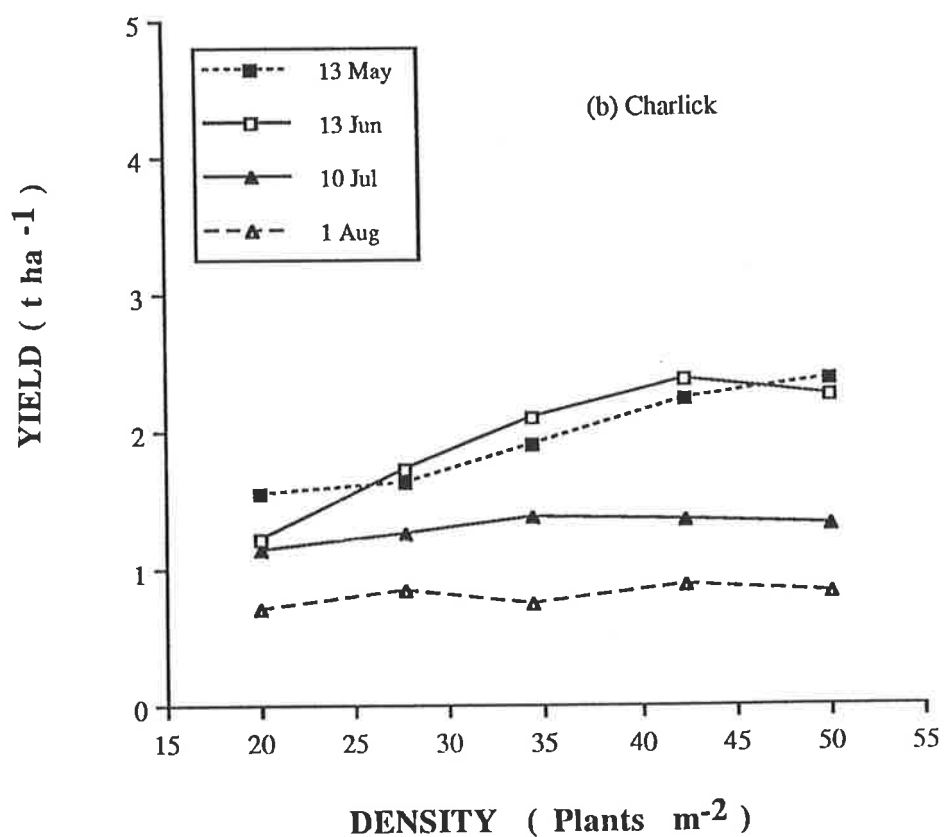
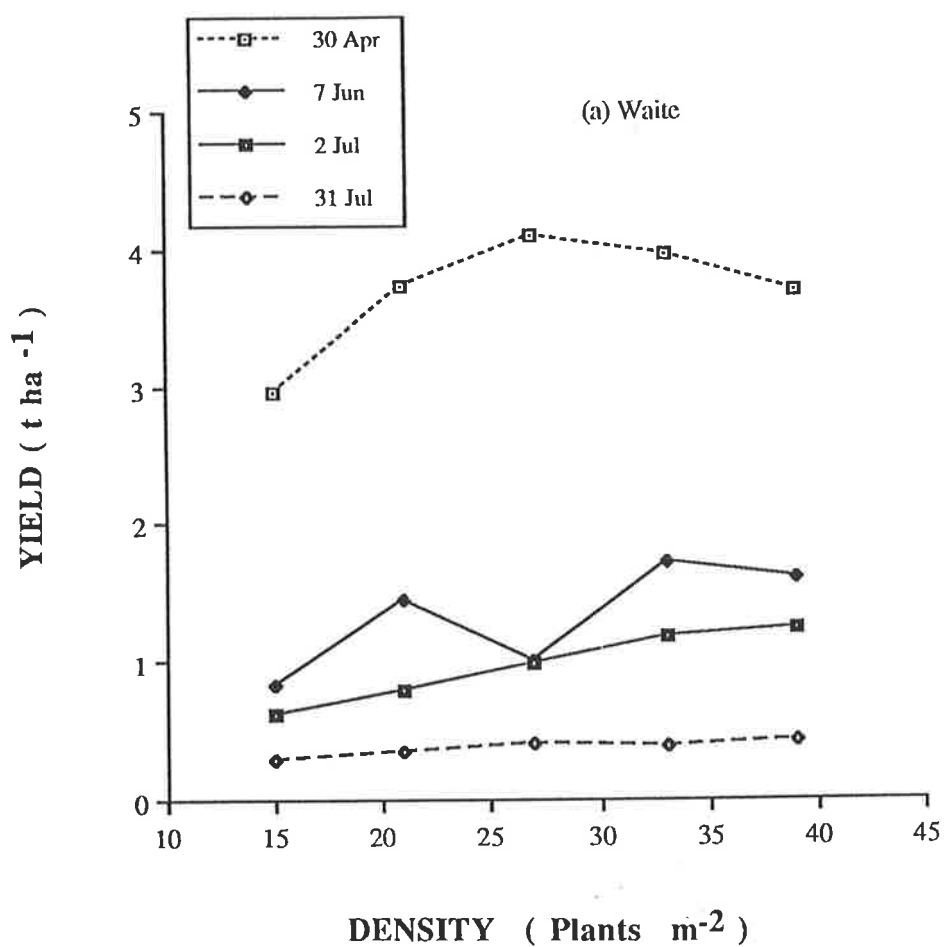


Fig.17 The relation between density and yield for different sowing dates at (a) Waite Institute and (b) Charlick in 1985

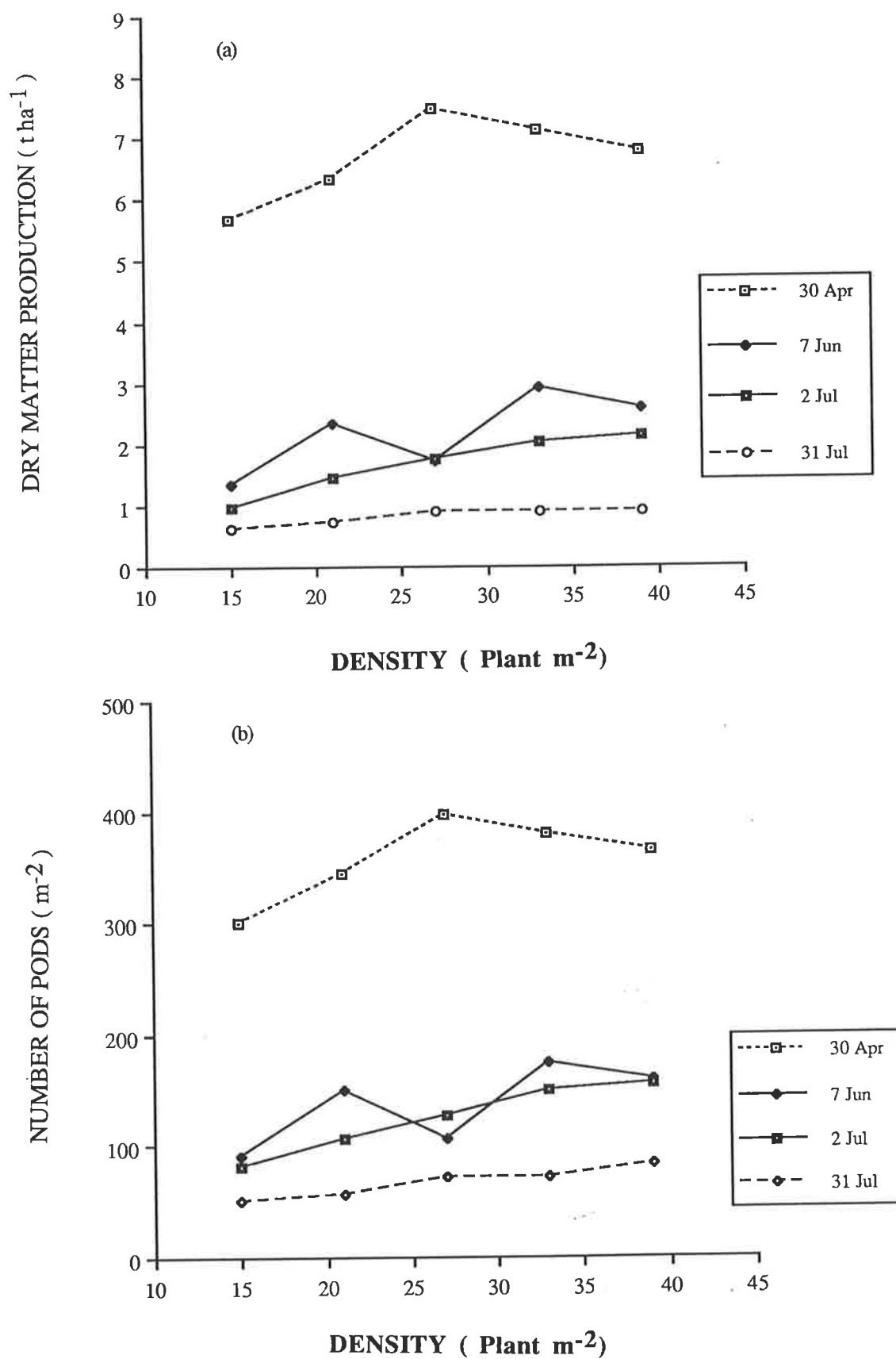


Fig.18. The relation between density and sowing dates for
(a) dry matter (t ha⁻¹) and (b) number of pods(m⁻²) at the Waite in 1985.

Table 7. Effect of sowing date and density on yield per plant and its components at the Waite in 1985.

Sowing time	Plants m ⁻²					Mean
	15.0	21.0	27.0	33.0	39.0	
Yield (g)						
30 April	15.6	10.3	13.0	10.6	8.1	11.5
7 June	7.5	7.5	5.3	7.2	4.7	6.4
2 July	3.2	2.8	2.6	2.9	2.8	2.9
31July	0.2	0.9	1.1	0.7	1.0	0.8
mean :	6.6	5.4	5.5	5.3	4.2	
LSD interaction 0.05 = 1.51						
Total dry matter(g)						
30 April	27.8	18.3	23.4	18.7	14.7	20.6
7 June	11.7	12.1	8.7	11.4	7.6	10.3
2 July	5.4	4.8	4.5	5.1	4.8	4.9
31July	0.8	2.2	2.3	1.6	2.1	1.8
mean :	11.4	9.3	9.7	9.2	7.3	
LSD interaction 0.05 = 2.51						
Number of pods						
30 April	14.9	10.3	12.6	10.1	7.9	11.2
7 June	7.9	7.5	5.6	7.1	5.0	6.6
2 July	4.4	3.9	3.5	4.1	3.9	3.9
31July	1.1	1.8	2.0	1.6	1.9	1.7
mean :	7.1	5.9	5.9	5.7	4.6	
LSD interaction 0.05 = 1.27						
Number of seeds per pod						
30 April	2.40	2.38	2.35	2.35	2.28	2.35
7 June	2.20	2.20	2.14	2.30	2.21	2.21
2 July	2.18	2.26	2.19	2.13	2.19	2.19
31July	1.44	1.83	1.96	1.63	1.88	1.75
mean :	2.06	2.17	2.16	2.10	2.14	
LSD 0.05 sowing date = 0.18						
Weight per seed(g)						
30 April	0.44	0.42	0.44	0.45	0.45	0.44
2 June	0.43	0.45	0.45	0.44	0.43	0.44
2 July	0.33	0.32	0.34	0.33	0.35	0.33
31July	0.14	0.28	0.29	0.25	0.29	0.25
mean :	0.34	0.37	0.38	0.37	0.38	
LSD 0.05 sowing date = 0.09						

If a value of LSD interaction is given it may be used to compared the values in the table.
 If LSD sowing date or LSD density are given ,they refer to the respective marginal means

The Waite Institute and Charlick 1986.

At both sites in 1986 environmental conditions for growth were much better than in 1985 and yields were much higher. This led to different relations between density and yield.

Yield, Dry matter, Pod number and Harvest Index.

For yield at the Waite, there was a very marked interaction between sowing date and density (Figure 19 a). Yield for the early sowing decreased almost linearly over the range of densities. However, for the later sowings yield increased with density from 20.0 to 47.0 plant m^{-2} and then fell slightly. The optimum density for early sowing would have been less than 20 plant m^{-2} . For the later sowing the density would have been between 35 and 50 plants m^{-2} .

At Charlick, for early sowing again the response showed an optimum but, with later sowing, yield (Figure 19 b) increased with density.

At the Waite, total dry matter was almost constant at 13 t ha^{-1} for the various densities, following early sowing, while for later sowing it increased with increasing density (Figure 20 a). The number of pods decreased with increasing density for early sowing and increased slightly for later sowing (Figure 20 b).

At Charlick, total dry matter showed similar responses to those obtained at the Waite but values were lower. For example dry matter from the early sowing was constant with density at only 10 t ha^{-1} . The number of pods increased as density was increased, for all times of sowing, but the values were less with later sowing (Figures 21).

At both the Waite and Charlick harvest index increased with delayed sowing and decreased with increasing densities (Table 6b). There was some indication that a maximum had been reached and still later sowings would have led to a decline as was found at the Waite in 1985.

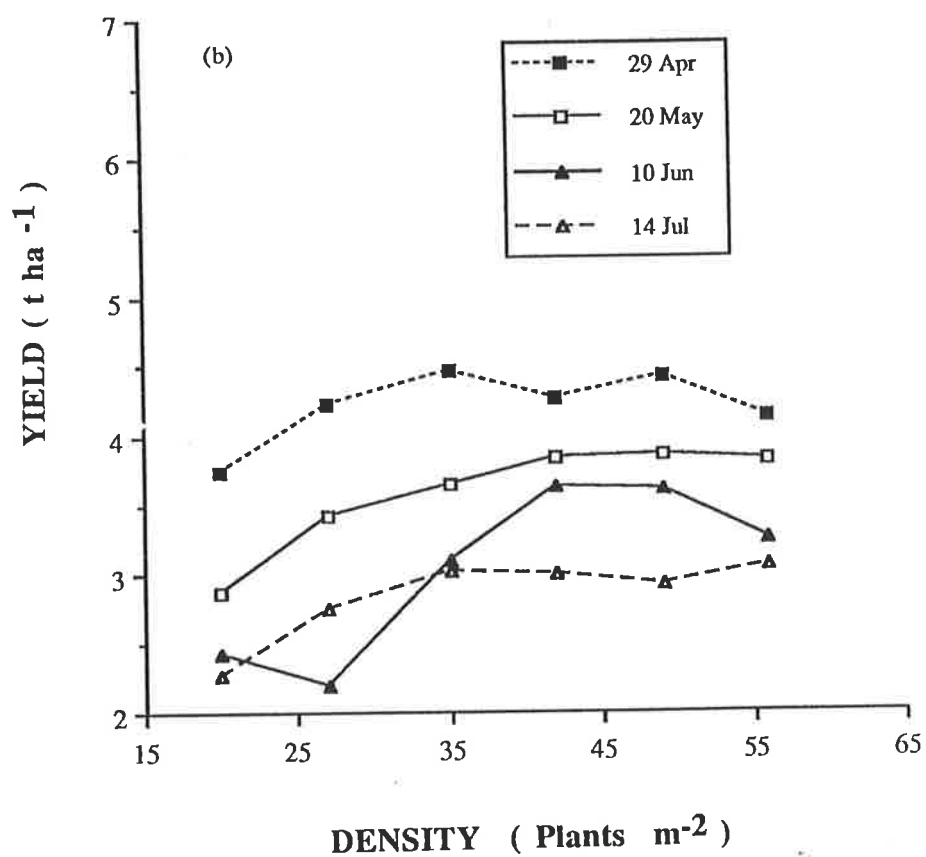
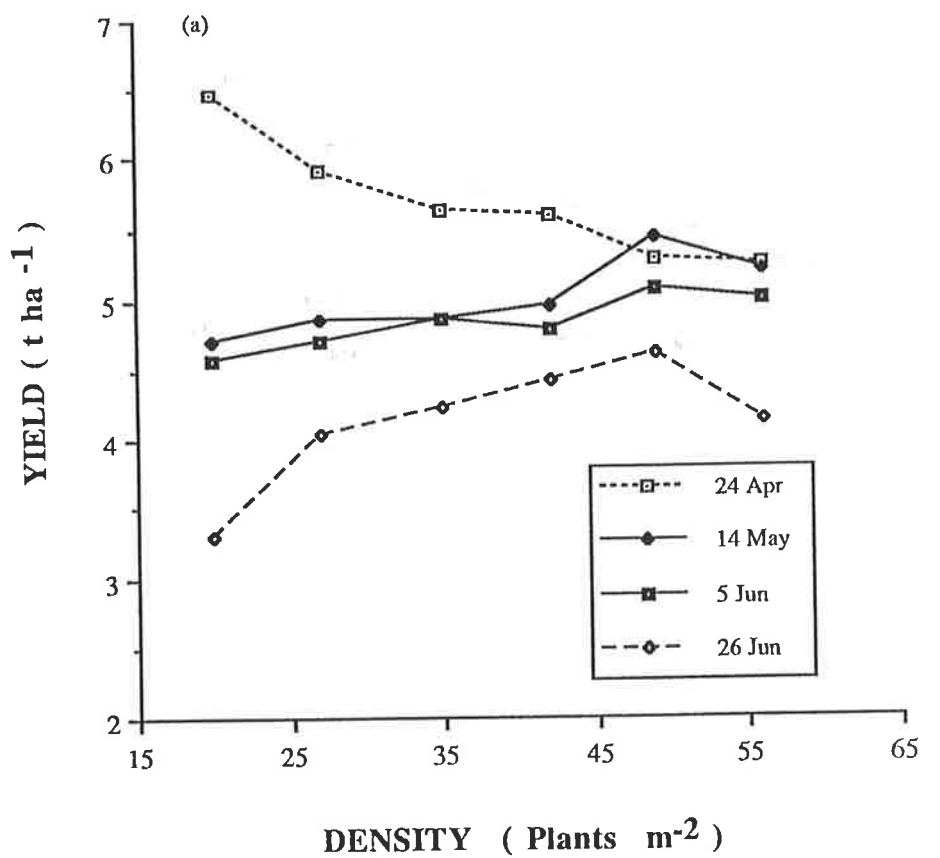


Fig.19 The relation between density and yield for different sowing dates at (a) the Waite and (b) Charlick in 1986

per unit area

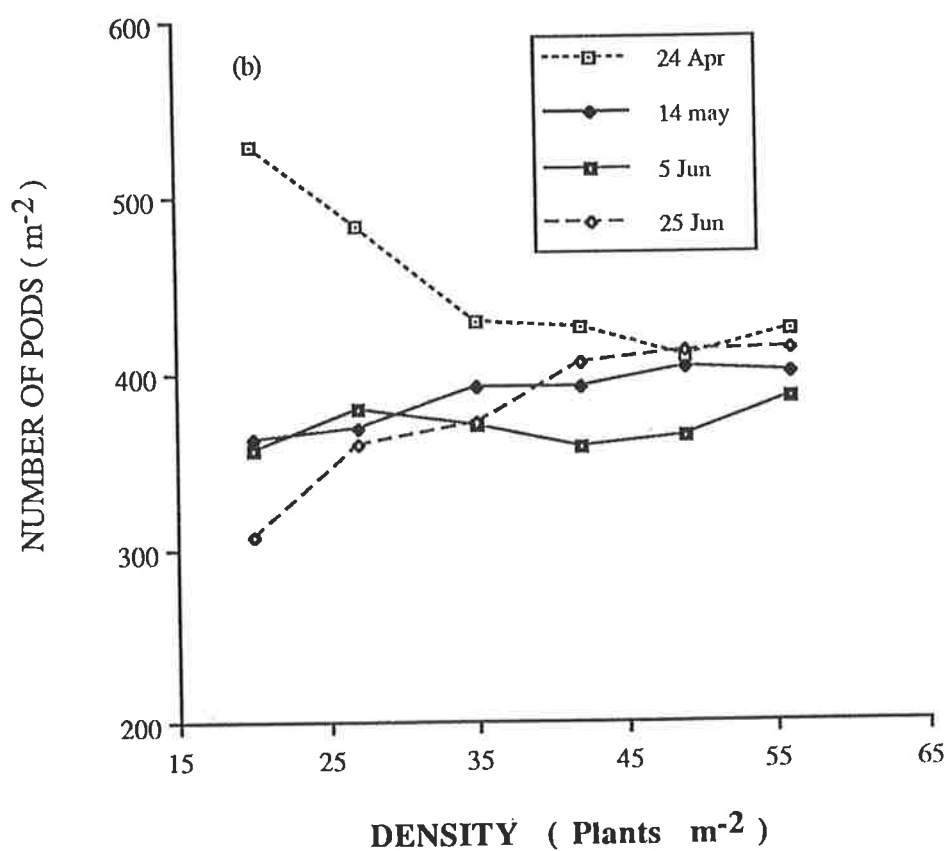
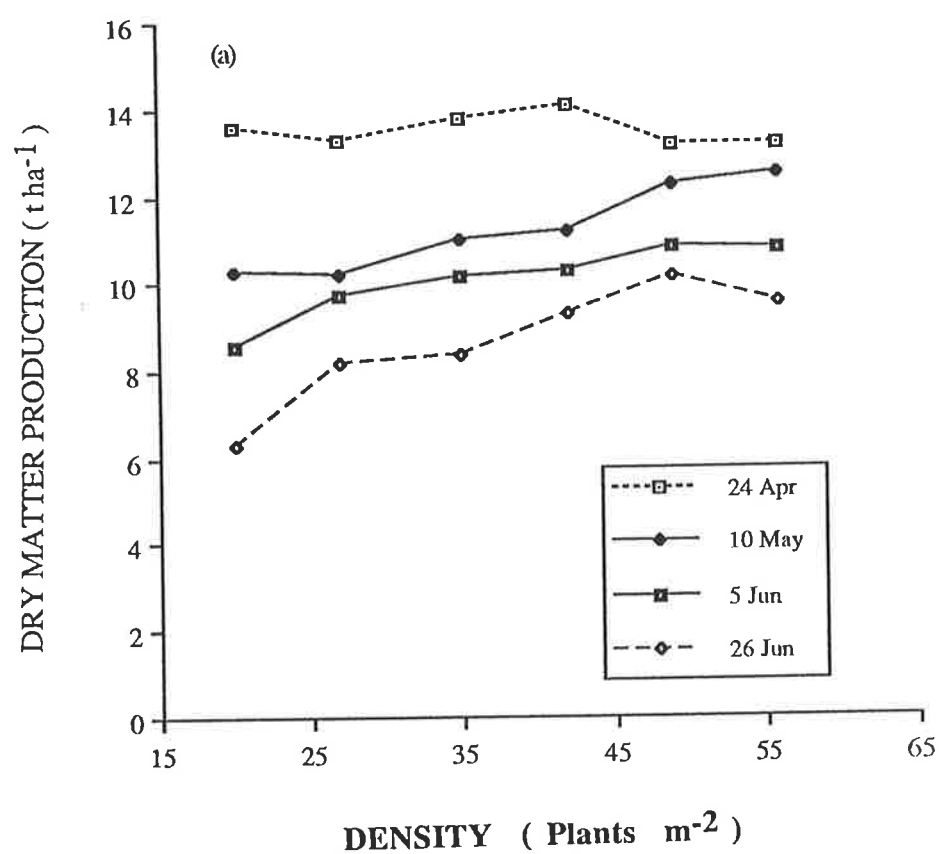


Fig.20 Relation between density and sowing dates for
(a) dry matter (t ha^{-1}) and (b) number of pods (m^{-2}) at the Waite in 1986

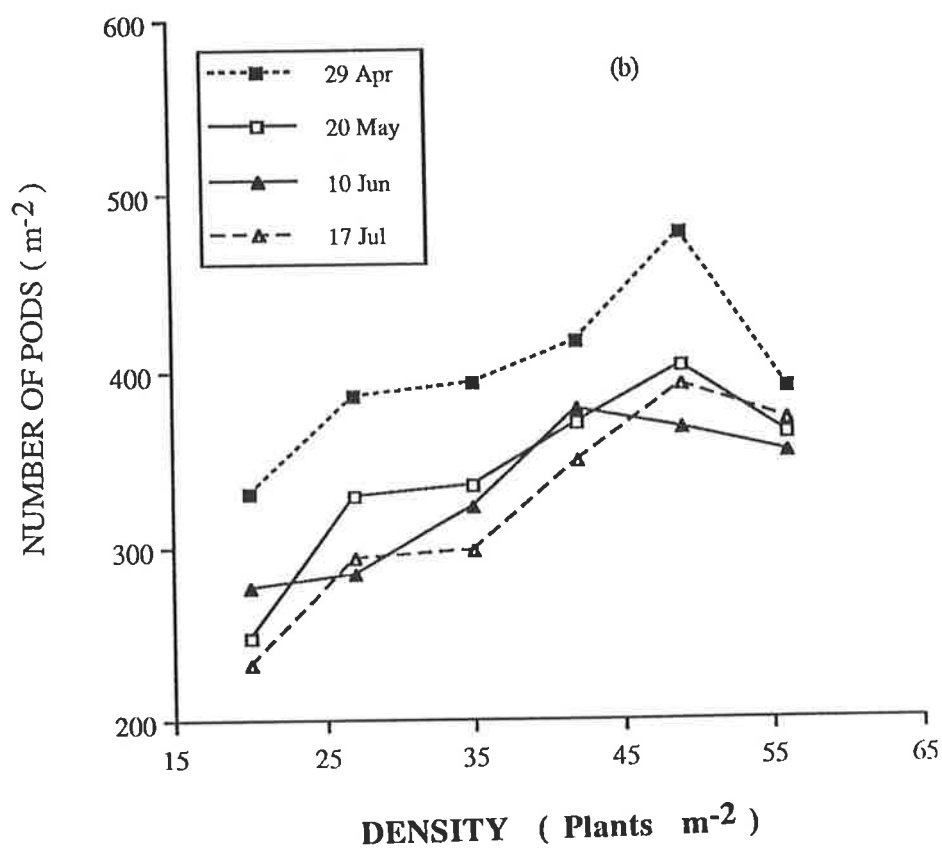
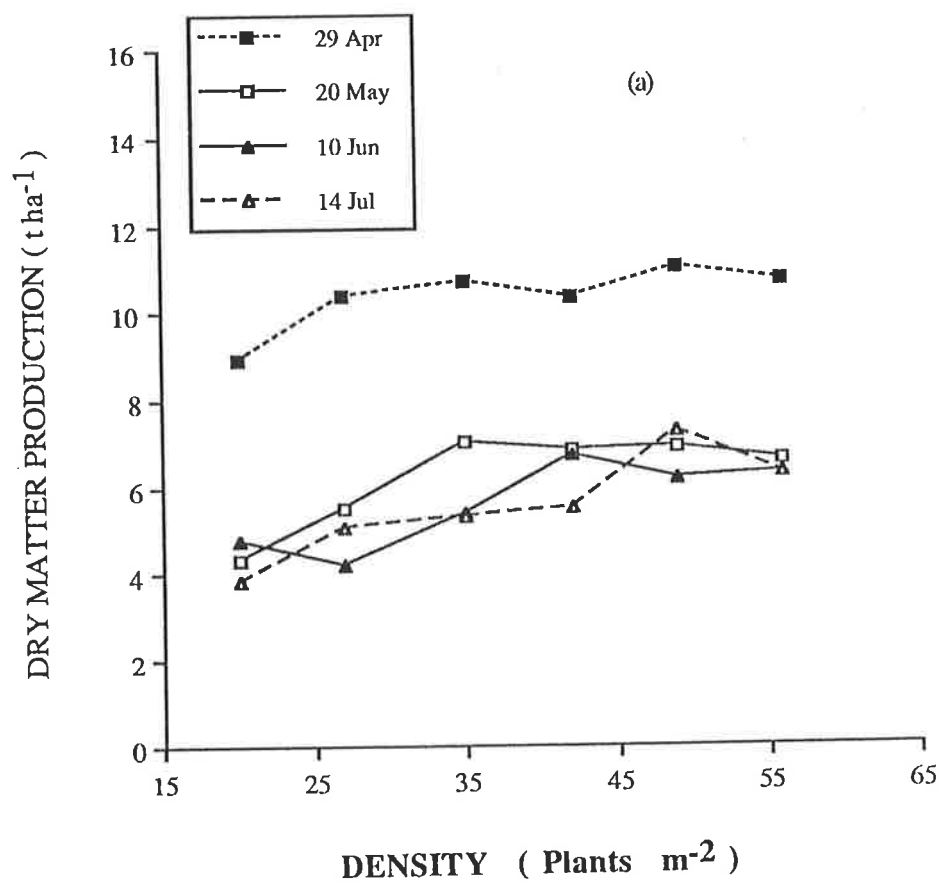


Fig.21 Relation between density and sowing dates for
 (a) dry matter (t ha^{-1}) and (b) number of pods (m^{-2}) at the Charlick in 1986

Yield and its components per-plant

Results for various characters, measured on a per-plant basis, are given in table 8. In general the presence or absence of trends in these results follow closely those found in 1985. Where there are differences, they may be attributed to the much better growing conditions experienced in 1986 and that the sowing dates were only three weeks apart, which meant that not as long a total period was covered. Thus the last sowing date at the Waite was 26 June against 31 July in 1985. As a result, seeds per pod and weights per seed were higher in 1986 and did not show a fall over the range of sowing dates. Again there was no effect of density on the mean values of these characters.

