THE EFFECT OF TEMPERATURE ON

GROWTH AND DEVELOPMENT

OF PEAS

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Paul Ragan
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ABSTRACT

The influence of temperature on the growth and development of the garden pea was studied at Massey University during 1978-79. Cultivars with single and multiple (double and triple) podding characteristics were grown in a greenhouse experiment with high, medium and low temperature treatments, a field experiment with four successive sowings and a climate room with alternating high and low temperature treatments between vegetative and reproductive growth phases. Plant response to temperature was examined using growth analysis and component analysis techniques.

High temperature produced a smaller plant with shortened internodes and a delay in pod set. Net assimilation rate was closely linked with final fresh weight yield and harvest index. There was a direct relationship of net assimilation rate and growth duration to yield when net assimilation rate was not limiting; fresh weight yield increased in direct relation to the number of yield components. High temperature effects complicated by flower and pod abortion indicated that the behavior of yield components must be considered along with harvest index as a selection criterion for earliness and high yield in peas.

In all cultivars, the number of yield components decreased as temperature increased, particularly the number of pods per node when high temperature occurred during the vegetative phase. High frequency podding cultivars exhibited the highest instability. Net assimilation rate and competition for assimilates between yield components (sinks) determined the number of yield components that were retained. No one component was identified as the main source of variation in pea yield. Positive interactions between components of yield were identified with yield increases when net assimilation rate was nonlimiting and yield decreases when net assimilation rate was limiting. Negative interactions were associated with yield stability. A balance of negative and positive interactions between components of yield combined with a nonlimiting net assimilation rate(assimilate supply) is needed in high yielding pea cultivars.

INTRODUCTION

The commercial production of peas for processing requires a high
yield of green peas at a precise stage of maturity. The final fresh
weight yield at this "optimum harvest date" is influenced to a large
extent by the temperature of the environment during the growth and
development of the pea plant. The influence of temperature on final
yield has been well documented, high temperatures in excess of 25 C
reduce yield. However, there has been little research into what
morphological changes occur and how these changes relate to final yield.
Further, most studies have been limited to one or two cultivars with
little reference to comparisons between cvs of different node-podding
characteristics. For these reasons cvs exhibiting three distinct node-
podding characteristics were studied in three experiments. Growth analysis
and yield component analysis techniques were used to examine structural
and morphological changes that occurred in response to temperature and how
these changes related to final yield.

The first experiment examined the growth and development of the pea
plant at three temperatures in the greenhouse. The second experiment was
an extension of the first and examined the pea plant in a succession of
four field sowings. Both studies confirmed the results of many reports
that high temperature reduced yield, however the yield obtained is a result
of a complex interaction between components of yield and a critical balance
in dry weight distribution between vegetative and reproductive growth.
Yield component analysis was most useful in assessing the "plastic" nature
of the pea plant, namely, how the pea plant adjusted fresh weight yield
to prevailing conditions.

The results lead to the third experiment which was concerned with the
question of the changes observed in the components of yield and whether
these changes were a result of a greater sensitivity to temperature at

some particular developmental phase. Pea plants were grown in climate rooms exposed to high and low temperatures during the vegetative and reproductive phases of growth and development. Component analysis techniques were used to assess the changes in yield components to temperature treatment and how these changes related to final fresh weight yield.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
AIS	alcohol insoluble solids
C	degrees celsius
cv	cultivar
DF	degrees of freedom
Dp	double-pod cultivar
Dp (Pk)	double-pod cultivar (Puke)
Dp (Vf)	double-pod cultivar (Victory Freezer)
FW	fresh weight
LAR	leaf area ratio
LWR	leaf weight ratio
n	podding node
NAR	net assimilation rate
OHD	optimum harvest date
R	reproductive growth phase
RGR	relative growth phase
SLA	specific leaf area
SE	standard error of mean
Sp	single-pod cultivar (William Massey)
Spl	single-pod leafless cultivar
Tp	triple-pod cultivar (Puget)
V	vegetative growth phase
#	number

CHAPTER 1

Review of Literature

1.1 Classification and Use

Pisum sativum, known simply as peas, is a tendril - climbing, cool
season, hardy annual. Peas are grown for the immature fresh, edible
green seeds (peas) and for the dry, mature seeds.

Pea cultivars now used in horticulture are classified into two
groups according to color: dark green, those with pigment in the skin;
and light green, those with less pigment (Anon 1977). Light green cultivars
are usually preferred for canning, largely for aesthetic reasons based
on appearance of the processed product. Dark green cultivars are only
occasionally used for canning and are generally used as fresh market
peas.

Pea cultivars are sometimes classified according to seed charac-
teristics; smooth and wrinkled characteristics which are related to the
starch type present in the cotyledons (Anon 1977). Smooth seeded
cultivars are preferred for dry seed production, wrinkled seeded cultivars
for processing in the immature form.

Historically, pea cultivars have also been classified according to
plant type, indeterminate and semi-determinate. Generally, semi-
determinate cultivars are relatively dwarf in habit and many produce
more than one pod at each podding node under favorable conditions.
Semi-determinate cultivars which produce their first flower from the
fifth to eighth node are early maturing; those which begin flowering
from the ninth to eleventh node are late maturing (Tedin and Tedin 1923).

Because of their relatively heavy, concentrated (in time) set of pods
and the high ratio of pods to vine weight, semi-determinate cultivars
are easier to harvest. They therefore have become the established
plant type for commercial production, whether for fresh market or
for processing.

1.2 Origin and Breeding Development

Little is known of the ancestry of the garden pea, but it seems
likely that its centers of origin are in the Abyssinian and Mediteran-
ean basin regions, though a diversity of forms can also be seen in
many Asiatic areas (Yarnell 1962). Peas have been an important crop
since the eleventh century, but no extensive breeding was undertaken
until the latter half of the nineteenth century when large numbers of
cultivars were developed. Cultivated peas that are now commonly grown
have probably arisen from a small genetic base.