Also evident from the table is that the number of lateral branches per plant fell with increasing density and later sowing.

At the Waite, the effect of sowing date on the distribution of pods on the nodes of the plants is shown in figure 22. These results are averaged across density and the separate effects of density are considered later. There were major differences attributable to sowing date. For the earliest sowing, the pods were distributed from nodes 3 to 30 and the average number of pods per node never exceeded 0.7 pods. In contrast for the last sowing the pods were concentrated on fewer nodes, from node 3 to 18, and with up to 1.4 pods per node. The percentage distribution of these pods on the nodes is presented in figure 23. The differences observed may be attributed to a combination of the longer growing season, a longer podding period and more nodes per plant that resulted from earlier sowing. In addition, for the early sowing, the flowers on the lower nodes would have opened during the coldest part of the year and this may account for the fewer pods per node.

The effect of density on the number of pods per node is evident from figures 24. Differences attributable to density are most apparent for the early sowing (Figure 24 a) which shows that at the low density of 20 plant m^{-2} the pods were more concentrated on the lower nodes with a maximum at approximately node 8 whereas at the high density of 56 plant m^{-2} the pods were distributed more widely over the nodes with a maximum at about 12.

Table 8. Effect of sowing date and density on yield and its component per plant at the Waite 1986.

Sowing date	Plants m ⁻²						mean
	20	27	35	42	49	56	
Yield (g)							
24 April	37.5	31.8	35.0	22.0	16.4	15.1	26.3
14 May	30.7	20.1	18.8	16.9	14.9	13.0	19.1
5 June	46.7	27.1	18.4	13.9	20.9	14.7	23.6
26 June	26.6	19.3	16.1	13.9	10.5	11.4	16.3
mean	35.4	24.6	21.3	16.7	16.5	13.5	
LSD interaction 0.05 = 6.2							
Total dry matter (g)							
24 April	71.4	59.4	61.7	46.6	34.1	33.6	51.1
14 May	62.7	40.9	38.7	34.3	30.0	26.9	38.9
5 June	74.2	45.2	35.8	27.1	35.7	26.6	40.8
26 June	42.7	33.2	28.1	25.0	19.3	21.0	28.2
mean	62.8	44.7	38.9	33.2	32.0	27.0	
LSD interaction 0.05=10.3							
No of pods							
24 April	30.3	25.9	29.1	18.0	13.3	12.3	21.5
14 May	25.4	16.2	15.6	13.0	12.3	11.0	15.6
5 June	40.3	21.5	15.1	11.4	17.1	11.8	19.5
26 June	25.6	17.9	14.1	13.3	10.2	10.3	15.2
mean	30.4	20.4	18.0	13.9	13.7	11.3	
LSD interaction 0.05=4.8							
No of seeds per-pod							
24 April	2.47	2.48	2.53	2.44	2.49	2.51	2.49
14 May	2.63	2.53	2.48	2.64	2.44	2.50	2.54
5 June	2.57	2.50	2.49	2.63	2.48	2.56	2.54
26 June	2.49	2.53	2.63	2.47	2.51	2.51	2.52
mean	2.54	2.51	2.50	2.55	2.51	2.52	
LSD 0.05 = non significant							
Weight per-seed(g)							
24 April	0.50	0.48	0.49	0.48	0.49	0.49	0.49
14 May	0.47	0.49	0.48	0.49	0.48	0.47	0.48
5 June	0.46	0.51	0.51	0.51	0.48	0.49	0.50
26 June	0.42	0.43	0.44	0.42	0.42	0.44	0.43
mean	0.46	0.48	0.47	0.47	0.48	0.48	
LSD sowing date 0.05=0.02							
No of lateral branches							
24 April	3.6	3.2	2.9	2.7	2.2	2.0	2.74
14 May	3.6	3.3	3.0	2.5	2.3	2.1	2.78
5 June	3.7	3.0	2.8	2.5	2.6	2.3	2.80
26 June	2.5	2.2	2.0	2.1	1.7	1.7	2.01
mean	3.31	2.90	2.53	2.44	2.29	2.00	
LSD interaction 0.05=0.37							

If a value of LSD interaction is given it may be used to compare the values in the table.
 If LSD sowing date or LSD density are given they refer to the respective marginal means.

Table 9. Effect of sowing date and density on yield and its components per plant at Charlick, 1986.

Sowing date	Plants m ⁻²						mean
	20.	27	35	42	49	56.	
Yield (g)							
29 April	20.4	19.7	16.2	12.1	10.7	8.2	14.5
20 May	20.4	15.1	10.3	10.1	9.5	9.1	12.4
10 June	20.1	17.9	12.2	8.9	9.1	7.2	12.6
17 July	14.7	11.0	9.6	8.4	8.0	6.8	9.7
mean	18.9	15.9	12.1	9.9	9.3	7.8	
LSD 0.05 sowing date = 1.57 ; density = 1.93							
Total dry matter (g)							
29 April	40.6	39.8	31.0	25.8	22.3	18.0	29.6
20 May	32.8	24.8	18.7	16.7	15.8	15.8	20.8
10 June	34.2	29.4	21.7	16.1	15.7	13.6	21.8
17 July	27.3	20.7	17.3	16.1	15.4	12.8	18.3
mean	33.7	28.7	22.2	18.7	17.3	15.1	
LSD 0.05 sowing date = 2.56							
No of pods							
29 April	19.1	17.5	12.7	11.2	9.8	7.4	12.9
20 May	19.4	14.2	9.7	9.8	8.8	8.6	11.7
10 June	23.6	20.0	12.7	9.8	9.4	7.3	13.8
17 July	18.7	11.7	11.7	9.7	9.5	7.3	11.4
mean	20.2	15.8	11.7	10.1	9.4	7.6	
LSD 0.05 interaction = 3.49							
No of seeds per-pod							
29 April	2.48	2.52	2.42	2.30	2.38	2.42	2.42
20 May	2.29	2.42	2.36	2.34	2.35	2.35	2.35
10 June	2.07	2.05	2.27	2.19	2.16	2.25	2.16
17 July	2.17	2.30	2.22	2.27	2.20	2.37	2.26
mean	2.25	2.32	2.32	2.28	2.27	2.35	
LSD 0.05 sowing date = 0.73							
Weight per seed(g)							
29 April	0.54	0.44	0.54	0.46	0.43	0.44	0.48
20 May	0.46	0.44	0.46	0.42	0.45	0.45	0.45
10 June	0.43	0.45	0.44	0.43	0.45	0.45	0.44
17 July	0.37	0.42	0.38	0.37	0.37	0.39	0.40
mean	0.45	0.44	0.46	0.42	0.43	0.43	
LSD 0.05 sowing date = 0.41							
No of lateral brachnes							
29 April	2.9	2.4	2.1	1.9	1.5	1.6	2.05
20 May	2.7	2.2	1.8	1.5	1.6	1.3	1.83
10 June	3.1	2.8	2.3	2.1	1.9	1.9	2.35
17 July	3.0	2.4	2.5	2.0	2.1	1.8	2.28
mean	2.93	2.44	2.16	1.86	1.75	1.62	
LSD 0.05 sowing date = 0.13 ; density = 0.16							

If a value of LSD interaction is given it may be used to compare the values in the table.
 If LSD sowing date or LSD density are given ,they refer to the respective marginal means.

Sowing date and density did not affect the mean number of seeds per pod (table 8), but these mean values concealed the variation found when individual pods were analysed .

Figure 25 illustrates how seeds per pod varied among the nodes of the plants for the different sowing dates. Following early sowing, pods on the lowest and highest nodes tended to have fewer seeds per pod, but over many intervening nodes (nodes 5 to 25) seeds per pod were relatively constant at about 2.55 seeds. Progressively for the later sowings, the number of intervening nodes with constant seed numbers was less, until finally, for the 26, June the nodes with constant seed weight were only nodes 4 to 7. The distribution of weight up the plant became more curvilinear with time. There was no evidence that the number of seeds per pod was affected by density (Figure 26)

The mean weight per seed decreased with later sowing from 0.49 g to 0.43 g per seed (table 8). Figure 27 shows the variation in weight per seed for the successive nodes of the plants from the different sowing dates. For the 24 April, weight per seed was very consistent for every node of the plant, but again with later sowing, the distribution was more curvilinear and it was the seeds formed on the upper nodes of the plants which were of lower weight. Plant density had no clear affect on weight per seed over the four sowing dates examined (Figure 28).

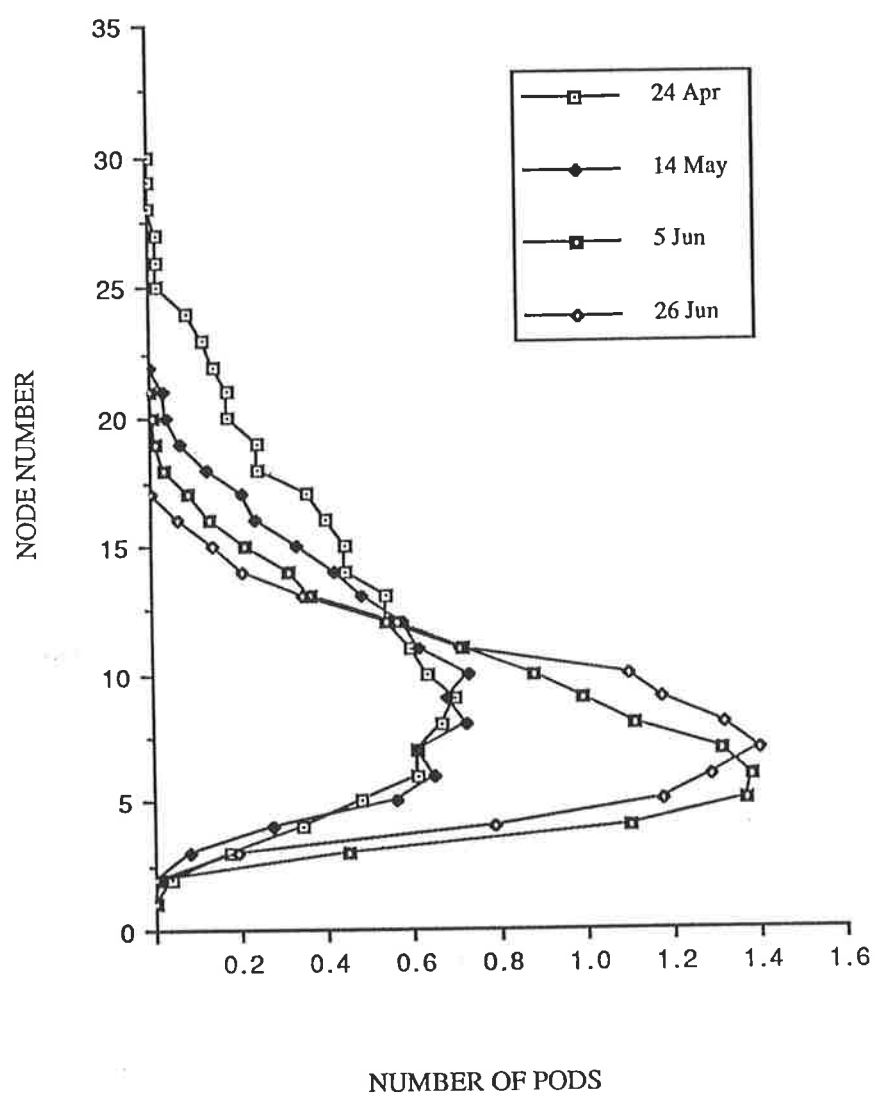


Fig. 22. The distribution of pods on the nodes of plants sown on different sowing dates at the Waite 1986.

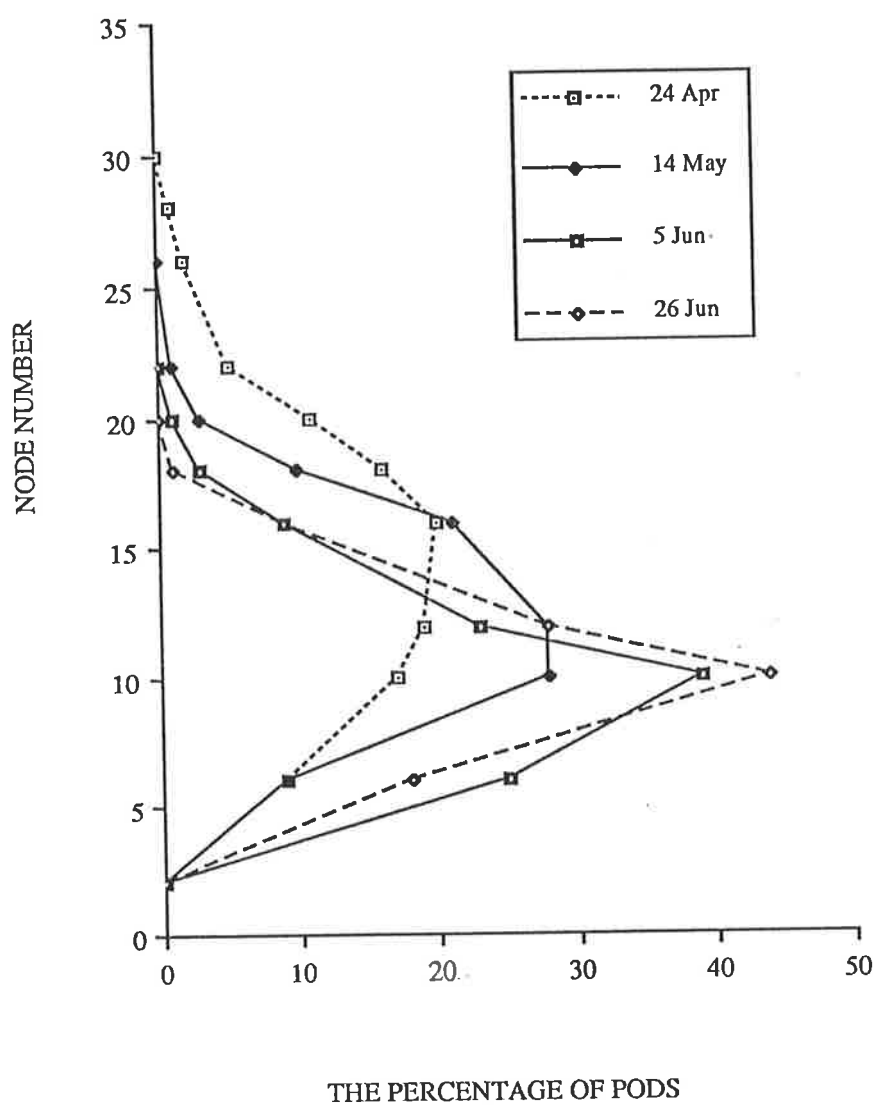


Fig.23. The percentage distribution of pods on the nodes of plants sown on different sowing dates at the Waite 1986.

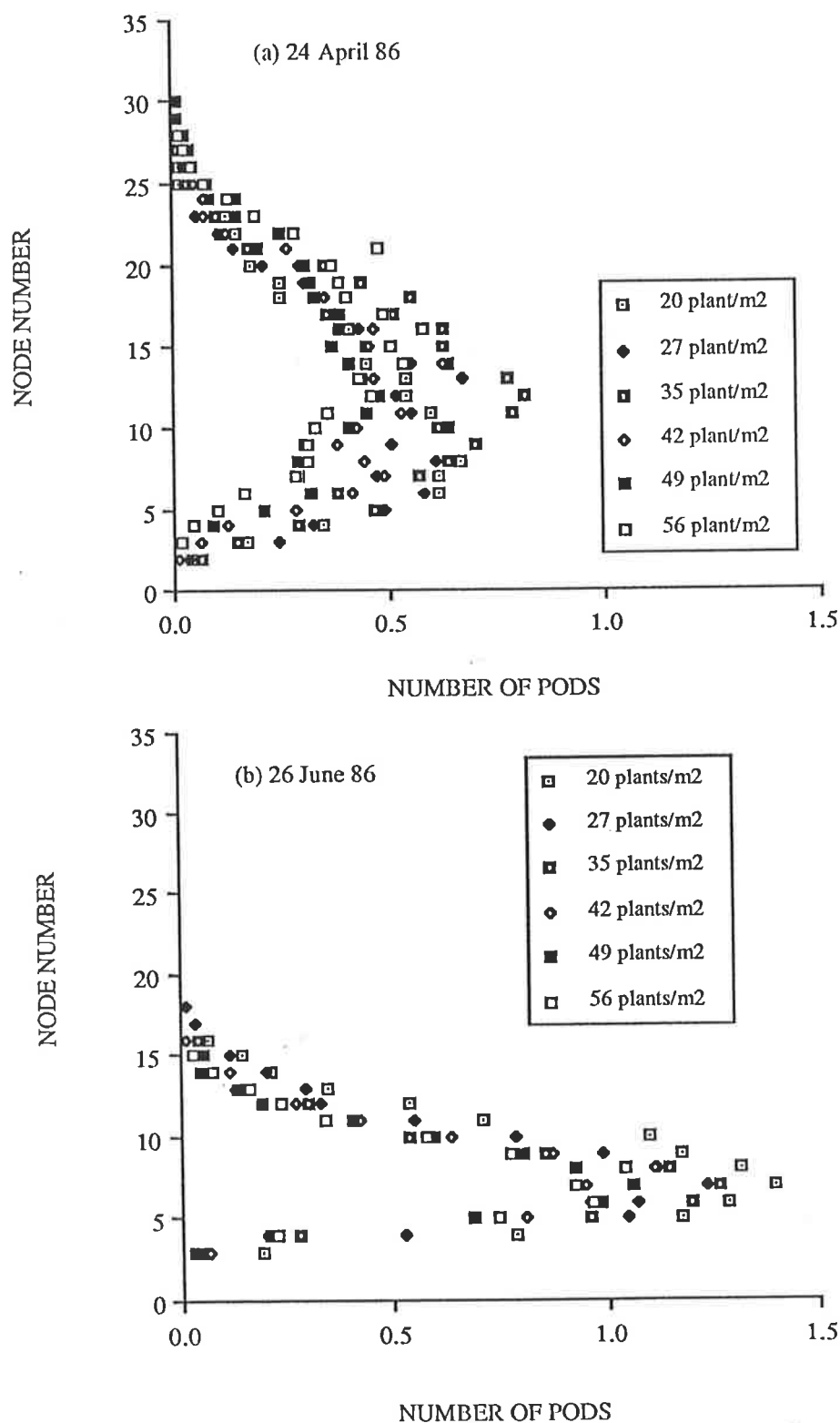


Fig 24 The distribution of pods on the nodes of the plants sown at different densities (a) early or (b) late sowing at Waite 1986.

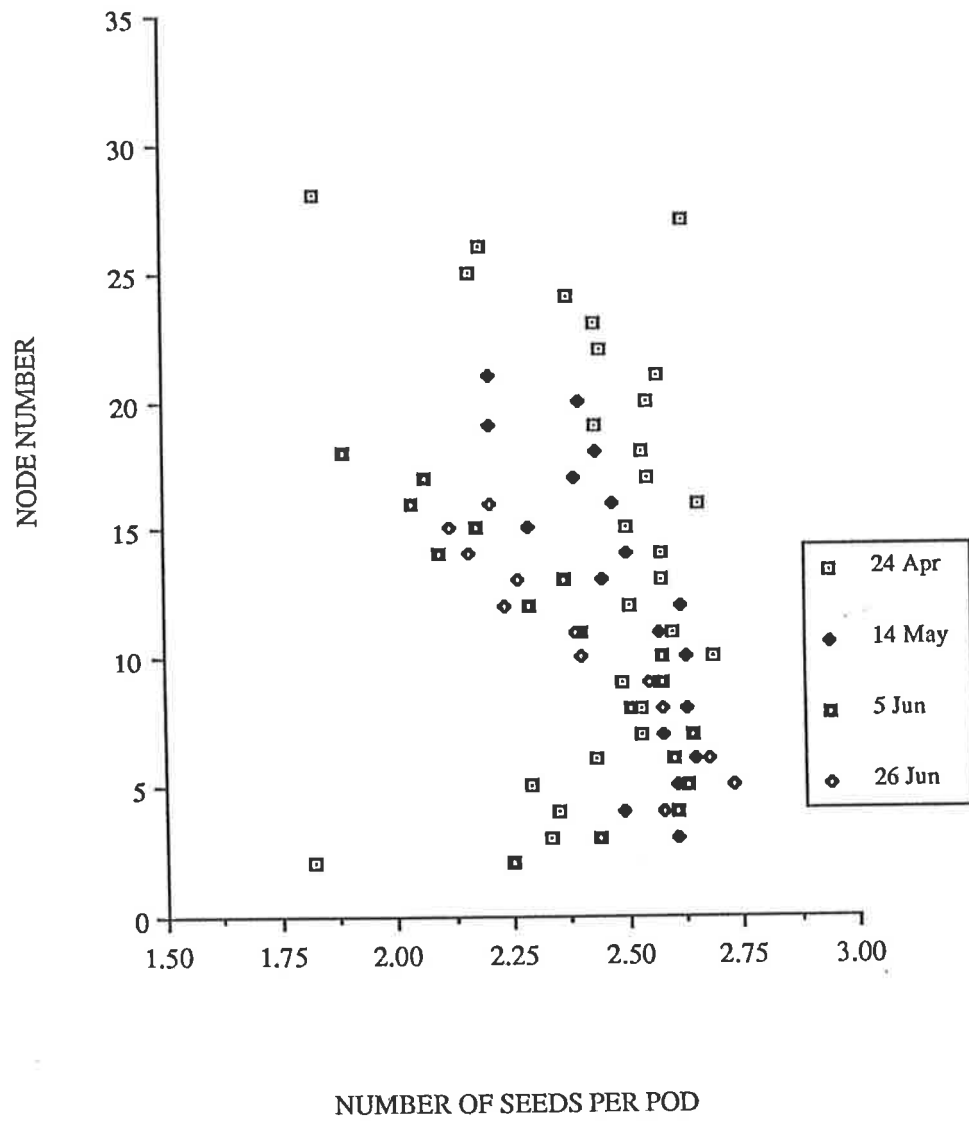


Fig 25 The distribution of seeds per pod for different sowing dates at the Waite 1986

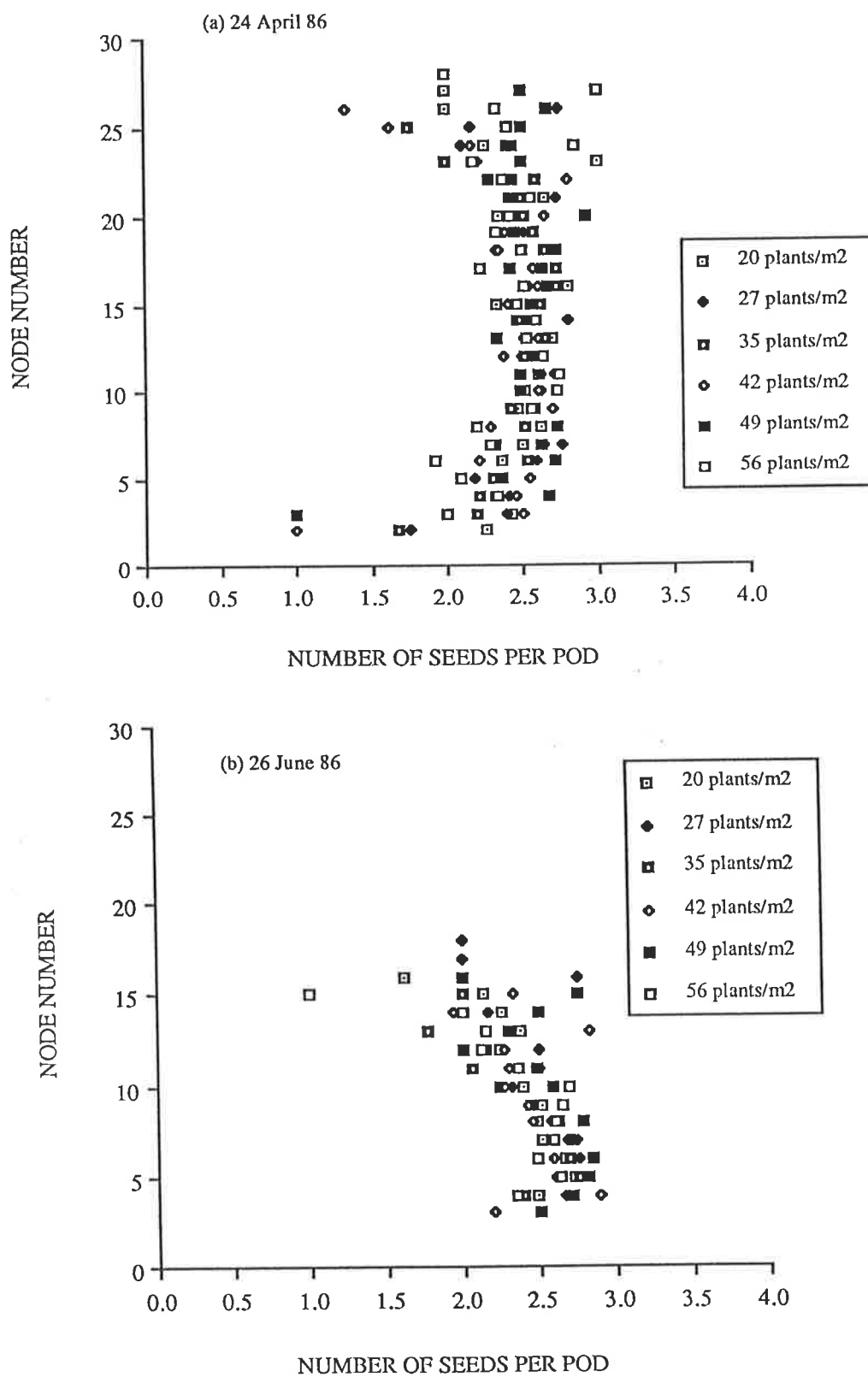


Fig 26 The distribution of seeds per pod on the nodes of the plants sown at different densities (a) early or (b) late sowing at the Waite 1986

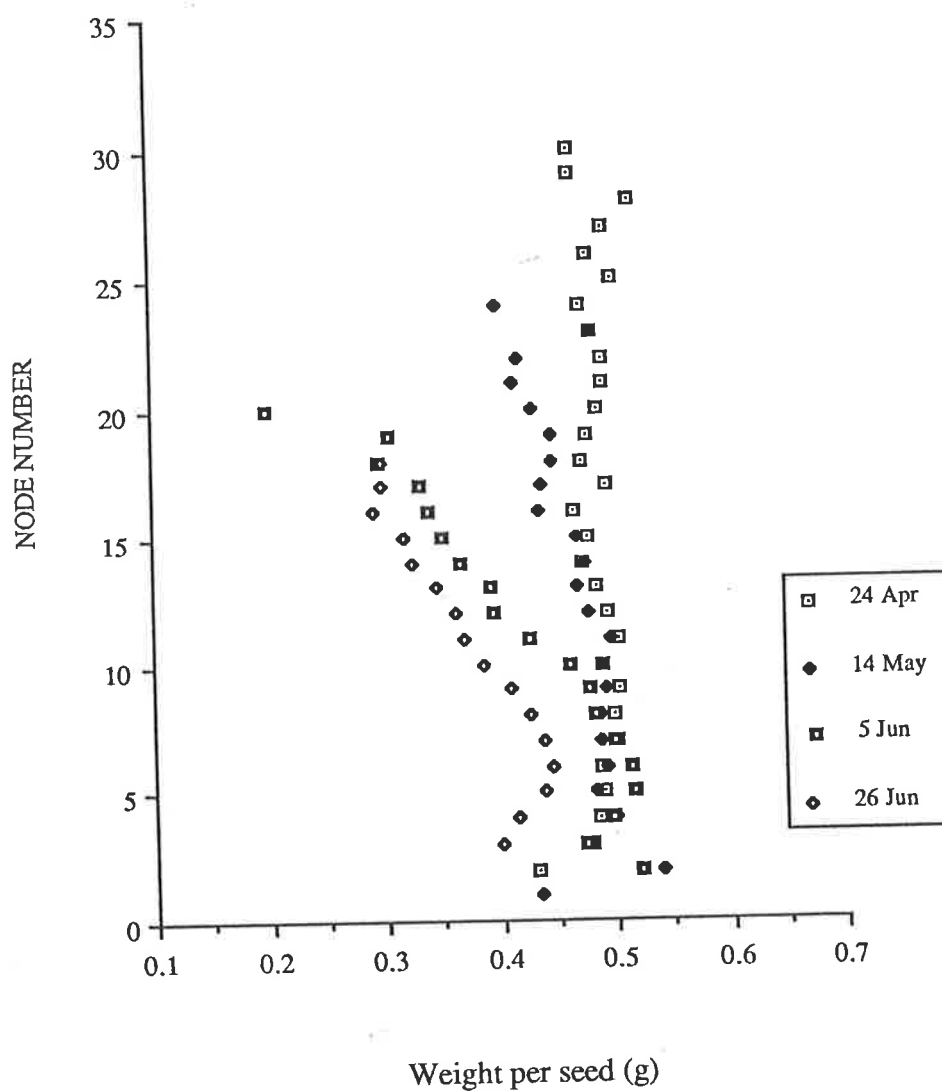


Fig 27 The distribution of weight per seed on the nodes of plants sown for different sowing dates at the Waite 1986

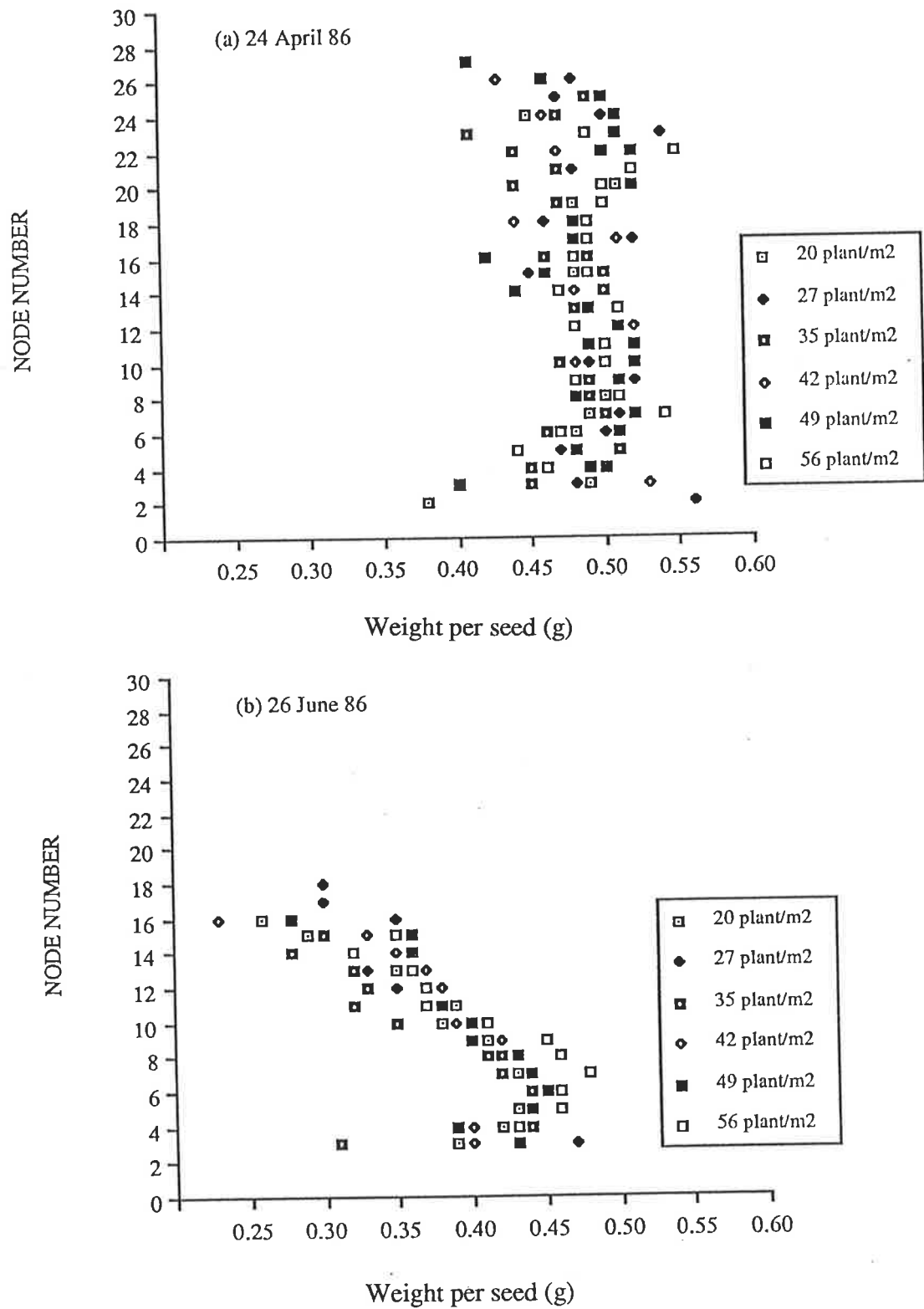


Fig 28 The distribution of weight per seed on the nodes of the plants sown at different densities (a) early and (b) late sowing at the Waite 1986.

DISCUSSION

Yield, Dry matter production and Harvest index.

All the responses in yield, dry matter production and harvest index, to varying sowing date and density, conform with the general findings for crops referred to in the Literature Review, including the interactions that may occur. This study has quantified these responses for the cultivar Fiord, when grown in southern Australia within the confines of the normal crop growing season, which is limited mainly by the date of commencement and the termination of rain.

The effect of very early sowing and good growing conditions can be seen in the results for the April 24 sowing at the Waite in 1986. Dry matter production at the various densities was almost constant at about 13 t ha⁻¹ (Figure 20). Yield however fell from 6.7 to 5.2 t ha⁻¹ (Figure 19) and HI from 48 to 38 percent with increasing density .

The important conclusions that can be drawn from this instance, of early sowing are, that Fiord has the potential for high yields under these circumstances, and that the optimal density was less than 20 plant m⁻². A farmer with very good soil conditions in an area with a comparable rainfall should sow as early as possible and at a density of about 20 plant m⁻². This will provide an opportunity for rapid emergence under warm soil conditions, and a long pod-setting period on the many nodes of well developed plants.

If these favorable conditions for growth cannot be met, and especially if sowing is delayed, then yields will not be as high and the optimal density will be different. The results indicate that yield and dry matter production increased slightly with increasing density from 4.6 to 5.2 t ha⁻¹ while the HI was about 46 percent. The optimal density was then more than 35 plants m⁻².

Finally if only a short growing season is possible because of late sowing, yield and dry matter production increase from 20 to 47 plant m⁻² and the higher density should be sown.

From figures 17 and 19 it is evident there were environmental differences between the Waite and Charlick in both years. In general the Waite provided better conditions than Charlick. At Charlick a fall in yield with increasing density, such as was found at the Waite in 1986, would only occur if the densities being studied commenced at 35 plant m^{-2} and went to very high levels. Any conclusions about the optimal density for Charlick are therefore different from the Waite and in general a higher density should be used because of the poorer conditions.

Fig.29, together with table 6, which contains values of HI, summarises the relation between yield and dry matter production found in this study. The results in the figure are for the Waite 1986 and are chosen because they illustrate most clearly the range in the relations. For the first sowing on 24 Apr and therefore for a long growing season, there was an opportunity for high dry matter production. This production was relatively constant across density, however as yield fell with density HI also fell with density. At the other extreme with the latest sowing on 26 Jun, both dry matter and yield increased with density (except for the highest density), but the increase in yield was less than the increase in dry matter and again therefore HI fell with density.

All of these results are consistent with general findings relating time, yield, dry matter production and density in annual crops. (Donald, 1963 ; Donald and Hamblin, 1976). Donald found that dry matter production (biological yield) rose with time and density but ultimately it plateaued at a ceiling level and there was little further increase with density. Yield similarly increased with density and time, but with sufficient time yield might then show an optimum and fall at higher densities. Donald (1963)" ---- suggested that the minimum density, giving the highest biological yield, may also be the density giving the maximum grain yield." For the first sowing at the Waite in 1986, and with a long growing season, dry matter had finally plateaued and grain yield was falling with density leading to a fall in HI. For the last sowing, dry matter production was below the plateau but was showing the curve leading up to the plateau. The yield curve had already changed more than the dry matter curve. It had begun to flatten with density as it approached its optimum and as a result HI again fell with density.

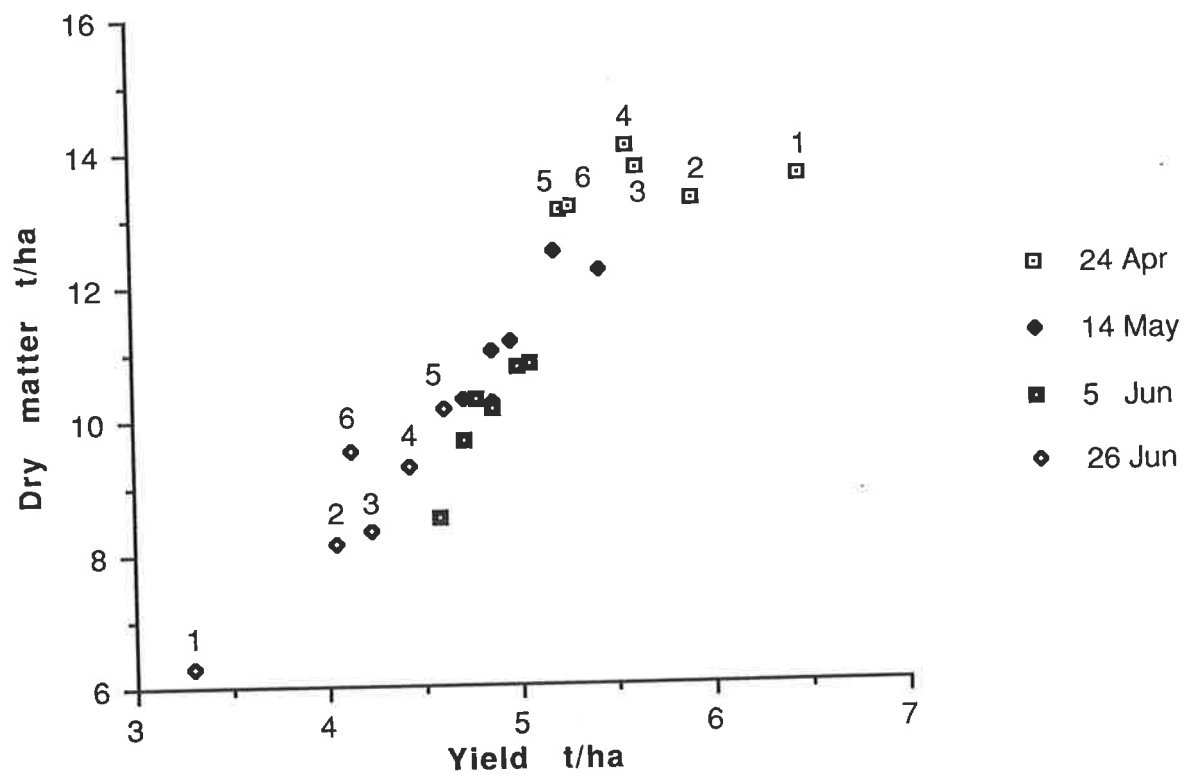


Fig 29. The relation between dry matter (t ha^{-1}) and yield (t ha^{-1}) for the Waite 86 exp. The numbers represent increasing density. For clarity only two sowings are numbered.

One feature of the time, yield, dry matter production and density relation that may occur in faba beans, more than in many other crops, relates to the fact that the yield is determined over a longer period of time. Pod set and seed formation is a prolonged process and if environmental stress occurs there may be dry matter production but insufficient time for yield to develop and yield may be very low. This would account for the fall in HI that occurred with the last sowing and shortened growing season at the Waite in 1985.

Yield and its components per plant.

Sowing date effect.

Yield per plant is the product of the number of pods, the number of seeds per pod and weight per seed. In the present study these components were affected by the sowing dates (Tables 7, 8 and 9). When there was a major reduction in yield from 11.5 g to 0.8 g as occurred between the sowings of 30 April and 31 July at the Waite in 1985 (table 7) the main component to show this reduction was the number of pods which fell from 11.2 to 1.7 per plant. The corresponding seeds per pod fell from 2.35 to 1.75 and weight per seed from 0.44 to 0.25 g. In the other site/years, yield did not show as great a fall, but it is still evident that the component that most closely reflects yield is the number of pods per plant. This is the result most commonly found (e.g. Neal and Mc Vetty 1984) in studies of this nature and it is not surprising in view of the fact that seeds per pod are never numerous in faba beans and therefore cannot show a great fall. With a mean of about 2.2 to 2.4 the number of seeds per pod can only fall to 1, or the pod will abort and not be counted. A stable weight per seed probably has evolutionary significance.

A further illustration and interpretation of the components of yield is provided by figures 30, 31 and 32 in which yield per plant and its components are related to the total above ground dry weight of the plants. The three figures have been drawn to the same scale to enable comparisons to be made across the three site/years.

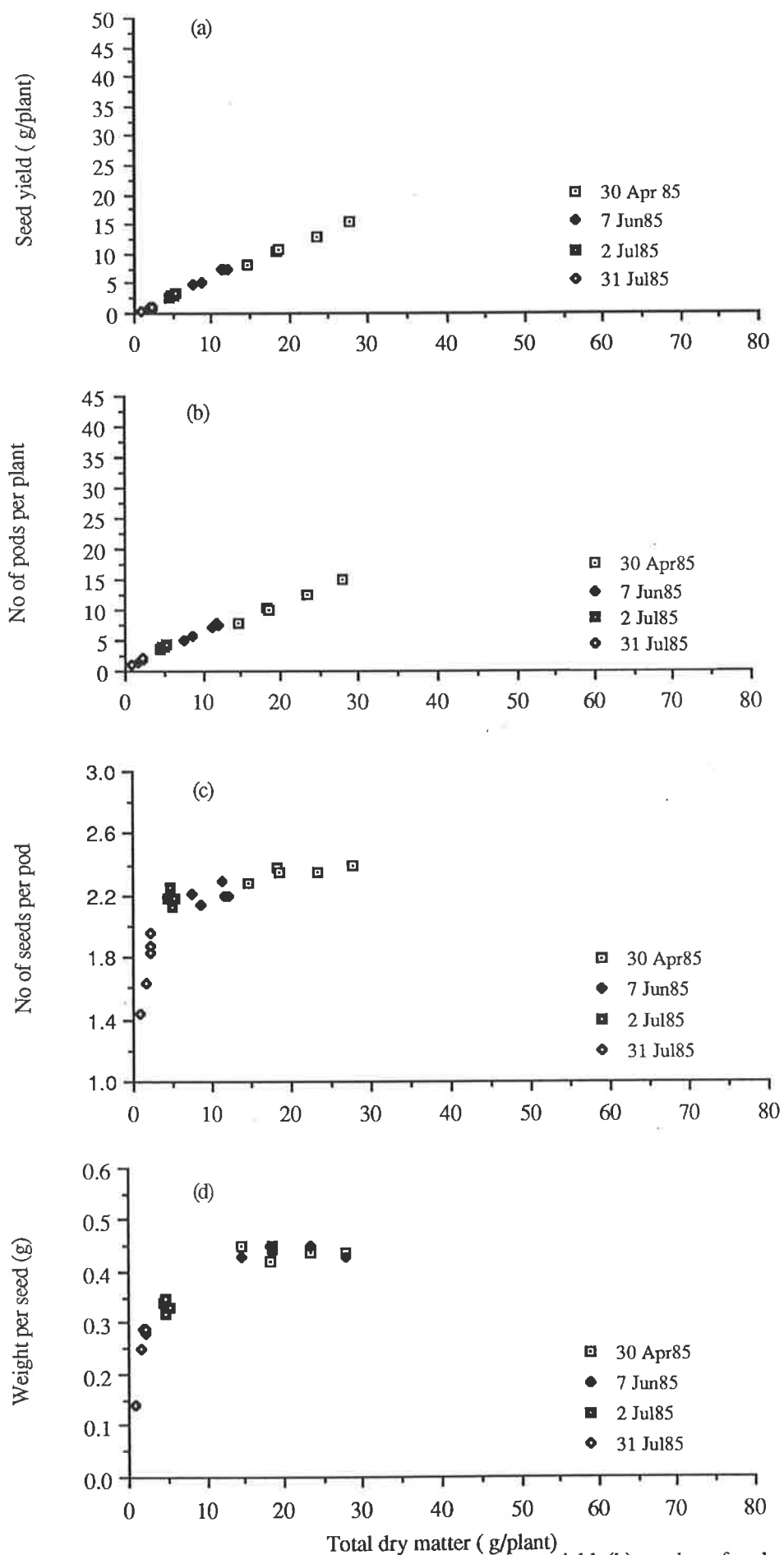


Fig. 30. The relation between dry matter and (a) yield, (b) number of pods, (c) number of seeds per pod and (d) weight per seed at the Waite, 1985

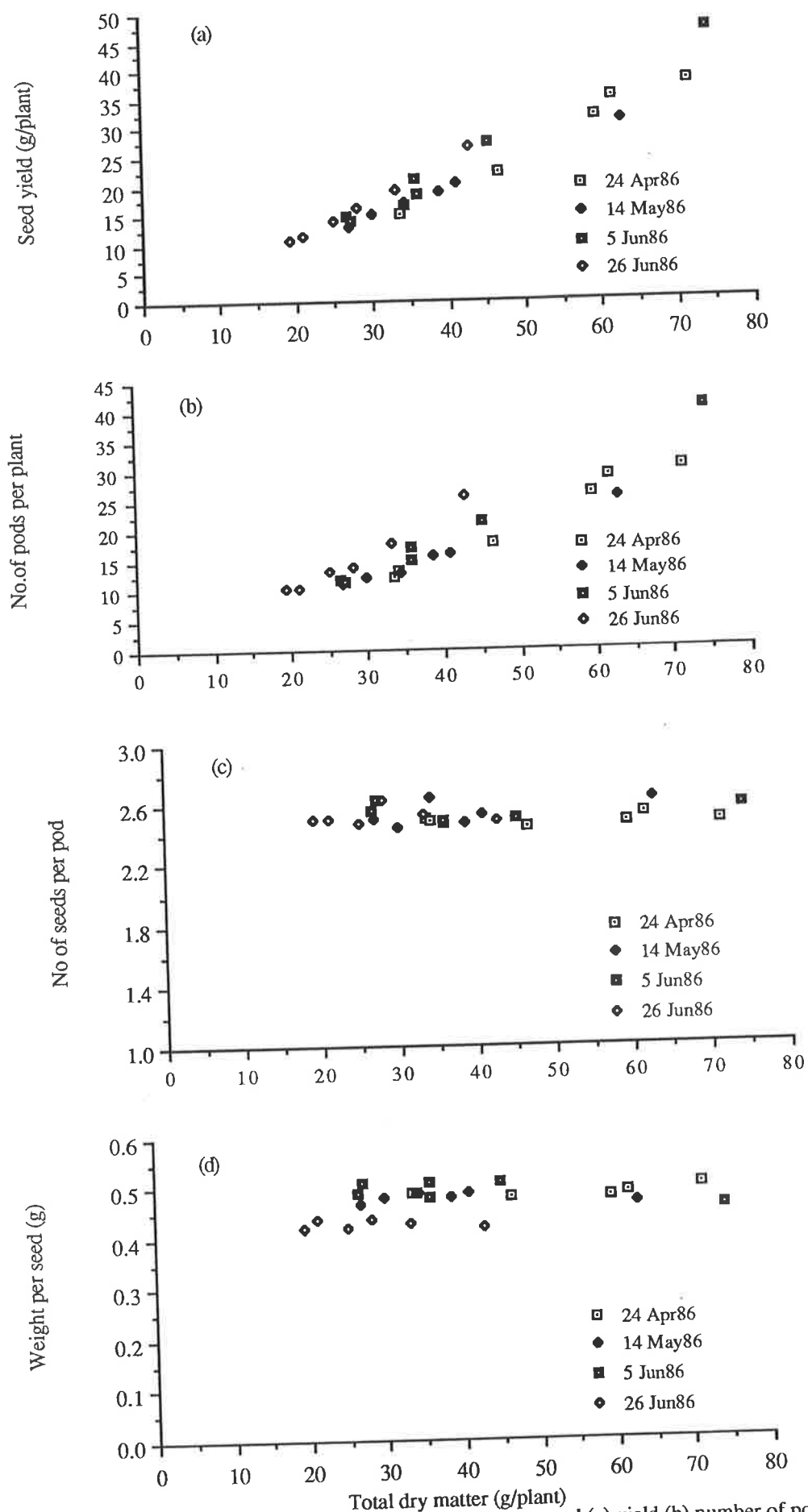


Fig. 31. The relation between dry matter and (a) yield, (b) number of pods, (c) number of seeds per pod and (d) weight per seed at the Waite, 1986.

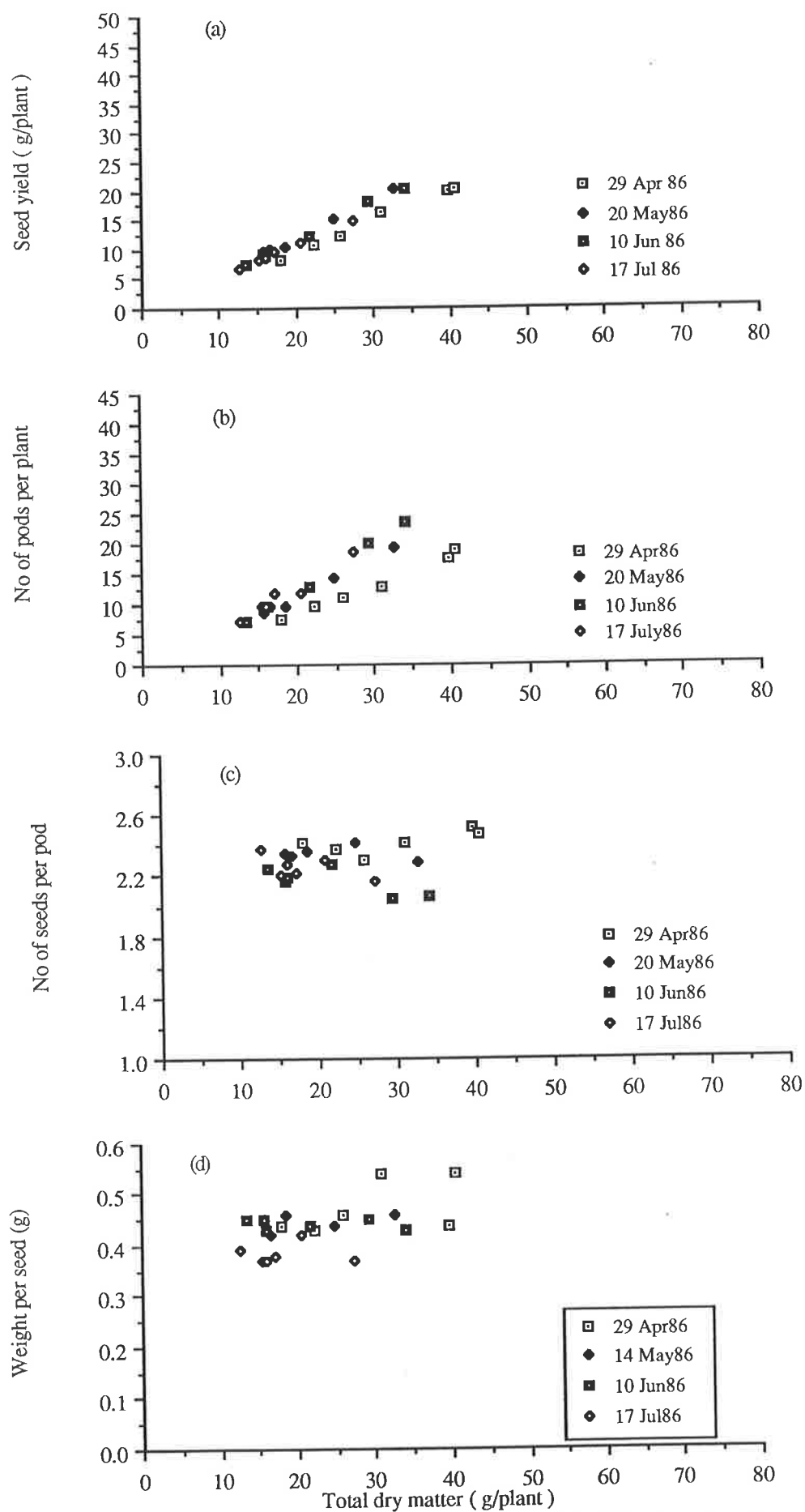


Fig.32. The relation between dry matter and (a) yield, (b) number of pods, (c) number of seeds per pod and (d) weight per seed at the Charlick, 1986

The figures show that yield per plant and the number of pods per plant increased linearly with total dry matter production for each time of sowing. It is also evident that the regression lines for the earlier times of sowing, if drawn on the graph, would be to the right of the regressions for the later sowings indicating, as shown elsewhere, that for early sowing yield had not increased relative to total dry matter to the same extent as later sowings. That is HI was lower. In contrast to this linear relation, the number of seeds per pod and the weight per seed was not associated with increases in total dry matter beyond values of about 10 g per plant. The relation was curvilinear and a plateau was evident across the site/years. Seeds per pod and weight per seed are characters which have probably a genetically determined upper limit that is specific to a genotype. For the cultivar Fiord, from these figures, these limits are about 2.4 seeds per pod and the weight per seed is 0.45 g (Fiord is a selected cultivar; it is strictly a population of similar genotypes)

Both these components of yield were less for the late sowings at the Waite in 1985. The lesser values were associated with the lower total dry matter which resulted from late sowing and unfavourable growing conditions. There may have been insufficient assimilate for the realisation of the genetic potential in seeds per pod and seed weight. Figures 30, 31 and 32 are presented to show the large differences that occurred between the late sowings of the Waite 85 and the sowings at the Waite and Charlick in 1986, however Fig 25 and 27 show that there were fine differences in seeds per pod and weight per seed even within the sowings at the Waite in 1986.

Figure 22 shows that with early sowing the pods were more evenly distributed over the nodes of the plant and were not concentrated at a few nodes. Concentration occurred with later sowing. If there is competition between pods on the same or adjacent nodes this would be detrimental to pods of the later sowing.

Differences in sowing date and changes in the duration of the pod filling period resulted in the changes in the number of seeds per pod and weight per seed (table 8). However figure 25 shows that the number of seeds per pod did vary with the nodal position of the

pod for different sowing dates. For the late sowing the highest number of seeds per pod was between nodes 3 and 7 which coincided with the greatest concentration of pods. This suggests that competition between pods was not a serious factor affecting seed numbers. When these numbers fell at the higher nodes of the late sown plants, it may have been due to water stress during the pod formation and seed filling periods.

For early sowing the distribution in weight per seed on the nodes of the plant was very constant but as sowing was delayed the distribution on the plant showed differences (Figure 27). These results indicate that for the early sowing the intensity of competition among pods was not great enough to affect the weight per seed.