In order to reduce the loss in potential yield due to the spread
in maturity, plant breeders are attempting in several ways to increase
the simultaneous development of pods on any given plant. One method
involves increasing the number of pods at any given node. The number
of pods per node in most present day commercial cultivars rarely ex-
ceeds two, but genetic variants are available which have as many as
six pods per node (Fell 1976).

Other research studies involve the simultaneous development of pods
at several successive nodes and there is the continual effort to increase
the number of peas per pod beyond the eleven found in the best cultivars.
Finally, there is the possibility of exploiting the fasciated condition

Increase number of flowers

Make entire plant resistant to powdery mildew, pea wilt and pea mosaic

Shorten internodes to create a more compact plant

Improve heat tolerance

Must be good for canning & freezing

Make pods darker green

Must be good for canning & freezing

Thicken stem to make self-supporting

Bushier habit needed

Make pod wall edible

Retain sweet, tender juicy flavour of peas.

Remove fiber and strings

Increase number of peas per pod to 10 and 11

Increase thickness of pod wall

Increase pod length

Improve nutritional value

Fig. 1.1 The pea plant of the future

which results in the compaction of the upper nodes and the simultaneous development of many pods (Snoad and Davies 1972).

During the 1940's the requirements for pea breeding changed. Until that time peas were grown mainly for marketing as a green crop and for harvesting as packeted, dried peas; only a small acreage was grown for canning. Breeders sought to increase yield by introducing taller and larger leaved plants.

With the introduction of the once-over mechanical harvest (viners) techniques associated with the development of the quick-freezing industry, entirely new objectives in the breeding of peas were required. The plants now had to be as prolific as possible and much smaller to facilitate easier harvesting. With a once-over method of harvesting, as many seeds as possible had to be at the same stage of development for processing at any given time. Even in current cultivars not all seeds will be at the same stage so that a portion of those harvested will be over-mature and under-mature. The correct stage is determined by taking measurements with a tenderometer or maturometer and considerable effort is devoted to timing to within a matter of hours the precise stage for harvesting (Reynolds 1966). Speed of harvesting is therefore an essential ingredient of success in this part of the industry.

1.3 Growth and Development

There is little information on the inheritance of morphological patterns in roots. Shoot growth affects root growth indirectly because of competition for a limited supply of assimilates (Lovell 1971).

The pea usually has only one dominant shoot (Maurer, Jaffray and Fletcher 1966), however, Husain and Linck (1967) found that low temperatures

Pea Plant (Vegetative)

Node 6
(second podding node)

Node 5
(first podding node)

Stipule

Node 4

Tendril

Node 3

Node 2

Node 1

Node Sub 1
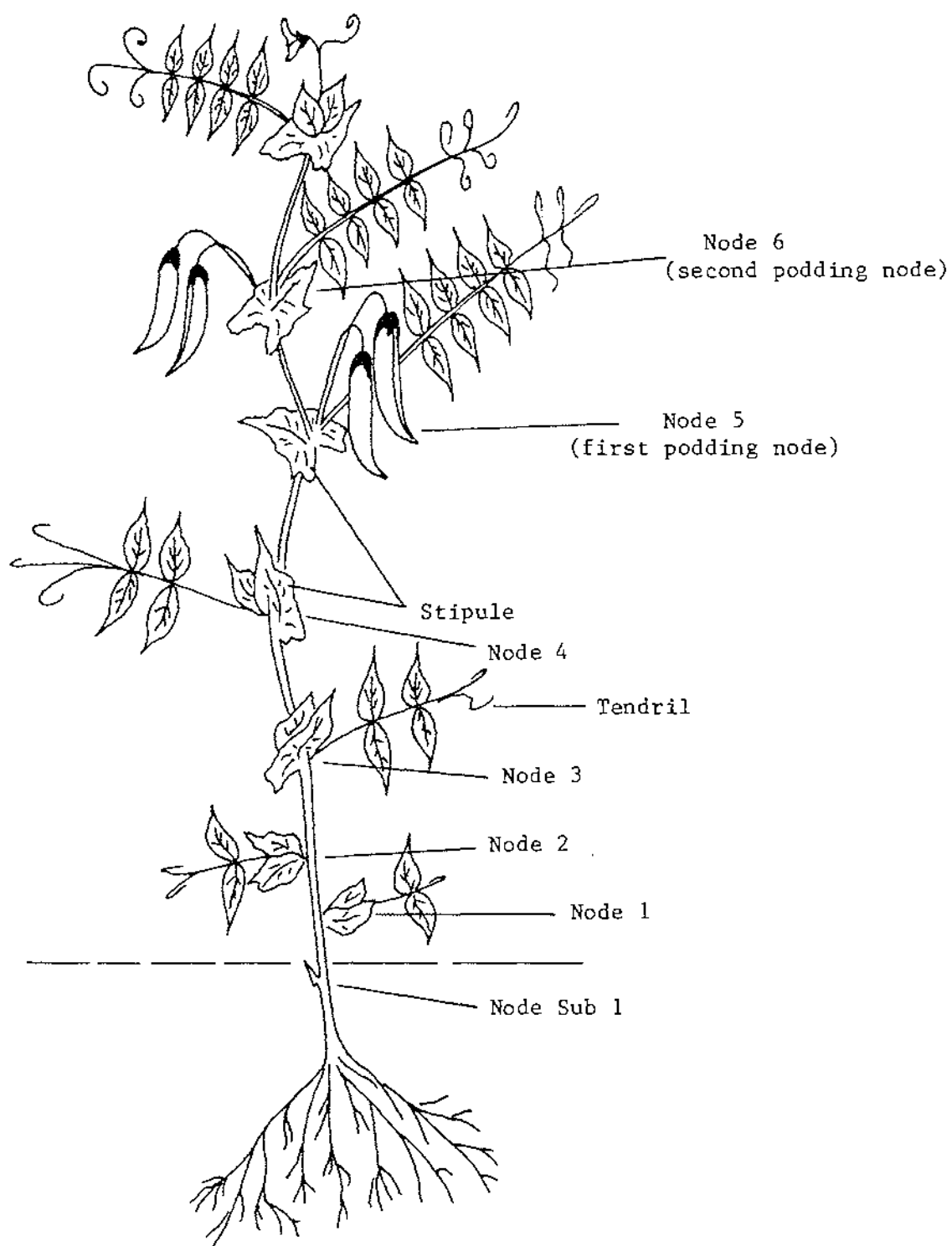
Fig. 1.2 The morphology of the pea plant relevant
to the definition of development stages