It would appear likely that the difference in weight per seed between upper nodes and lower nodes for the later sowings was due to inadequate supply of assimilates during seed filling because of the shorter growing season and pod-filling period. In smaller plants, there is less assimilate available for subsequent redistribution to growing seeds. This study has shown that a lower weight per seed occurred when the period over which a seed is growing is reduced and the rate of growth increased. Skjelvag (1981 a) also suggested smaller seeds arise from a combined effect of a shortened seed production period and an increase in the seed growth rate with rising temperature.

Plant density effect.

The number of pods per plant decreased as density and competition increased ; an effect which may have been caused by fewer flowers, less pollination or greater pod abortion. The number of flowers per node and per plant were not recorded in this study but Barry and Storey (1979) found that differences in seeding rate had a significant effect on the number of flowers and on pod production. The percentage of flowers forming mature pods was not affected. Hodgson and Blackman (1956) also found there was a reduction in the number of flowers per node and node bearing flowers. Ingram (1976) found that number of pods per node was reduced with increasing density.

The number of seeds per pod was unaffected by density (Figure 28). This character is the most stable component of yield. The present finding agrees with those of Ishag (1973), Seitzar and Evans (1973), Sprent *et al* (1977), Salih (1985) and Mc Vetty *et al* (1986) but differs from that of Hodgson and Blackman (1956) who reported that the number of seeds per-pod declined significantly as density was increased from 11 to 68 plant m⁻².

Weight per seed also was unaffected by density (Figure 25). A similar result was found by Hodgson and Blackman (1956), Ingram (1976), Salih (1985), and Day *et al* (1979) but other published reports have suggested seed size either increased with increasing density (Ishag, 1973 ; Seitzar and Evans 1973 ; Kellar and Burkhard, 1981) or decreased with increasing density (Mc Vetty *et al*, 1986 ; Sprent *et al* , 1977).

The variation in seed weight was related to the variation in duration of the seed filling period and to differences in the time of the beginning of seed growth and time to physiological maturity.

The number of lateral branches per-plant was not measured in 1985 but there was significant effect of density at the Waite Inst and Charlick in 1986. The numbers of lateral branches were suppressed by high density but it is not clear whether the size of stems were also reduced. Similar results were found in the UK by Ingram (1976) with winter bean. Poulain *et al* (1986) found that variation in stem number per plant, or per unit area, explained differences in leaf area index among densities.

CHAPTER 4.C.

EFFECT OF SOWING DATE ON POD AND SEED DEVELOPMENT

RESULTS

The rate and duration of seed development are dynamic components of yield. A seed's growth rate may be influenced by the position of the pod on the plant, by its position in the pod, and by environmental conditions during pod development.

Individual seed growth was followed on pods on plants from the first pods until the final pods (the pods had turned black and maximum seed weight attained) for each sowing date (Figure 33). The period of development of a seed averaged 75 days for the early sowing and 45 days for the latest sowing (Table 10). Within each sowing date the seeds on the earliest formed pods on a plant developed over a more prolonged period than on the later formed pods. Final seed size varied with the duration of this period. Average values for seed development are presented in figure 34. One again it shows that duration of seed development was longer from the early sowing and declined with later sowing resulting in a lower seed weight.

The moisture content of the seed was greater than 80% when the weight of the seed was increasing rapidly and declined progressively during seed development, reaching about 55 % as the seed approached maximum seed weight (Figure 35) These changes in percentage moisture during seed development were consistent for both sowing dates. Further moisture content loss would have occurred as the seed matured but this was not recorded.

The growth of the seeds in a pod in relation to the pod shell is given in Figure 36. Initially both the shell and seed gained in dry weight but eventually the pod lost weight while the seed continued to grow. This suggests that shell and seeds may compete for assimilate. The early pods, from the first sowing, reached their maximum weight of shell 15 days before the late pods but for the last sowing there was no

difference in time for the early or late pods to reach their maximum weight. For both sowings early pods had higher shell and seed weights.

Table 10. The duration of seed development for early and late developing pods on plants from the first and last sowing date at the Waite Institute in 1986

	First sowing		Last sowing	
	early*	late@	early*	late@
Duration (days)	90	60	50	40
Seed size (g seed ⁻¹)	51	41	47	28

* first pods to develop on the plant

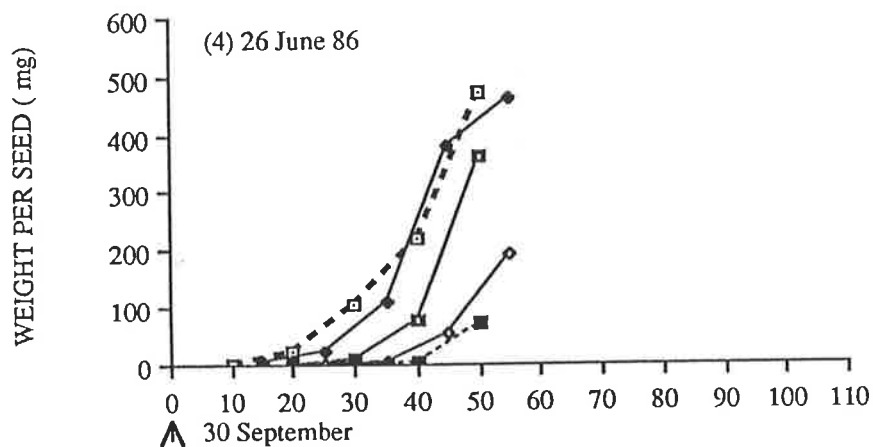
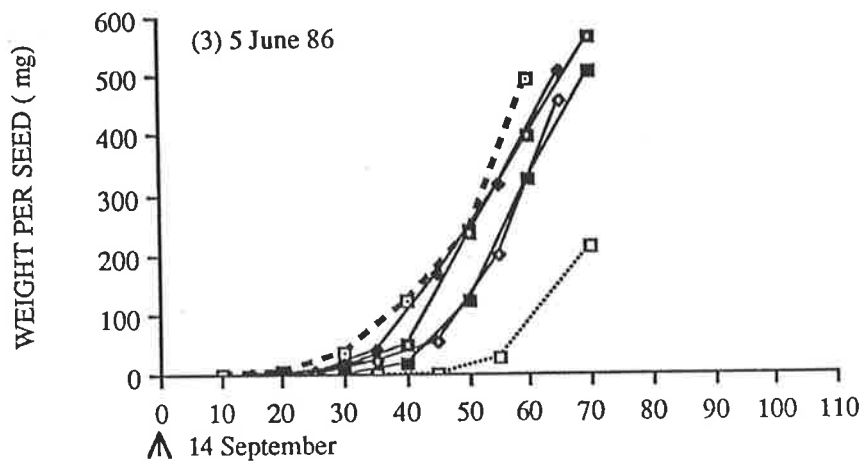
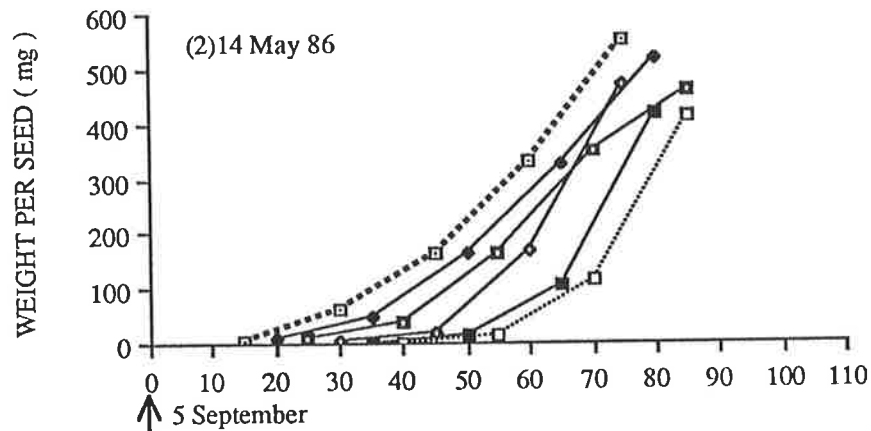
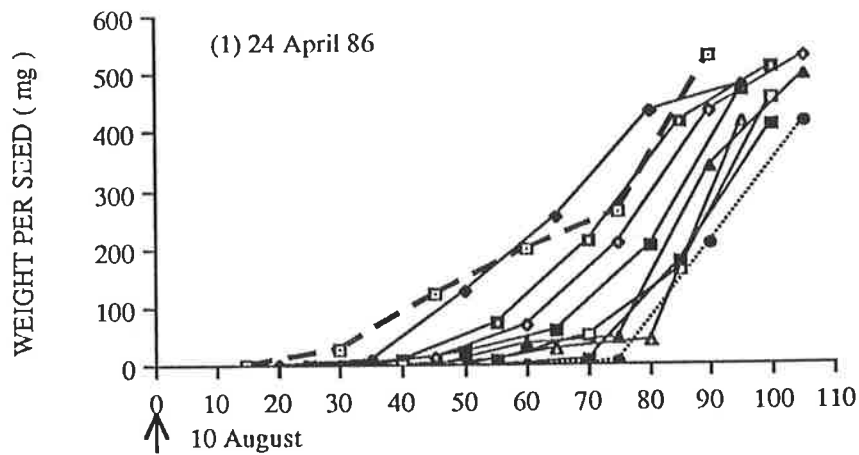
@ last pods to develop on the plant.

Table 11. Mean weight of seed in different positions in pods for the four sowing dates. The seed positions are numbered, with number one being near the pod's tip at the Waite Institute in 1986.

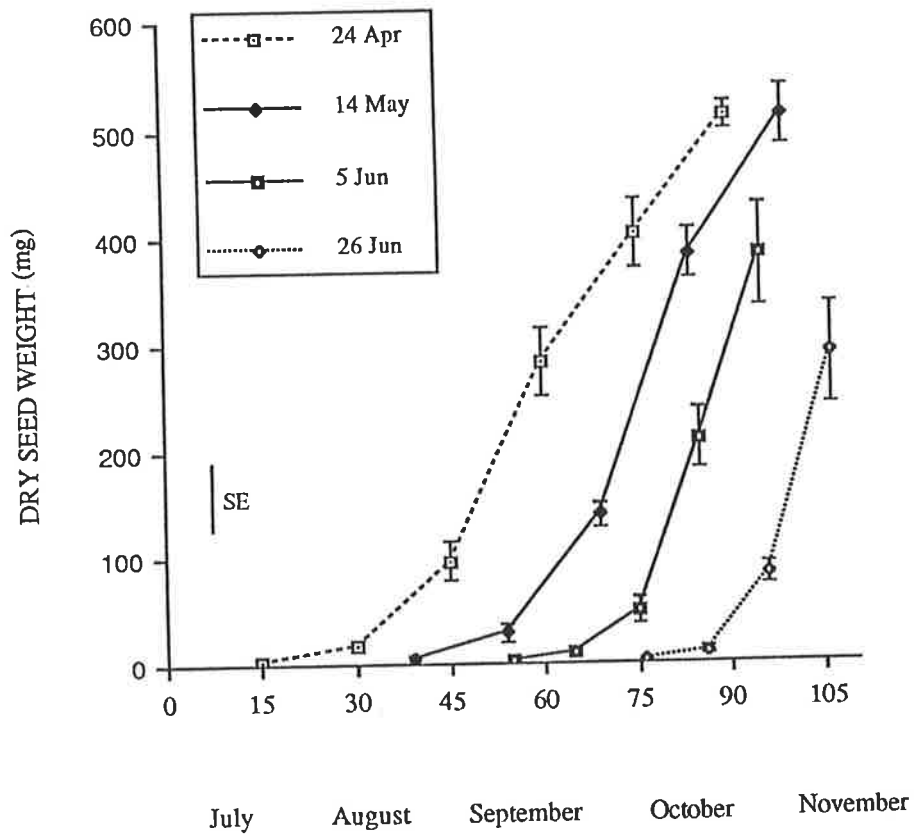
Sowing dates	Seed position and seed dry weight (g) in the pods				
	1	2	3	mean	S.E
24 April	53.4	53.1	48.9	51.8	1.7
14 May	51.8	52.6	50.1	51.5	0.7
5 June	56.2	57.8	52.8	55.6	1.5
26 June	47.0	49.1	44.5	46.9	1.3
Mean	52.1	53.2	49.1		
S.E	1.9	1.8	1.7		

A seed's weight in relation to its position in a pod was examined. In general seeds in the middle of the pods (position no. 2) were heavier than seeds in positions 1 or 3.

Fig 33. The duration of seed development on plants from different sowing dates at Waite 1986. The 10, 6, 6, and 5 curves for the respective sowing dates are the weight of seeds in pods that commenced development in successive weeks. The arrows indicate the date of the first pod developed for each sowing date.



DAYS AFTER THE FIRST POD DEVELOPMENT OF EACH SOWING DATES



NO OF DAYS AFTER FIRST SEED DEVELOPMENT OF THE FIRST SOWING

Fig.34. The duration of seed development on plants from different sowing dates at the Waite 1986.

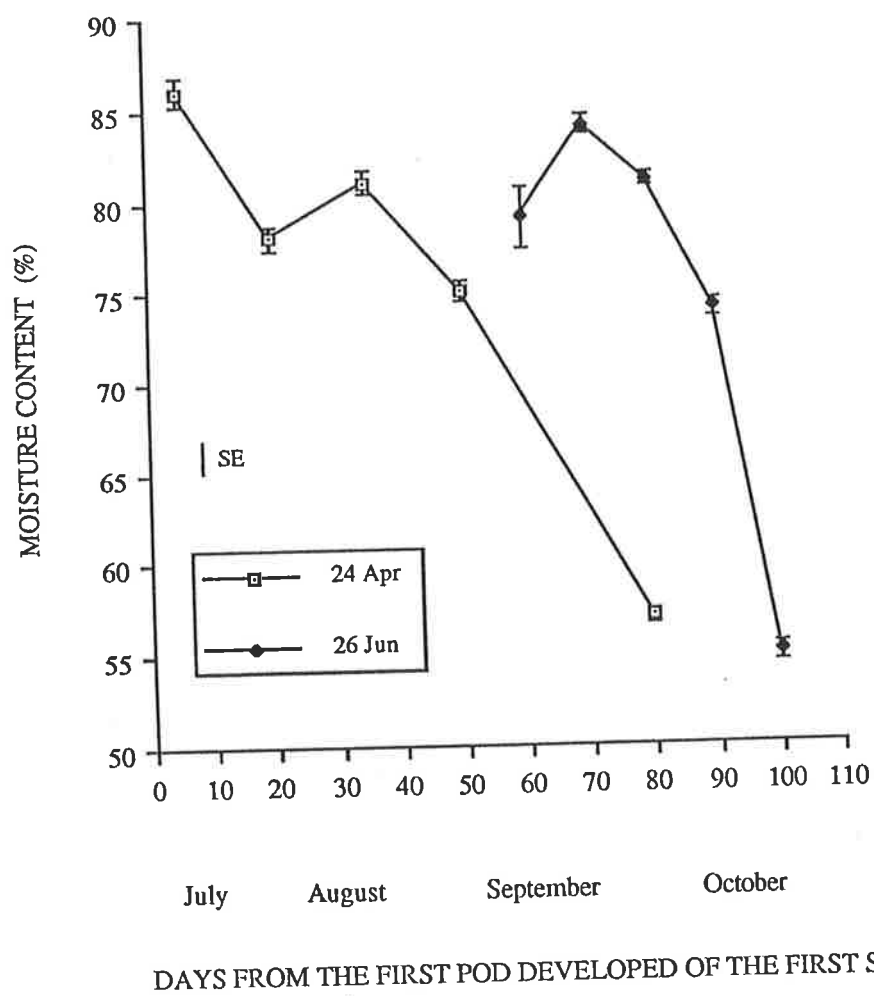


Fig 35 The moisture content(%) of the seed of two different sowing dates from the first pod development to maturity.

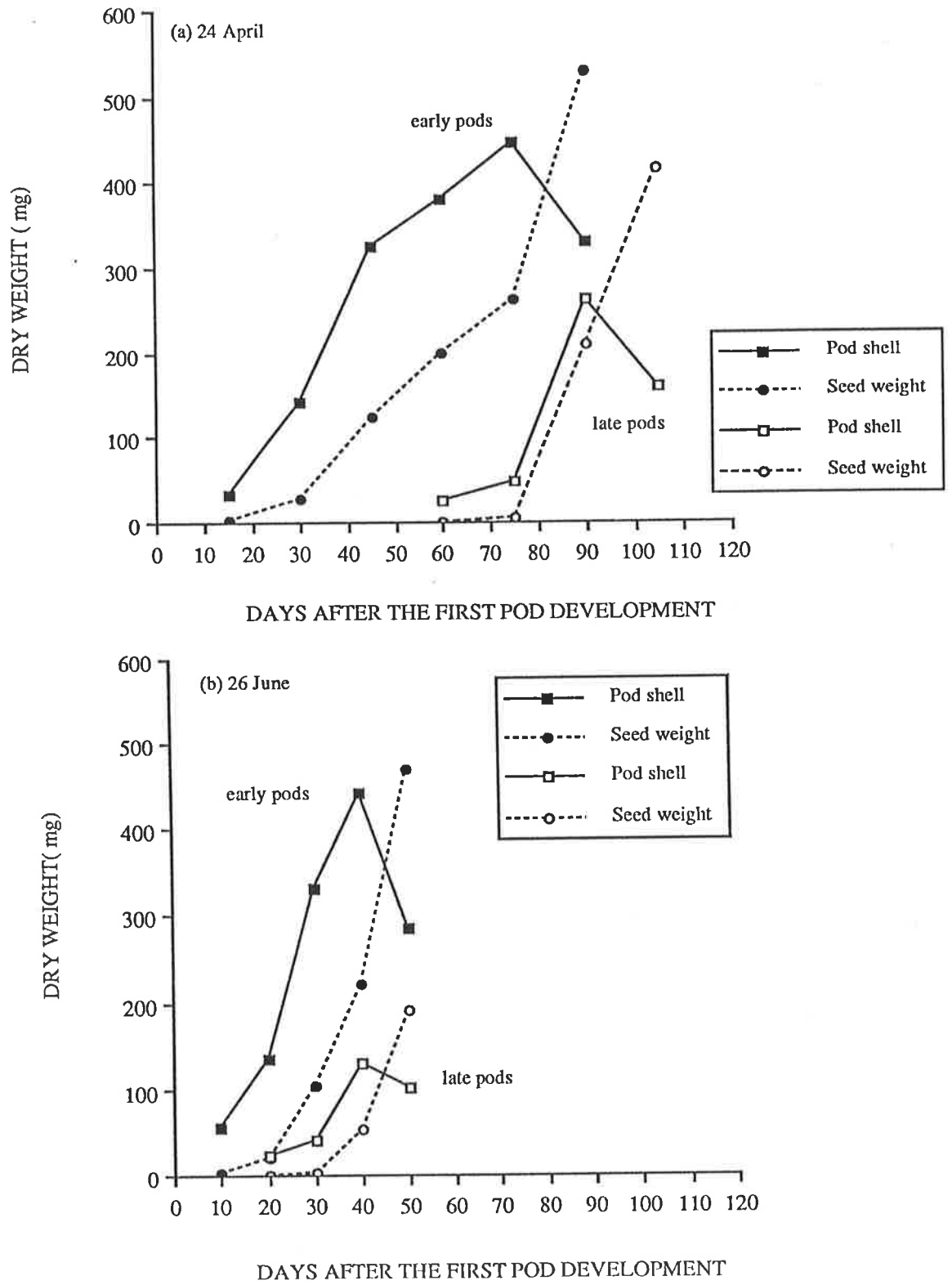


Fig 36 The development of the pod shell and seed for the early and late pods from (a) early and (b) late sowing at the Waite 1986.

DISCUSSION

The date a pod developed had a marked effect on the length of time the seed within the pod continued to grow, but a long period of growth did not lead to proportionately larger seeds. The later developing seeds, those in pods attached to upper nodes or from later sowings, had a faster rate of dry matter accumulation and a shorter growing period. It was only in the very late developing pods, particularly for the last sowing, that seed weight was reduced as the pod filling period was shortened.

The higher rates of growth for the later sowings might have been due to the higher temperatures, and solar radiation during the pod filling period. Other studies have suggested the higher temperatures during the pod filling period hastened leaf senescence (Bull, 1968) and resulted in a decrease in seed weight (Dekhuijzen and Verkerke, 1986).

The seed on plants from both sowing dates had a high water content during early development but this declined at later stages. The moisture content when the seeds were fully developed was at about 55 %. These results are similar to those obtained by Ellis *et al* (1987) who stated that physiological maturity (maximum seed dry weight) coincided with the time when the moisture content of seeds on the plant was 55 to 60 percent.

From figure 36 it can be seen that, with late sowing the early and late pods are developing at the same time and there could be competition for assimilate, limiting the size of the pods and seeds.

In each pod, the seeds were usually bigger in the middle of the pod compared with other positions.

This study has shown that the important factor affecting final seed weight is the date of pod development which in turn affect seed growth rate and the duration of pod filling.

CHAPTER 5

RESPONSE OF THE ACCESSIONS TO SOWING DATES

RESULT

1. Phenological development.

The effect of sowing dates on the phenological development of the eleven accessions and one cultivar is illustrated in figure 37.

Emergence

All accessions emerged more rapidly from the 1 May sowing than the 3 July sowing with the average number of days being 16 and 19 respectively. Within a sowing date, there was no consistent relation between rate of emergence and seed size .

Emergence to flowering.

The pattern of response for the period from emergence to flowering is presented in Figure 37 and Table 12. Flowering commenced in early July for the first sowing at a time when the plants of the second sowing were just emerging. Flowering for the second sowing occurred in mid September. There was high variation in the number of days from emergence to flowering for the first sowing (41 to 76 days) and much less variation for the later sowing (50 to 62 days). Table 12 shows that Acc 286 was consistently the earliest to flower at 41 days and 50 days and Acc 176 and Acc 863 the latest at 76 and 61 days. The reason for Acc 286 taking longer to flower for the later sowing whereas Acc 176 and 863 take less time to flower is discussed below. For Fiord (ie Acc 59), flowering averaged 55 days and 58 days for the two sowings. A similar results of 56 days was obtained at the Waite in 1985 for a 2 July sowing.

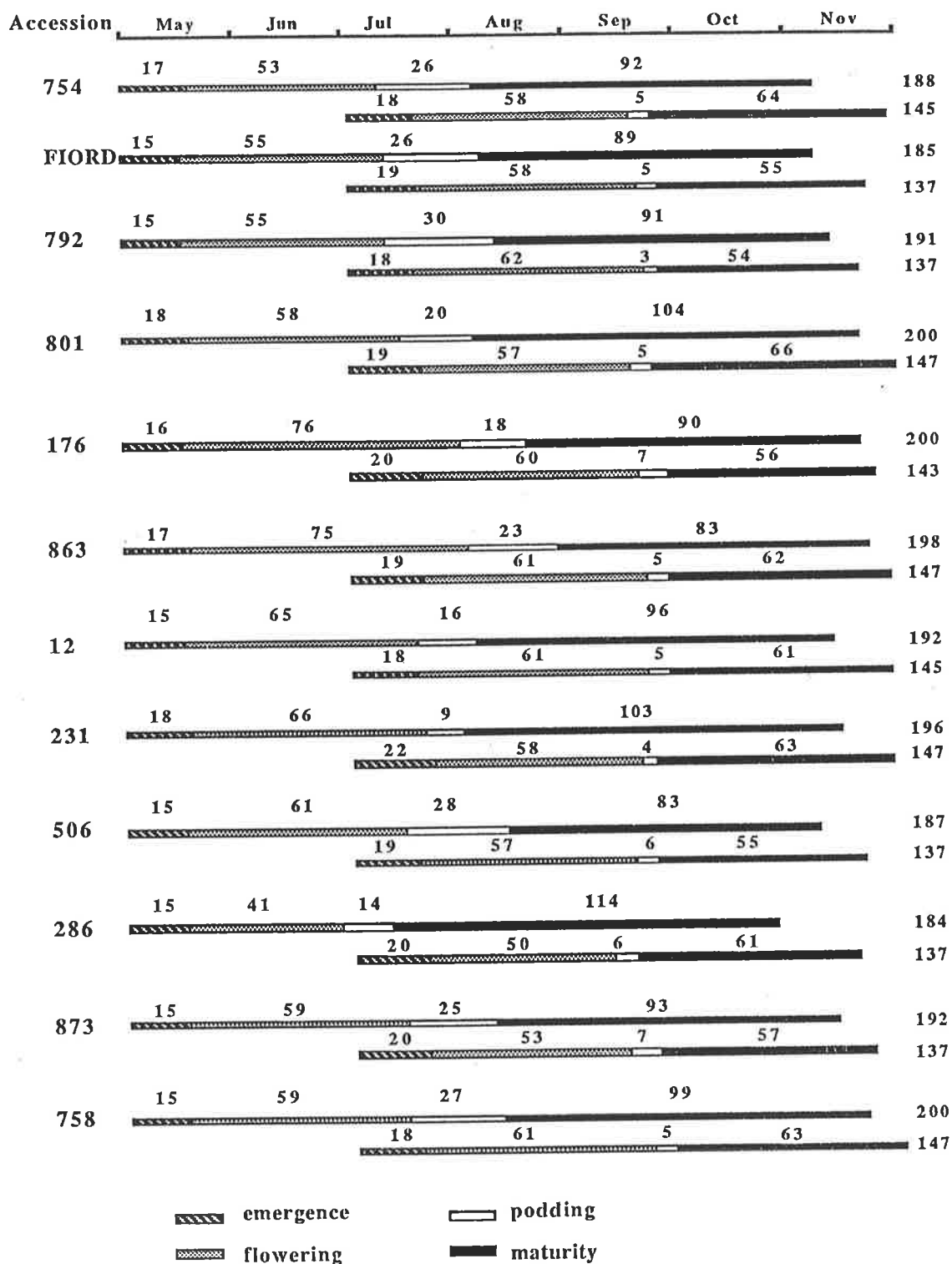


Fig.37. The phenological development of different accessions sown in May or in July.

Relation between flowering and climatic factors.

The same results for flowering are depicted in two ways in figure 37. The upper diagram is presented to show that the change in flowering for the two sowing dates is not closely related to the country of origin and the related latitude. Similar responses were obtained for Acc 176 and 863 although the former is from France, a country with a mean latitude of approximately 47° N, and the latter from Colombia, with a mean latitude of approximately 5° N. Dissimilar responses were obtained for Acc 12 and 286 which originated from Morocco and Crete, two regions with very similar latitude.

Figure 38, the lower diagram, shows the strong interaction that occurred for the different accessions when sown at the two times; some flowered more rapidly others more slowly from the second sowing

The relation between enviromental factors and progress towards flowering in the 12 Accessions.

In fig 39 the seasonal variation in photoperiod (continuous curve) and temperature (broken curve) are depicted and the flowering dates for the various accessions are marked on the photoperiod curve for the two sowings 1 May and 3 July. The graph illustrates for the two sowings that the differences between them were that temperature was falling from a relatively high level for the preflowering period of the first sowing and that photoperiod was also declining, whereas for the second sowing, temperature initially was very low and was increasing and photoperiod was much greater for most of the preflowering period.