reduce growth rates and a short period of cooling inhibits apical dom-
inance and causes the plant to throw laterals; the effect is not reversed
when the plants are returned to higher temperatures. Auxin transport
may be involved. Generally, the first two nodes from which tillers may
originate are found below the soil surface producing vestigal leaves.
They are normally designated as node one. Growth of the stem is
affected dramatically by simple genetic factors. Stem length is affected
by flowering time (Wellensiek 1973). It was once believed that tall
cultivars which tend to flower later than short-stemmed cultivars
produced a growth stimulating factor which was synthesized at a higher
rate in tall cultivars. However, reciprocal grafts between tall and
short cultivars supports the theory that growth can be interpreted as a
balance between growth stimulatory and growth inhibitory processes in
the plant (Brian 1957).

Successive nodes develop as the stem elongates. A compound leaf
develops at each node and it can be considered growth and elongation at
a given node is completed as each compound leaf is fully expanded (Anon
1977). Patterns of leaf development are genetically controlled and breeders
speculate that lamina expansion is physiologically controlled independ-
ently of the branching system of the leaf axis and main veins. Smillie
(1962) observed that during the early vegetative growth of peas the
first-formed leaves each established a period of approximately five days
when they maintained a near maximal activity in photosynthesis. The
attainment of the maximum rate of CO_2 uptake often coincided with the
completion of leaf expansion. Pea leaves reach their maximum photo-
synthetic activity at the time of full expansion, losing activity
thereafter at a rate somewhat faster than the loss of chlorophyll
(Smillie 1962). The longevity of the optimum period for later leaves
is variable and is affected by genetic and environmental factors. The
maximum rate of CO_2 uptake attained by each successive leaf of peas

appears to be a basic characteristic of the genotype and not markedly influenced by the transition from vegetative to reproductive phase. This does not exclude the possibility that developing pods can increase the overall output of adjacent leaves by increasing the period which they function at near maximum activity (Smillie 1962).

More recent evidence has indicated that growth of fruit influences markedly the photosynthetic potential of the subtending leaf. There are two phases of markedly increased rate of net CO_2 uptake, one corresponding with the attainment of maximum elongation of the pod, the other with the main period of swelling of the seeds (Flinn 1974).

Stipules are found at the petiole base of each foliage leaf; with upper leaves the terminal and sometimes subterminal leaflets are present as tendrils. Photosynthetic activity of stems and petioles does not appear to have been studied but stipules (Flinn 1969) and tendrils (Snoad and Davies 1972) are reported to be as efficient in photosynthesis (measured as CO_2 uptake) as sister leaflets.

With increase in size and complexity of leaves there is a corresponding increase in length and diameter of successive internodes, this trend being evident at least until flowering is under way. The development which takes place between nodes follows a set pattern and by describing stages between nodes it is possible to relate the effect of environment to the growth and development of pea plants over relatively short time intervals.

At about the time of initiation of flower primordia, root growth reaches a maximum and then begins to decline as flowering commences (Salter and Drew 1965). Reproduction is by means of auxiliary inflorescences bearing one or more flowers, the basic pattern of fruit maturation

being therefore a sequential one (i.e. the peas contained in the pods
in the lower nodes are larger and more mature than those appearing at
succeeding nodes). Shoot morphology and reproductive behaviour may be
greatly influenced by genotype and environment (Evans 1975). It
would seem, however, that much of the variation in flowering behaviour
in peas is regulated through an unknown flower promoter-inhibitor
balance (Murfet 1973).

The pea is self-fertile and its flowers are usually self-pollinated
(Cooper 1938). Pollination takes place in the late bud stage, 24-36
hours before the flower is fully open, and by the time of full blossom,
fertilization has taken place (Cooper 1938). It is usual for all ovules
of a pea pod to be fertilized, but a considerable proportion of them
may fail to develop into mature seeds. Linck (1961) showed that space
restrictions in the pod may cause ovule abortion. High frequencies of
ovule abortion at the pre-fertilization stage has been observed in peas
grown under adverse environmental conditions (Linck 1961).

Rapid increases in pod length and width occur during early growth
and these are accompanied by a thickening of the pod wall. Gas exchange
on the pod's outer surface is facilitated by the presence of stomata,
although their density is much lower than on the surfaces of stipules
or leaflets (Flinn 1969).

The initial increases in length and width and then in wall thickness
of the pod allow for maximum fresh weight before the contained seeds
become active in laying down starch and sugar storage reserves (Flinn
and Pate 1968). After this pods lose dry matter and final drying out
is accompanied by a rapid loss of chlorophyll and photosynthetic
capacity.

1.4 Components of Yield

The pea is a highly plastic plant (capable of altering its pattern of growth and development) which possesses a number of physiological mechanisms by which it adjusts its yield to prevailing conditions. These changes considerably complicate the picture of yield production, but because of the plastic responses, once made, cannot be reversed, they are preserved in the plant's structure until harvest.

1.4.1 Branches

Lateral branches from the main stem under normal commercial conditions contribute only a small fraction of the total yield (Hardwick and Milbourn 1967). The amount of branching is a cultivar characteristic which is plastic, branches are completely suppressed at high plant densities. Branches arise at the basal nodes of the main stem or at a later stage, just below the first podding node. The pods on both types of branches are younger than those on the main stem and when cultivars with a propensity to branch are grown at low density, they may yield well, but will also have a wider range of pea maturity than is commercially desirable. Branching is therefore unlikely to be a desirable breeding characteristic unless the lag in development of branch pods can be overcome (Singh and Singh 1972).

1.4.2 Podding Nodes

The inflorescence of the pea is racemose, bearing one or more flowers in the axil of each leaf in the upper part of the stem which is of variable length. The number of nodes on the lower or vegetative part of the stem (i.e. below the first podding node) is genetically determined and in mid-summer cultivars at least, the number of vegetative nodes cannot be altered by day length treatments (Moore 1964).

The number of flowering nodes on the upper flowering part of the stem can again vary between cultivars, but it also varies with plant density. Harwick and Milbourn (1967) observed that widely spaced plants produced more flower primordia than closely spaced plants. The number of nodes that eventually bear flowers is less than the number laid down earlier. This must reflect competition within the plant, possibly for assimilates (Lockhart and Gottschall 1961). The abortion in upper nodes may appear to represent a loss of potential yield, but had they been retained they would only have contributed small, immature peas with a resultant increased range in maturity of the harvested sample. As the pea is harvested when young, an increase in the component "number of podding nodes" causes only a relatively small increase in yield, and this component is only worth increasing in the vining crop if the lag between nodes can be reduced.

1.4.3 Number of Pods per Node

The number of pods per node is an important yield component. Most cultivars in current commercial use carry either one or two pods per node. Early workers in pea breeding programmes recognized that one of the best ways to increase yield of peas which mature at the same time was to increase the number of pods produced at each node (Wellensiek 1925; Lamprecht 1952).

The environmental contribution to variability of pod number per node has been shown to be considerable (Clay 1935; Lamprecht 1952; Ibarbia and Bienz 1970). Fluctuations in the number of pods at each node must be the outcome of differences either in number of pods produced or in numbers lost. Pods are produced by the apical meristem as flower primordia, in regular succession, starting when the plant enters the phase of ripeness to flower. From this stage onwards, pairs

of primordia are laid down in the axil of every node produced. Of the
pairs of primordia the first primordium always becomes a flower; but
the second may develop into either a flower or a blind stalk-like
appendage. The failure of the second primordia to develop represents
a loss of potential yield and is of considerable commercial importance.

Potential yield may be reduced secondarily if pods, once formed,
abscise. At commercial plant densities most flowers turn into pods and
few are abscised. Up to forty percent losses of pods have been observed
in very dense populations of peas, but it is not clear how far this can
be ascribed to true abscission and how far it is the result of pods
becoming casualties in the mass of rotting leaves which develop at
the base of the crop (Hardwick and Milbourn 1967).

However, breeding multipod cultivars of the normal type has not
lost its practical importance. Though the influence of pod number on
the uniformity of maturity is slight, that on the yield per plant is
large (Drijfhout 1972). Drijfhout noted that with a good pod frequency
and about an equal number of seeds per pod the yield can increase
almost proportionally to the number of pod places.

1.4.4 Number of Peas per Pod

Multiple regression analysis indicated that the number of seeds
per pod was an important yield component and accounted for great
variability in seed yield of forty pea cultivars (Singh and Singh 1972).
When a pea pod is shelled it is often found to contain, in addition to
the fully grown peas, a few aborted ovules at either end of the pod
which have not developed (Cummings 1914). The maximum number of peas
per pod is a cultivar characteristic which can be manipulated by the
plant breeder. The manipulation of pea number will be to the advantage

of yield, provided that a high number of peas per pod is not achieved at the expense of the other components of yield.

1.4.5 Weight per Pea

Individual pea weight is quite unlike the other components of yield. It cannot be assumed that an increase in the value of this component will cause a corresponding increase in yield because the vining pea is harvested at a date decided by the stage of maturity of the crop. Stage of maturity is a function of pea weight and if the stage of maturity is fixed than pea weight is not free to vary (Hardwick and Milbourn 1967).

The situation is further complicated by the pea's indeterminate growth habit which results in the crop being made up of a range of pods at different stages. To use pea weight as a component of yield is an oversimplification; there is in fact a range of pea weight, decreasing by an approximately constant amount at each succeeding node (Hardwick and Milbourn 1967).

The range of pea weights that occurs at the vining stage does suggest that some potential yield is foregone by once-over picking. If the plant breeder could produce a cultivar having a smaller lag between nodes, the yield would be increased by a larger contribution from the upper nodes and the product would be much more homogeneous.

1.5 Pea Maturity

The relationship between yield and maturity is of considerable economic importance. In the past it has not been possible to find a simple universal curve which would relate yield and maturity. The

relationship varies between seed rates and between seasons (Ottoson 1958; Berry 1966). It is suggested that this is because the age of the pod population varies. It has been found that if the differences in this respect between populations are taken into account by comparing nodes separately, a repeatable relationship emerges between maturity and pea weight (Hardwick and Milbourn 1967).

1.6 Influence of the Environment

1.6.1 Light (day length)

Kopetz (1941, 1943) observed that early cultivars were essentially day-neutral whereas the flowering of late cultivars was significantly delayed by short days. Haupt (1957, 1969) suggested that the absence of a photoperiod respose in early cultivars was not so much a consequence of a particular genetic situation but rather followed automatically because flower initiation takes place so rapidly after germination that there is no apportunity for the seedling to respond to photoperiod. Barber (1959) and Aitken (1971) classed the pea as a long-day plant which will bloom in continous light. Early maturing cultivars are the least sensitive to photoperiod while mid and late season cultivars respond and are induced to bloom earlier by an increased day length. The latter are impeded by short days with respect to both number of pods and days required to bloom (Aitken 1971). Barber (1959) and Marx (1969) found that flowering of late peas showed little change as the photoperiod decreased from 24 to approximately 20 hours but as the photoperiod further decreased the flowering process began to rise slowly at first and then more steeply between a photoperiod of 16 and 12 hours. Aitken (1978) later found that flowering in peas was related to photoperiod and also temperature. Aitken measured the development rate in peas and saw that it was controlled directly by temperature. She found that in each successive sowing from spring to winter as the

temperature increased there was an increasing sensitivity to photo-
period and a lesser sensitivity to temperature. Along with the
increasing temperatures pods grew less efficiently with respect to
respiratory CO_2 efflux (Hole and Scott 1983) and as earlier observed
by Phumphrey, Ramig and Allmaras (1979), yield in peas as a result
decreased as temperature increased.