The relation between progress towards flowering ($1/f$) and mean diurnal preflowering temperature is given in Fig 40 for the 12 accessions which are designated on the graph by their accession numbers. Values for the two sowing dates are distinct. Those to the right of the graph were for the May sowing, when seasonal temperatures were falling with time from a high level, whereas for the July sowing temperatures were

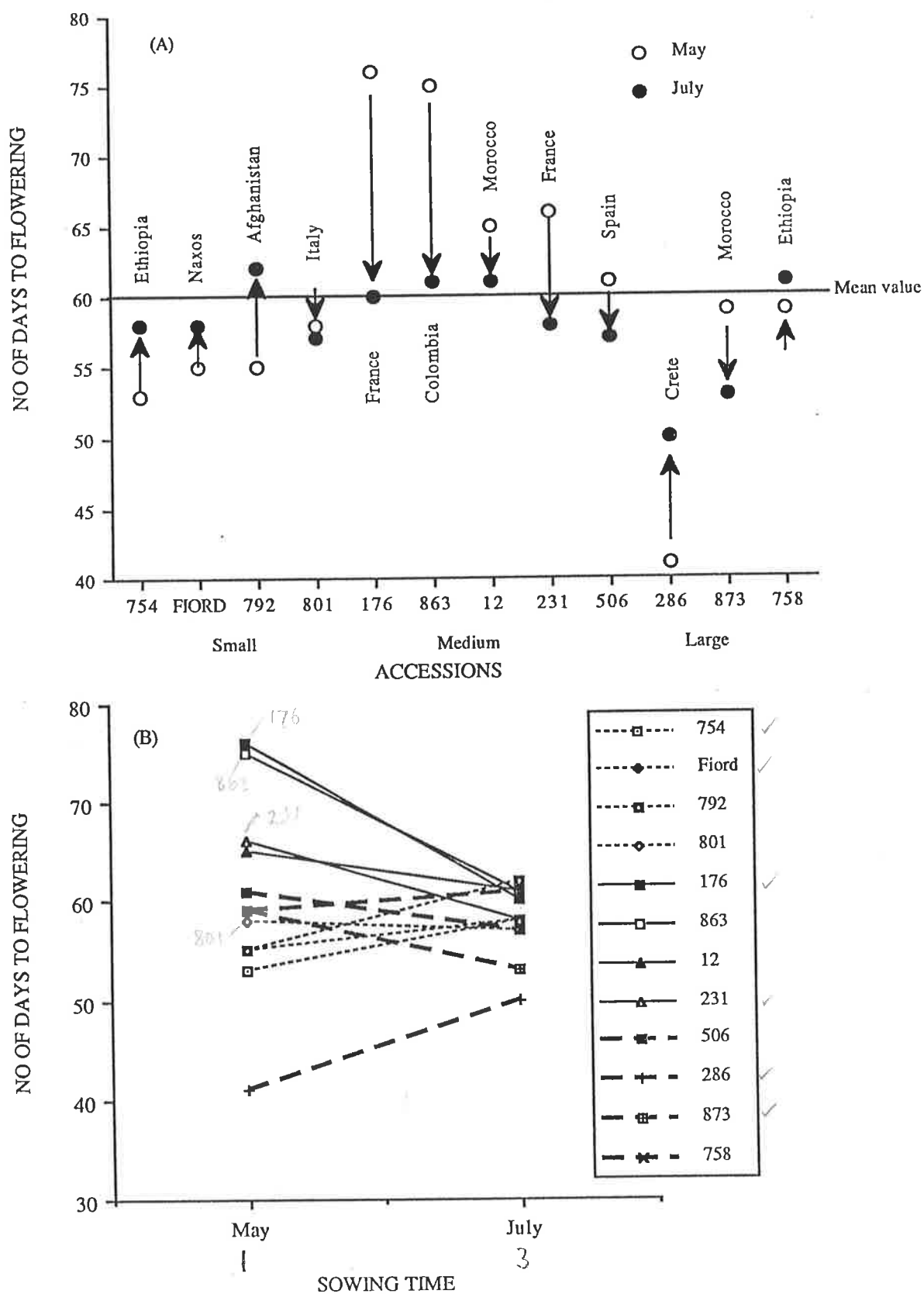


Fig.38. The relationship between sowing dates, accessions and the number of days to flowering.

increasing with time from a low level. An accession that was early to flower such as Acc 286 therefore had the highest mean preflowering temperature from the May sowing and had the equal lowest temperature from a July sowing. For other accessions, such as Acc 176 and 863 that took a long time to flower, the effect of a declining seasonal temperature from a May sowing or an increasing seasonal temperature from a July sowing were averaged, when the mean was calculated, and they had a similar mean preflowering temperature for the two sowings.

It is possible that the base temperature for development towards flowering differs among the 12 accessions studied, but it would be clearly inappropriate to calculate the separate regressions from these field data where mean values are being calculated from various parts of a curve of environmental factors changing with seasons of the year. If they were calculated some unacceptable values would be obtained. For some of the accessions the regressions are negative, but they are not indicative of supraoptimal temperatures. For example progress towards flowering ($1/f$) for Acc 176 and 863 would be zero at a temperature of approximately 14°C

To estimate a common value, a set of base temperatures, varying by one degree from 0°C to 9°C , was used to calculate GDD values for each accession for the two sowing dates (See Appendix table 13). Correlations were then calculated between the sowing dates for the 12 accessions using each of the base temperatures. It was found that the correlation increased from .48 at 4°C to .51 at 7°C and 8°C before falling to .48 at 9°C . It was concluded, the lowest variation in GDD across two sowing dates occurred when the base temperature was similar to that established for FIORD at 7°C .

The relation between progress towards flowering ($1/f$) and photoperiod is given in Fig 41 where the results to the left of the graph are for the May sowing and to the right the July sowing. If this analysis, based on mean values of varying field results, were acceptable it would suggest Acc 286, 754 and 792 were slower to flower and Acc 176 and 863 quicker to flower in a long photoperiod. If the regressions were calculated for Acc 286, 754 and 792 they would have negative slopes indicating long days delay

flowering in these accessions. In the Discussion it will be suggested these results are not an indication that Acc 286, 754 and 792 are short day plants but the result is a consequence of evaluating P from a natural environment that shows seasonal variation.

With only two results for each accession it was not possible to calculate multiple regressions relating $1/f$ to temperature and photoperiod.

The problems associated with using mean values of temperature and photoperiod when these factors vary seasonally in a field experiment have been emphasised, however to provide an illustration of differences between accessions fig 42 is presented relating days to flower to GDD at the May and July sowings. Groups of responses are apparent as a result of the sowings which differed mainly in that temperature was lower but daylength longer at the July sowing. At one extreme Acc 863 and 176 flowered in fewer days from the July sowing and with far less GDD. Flowering of these accessions was apparently strongly accelerated by the longer daylengths of the July sowing or by some factor correlated with daylength. The accessions 231, 12, 506 and 873 showed a similar but less pronounced response. At the other extreme Acc 286 and 792 required more days to flower from the July sowing and the GDD, though fewer, were not very different between the two sowings. Flowering of these accessions appears to be far less influenced by daylength and more determined by temperature. Each of the remaining accessions including 59(FIORD) 754, 758 and 801 all flowered after a similar number of days after the two sowings but with fewer GDD. The GDD do not therefore on their own determine flowering to the same extent as in 286 or 792.

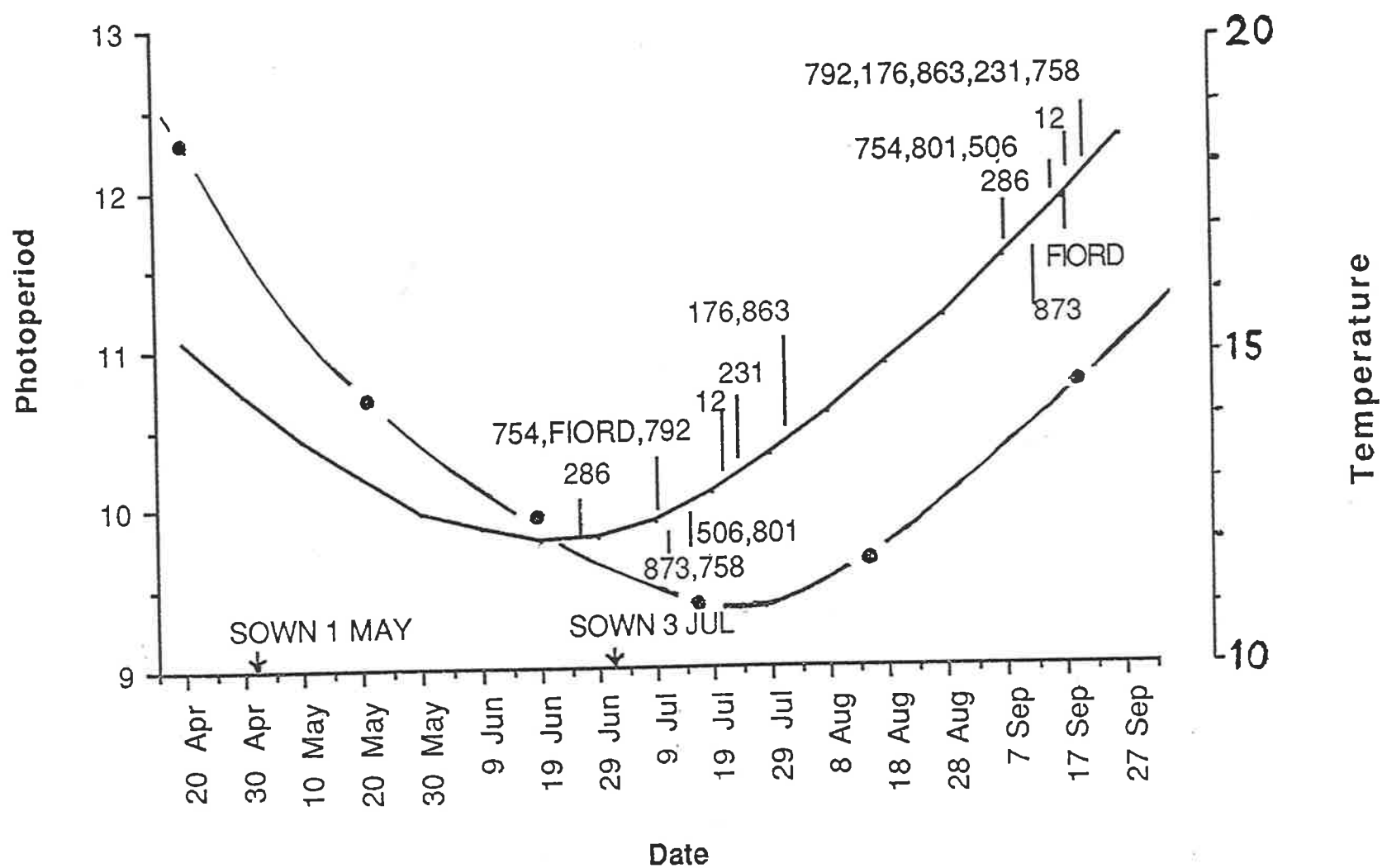


Fig.39 Seasonal variation in photoperiod(solid line) and temperature(broken line). The two dates of sowing and the respective dates of flowering are indicated for the 12 Accessions. Fiord is Acc 59

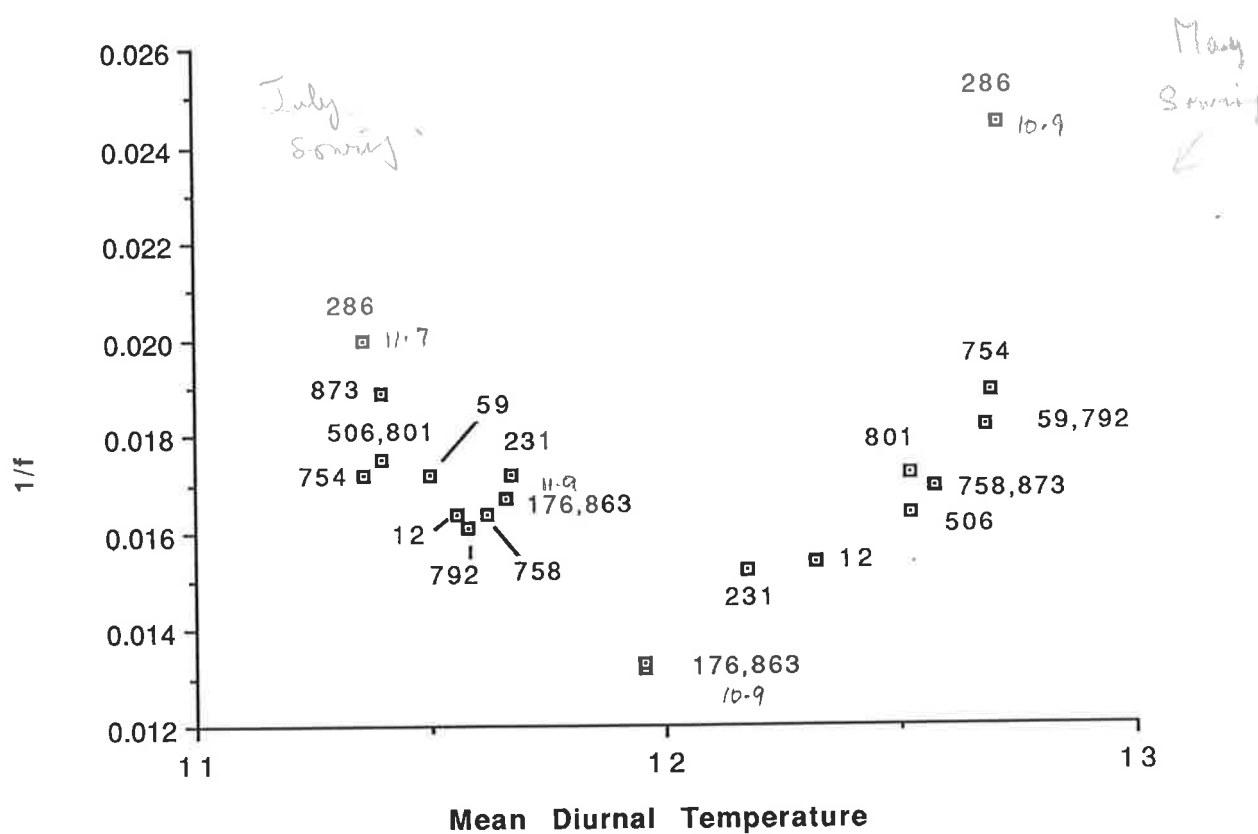


Fig.40. The relation between progress towards flowering($1/f$) and mean diurnal temperature for 12 accessions. Results to the right are for the May sowing and to the left for the July sowing.

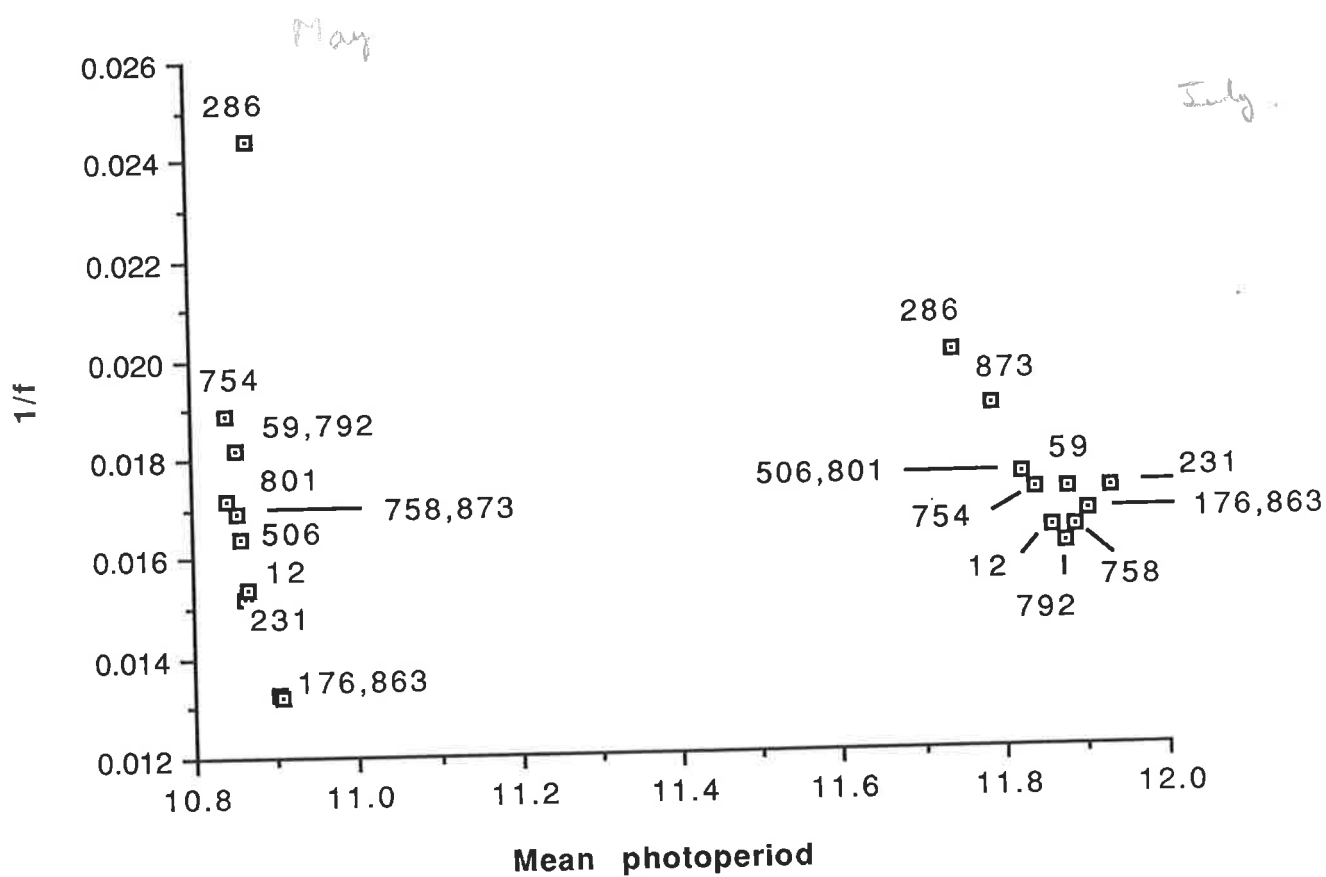


Fig.41 The relation between progress towards flowering($1/f$) and mean photoperiod for 12 accessions. Results to the right are for the May sowing and to the left for the July sowing.

left

July

right

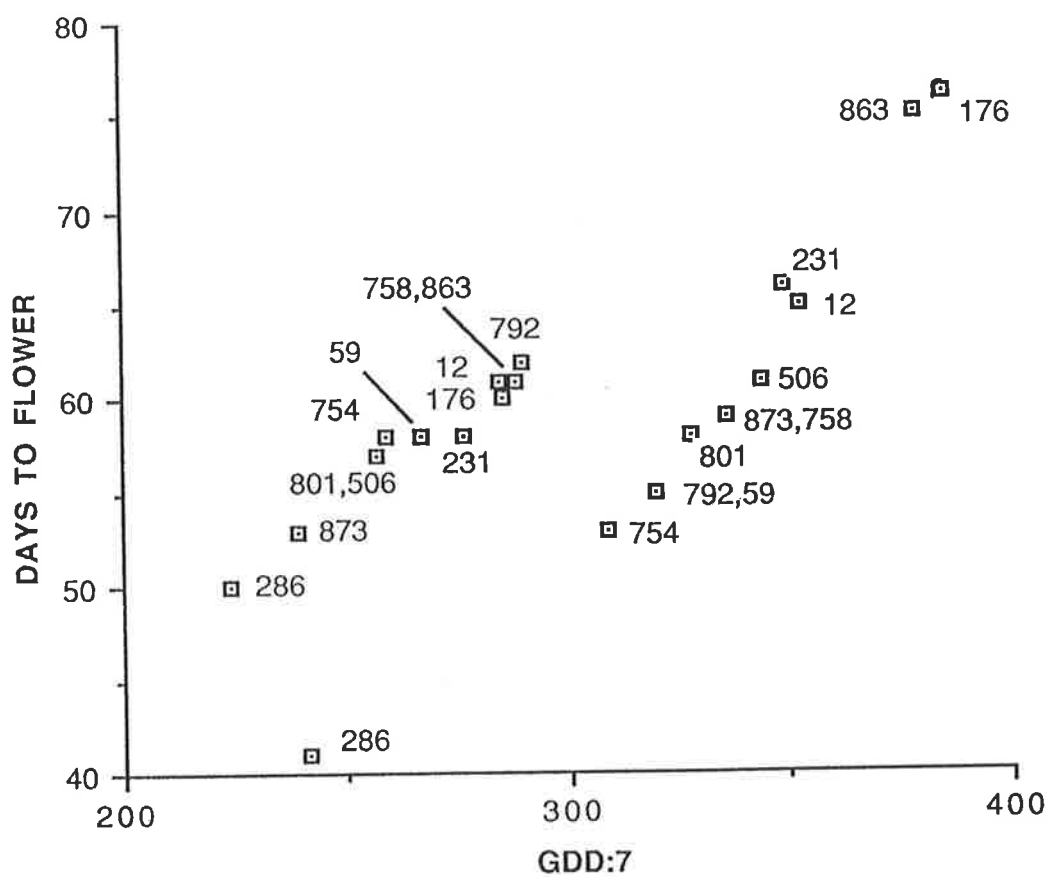


Fig.42 The relation between number of days to flower and GDD7 for 12 accessions. Results to the right are for the May sowing and to the left for the July sowing.

Flowering to podding

The time interval between the first flower and the first pod is also evident from figure 37. This interval was much longer for the first sowing, and varied more between accessions ranging from 9 to 30 days. Whereas for the second sowing, it only ranged from 3 to 7 days. For the first sowing the interval between first flower and first pod coincided with the coolest part of the year with daily temperatures of approximately 11 °C. For the second sowing the mean temperatures were approximately 12.5° C. Similarly, for the second sowing, hours of bright sunshine and solar radiation were much higher during the flower-to-pod interval.

Podding to Maturity.

The time from the first pod being evident, until maturity was also greater for the first sowing and ranged from 83 to 114 days among accessions. For the second sowing it ranged from 54 to 66 days. It will be suggested the shortening of this period with late sowing significantly reduced yield. There was much less variation in the duration of pod filling for the later sowing.

The earliest plants to reach maturity (Acc 286 from the May sowing) had begun to turn black by the end of October which was two weeks before the latest Accession from this sowing, and one month before the latest plants (Acc 801, 863, 231 and 758 from July sowing). This raises the issue again of what factors, within the plant, or the environment, caused the plants to mature. None of the accessions was determinate in growth. The matter is considered in the Discussion.

Table 12. Effect of sowing date on days to emergence, flowering, podding and maturity at the Waite Institute in 1987.

Accession	Sowing to		Emergence to		First flower		First pods to	
	Emergence		First flower		to First pod		Maturity	
	May	July	May	July	May	July	May	July
Small								
754	17	18	53	58	26	5	92	64
Fiord	15	19	55	58	26	5	89	55
792	15	18	55	62	30	3	91	54
801	18	19	58	57	20	5	104	66
Mean	16	19	55	59	26	5	94	60
Medium								
176	16	20	76	60	18	7	90	56
863	17	19	75	61	23	5	83	62
12	15	18	65	61	16	5	96	61
231	18	22	66	58	9	4	103	63
Mean	16	20	71	60	17	5	93	61
Large								
506	15	19	61	57	28	6	83	55
286	15	20	41	50	14	6	114	61
873	15	20	59	53	25	7	93	57
758	15	19	59	61	27	5	99	63
Mean	15	20	55	55	24	6	97	59
G.mean	16	20	60	59	22	5	95	60
SE	0.36	0.33	2.76	1.02	1.86	0.33	2.61	1.19

Yield per unit area.

There was a significant interaction ($P < 0.01$) between sowing date and accession, for yield (Table 13) with the small-seeded accessions showing a much greater fall in yield with later sowing than occurred with the large-seeded accessions. The medium-seeded accessions were intermediate in their decline (Figure 43 a). In figure 43 b the yields for the second sowing are expressed as percentages of the yields of the first sowing. The accessions are ranked according to seed size, in the order used throughout this chapter. The small-seeded accessions had only 22% of the yield they had from early sowing and large-seed accessions about 63%.

The relation between number of days from podding to maturity and yield shows that higher yields were obtained if the period from podding to maturity was longer (Figure 44 a). It is also evident from this diagram that the slope of regressions for all the small-seeded accessions were similar, suggesting that each accessions benefited similarly by the longer interval. Within the large-seeded accessions as a group, regressions again were similar although understandably the slopes were different from the small-seeded group as the yields of these accessions were not reduced to the same extent by the late sowing. This diagram illustrates that for each accession a long period for podding increases its yield, but it also illustrates that the length of podding period is not the sole determinant of yield, as accessions with similar podding periods differed considerably in their yield, a difference related to seed size.

Dry matter production per unit area.

The dry matter production of the accessions fell with the later sowing (Table 14) but unlike yield there was no interaction between sowing date and accessions. The relationship between dry matter production and yield is given in figure 44 b.

Harvest index

In view of the differences between the accessions in their yield and dry matter production it is understandable there was a significant interaction between sowing dates and accession for harvest index ($P < 0.01$). For the small-seeded accessions harvest index decreased with later sowing while for the large-seeded accessions it increased (Table 14).

Table 13. Effect of sowing date on yield, plant weight and harvest index at Waite Institute in 1987.

Accession	Yield.t.ha ⁻¹		Plant wt.t.ha ⁻¹		Harvest index	
	May	July	May	July	May	July
Small						
754	1.95	0.41	3.85	0.88	0.49	0.41
FIORD	2.82	0.55	6.45	1.37	0.45	0.40
792	2.69	0.56	5.75	1.57	0.48	0.40
801	2.75	0.81	6.33	1.75	0.45	0.48
Mean	2.55	0.58	5.60	1.39	0.47	0.42
Medium						
176	2.78	0.96	7.08	2.37	0.39	0.40
863	2.75	1.06	6.64	2.58	0.42	0.41
12	3.37	1.37	8.20	2.63	0.41	0.52
231	2.52	1.63	7.28	3.31	0.36	0.49
Mean	2.86	1.26	7.30	2.72	0.40	0.46
Large						
506	3.14	1.86	8.48	3.47	0.37	0.54
286	3.62	2.22	8.58	3.78	0.43	0.59
873	2.97	1.96	7.57	3.26	0.39	0.59
758	2.69	1.78	8.56	3.42	0.32	0.52
Mean	3.11	1.96	8.30	3.48	0.38	0.56
SE	0.12	0.18	0.40	0.28		

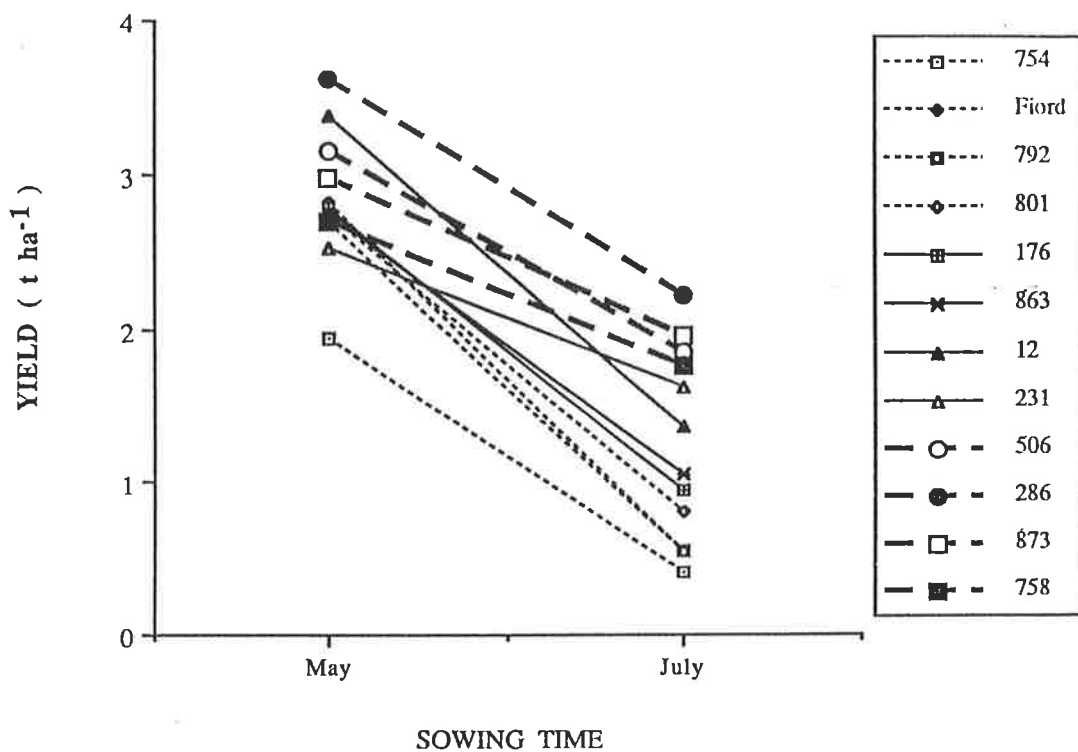


Fig.43.a. Reduction in yield of different accessions.