There is clear evidence that the photoperiod response is reduced
by low temperatures (Barber 1959; Wellensiek 1969) and may even be
nullified if vernalization is followed by continued cold nights (Murfet
and Reid 1974). Flowering response to temperature has been interpreted
under the "balance" concept noted by Murfet (1971). It is assumed
that the reaction producing inhibitor has a higher temperature coef-
ficient than the reaction controlling the formation of promoter, and
secondly, that inhibitor production is suppressed by continuous light.

Much time and effort has been devoted over the years to the search
for the endogenous substances believed to regulate flowering in peas.
Despite these efforts, the flowering hormones have remained elusive.
However, it is proposed that the level of these hormones may vary in a
quantitative manner with flowering being evoked by the gradual achieve-
ment at the apex, of a balance (or ratio) of promoter to inhibitor
in excess of a critical ratio (Murfet 1971). Leaves are believed to
play a prime role in the formation of the flowering hormones, yet the
relative proportions of the hormones contributed by a leaf might be
expected to vary with the genotype, the physical environment in
which the leaf is functioning and possibly the age of the leaf (Paton
1971). Back in 1968, Paton showed that the number of green foliage
leaves at flower initiation was related to a quantitative leaf require-
ment. Leaf requirement was least in continuous light. Dolan (1973)
found that the greatest degree of flowering and vegetative growth in
peas was obtained with the combination of long days with high light

intensity. He indicated that optimum conditions for pea growth would combine medium temperature, long day length and high light intensity.

Wellensiek (1973) observed that the number of nodes per stem of young vegetative plants is not affected by day length. In older plants node numbers tend to increase with day length but the rate of node formation decreases with flower formation. Internode length increases with day length even in very young plants and shows a further considerable increase when flower formation starts. Hence, flower formation clearly marks changes in the growth pattern, consisting of a decrease in node formation and an increase in internode length.

1.6.2 Temperature

1.6.2.1 Germination

Pea seeds are not long-lived, nor do they exhibit after-ripening or secondary dormancy. As with other species, viability decreases markedly at high storage temperatures and high seed moisture content.

Germination tests on peas carried out at optimal laboratory temperature are often very poorly correlated with ability to germinate and become established in the field, partly due to varying tolerance of prolonged exposure to damp, cold conditions and partly to attack by pathogens whose growth may be stimulated by solutes exuded by seeds (Torfason and Nonnecke 1959). Most of the leaked solutes come from the cotyledons; Larson (1968) and Perry and Harrison (1970) have suggested that it is the sudden inrush of water during inhibition which causes the injuries resulting in leakage. Simon and Harun (1973) considered that drying out of the embryo during seed ripening causes cell membranes to lose their integrity, thus rendering cellular

contents susceptible to leaching. Losses can involve substantial fractions of the sugar, amino acid and inorganic solutes of the seed so that particularly leaky seeds may give rise to poor crop establishment (larson and Kyagaba 1969).

The major problem in pea seed emergence and establishment is the poor emergence of some commercially available seed lots which are in a poor physiological condition, especially in cold wet soils (Jones 1931; Clark and Little 1955). This seed condition reveals itself in the poor retention of solutes (when seeds are placed in water) and in low respiration. Poor solute retention appears to be attributable to defective membranes within the cells (Mathews and Carver 1971).

Although death from the direct effect of the inadequate provision of the physiological requirements of the emerging seed, such as oxygen and water, might occur under some extreme circumstances, the more important cause of failure to emerge appears to be infection by the soil-borne fungus *Pythium ultimum* before or just after germination (Perry and Harrison 1970). The suggestion was made that low temperatures and high soil moistures combine to both prolong the time when the seed is vulnerable to infection and increase the susceptibility of the seed to the pathogen. Low resistance to infection in the cotyledons of seeds that are in poor physiological condition is considered more important than the leaching of nutrients into the soil which might stimulate fungal growth. It is suggested that seeds which are viable but in poor physiological condition are produced by the harvesting and drying of immature seeds and by prolonged storage in unfavourable conditions (Powell and Mathews 1977).

Electrical conductivity of the leachate has been shown to be a reliable method to predict field emergence of pea cultivars whether

round or wrinkled seeded (Bedford 1974). A high conductivity is indicative of poor emergence.

The epigeal pattern of germination, the large and rich cotyledon reserves and the overall sensitivity of pea seeds to factors in the soil environment are likely to create some serious problems for the agronomist. Much has to be overcome before germination and establish-ment of pea crops becomes as reliable as it is with most other species.

1.6.2.2 Root Growth

Ying (1966) found pea root growth rate depended on temperature and was greatest at 20 and 25 C. Kung and West (1968) found that extension growth of pea roots attained its maximum at 20 C and at 30 C was forty percent less.

The relation between root growth and temperature shows an optimum at a lower temperature than the same relation for shoot growth. The root is most active and produces the highest shoot weight per gram of weight where growth is optimal (Brouwer 1962).

1.6.2.3 Shoot Growth

Boswell (1926) summarized the results of successional sowings at weekly intervals over three years. As temperatures increased at later plantings, less time was required to reach each stage of development and the weight of plant, weight and number of pods and the number of peas per plant was lower.

Later, work by Ibarbia and Bienz (1970) confirmed Boswell's report that pod number is temperature sensitive. They found that single and

double podded parent lines were extremely uniform producing almost 100 percent single and double pods respectively at both temperature regimes (7 C night, 15 C day; 15 C night and 24 C day). The triple podded parent produced mainly three-podded determinate nodes at the lower temperature but tended to produce indeterminate nodes, with two, three and four pods at the higher temperature. Variability of pod number in the field (Fletcher, Ormrod, Maurer and Stanfield 1966) and in controlled environments (Stanfield, Ormrod and Fletcher 1966) had been demonstrated. Variations in the number of pods per node between successive sowings of Dark Skin Perfection was found to be partly due to variation in the frequency of formation of single and double flowers; flower initiation and subsequent loss setting the potential or upper limit for pod number (Milbourn and Hardwick 1968).

There are several conflicting views on causes of flower and pod loss. Many young pods fail to survive to maturity. This suggests some form of competition is occurring to limit the eventual number of pods. Support for this view comes from the observation that flower failure within an inflorescence is not at random (Clay 1935; Lamprecht 1952; Ibarbia and Bienz 1970). The basal flowers are commonly the most successful, presumably because they are the first to open and have an advantage over the rest.

In pea cultivars incapable of producing more than two flowers per node, flower number per node was negatively correlated with temperature during the period of flower initiation (Ormrod, Maurer, Mitchell and Eaton 1970; Hole and Hardwick 1974). When multiflowered cultivars were tested, they produced more flowers at high temperature than they did at low temperature (Hole and Hardwick 1974). This response was the opposite of that shown by the two-flowered cultivars. Analysis of soluble sugar levels suggested that the availability of assimilate

was an endogenous factor involved in the temperature control of flower number. Assimilate level was not implicated in the variation of stability of flower number per node to temperature change (Hole and Hardwick 1974; Hole 1977).

Boswell (1929) could not point out any one specific period during which high temperatures were most critical for pod set. Using controlled light and temperature conditions, Karr, Linck and Swanson (1959) found the critical period for pea plants given high temperature treatments only during the light period was nine to eleven days after full bloom; while the critical period for those given high temperature treatments only during the dark period was six to nine days after bloom. The critical period found by Karr et al (1959) was similar to the period of five to ten days after full bloom found to be critical by Lambert and Linck (1958).

High temperatures reduced number of pods and some cultivars showed a reduced pea size as well. The deleterious effects of high temperature on these components of yield agree with reports by Reath and Wittwer (1952); Karr et al (1959); Ormrod et al (1970); Nonnecke, Adedipe and Ormrod (1971).

The ultimate effect of high temperature is reduced pea yield. Lambert and Linck (1958) hypothesized that the high temperature re- duced yield by causing an increase in respiration or by reducing translocation of assimilates into the pods and peas. High temperatures also may have interfered with the balance of nitrogenous compounds and the synthesis of proteins. Other conditions such as the effect of high temperature on genetic expression may have also influenced the yield of peas. However, because of the complexity of conditions in the environment, it is often impossible to identify these causes.

1.6.3 Moisture

1.6.3.1 Humidity

Reports that relative humidity may influence development of peas are few. Nagy (1966) found that the development of peas was adversely affected by low humidity; Parek, Sivanayagam and Heydecker (1969) indicated that high humidity resulted in small and thin leaves. Nonnecke et al (1971) reported that humidity has no significant effect, irrespective of cultivar, however, relative humidity effects on pea yield were closely related to air temperature when soil moisture is limiting.

1.6.3.2 Soil Moisture

Research dealing with morphological responses of peas to water stress is somewhat limited, most have dealt with water sensitive stages of growth on seed yield (Sprent 1957; Stanhill 1957; Brouwer 1959; Frohlick and Henkel 1961; Salter 1962; Salter 1963; Salter and Goode 1967; Behl, Sowhney and Moolani 1968; Gautum and Lenka 1968; Pumphrey and Schwanke 1974). It has been shown that on green pea yield, the flowering phase of plant development is more sensitive to water stress than the vegetative phase (Monson 1942; Salter and Goode 1967). Brouwer (1959); Maurer, Ormrod and Fletcher (1968) found that high water regimes were essential to high yields. They also observed that high water regimes increased plant height and internode length, number of nodes, increased foliage yield and fresh vine weight of peas. Further studies by Miller, Manning and Teare (1977); Stoker (1977); Martin and Tabley (1981) and White, Sheath and Meijer (1982) found that irrigation increased pea yield. Both White et al (1982) and Miller et al (1977) showed that vine height increased with a resulting

increase in total plant dry weight as soil moisture levels increased.
White et al further showed that pea yield increased as a result of
increased number of pods per plant, seeds per pod and seed weight.
It was the flowering period to pod filling that was most critical in
irrigation and yield (Stoker 1977; Falloon and White 1978; Cannell,
Gales, Snaydon and Suhail 1979; Jackson 1979 and White et al 1982).
Once soil conditions became waterlogged leaf senescence increased,
growth decreased and consequently there were fewer podding nodes
and yield decreased (Cannell et al 1979; Jackson 1979 and Belford,
Cannell, Thomson and Dennis 1980). Further, water stress reduced
branching and McIntyre (1971) and Falloon and White (1978) suggested
that it may be necessary to seed in early spring thereby avoiding the
effects of water stress with later sowings if irrigation is not
available. Miller et al (1977) also observed that the number of nodes
per plant remained constant but internode length varied in relation
to water level and irrigation scheduling. Plant height was significant-
ly reduced with decreasing water levels for constant water regimes.
They found that with the exception of stem diameter there were no
definite, observable changes in the tissue systems of the stem or pod
nodes that could be identified with soil water stress. Thickness of
the leaflet blade was significantly less in plants grown at 100 percent
field capacity than those grown at 80 to 60 percent to 60 to 40 per-
cent of field capacity in a greenhouse soil mix (3 Palouse loam:
3 sand: 2 parts peatmoss). Plants grown at 40 to 20 percent of field
capacity had significantly thinner leaflets than did those grown at
higher moisture regimes.

1.6.4 Planting Date

In the earliest reported studies of environmental effects on pea
yields, Boswell (1926) reported that late season plantings required

less time to reach any particular stage of development but higher temp-
eratures had an increase depression on pod set. There was no reduction
in number or weight of peas per pod with later plantings. Wang (1962)
indicated that the combination of a warm spring (during the seedling
stage) and a cool summer (during the reproductive period) produced a
high yield while the combination of a cool spring and a hot summer
produced a low yield. He observed similar effects of temperaute on
yield components as Boswell.

Studies by Fletcher et al (1966) indicated that where temperatures
exceeded the optimum for most growth characteristics in late plantings,
the mean of maximum temperature was negatively correlated with total
dry matter yield, peas per pod and pea yield; was positively correlated
with branching and had no effect on pods per plant. Where temperatures
were sub-optimum for early plantings and approached optimum for the
later plantings, the mean of maximum temperatures was positively cor-
related with total dry matter yield, but had no effect on peas per
pod or branching. A seasonal mean maximum of 20 to 22 C was considered
to be optimum for peas.