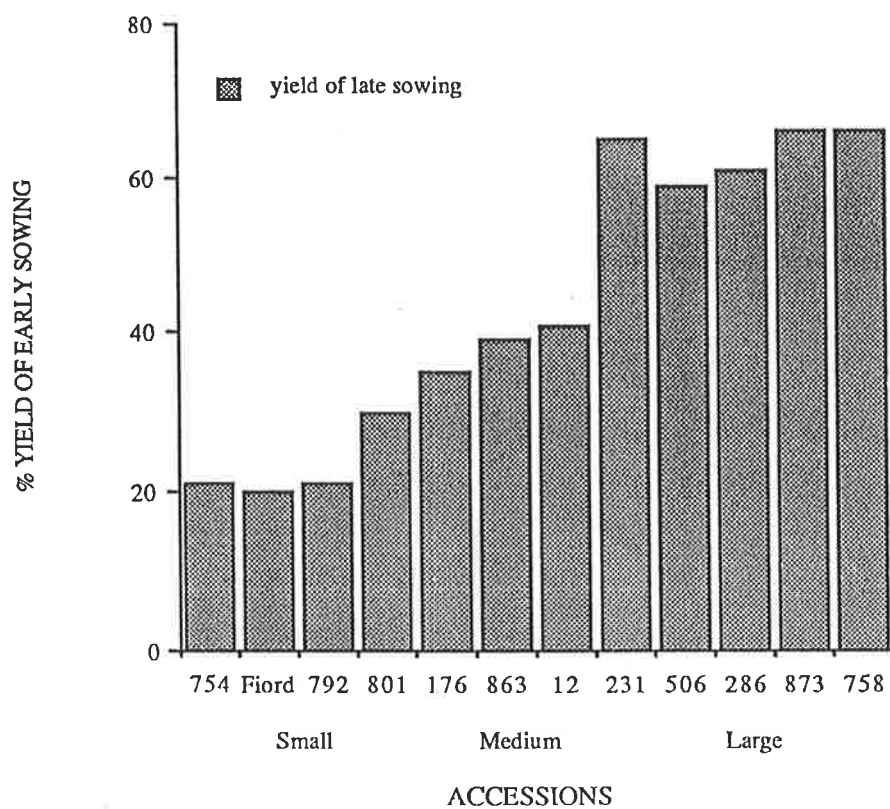


Fig.43.b. The yield of the late sowing as a percentage of the early sowing.

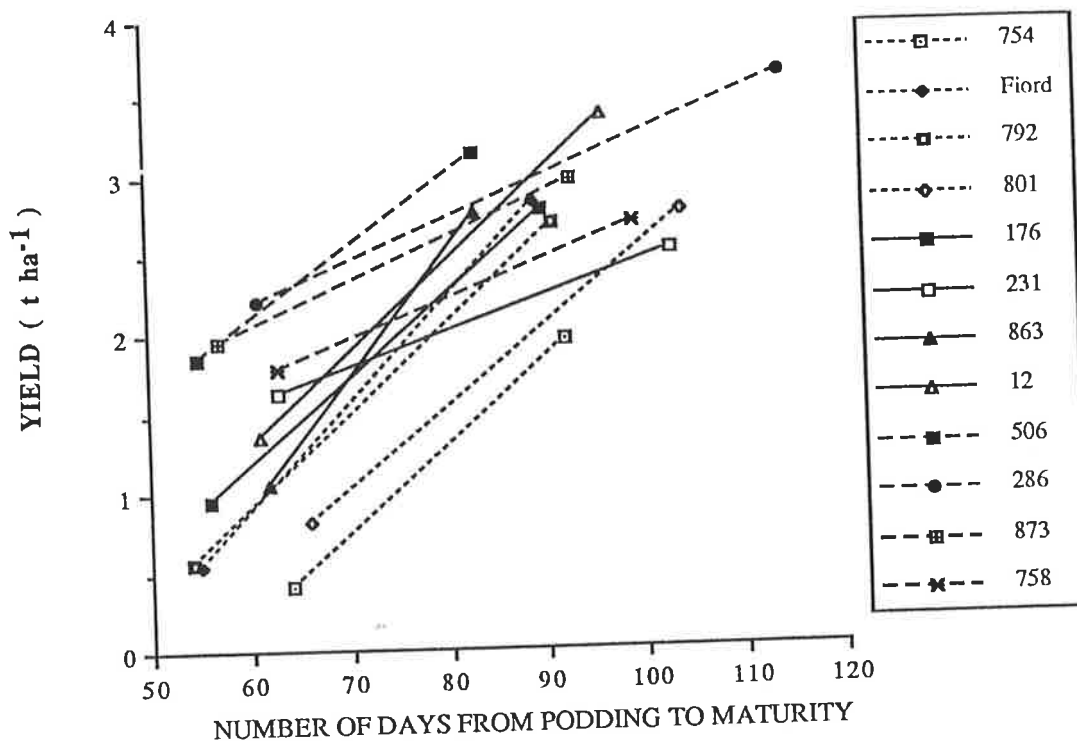


Fig. 44 a. The relationship between yield and the number of days from podding to maturity. For each accession there are two values corresponding with the two dates of sowing. The higher values were obtained from the earlier sowing.

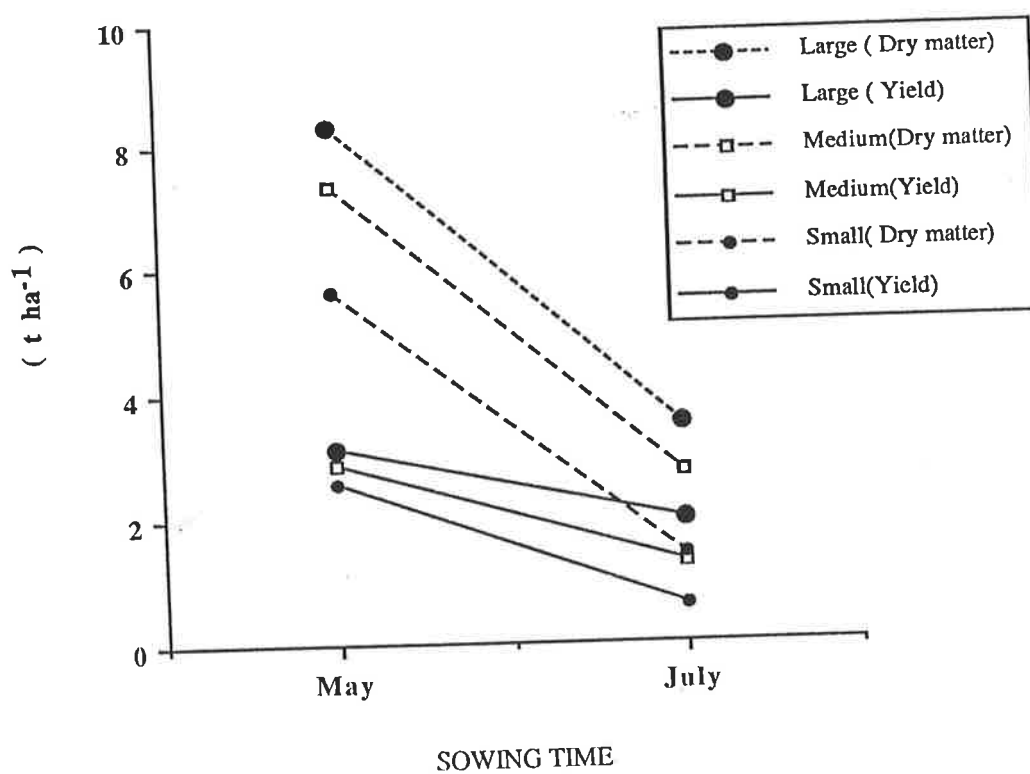


Fig. 44 b The effect of sowing date on the average yield and dry matter production of the small, medium and large seeded accessions.

Plant characters.

For the characters plant height, node of the first pod and height of the first pod there was a significant interaction between sowing date and accession ($P < 0.01$).

Plant height

Average plant height at the first sowing tended to increase with seed size but no relation was evident for the later sowing. Plant height was less with later sowing but the fall in height differed between accessions and was not related to seed size (Figure 45 a).

The lowest node bearing a pod.

Following early sowing more nodes developed before the first pod was formed than for the later sowing (Figure 45 b). The decline was not constant for the accessions leading to the interaction. In some accessions such as Fiord, 792 and 801 the first pod was formed at approximately the same node irrespective of the sowing date whereas in 754, 873 and 758 the first pod was formed at a much lower node with late sowing. The differences in node number were reflected in the height above ground of the lowest pods (Figure 45 c).

Yield, the components of yield, and their distribution on nodes of the plant.

As with the plant characters, there was a significant interaction between sowing date and accessions for yield and its components ($P < 0.01$) except for the character seeds per pod. The reduction in the yield per plant with later sowing was similar to the reduction in yield per unit area (Table 14), any difference being attributable to sampling error. Yield loss with delayed sowing was a consequence of a reduced number of pods and weight per seed whereas seeds per pod was little affected.

It is evident from table 14 that, for small-seeded accessions, the fall in yield with late sowing was due mainly to fewer pods although the fall in weight per seed was a

contributing factor. For the large-seeded accessions the fall in seed weight was much more significant and, on average, was as important a factor as the fall in pod number in affecting yield.

The distributions of yield per node on each sowing date illustrates the differences among accessions in achieving their yield. The small-seeded accessions continued to have pods and yield up to higher nodes than the large-seeded accessions both for the May sowing (Figure 46) and the July sowing (Figure 47). A comparison of these two figures shows that the affect of late sowing was to concentrate yield on lower nodes.

Pods per plant.

The yield component showing the greatest change with late sowing was pods per plant and it was the smaller seeded accessions which showed the greatest reduction in this character. Despite the reduction, the small-seeded accessions continued to produce more pods than the large-seeded accessions.

The number of pods per node for the sowing dates is shown in figures 48 and 49. The maxima were similar for the two dates ; for the small and large-seeded accessions being approximately 1.1, and 0.6 pods per node respectively. But, the distribution of pods up the plant were different with the maximum number per node being higher up the plant and there being a wider distribution of pod-bearing nodes with early sowing.

Seeds per pod

Of the yield components, this character showed the least change with late sowing. On average the number of seeds per pod declined by only 3% between sowing dates. There was no indication this decline differed significantly among the accessions.

In all accessions the number of seeds per pod declined on the higher nodes (Figures 50 and 51). There was also evidence for some accessions that numbers were less on the lowest nodes of the plant (e.g. Acc 176 in Figure 51) suggesting there was an optimal node number but this was not obvious for all accessions.

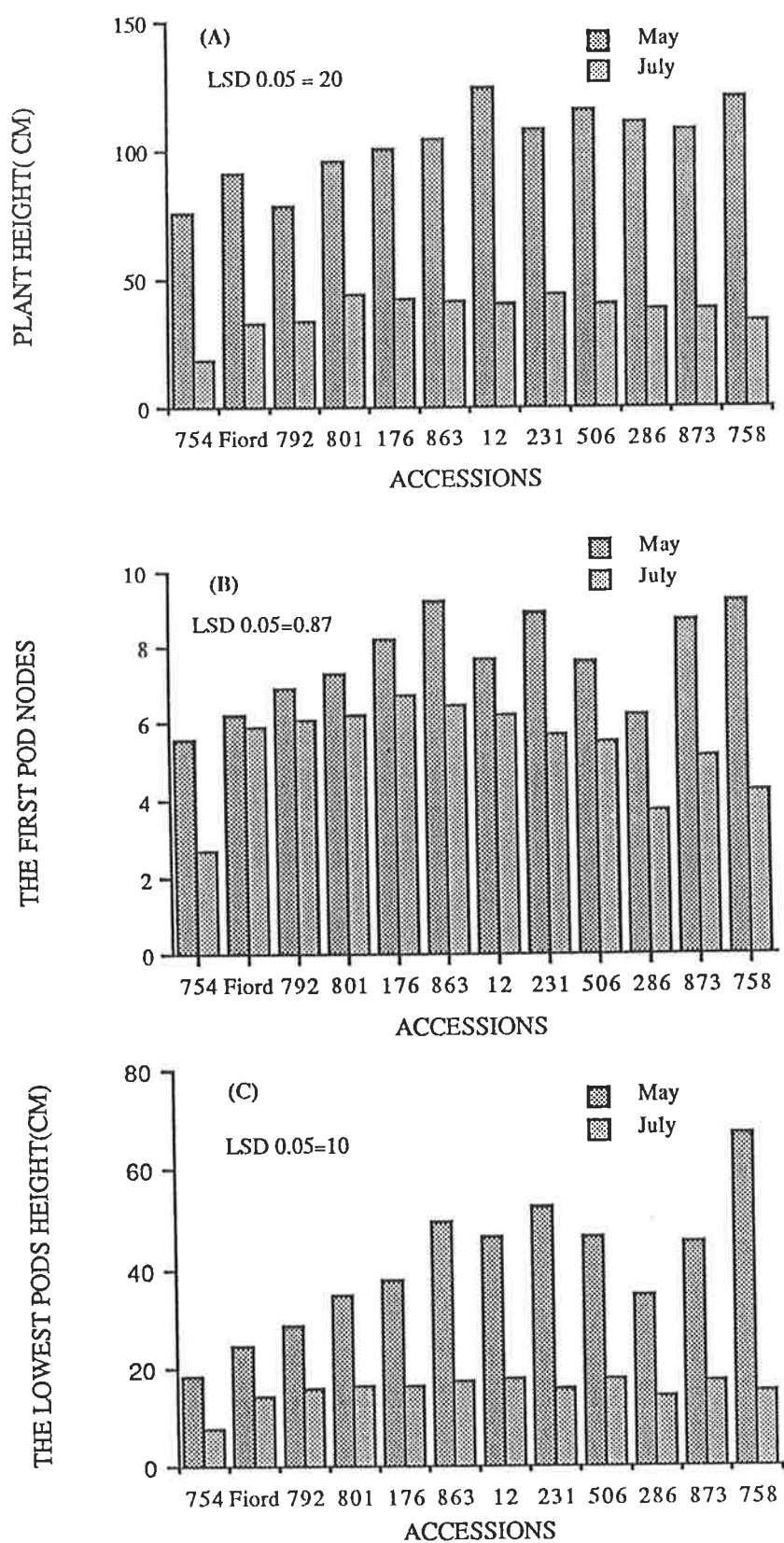


Fig 45. Effect of sowing dates on (a) plant height, (b) the node of the first pod and (c) the height of the lowest pod.

Weight per seed (Seed size).

This yield component changed with late sowing, more than seeds per pod, but less than pods per plant. The greatest change occurred in the large-seeded accessions and the least in the small-seeded accessions. This was opposite therefore to pods per plant but was insufficient to compensate for the very large change in pod number of the small-seeded accessions which resulted in their lower yields.

Figures 52 and 53 show the mean weight of seed for each node of the plants. There was some variation, much more for the large-seeded accessions in which seed size clearly fell at the upper nodes.

Table.14. Yield and its components per plant for twelve accession sown on different dates at the Waite 1987. The figures in parenthesis are the percentage reductions as a consequence of later sowing.

Accession	Yield(g)		Pods plant ⁻¹		Seeds pod ⁻¹		Weight per seed (g)	
	1May	3July	1May	3July	1May	3July	1May	3July
Small								
754	188.9	17.3(81)	6.9	3.9(43)	2.30	2.18(5)	0.40	0.37(7)
Fiord	164.2	65.1(60)	8.4	4.9(42)	2.44	2.40(2)	0.51	0.38(25)
792	138.3	42.0(70)	8.1	2.9(64)	2.76	2.99(+8)	0.50	0.47(22)
801	194.9	75.1(61)	8.7	4.5(48)	2.59	2.41(7)	0.59	0.47(20)
Mean:	171.6	50.0(70)	8.0	4.1(49)	2.52	2.50(2)	0.52	0.42(19)
Medium								
176	162.3	50.3(69)	7.9	4.5(43)	2.26	1.82(19)	0.66	0.46(30)
863	172.6	62.1(64)	6.4	3.2(50)	2.43	2.40(1)	0.78	0.56(28)
12	206.3	81.3(61)	5.2	3.3(47)	2.42	2.36(2)	0.89	0.58(35)
231	189.4	82.2(57)	5.8	3.6(38)	2.30	2.24(6)	0.94	0.67(29)
Mean:	182.7	69.0(63)	6.3	3.7(41)	2.35	2.21(6)	0.82	0.57(30)
Large								
506	173.6	107.3(38)	3.1	2.8(10)	2.65	2.88(+8)	1.28	0.84(34)
286	247.1	111.4(55)	4.9	2.9(41)	1.99	1.90(5)	1.22	0.99(19)
873	202.1	99.1(51)	3.2	2.6(29)	2.58	2.35(9)	1.31	0.90(31)
758	151.7	87.7(42)	1.9	1.8(5)	3.83	3.51(8)	1.52	1.06(30)
Mean:	193.6	101.4(48)	3.3	2.5(25)	2.54	2.46(3)	1.33	0.95(29)
SE	8.34	8.01	0.66	0.26	0.13	0.14	0.11	0.07