Porjazov (1970) measured in time and integrated temperature the
requirements for five garden pea cultivars sown on five dates at
fifteen day intervals. Delayed sowing shortened the growing period,
sowing to emergence being the most affected and flowering to maturity
the least. The length of the growing season expressed in days varied
little in mid season whereas expressed as integrated temperature re-
quirements the early cultivars showed little variation.

1.7 Growth Analysis

1.7.1 Introduction

The continuing pressure to produce higher yielding cultivars has

stimulated interest in physiological factors contributing to final yield and in the possibilities of using such factors in selection. Growth analysis attempts to describe the form of growth a plant takes and if the mode of growth is known then it is possible to concentrate efforts into areas that will produce high yielding cultivars.

The classical methods of growth analysis involve a series of relatively infrequent large harvest (with much replication or measurement) and the derivation of growth parameters, using the formulae (Gregory 1917; Blackman 1917; Briggs, Kidd and Went 1920):

mean relative growth rate

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

mean net assimilation rate

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

mean leaf weight ratio

$$LWR = \frac{LW_2 - LW_1}{W_2 - W_1} \times \frac{\log_e W_2 - \log_e W_1}{\log_e LW_2 - \log_e LW_1}$$

leaf area ratio

$$LAR = \frac{L_2 - L_1}{W_2 - W_1} \times \frac{\log_e W_2 - \log_e W_1}{\log_e L_2 - \log_e L_1}$$

specific leaf weight

$$SLW = \frac{L_2 - L_1}{LW_2 - LW_1} \times \frac{\log_e LW_2 - \log_e LW_1}{\log_e L_2 - \log_e L_1}$$

W = dry plant weight; L = leaf area per plant; LW = leaf weight per plant; t = time. The subscripts 1,2 denote first and second harvests.

If one abandons the commitment to calculations on the classical
harvest interval method, than several advantages accure if one is able
to adopt what Radford (1967) has called the dynamic approach to plant
growth analysis (Hunt 1978). Mathematical functions by regression
techniques are fitted to experimental data and describe the relationship
between data and time. From these functions (growth curves), fitted
values of data are extracted which may subsequently be plotted as
fitted instantaneous values. The regression technique utilizes in-
formation from all available harvests in determining values at any
point of time whereas the classical method only uses data from the two
immediate harvests. Also, pairing of plants across the harvest interval
becomes unnecessary and small deviations from the overall trend of
the original experimental data against time are "smoothed" often
making the final results less erratic (Hunt 1973). The only assumption
necessary for the adoption of this approach is that the fitted growth
curves adequately describe the trends in the raw data. This in turn
depends on the assumption that the raw data adequately describes what
is really happening in the plants under investigation.

1.7.2 Application to Peas

Early attempts to find differences between crop species in terms
of growth analysis, in particular NAR, were largely unsuccessful (Heath
and Gregory 1938). Later work by Watson and Witts (1959) on beets;
Muramoto, Heskieth, El-Sharkway (1965) on cotton; Stoy (1965) on wheat
and Cannell (1967) on cereals, showed little difference between cult-
ivars in terms of NAR or of net photosynthetic rate. Watson (1952)
stated that although there were differences between and within species
in NAR, productivity was much more closely related to the leaf area
component of growth analysis.

Buttery and Buzzell (1972) working with soybeans found that plants

with a low LAR had a larger "sink" for their photosynthetic products
than did leaves in plants with a high LAR, low LAR may therefore
favour high rates of photosynthesis. Eastin and Gritton (1969) in-
vestigated the leaf area relationship in peas and observed that during
the period just prior to bloom through canning stage and especially
while the pods were filling, a given unit of leaf area was more ef-
ficient in producing above ground dry matter than at the immediately
earlier growth stages. They postulated that the increase in efficiency
may have been due to: 1. a diversion of growth from the roots to the
tops, 2. photosynthesis of chlorophyllus pods which were not included
in the leaf area measurements or 3. a positive effect of the physio-
logical status of plant parts other than the leaf in the photosynthesis
of a given unit of leaf area. Eastin and Gritton believed that it
was sink size that had a positive effect on photosynthesis. The effect
could be by preventing accumulation of assimilates in the leaves, by
providing some positive stimulatory factor or preventing accumulation
of an inhibitor. Later reports on other crops supported the theory
that highest photosynthetic rates and enzyme activities occur when
growth and sink demand are highest (Blenkinsop and Pate 1974; Pate
1975). This implied that high growth rates caused high photosynthetic
rates rather than vice versa.

All evidence suggests that the pea leaf exhibits a normal C_3
pattern of photosynthesis (Hellmuth 1971). CO_2 uptake by pea leaves
increased as temperature increased. Further studies by Hellmuth (1971)
indicated that leaf temperature markedly influenced the magnitude of
the maximum rate of net CO_2 uptake in relation to light intensity.
The compensation point and saturation value for light were found to
be markedly dependent on leaf temperature.

Photosynthesis in peas is subject to both environment constraints

and internal regulation which takes the form of source/sink feedback control over carbon dioxide assimilation. The effect of sinks on photosynthesis has been documented as have current reports on enzyme and hormone regulatory effects (Wareing and Patrick 1973; Kriedmann, Loveys, Possingham and Satoh 1976). Thus an increase in demand of a sink may result in a rise in the assimilation rate of the source organ; a decrease in demand may lead to a fall in the assimilation rate.

In the pea the onset of flowering and subsequent growth of the fruit leads to a rapid doubling in the photosynthesis of the whole plant (Lawrie and Wheeler 1974). Studies by Flinn (1974) suggests that leaflet photosynthesis rises and falls in response to the swings in demand for assimilates by the developing pod, but responds to a lesser extent to the demand for assimilates by the maturing seed, a primary component of yield. The results suggest that the presence of seeds in a pod may exercise a stimulatory effect on pod activity in translocation and possibly a stimulus also to its photosynthetic performance.