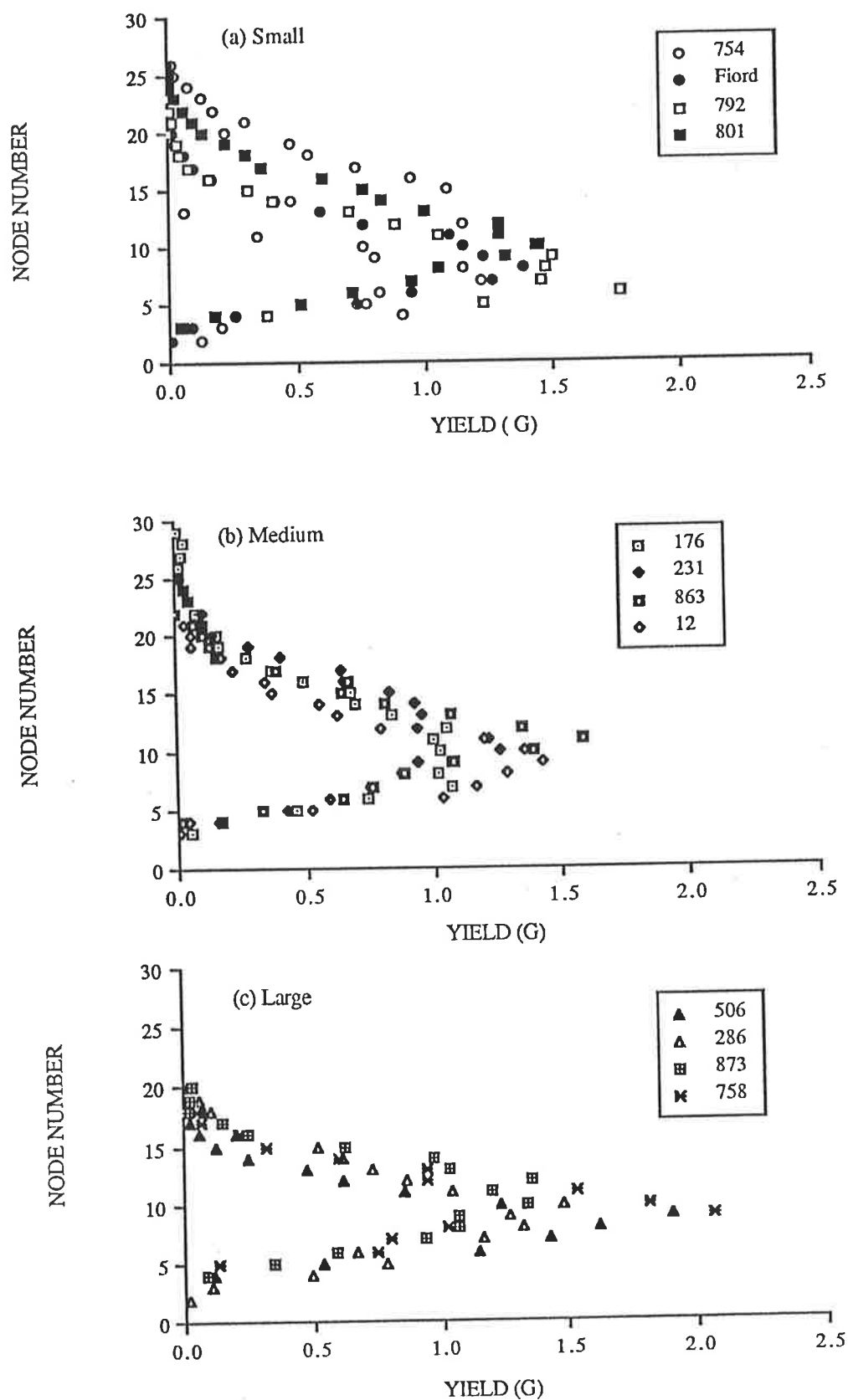


Fig 46.. The distributions of yield (g) per node for the May sowing

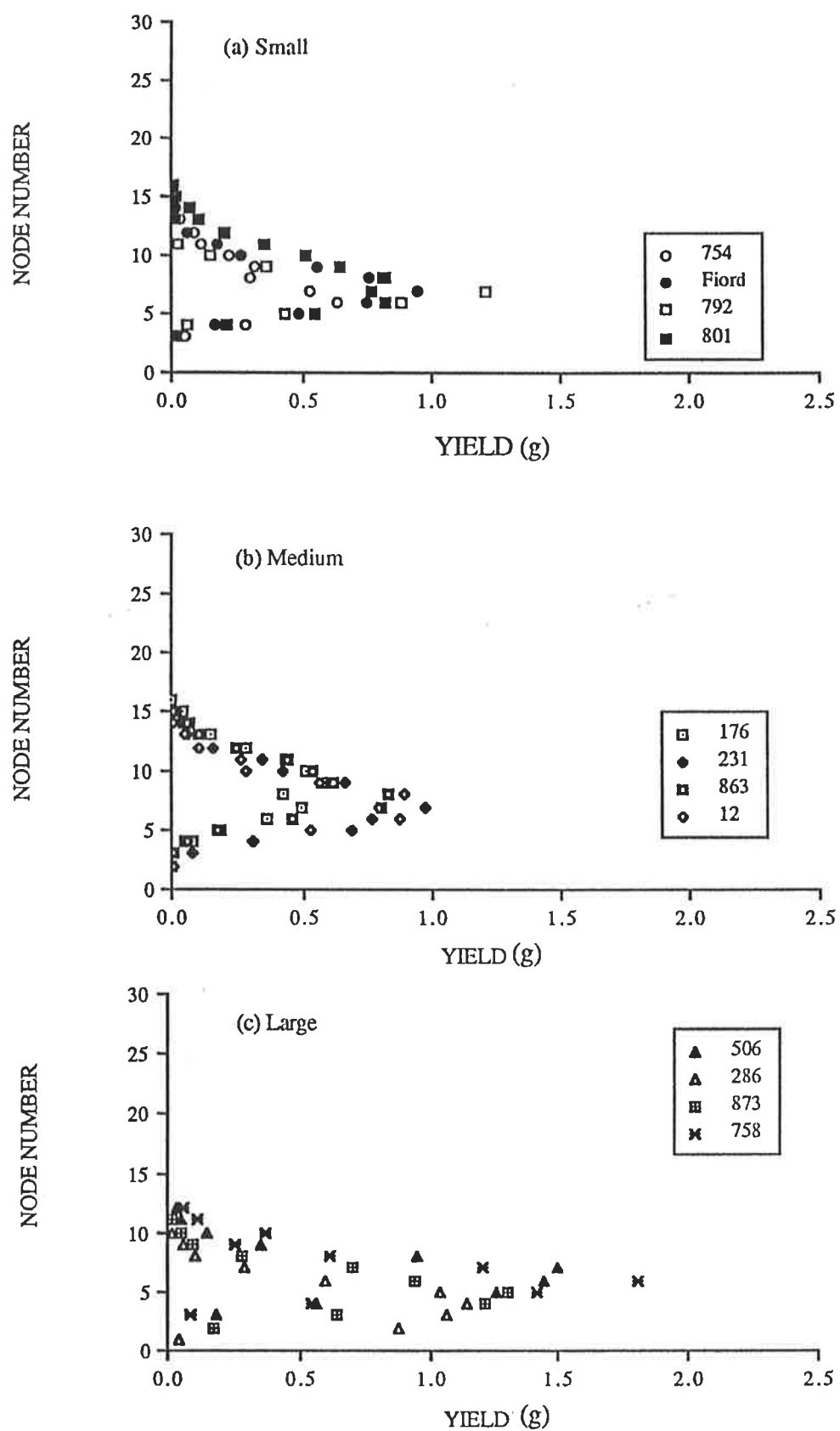


Fig 47. The distributions of yield (g) per node for the July sowing

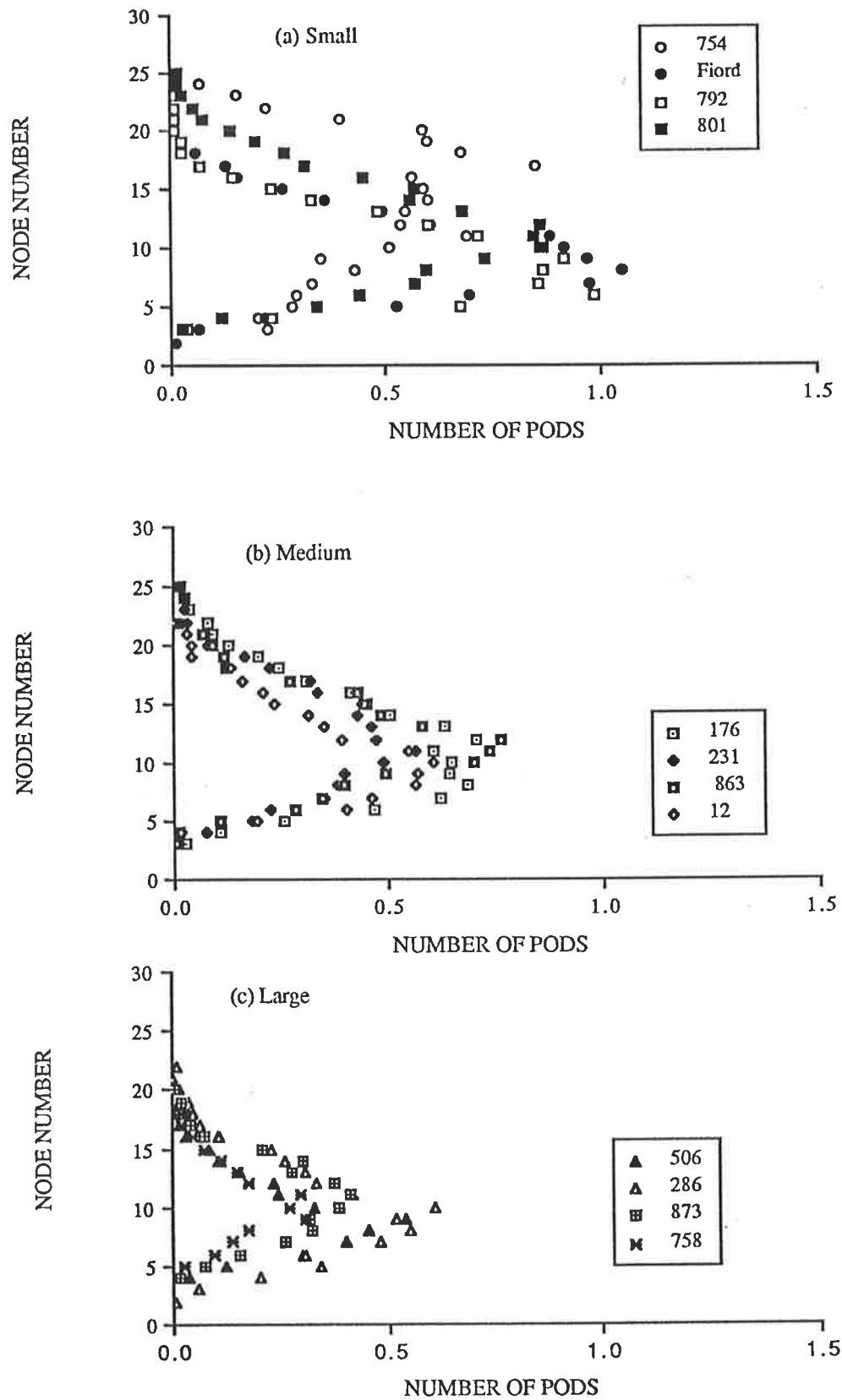


Fig 48. Number of pods per node for the May sowing

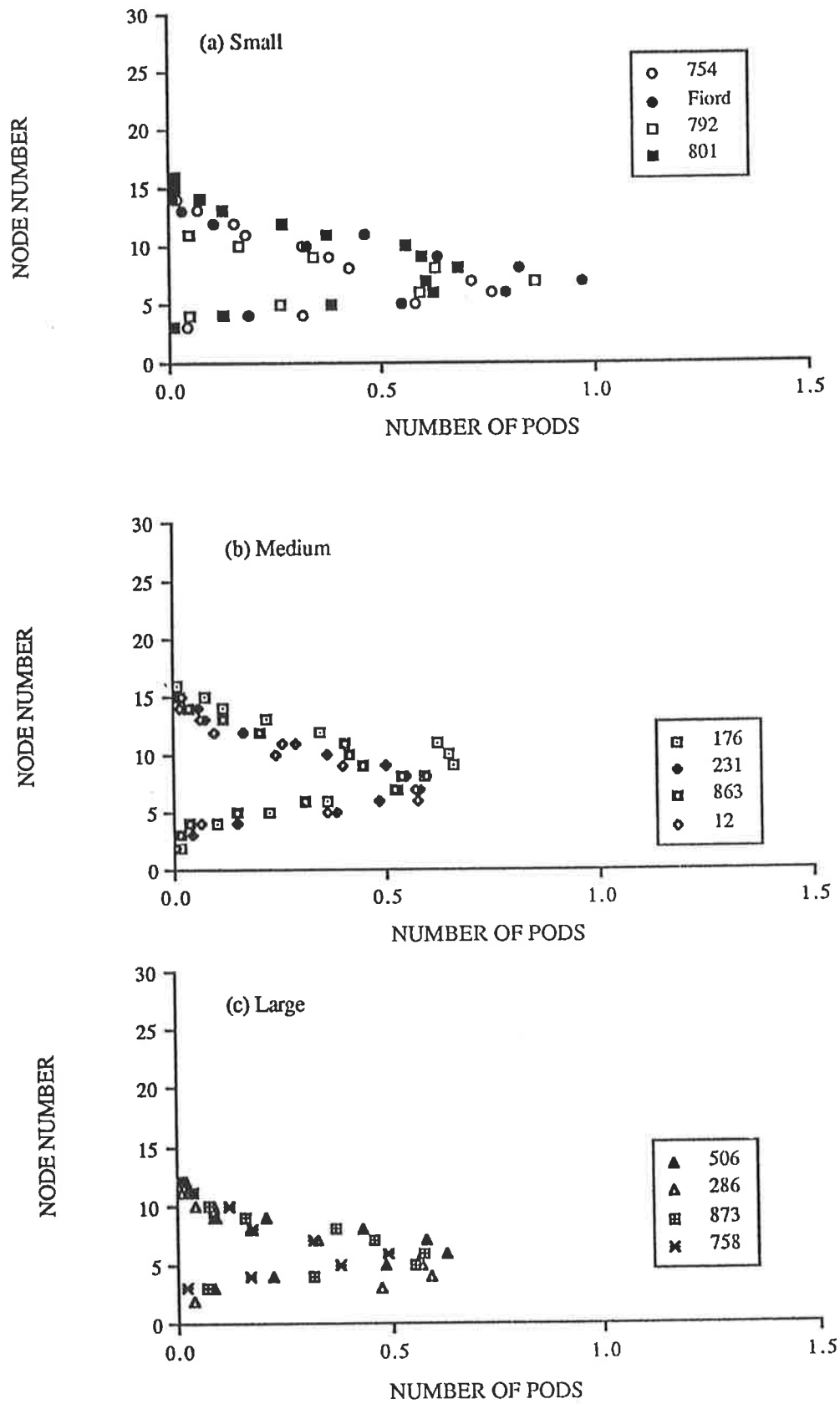


Fig 49. Number of pods per node for the July sowing

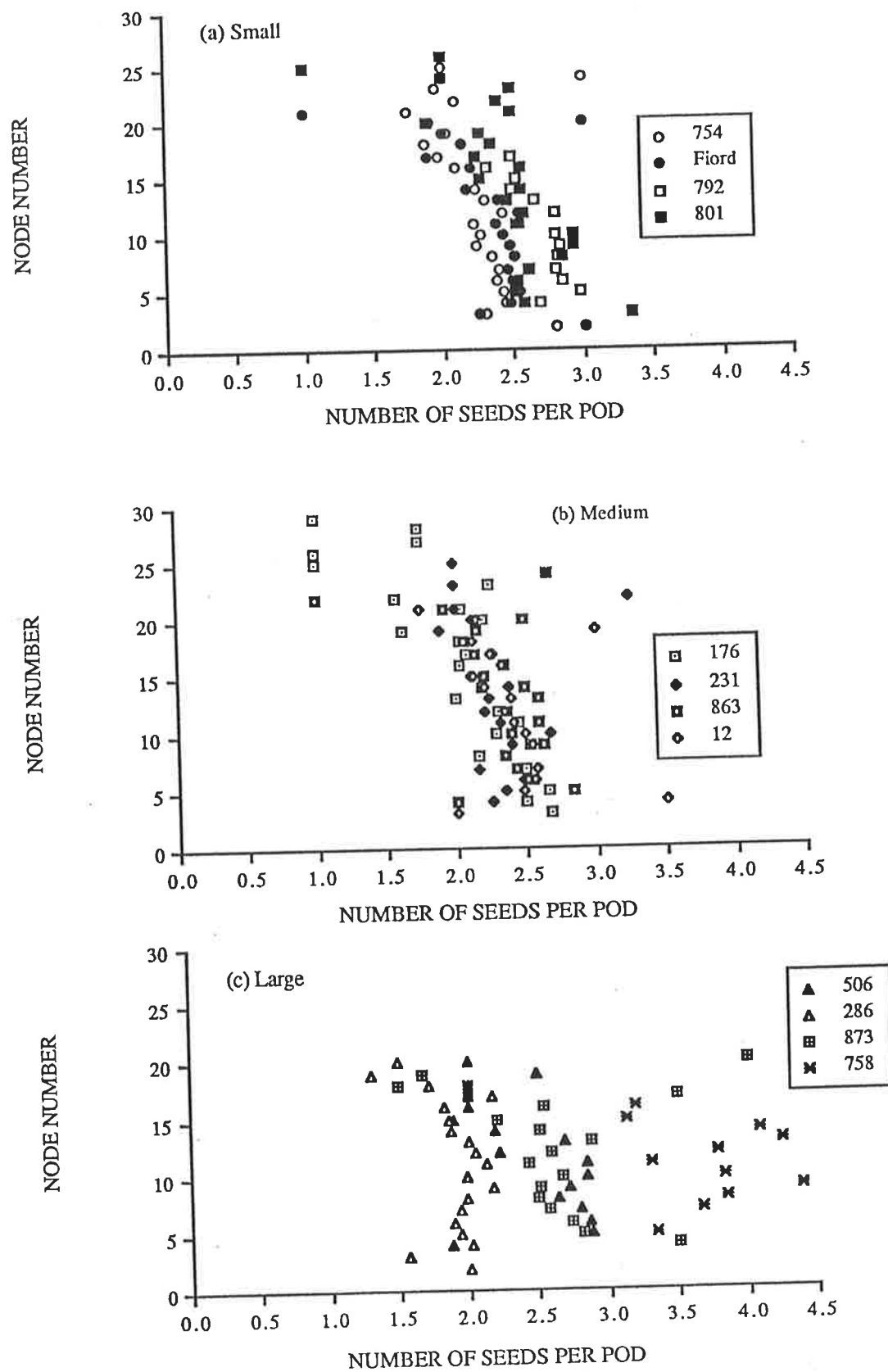


Fig.50 . The distributions of seeds per pod for the July sowing

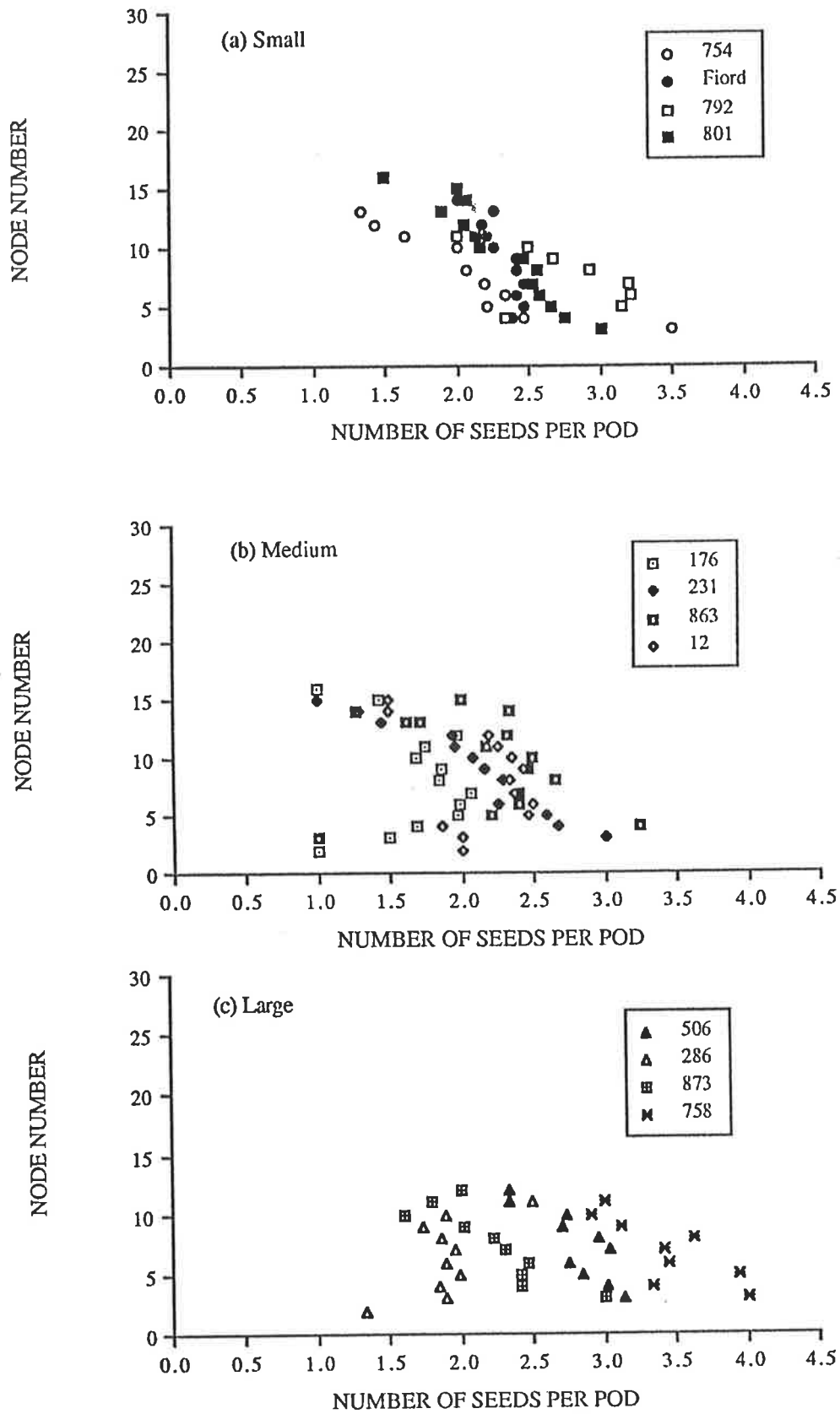


Fig.51. The distributions of seeds per pod for the July sowing.

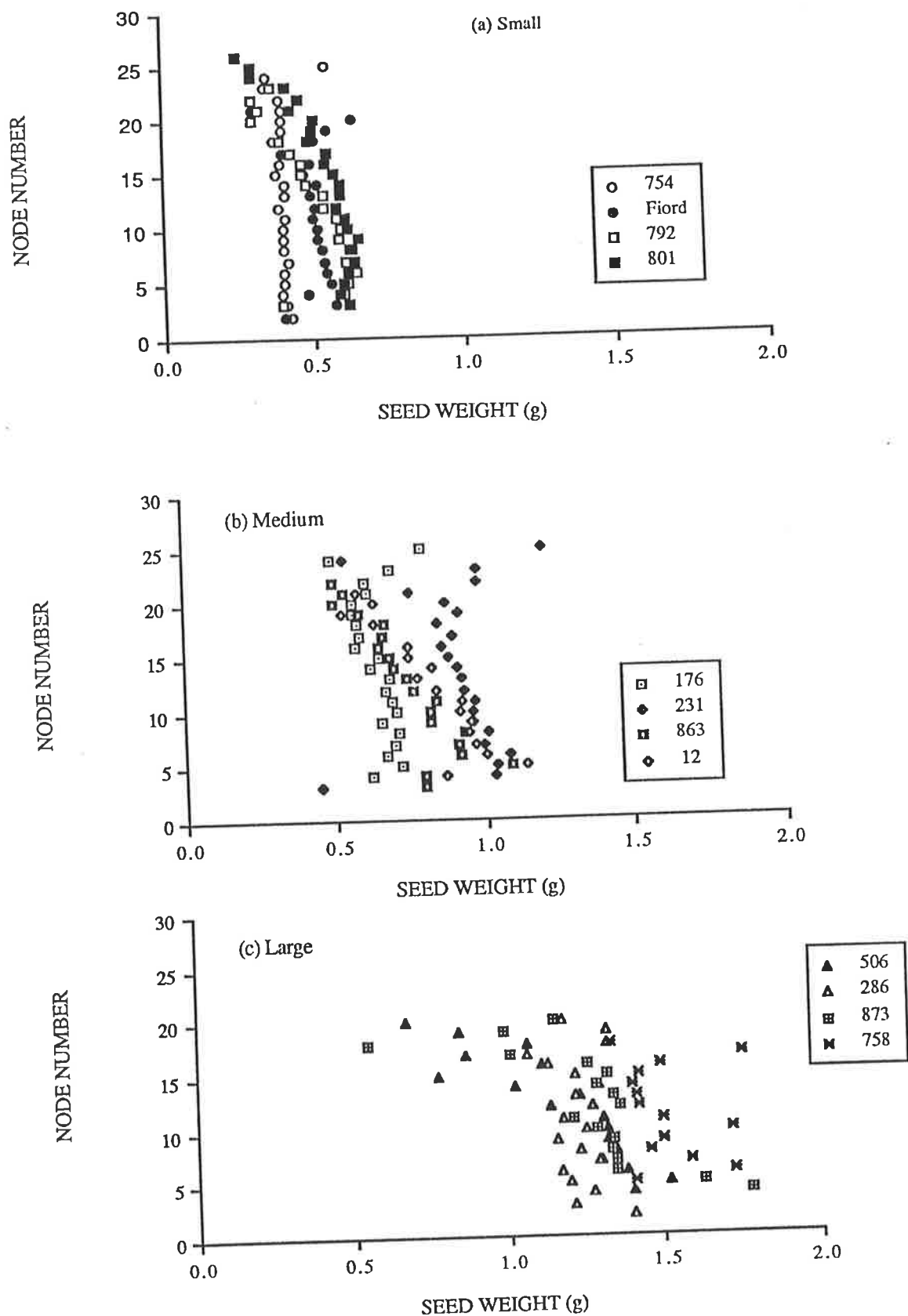


Fig 52. The distributions of mean weight per seed per node for the May sowing.

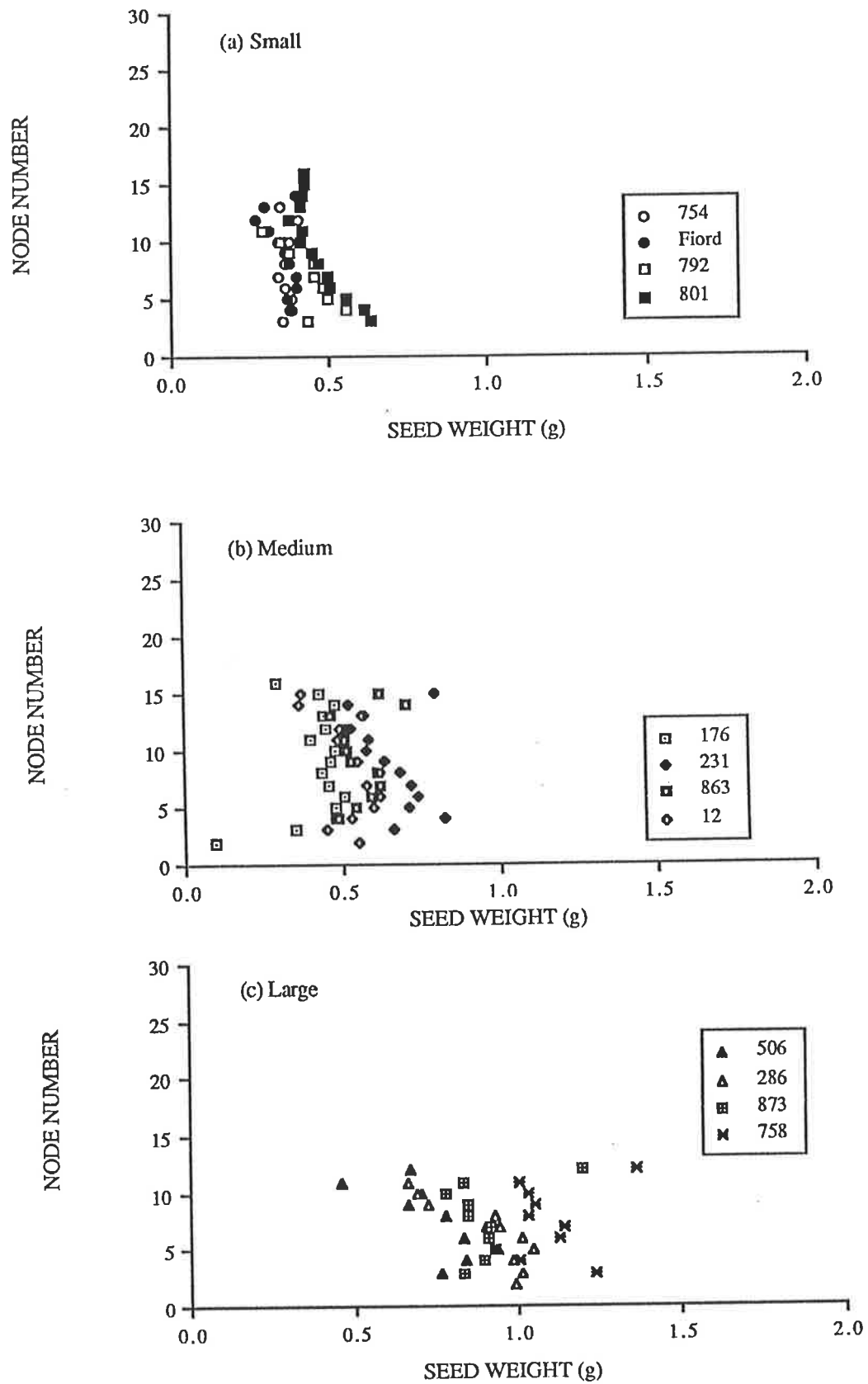


Fig 53. The distributions of mean weight per seed per node for the July sowing.

DISCUSSION

The results have shown that yield in this sample of faba beans was influenced strongly by the seed size of the accessions. Some aspects of the growth of the plants were also influenced by seed size but others such as phenological development were not.

Phenological development.

Emergence was delayed (16 days versus 19 days) with later sowing due probably to the lower temperatures (16 ° versus 12 °C) during the period from sowing to emergence (Table 14 in Appendix). Although variation in seed size is indicative of embryo size, the shoot from the large seeds did not emerge earlier than from the smaller seeds.

A most significant finding in the results was the interaction with sowing date in the time taken by accessions to flower (Figure 38). Early sowing revealed there were large inherent differences between accessions in their flowering response to the environment, whereas with late sowing the differences were lessened. The observed variation may have been due to differences between accessions in their need for vernalization, the occurrence of a juvenile phase and their subsequent response to photoperiod and temperature, but nothing is known at present about these requirements for the particular accessions under study. It could be conjectured that Acc 286 has no vernalization requirement or juvenile phase and was able to flower rapidly with early sowing. When sown late, its flowering may have been delayed by the low temperatures of July and August. In contrast those accessions such as 176 and 863 that took a long time to flower, from early sowing, may have a vernalization requirement which was not met until July. When sown late (e.g July) this requirement was met quickly. The relation between days to flowering and environmental factors is discussed more fully in the final Discussion where all the results are considered.

The agronomic significance of the results on flowering is exemplified by Acc 286. Given that the opening rains of the growing season, in large areas of southern

Australia, occur in late April, there are accessions within *Vicia faba* that can be respond to the environment of that date, with its moderate but falling temperatures and daylengths. They flower very quickly, have a long pod-filling period and potentially a high yield. However if the rains are late and sowing occurs when the temperatures and daylength have declined, very rapid flowering will not occur and these accessions will not show a big advantage over other accessions. The cultivar Fiord which was moderately quick to flower does not have the exceptional response of Acc 286. It would appear the exceptional response is not directly related to country of origin and latitude (Figure 38) but it is a character which could be simply assessed in collections of faba beans by sowing early.

For all accessions irrespective of their flowering response, the earlier sowing resulted in a longer pod -filling period and a higher yield (Figure 44 a). Similarly in 1985 and 1986, for the cultivar Fiord, it had been found that yield was positively related to the duration of the pod filling period, which had resulted in a greater number of pods. In 1987, for the first sowing, the period from the first pod to maturity occurred between August and November, and for the second sowing from late September to November. As both water and high temperature stress are experienced from October onwards in this environment these stresses were particularly severe on the podding of plants from the second sowing. The stress caused the period of pod filling to be shortened or terminated. However it appears that the cessation of growth and maturity are not always determined by these environmental factors as Acc 286, when sown early, matured in October. Other entries in the trial were still green at that time and they continued to grow for another month. It might be argued that the early maturity of Acc 286 was due to its high biomass, which led to a greater water stress, but there were other accessions with high biomass that did not mature early. It is concluded from these results, as other authors have done (Davies and Williams, 1986) that plants may mature as a result of an internal physiological mechanism. It might be possible to obtain higher yields if this mechanism could be overcome and growth continued as long as possible to be terminated by water stress.

Yield per unit area.

It is evident that the reduction in yield of the small-seeded accessions, caused by late sowing was much greater than for large-seeded accessions. The explanation probably lies in the need of small-seeded accessions to continue to produce pods on many nodes of the plant to achieve their yield whereas large-seeded accessions achieve their yield by fewer pods and very large seeds. These can be borne by a few early-formed nodes.

However, a possible alternative explanation needs to be discussed. It is based on the supposition that the large-seeded accessions have inherently a capacity to produce large plants and a higher yield. Being potentially large plants their yield density relations would be dissimilar from those of small-seeded accessions and the density used in the experiment may not have been optimal for the large-seeded accessions following early sowing. Had the density been optimal for the large-seeded accessions (i.e. a lower density) they may have given an even higher yield at the earlier sowing. Some evidence for the density being above the optimum is provided by the harvest index values discussed below. It is possible therefore that if density were optimal, and the large-seeded accessions had given a higher yield at the early sowing, they may have shown a relative fall in yield with late sowing that was similar to that shown by small-seeded accessions.

There was an interaction for harvest index between sowing dates and accessions. HI declined for the small-seeded accessions, with later sowing, but increased for the large-seeded accessions from an initial very low level. The low level is indicative perhaps that plant density (20.0 plants m⁻²) was too high for these accessions when they experience a long growing season. A similar response was found for the small seeded cultivar Fiord when sown at too high a density in 1986 (See table 6 b) and similar effects have been found elsewhere by Grotehusman and Robbelen (1985).

The question of whether the smaller reduction in yield shown by large-seeded accessions in this experiment is a consequence of the manner in which they achieve their

yield - a few pods with large seeds - or occurred because density was too high, given the long growing season, needs to be resolved by an experiment that varies accessions, sowing date and density. It is a question of great economic significance for farmers.

Plant characters.

Delays in sowing affected plant height, and the height and number of the node bearing the first pod. The result has an agronomic significance as pods that are borne very low on a plant are difficult to mechanically harvest and represent a loss in terms of grain harvested, although their presence in the stubble enhances its quality as animal feed.

Yield and its components per plant.

The components of yield that showed changes with late sowing differed between accessions. For the small-seeded accessions the greatest reduction was in the number of pods (Table 14) which averaged 49%. In contrast the large seeded accessions showed a reduction of only 25% and the medium-sized accessions 41%. The number of seeds per pod was relatively constant for all accessions on both sowing dates. But weight per seed was reduced by late sowing particularly in the large-seeded accessions.

The figures 46 to 53 illustrate how the faba bean accessions differ in the manner in which they achieve their yield. The small-seeded accessions produce more pods and continue to produce pods on higher nodes than large-seeded accessions. The lowest nodes of a plant do not have a high frequency of pods (Figure 48 and 49). The frequency increases up to node 10 to 12 and then falls again at the higher nodes. The effect of late sowing is to lower the node at which these maxima occurred (nodes 5 to 7) and to reduce the spread of pod bearing nodes up the plant.

The number of seeds per pod showed considerable variation, with maxima either at the lower nodes or an optima occurred at a node above the lowest. As an illustration of the variation in seeds per pod, Acc 801 showed a very clear fall from 3.0 to 1.5 from the lowest to the highest pod on the plant, with a mean of 2.4 seeds per pod. This range in seeds per pod was very similar with late sowing, resulting overall in a very small change.

Variation in seed size was much less, particularly for the small-seeded accessions. Some such as Acc 754, the smallest-seeded accession in the study, had very little variation in seed size among the nodes of a plant or between sowing dates. However the large-seeded accessions did have smaller seeds on the higher nodes.

In conclusion it appears that large changes in yield are attributable to fewer pods and a restriction of these pods to fewer nodes on a plant. Whereas the number of seeds per pod falls progressively with pods higher up the plant the fall is similar between sowing dates and the mean number of seeds per pod shows only a very small decline with late sowing. Seed size is fairly constant for the smaller-seeded accessions, but can show considerable variation, both up the plant and between sowing dates, in the large-seeded accessions.

It would appear to be far simpler for farmers to produce a uniform product when growing small-seeded fababeans than when growing large-seeded beans although a large size and uniformity are characteristics of the section of the market destined for human consumption.

CHAPTER 6

YIELD RESPONSE TO NITROGEN FERTILIZER

RESULTS

1. Response to add nitrogen fertilizer as starter.

Experiment (1) at the Waite and Charlick 1985.

Yield and related characters.

The effect of relatively low levels of nitrogen fertilizer applied at sowing on several characters is given in Table 15. There were no interactions between sowing date, plant densities and nitrogen fertilizer for these characters at either location. At the Waite Insitute there was no significant increase in yield or dry matter production between 0 and 10 kg N ha⁻¹ but the between 0 and 20 kg N ha⁻¹ was significant. The number of pods per metre square was increased by the application of nitrogen. At Charlick Exp Station there was a small reduction in yield from the application of 10 kg N ha⁻¹ and no response to the higher nitrogen rate.

Nodulation.

Five plants were sampled at random, for all sowing dates, during early growth, to evaluate nodulation. At the Waite, no nodules were developed indicating that soil conditions were not suitable for their development. The possible reasons for this include the acid soil (pH 5.9 at 0-10 cm) and the fact that the paddock had not been planted to fababeans previously. The crop rotation during the previous three years has been wheat, barley and oats before the experiment. In contrast at Charlick, the nodules were well formed. The pH at the site was 8.1. Since 1978 the Charlick site had grown crops of barley with occasional undersowing of subterranean clover.

Table15. Effect of starter nitrogen on yield and its components, Waite and Charlick 1985. The values are the mean derived from 80 plots (4 sowings + 5 densities+4 replication).

Item	Nitrogen fertilizer (kg ha ⁻¹)			SD
	0	10	20	
Grain yield(t ha ⁻¹)				
a.	1.48	1.53	1.74	0.14
b.	1.50	1.46	1.50	0.02
Dry matter(t ha ⁻¹)				
a.	2.57	2.75	3.16	0.30
Number of pods m ⁻²				
a.	157	173	185	14.05

a. Waite Institute

b. Charlick.

2. Yield response to different times of nitrogen application.

Experiment (4) at the Waite Institute 1987.

Yield and related characters.

The effect of the time of nitrogen application on various characters is given in table 16. None of the differences were significant, although the values for the yields of the plots to which N had been applied at emergence tend to be higher (See Table 12 in Appendix).

Table 16. Effect of Nitrogen fertilizer yield, dry matter and harvest index at Waite Institute in 1987

Treatment	Yield t.ha ⁻¹	Dry matter t ha ⁻¹	Harvest index
Control	1.10	2.01	0.55
Emergence	1.55	2.51	0.62
Flowering	1.07	2.03	0.53
Podding	1.07	1.98	0.54
Emergence+flowering	1.40	2.61	0.54
Emergence+podding	1.40	2.72	0.51
Emer+flower+podding	1.38	2.36	0.58
Mean	1.28	2.32	0.55

DISCUSSION

It was shown that an application , at sowing, of 20 kg N ha⁻¹ increased yield and dry matter production at the Waite Institute in 1985 in plants that had no nodules. This suggests that the availability of nitrogen in the soil was insufficient and that further investigations are needed to find an optimum level of nitrogen fertilizer. Also needed are studies into why no nodules were formed in the particular circumstances of the experiment. In contrast at Charlick where nodules were formed, there was no influence of N treatments due presumably to N fixation.

A possible reason for the failure of applied nitrogen to have a significant effect on yield and other characters in the 1987 experiment was the very high rainfall experienced after the applications were made. These results also agree with other investigations in which yield of fababean were not affected by the addition of N (Mc Ewen, 1970 b ; Newton and Hill, 1987). Although these experiments were inconclusive, there were indications that N fertilizers might have an effect in this environment and further studies are required.

CHAPTER 7

GENERAL DISCUSSION

The present studies were undertaken to provide information on the agronomy of faba beans in southern Australia.

Attention was given to sowing date and density as these are factors easily modified by farmers. The effects of these factors were tested in two years, 1985 and 1986, using the cultivar Fiord. The effect of nitrogen, as a starter application was also explored in the 1985 experiment but was not pursued in 1986. The experiment in 1987 was designed to assess the effect of sowing dates on a number of accessions which differed in weight per seed.

Although results for each year have been discussed separately this final Discussion considers briefly some aspects of the results for the three years and arrives at a final conclusion.

a. Phenological developments.

A most important finding from these studies was that the number of days to flowering and the duration of pod filling varied, depended on the accession, and on the date of sowing. In general the number of days to flowering was less with later sowing, but it was evident that some accessions, such as Acc 286, would respond to early sowing by flowering exceptionally early. Acc 286 was always earlier than Fiord.

The difficulty associated with trying to relate progress towards flowering to mean temperature or mean photoperiod when these factors show seasonal variation in field experiments, was clearly illustrated by the analysis of the results for the 12 accessions. Acc 286 was characterised as having a preflowering requirement for the highest mean temperature among the 12 in one instance and the lowest mean temperature requirement among the 12 in another (Fig 39). This result was a consequence of the fact that Acc 286 was the quickest to flower and that seasonal temperatures were falling from a high temperature in the first instance and rising from a low temperature in the second.

The mean temperature for Acc 286 related closely to current temperature. The same preflowering temperatures, calculated for Acc 286, were also experienced by the other accessions during the early part of their growth, but because they took longer to flower, their mean preflowering temperature requirements were affected by later temperatures resulting in intermediate mean temperatures. Photoperiod also was showing seasonal variation and concerns relate similarly to its analysis when based on mean values of P

The same diagram also illustrates that negative regressions may be obtained and that estimates of base temperature may be unacceptable from field observations. For the accessions 176, 863 and 231 there was a negative association between progress towards flowering($1/f$) and mean preflowering temperature. For the May sowing, these accessions show slower progress towards flowering at a higher temperature than for the July sowing when they show more rapid progress at a lower temperature.

The results for the 12 accessions were obtained from only two sowings and a more comprehensive set of results was obtained for Acc 59 (FIORD). For the 14 site/years in which FIORD was grown, the interpretation may be taken further. Fig 15 is produced again as Fig 54 but now the sequence of sowing dates is indicated. For the four sowings in any one year the mean preflowering temperature fell from the first sowing but then rose again. As a result , between any two sowings the regression of $1/f$ on mean temperature may be positive or negative. For the W85 environment there is a negative regression from the first to the second sowing (30 Apr-7 Jun) and for the C86 environment from the first to both the third and fourth sowings (29 Apr-6 Jun and 14 Jul). These negative regressions and the positive ones are attributable to the seasonal variation in temperature. It needs to be emphasised however that when all the 14 results were analysed in one regression a statistically significant positive regression was obtained and a base temperature of 7°C was estimated from the equation $1/f = a + b T$. Clearly this estimate is very suspect as it will be determined by the sample of sowing dates. This criticism arising from the confounding of time with seasonal environmental factors probably affects many other studies of estimates of base temperatures and GDD and other

studies relating flowering responses in annual crops to mean measurements of environmental factors.

As it is to be expected(Roberts and Summerfield 1987) that progress towards flowering is positively associated with mean temperature up to an optimum temperature (supraoptimal temperatures are unlikely to have been experienced in the present study) it is the negative regressions which must be considered atypical. The negative regressions observed could be readily interpreted if there were a juvenile phase during which no progress towards flowering would occur. For instance, with the results for the accessions 176, 863 and 231 the initial high temperatures experienced in May would then have contributed to their high mean preflowering temperature but would not have resulted in progress toward flowering. The initial low temperatures, following the July sowing, will have led to a low mean preflowering temperature but would have not delayed flowering. It was the temperature later in the preflowering period that was probably significant and these temperatures were the opposite of those experienced soon after emergence, changing from high to low and from low to high for the two sowings respectively. Similarly if these accessions had a vernalisation requirement which was not met until late in their growth from the first sowing and early in their growth in the second the effect would be the one observed. Lastly it may have been that the photoperiod was delaying flowering at certain times of the year and not others. It is not possible to resolve these matters from the present results as the factors need to be evaluated separately.

This illustration of the difficulty of analysing field results is based on data arising from a study of different genotypes but it can be postulated that if a treatment such as a herbicide spray or density difference affected the number of days to flowering relative to the controls in the experiment, they would cause an apparent relationship of flowering with seasonal factors such as temperature and photoperiod that vary with time.

It is concluded that only an accession that had no juvenile stage, no vernalisation requirement , was daylength insensitive and flowered quickly would show a strong linear regression of $1/f$ with temperature. If any one of these conditions is not met in an accession highly variable results may be obtained, including negative regressions. As

Roberts and Summerfield(1987) point out " it is difficult, if not impossible to discern the separate effects of temperature and photoperiod from field data without supporting evidence from investigations in controlled environments."

b. Yield and its components.

This study has demonstrated that early sowing leads to a more rapid emergence, larger plants and longer flowering and pod-filling periods. This, in turn, results in a more even distribution of pods among the many nodes of the plants, a constant number of seeds per pod, and seeds of a higher and more uniform weight among the pods of the various nodes. Altogether, these factors result in the higher yields. There is also the advantage, in early sowing that the optimal density is lower and less seed needs to be sown.

The only disadvantage is that a long growing season and abundant growth during the coolest and wettest part of the year is conducive to the development of the diseases chocolate spot, (*Botrytis fabae*) and ascochyta blight (*Ascochyta fabae*). Neither of these diseases had any affect in the present study, as they were completely controlled with fungicides. At present, the total cost to a farmer of an effective fungicide application is less than \$30 a heactare. Two or occasionally three applications may be needed in long growing seasons with high rainfall.

A present, the return for fababeans is in excess of \$ 150 a tonne and at times has been \$ 200 a tonne. It would appear that the most profitable approach is to sow early and, in anticipation of higher yields, to spend funds on effective disease control. The alternative approach, of delaying sowing to late June or July, to avoid disease and the cost of fungicide, leads to too high a penalty in terms of lost production.

This study has also revealed, that there are large-seeded accessions with the potential for much higher yields than Fiord, although to use such material farmers may have to modify their sowing equipment. If these accessions are able to maintain higher yields than Fiord in shorter growing seasons, as a result of their different pathway to achieving yield, they may be of interest when attempting to expand the area of faba bean culture into more marginal areas.

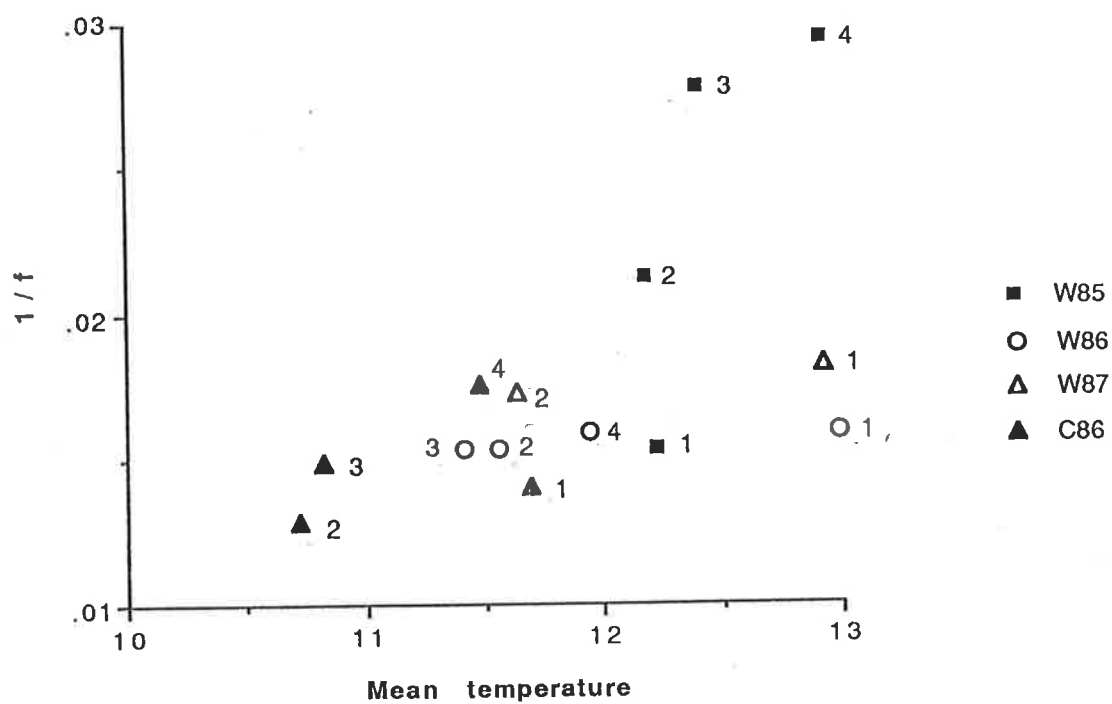


Fig. 54. The relation between progress towards flowering($1/f$) and temperature. The values on the graph are sequences of sowing in each site/year.

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APPENDIX

Table 1. Mean rainfall, air temperatures, hour of bright sunshine, and solar radiation for the years 1925 to 1983 at the Waite Institute.

Month	Rainfall (mm)	Average Daily Temp(°C)			Hour of Bright Sunshine per day	Solar radiation Meg J/m ² /day
		Max	Min	Mean		
Jan	23.8	27.9	16.4	22.1	9.25	26.95
Feb	25.8	27.7	16.5	22.1	8.80	23.91
Mar	23.8	25.5	15.4	20.5	7.65	19.02
Apr	56.2	21.4	12.9	17.2	5.57	12.81
May	78.7	17.8	10.7	14.2	4.07	8.69
Jun	73.9	15.1	8.6	11.8	3.35	7.25
Jul	86.1	14.2	7.8	11.0	3.25	7.34
Aug	72.9	15.2	8.1	11.7	4.42	10.35
Sep	62.2	17.6	9.4	13.5	5.55	14.38
Oct	54.0	20.3	10.9	15.6	6.66	19.52
Nov	37.6	23.4	12.8	18.1	7.80	23.61
Dec	29.5	25.8	14.7	20.3	8.40	25.90
Year	624.5	21.0	12.0	16.5	6.23	16.64

Table 2. Mean rainfall, air temperature, hour of bright sunshine, and solar radiation at the Waite Institute in 1985.

Month	Rainfall (mm)	Average Daily Temp(°C)			Hour of Bright Sunshine per day	Solar radiation Meg J/m ² /day
		Max	Min	Mean		
Jan	1.6	28.1	16.1	22.1	9.92	27.72
Feb	3.2	27.9	16.6	22.2	9.97	25.91
Mar	49.4	27.0	17.0	22.0	8.19	19.47
Apr	55.6	22.5	13.8	18.1	6.58	13.32
May	100.2	18.2	11.0	14.6	4.57	9.01
Jun	65.2	14.8	9.0	11.9	2.68	6.74
Jul	58.6	14.8	8.9	11.8	3.69	7.86
Aug	94.0	15.3	9.1	12.0	3.69	9.13
Sep	71.6	16.6	9.0	12.8	5.76	14.62
Oct	37.8	20.7	12.1	16.4	6.96	19.24
Nov	27.4	23.5	13.7	18.3	7.56	22.64
Dec	59.6	23.3	13.9	18.6	6.74	22.83
Year	624.2	21.1	12.5	16.7	6.36	16.54

Table 3. Mean rainfall, air temperature, hour of bright sunshine, and solar radiation at the Waite Institute in 1986.

Month	Rainfall (mm)	Average Daily Temp(°C)			Hour of Bright Sunshine per day	Solar radiation MegJ/m ² /day
		Max	Min	Mean		
Jan	10.2	26.5	14.8	20.7	10.45	28.62
Feb	1.6	26.7	15.6	21.2	8.31	23.15
Mar	1.8	28.7	16.7	22.7	8.45	19.97
Apr	75.6	21.2	13.0	17.1	5.43	12.60
May	57.4	18.1	11.5	14.8	3.57	8.22
Jun	46.8	14.9	9.1	12.0	3.32	6.99
Jul	168.2	13.2	8.1	10.7	2.62	6.65
Aug	129.8	15.0	8.9	12.0	4.81	10.30
Sep	77.6	16.8	9.7	13.3	5.70	14.60
Oct	62.2	18.6	10.2	14.4	6.15	17.62
Nov	10.0	23.5	12.5	18.0	8.88	25.63
Dec	42.0	23.9	14.1	19.0	6.80	22.84
Year	683.2	20.6	12.0	16.3	6.21	16.43

Table 4. Mean rainfall, air temperature, hour of bright sunshine, and solar radiation at the Waite Institute in 1987.

Month	Rainfall (mm)	Average Daily Temp(°C)			Hour of Bright Sunshine per day	Solar radiation Meg J/m ² /day
		Max	Min	Mean		
Jan	27.0	24.8	14.0	19.4	8.91	26.5
Feb	22.8	27.6	16.4	22.0	8.54	23.45
Mar	28.4	23.8	14.4	19.1	7.62	19.08
Apr	25.8	23.1	14.2	18.7	6.63	13.89
May	139.4	17.4	11.2	14.3	3.23	7.84
Jun	111.6	15.8	9.5	12.7	2.68	6.71
Jul	142.4	14.2	8.1	11.2	4.05	7.64
Aug	53.6	15.1	8.8	12.0	4.79	10.15
Sep	22.2	18.5	10.2	14.4	6.44	15.40
Oct	50.6	20.4	10.5	14.4	7.74	20.61
Nov	8.8	24.3	14.1	19.2	8.59	23.64
Dec	47.2	26.6	15.0	20.8	9.18	24.20
Year	679.8	21.0	12.2	16.6	6.53	16.68

Table 5. Mean rainfall and air temperature at Charlick. in 1985.

Month	Rainfall (mm)	Average Daily Temperature (°C)		
		Maximum	Minimum	Mean
Jan	5.6	27.3	13.8	20.6
Feb	5.8	25.6	12.3	19.0
Mar	61.0	25.5	14.5	20.0
Apr	44.4	21.8	9.8	15.8
May	29.4	18.9	6.4	12.7
Jun	51.4	15.7	6.9	11.3
Jul	37.4	15.0	6.6	10.8
Aug	83.2	15.4	6.6	11.0
Sep	74.6	16.5	6.9	11.7
Oct	50.0	20.6	9.8	15.2
Nov	12.8	22.3	11.1	16.7
Dec	44.4	24.0	12.6	18.3
Year	500.0	20.7	9.8	15.3

Table 6. Mean rainfall and air temperature at Charlick. in 1986.

Month	Rainfall (mm)	Average Daily Temperature(°C)		
		Maximum	Minimum	Mean
Jan	7.2	25.3	11.5	18.4
Feb	3.5	26.3	13.0	19.7
Mar	2.5	27.8	13.2	20.5
Apr	52.4	21.4	10.3	15.9
May	39.0	18.3	8.6	13.5
Jun	28.8	15.4	6.3	10.9
Jul	119.9	13.9	6.9	10.4
Aug	84.4	15.0	6.5	10.8
Sep	47.1	16.6	7.2	11.9
Oct	66.0	20.1	7.2	13.7
Nov	17.4	23.9	8.7	16.3
Dec	32.2	24.0	10.9	17.5
Year	500.4	20.7	9.2	15.0

Table 7. Mean soil temperature maximum and minimum at 2.5 cm depth from sowing to emergence at the Waite Institute in 1985.

Sowing dates	30 Apr		7 Jun		2 Jul		31Jul	
	max	min	max	min	max	min	max	min
Days after sowing								
1	35.0	16.3	21.0	4.7	20.2	8.7	18.2	8.0
2	37.0	16.4	19.4	6.8	22.5	7.7	19.8	6.9
3	34.4	15.1	13.2	9.3	23.4	8.5	20.9	8.3
4	33.7	15.2	18.2	9.5	23.9	8.2	16.4	9.6
5	34.5	16.4	18.0	9.2	25.0	7.9	18.2	11.9
6	19.3	12.0	16.8	7.8	23.5	8.2	12.5	9.3
7	20.3	11.5	18.5	10.4	18.0	7.0	19.1	9.2
8	21.9	10.5	17.0	10.9	21.2	6.1	21.0	7.2
9	21.4	11.2	16.7	10.7	15.5	7.1	16.5	7.4
10	19.6	12.3	21.2	8.7	17.8	6.4	18.8	7.8
11	26.6	13.4	18.0	9.0	16.7	6.8	19.6	8.9
12			17.9	8.4	22.2	4.8	14.6	8.7
13			15.6	8.5	12.6	8.9	19.1	7.8
14			18.9	7.8	15.1	7.7	18.0	7.6
15			18.7	6.9	17.7	6.9	19.7	7.4
16			18.6	5.8	19.4	8.2	19.7	10.4
17			19.7	7.1	14.3	7.7		
18			14.0	7.8	19.9	6.3		
19					15.9	6.4		
20					16.1	8.5		
Mean	27.6	13.6	17.8	8.2	19.0	7.4	18.2	8.5

Table 8. Mean air temperature maximum and minimum from sowing to emergence at the Waite Institute in 1985.

Sowing dates	30 Apr		7 Jun		2 Jul		31 Jul	
	max	min	max	min	max	min	max	min
Days after sowing								
1	26.4	18.1	12.7	5.4	19.1	12.9	12.8	7.8
2	25.5	15.7	14.9	9.5	17.7	9.1	13.2	8.5
3	26.3	15.7	14.9	9.3	18.1	10.3	12.0	7.4
4	25.6	17.1	13.0	9.3	18.1	10.3	12.0	7.4
5	26.2	18.5	15.0	9.4	18.0	9.2	17.4	11.8
6	27.1	11.3	15.2	9.3	17.5	8.9	15.4	10.8
7	16.0	12.1	13.9	10.7	13.4	6.7	14.8	10.0
8	15.6	10.4	15.6	10.1	11.9	6.3	11.4	8.0
9	16.8	10.1	14.5	11.1	12.7	5.8	14.3	6.4
10	17.7	12.0	14.6	8.5	11.7	6.7	13.1	5.6
11	18.0	12.9	16.1	10.4	13.1	7.1	10.5	7.8
12			16.6	9.3	13.2	5.3	14.5	9.0
13			13.8	9.2	15.5	9.6	14.6	9.3
14			13.2	8.2	12.9	9.8	12.6	10.1
15			14.2	6.5	13.3	7.3	10.9	9.2
16			13.5	5.5	13.1	9.7	13.7	7.4
17			13.4	7.4	13.6	6.8		
18			15.8	9.0	11.5	6.6		
19					14.5	9.4		
20					14.7	7.2		
Mean	21.9	13.9	14.4	7.9	14.6	8.2	13.3	8.5

Table 9. Mean soil temperature maximum and minimum at 2.5 cm depth from sowing to emergence at the Waite Institute in 1986.

Sowing dates	24 Apr		14 May		5 Jun		26 Jun	
	max	min	max	min	max	min	max	min
Days after sowing								
1	19.7	11.21	16.2	12.9	22.0	7.4	11.9	9.2
2	18.5	10.3	25.4	13.1	22.2	8.1	18.5	7.8
3	22.0	10.5	21.3	13.1	22.0	10.5	22.3	10.8
4	25.0	9.0	17.4	12.3	17.5	10.6	19.7	9.3
5	21.3	8.8	19.1	11.9	16.3	11.3	15.1	11.6
6	20.8	9.5	18.6	9.9	16.3	11.0	17.0	12.9
7	20.7	11.7	18.5	10.8	20.8	11.7	12.9	11.3
8	22.3	9.0	22.0	9.4	24.5	8.8	18.5	10.3
9	26.9	8.9	16.6	12.3	21.2	8.8	18.9	10.0
10	24.8	11.9	22.0	10.4	21.7	6.9	18.0	9.9
11	25.2	10.6	19.3	10.0	20.5	6.8	18.2	9.0
12	30.0	10.4	22.1	8.8	12.2	7.9	12.2	5.1
13	23.5	12.5	18.7	9.7	16.4	6.8	16.4	5.4
14	24.8	12.0	18.6	8.9	15.9	8.5	17.0	7.0
15					17.9	6.8	18.2	7.9
16					15.8	7.1	18.5	7.3
17							17.5	5.0
18							17.4	4.6
Mean	23.3	10.9	19.7	11.0	19.0	8.7	17.1	9.7

Table 10. Mean air temperature maximum and minimum from sowing to emergence at the Waite Institute in 1986.

Sowing dates	24 Apr		14 May		5 Jun		26 Jun	
	max	min	max	min	max	min	max	min
Days after sowing								
1	16.2	13.3	19.3	14.4	14.7	9.0	14.7	9.1
2	15.3	11.2	19.8	12.6	16.6	10.7	10.9	8.9
3	15.8	12.2	21.7	10.1	18.0	11.5	14.9	10.4
4	15.0	8.2	15.8	12.2	16.4	10.7	19.4	10.3
5	15.7	8.7	15.0	11.6	14.5	11.3	19.2	10.8
6	16.2	9.1	15.1	9.1	14.4	10.1	14.6	12.2
7	16.2	11.7	14.3	10.4	14.1	10.9	14.1	11.3
8	15.5	9.0	16.8	10.3	16.1	10.2	12.5	9.4
9	15.5	9.2	19.7	13.6	18.1	10.2	13.9	8.0
10	21.4	15.1	15.0	11.5	17.0	9.0	13.7	10.1
11	21.5	11.9	16.6	11.9	16.4	9.4	15.6	8.9
12	20.6	11.4	16.6	10.8	17.4	10.8	12.7	5.6
13	21.5	14.3	18.5	13.3	11.6	8.7	9.1	5.1
14	22.0	13.4	17.4	8.9	12.9	10.3	12.3	7.2
15					13.7	7.3	12.2	7.2
16					12.2	6.0	12.7	7.8
17							13.5	7.1
18							12.7	7.3
Mean	17.7	11.3	17.2	11.4	15.3	9.7	13.8	9.8

Table 11. Mean air temperature maximum and minimum from sowing to emergence at the Charlick Exp.Sta. in 1986.

Sowing dates	29 Apr		20 May		12 Jun		14 Jul	
	max	min	max	min	max	min	max	min
Days after sowing								
1	16.0	11.0	14.0	9.0	18.0	4.0	15.0	5.0
2	15.0	11.0	18.0	6.0	17.0	3.0	18.0	8.0
3	15.0	10.0	21.0	10.0	17.0	0.0	12.0	6.0
4	16.0	3.0	17.0	11.0	17.0	0.0	14.0	9.0
5	19.0	3.0	17.0	10.0	18.0	5.0	14.0	7.0
6	16.0	4.0	19.0	7.0	14.0	7.0	16.0	6.0
7	18.0	5.0	18.0	5.0	14.0	10.0	16.0	5.0
8	23.0	7.0	17.0	11.0	15.0	7.0	14.0	7.0
9	21.0	7.0	17.0	10.0	13.0	6.0	14.0	9.0
10	24.0	13.0	15.0	7.0	14.0	7.0	16.0	11.0
11	22.0	10.0	16.0	0.0	13.0	7.0	15.0	6.0
12	20.0	6.0	10.0	6.0	14.0	2.0	10.0	0.0
13	18.0	10.0	15.0	4.0	15.0	5.0	10.0	3.0
14	23.0	10.0	17.0	10.0	15.0	10.0	11.0	6.0
15			16.0	11.0	16.0	6.0	13.0	6.0
16			14.0	5.0	11.0	7.0	15.0	9.0
17					14.0	7.0	15.0	5.0
18					20.0	3.0	15.0	2.0
19					16.0	8.0	16.0	5.0
20					14.0	11.0	14.0	8.0
21							13.0	8.0
Mean	19.0	7.8	16.3	7.6	15.2	5.7	14.0	6.3

Table 12. Analysis of variance of times N applications on (a) Yield, (b) Dry matter, (c) Harvest index, at the Waite Institute in 1987.

Source	Degree of freedom	Sums of Square	Mean Squares	F-ratio	Prob>F
(a).Yield					
Replication	3	0.170	0.057	0.089	0.505
Treatment	6	0.108	0.185	2.631	0.052
Error	18	1.264	0.070		
Total	27	2.542			
(b). Dry matter.					
Replication	3	2494.107	831.369	0.362	0.781
Treatment	6	31385.005	230.833	2.277	0.082
Error	18	41350.143	2297.230		
Total	27	75229.250			
(c).Harvest index.					
Replication	3	10.679	3.560	0.567	0.644
Treatment	6	20.357	3.393	0.540	0.771
Error	18	113.071	6.282		
Total	27	144.107			

Table 13. Effect of various base temperatures on number of growing degree days from emergence to flowering of different sowing dates at the Waite Inst in 1987.

	Acc	GDD1:4	GDD2:4	GDD1:5	GDD2:5	GDD1:6	GDD2:6	GDD1:7	GDD2:7	GDD1:8	GDD2:8	GDD1:9	GDD2:9
1	754	469	434	415	375	362	317	309	259	256	201	203	143
2	59	485	442	430	383	375	326	320	267	265	209	210	151
3	792	485	477	430	414	375	352	320	290	265	228	210	166
4	801	502	429	444	371	386	314	328	257	270	200	212	143
5	176	612	467	536	406	461	346	386	286	311	226	236	166
6	863	604	472	529	410	454	350	379	288	304	227	229	166
7	12	549	469	483	407	418	346	353	285	288	224	223	163
8	231	548	452	481	393	415	336	349	277	283	219	217	161
9	506	528	429	466	371	405	314	344	257	283	200	222	143
10	286	365	375	324	324	283	274	242	224	201	174	160	124
11	873	514	399	454	346	395	293	336	240	277	187	218	134
12	758	514	472	454	410	395	350	336	288	277	227	218	166

Table.14. Mean air and soil temperature from sowing to emergence at the Waite Institute in 1987

Sowing date	1May		3July	
Days from sowing	Air	Soil	Air	Soil
1	17.1	17.7	13.7	15.1
2	15.3	16.5	13.8	13.3
3	12.9	14.5	13.4	14.4
4	14.7	17.7	14.2	14.1
5	14.7	15.8	13.5	14.2
6	13.1	15.7	13.2	13.7
7	15.2	17.2	15.7	15.7
8	18.8	20.1	13.1	14.7
9	19.9	20.6	10.5	11.5
10	22.5	23.0	10.3	13.8
11	24.1	25.1	10.3	8.7
12	17.0	16.9	12.0	12.3
13	15.3	17.2	11.0	11.8
14	15.2	15.7	10.4	11.2
15	13.7	17.4	11.5	13.9
16	12.3	15.7	10.2	9.8
17			7.8	11.1
18			8.0	10.0
19			10.2	12.3
20			10.0	12.6
Mean	16.4	17.9	11.6	12.7