Pea response to environment measured in the behavior of yield components is a complex subject still under study. Studies to date on component behaviour have shown that pea yield increased as component number increased. However, such behaviour has been shown to markedly decrease the growth of first formed fruit (Hole and Scott 1983). Hole and Scott also noted that the actual proportion of dry matter allocated to different fruit were not changed by an increasing number of competing fruit if assimilate supply was adequate. If assimilate supply was limited, however, two fruits on the same or successive nodes competed significantly for assimilates (Salter, Hole and Scott 1979).

Gifford and Evans (1981) stated that the leaves were the primary source of assimilates and that demand by sinks for assimilates can also determine photosynthetic supply. Falloon and White (1978) earlier stated that photosynthetic supply in a pea plant can be limited by insufficient active photosynthetic tissue capable of producing adequate supplies of assimilates and/or that competition between vegetative and reproductive growth for the available assimilates exists. With any decrease in the amount of assimilates Hole and Scott (1983) observed that there was a decreased fruit growth rate and that fruits at lower reproductive nodes on the pea plant were less affected. Mahon and Hobbs (1983) observed that lower reproductive nodes were dominant sinks and that even within individual nodes there was considerable variation in total sink strength. Mahon and Hobbs also observed that seeds in the same pod developed at different rates and that final pod weight was highly correlated with the rate of pod filling and both were significantly related to seed yield per plant. Therefore, plants with strong seed sinks were generally more likely to attain a high harvest index (Hedley and Ambrose 1980).

Pea yield decreased by seed abortion which was linked to sink demand and when demand for assimilates exceeded the supply seed in the pods aborted (Hedley, Smith and Hayward 1982). Falloon and White (1978) found that the number of ovule initials per pod were predominately under genetic control, however, photosynthetic area may have influenced development of ovules within pods, therefore, any decrease the the photosynthetic area of the pea plant after flowering increased the percentage of ovule failure. The abscission of any plant part was enhanced by water deficit, a decrease or increase in

photoperiod and temperature extremes and any differences between
cultivars in number of structures lost under such conditions may be
related to ability to maintain a higher photosynthetic area per repro-
ductive structure (Falloon and White 1978). Hobbs and Mahon (1982)
concluded that in areas with short growing seasons, rapid growth
for a limited period with more assimilates being placed into seeds
(high harvest index) may be desirable. Combination of such characters
in pea cultivars might produce maximum yield potential in the short
time available.

There is evidence from several species that a consuming organ
(sink) can exercise a controlling influence over the production and
export of assimilates by "source" organs such as photosynthesizing
leaves. Lovell, Oo and Sagar (1972) have found that the rate of C^{14}
export from pea leaves can be greatly increased if, 20 hours before
feeding, all other leaves are removed from the shoot. Since this
increase in export is not evident if root or shoot apicies are removed
at the time of defoliation, it appears to be the demand for assimilates
by these sinks which sets the tempo of export. Competition for
assimilates is likely to result in organs of low competing power
functioning at less than full capacity. Then if a dominant sink be
removed, assimilates are likely to become readily available to less
favoured organs. Evidence of such a diversion of assimilates has been
shown in tracer studies in peas by Hasain (1967) and Morris and Thomas
(1968).

Studies by Harvey (1973) indicated that a leaf at a reproductive
node exported assimilates principally to its subtended fruit, but
a leaf at a vegetative node exported mainly to the nearest fruit above
it on the same side of the haulm. Genetically induced changes in
leaf morphology did not markedly affect the translocation potential

or pattern of partitioning of assimilates in the plant. Harvey postulated that new foliage forms would be unlikely to exhibit any large scale imbalance in dry matter accumulation in vegetative or reproductive organs.

Carr and Pate (1967) studied the effects of leaf age on translocation from leaves and found that distribution and quantity of assimilates change as the leaf ages. As further leaves unfold so an older leaf becomes further and further removed from the influence of the apex it is less likely to respond to demands from the apical sinks. Pate (1966) believed that auxin produced in the apex regulated leaf production and export of assimilates. This was supported by the findings of Seth and Wareing (1967) and Davidson (1971).

In terms of assimilate origin, Flinn (1969) found that the stipule and the subtending leaf had a similar photosynthetic efficiency per unit area and a similar surface area. Despite this the stipules were somewhat important contributors during the very early stages of pod growth. Flinn (1969) showed that the stipules contributed two-thirds of the total assimilate requirement of the seed borne at the node, the remainder was presumed to come from elsewhere in the plant to the seed.

Flinn and Pate (1970) and Harvey (1972, 1974) have shown that although each blossom leaf is deeply committed to supplying assimilates to its subtended fruit, during its early life it supplies quite sizeable amounts of photosynthate to other parts of the plant. Stipules make a larger contribution to the subtended fruit than do the companion leaflets, not necessarily because the stipules are less active photosynthetically, but because the stipules participate more than

leaflets do in transporting assimilates up and down the stem. This
is because stipules possess less direct vascular connections with
the fruit stalk than do leaflets (Brennan 1966).

Unlike the blossom leaf, the pod is entirely committed to trans-
port to its seeds, the extent of this involvement increasing in
proportion to the mass of seeds present (Lovell and Lovell 1970).
Seeds do not seem to be capable of significant photosynthesis while
in their pod despite their intense green color (Flinn 1969).

To use the classical technique of growth analysis, in which the
growth of the crop is analysed in terms of leaf area and leaf activity
is one apporach to the problem of crop yield. Although this method is
valuable in the analysis of the vegetative phase of pea growth, it has
proved less useful when the crop is in the reproductive phase. For
example, at flowering much of the leaf canopy is senescent and likely
to be past its peak activity (Smillie 1962). Also, during the repro-
ductive phase of growth, the true leaf area is difficult to estimate
for at this time leaf loss proceeds faster than leaf production.
Estimation of effective photosynthetic area is further complicated by
the considerable area of stem and green pods present in the crop.
Finally, the complexity of the source/sink relationships and the in-
ternal and external influences on photosynthesis make interpretation
of growth analysis on pea growth and development difficult.

In view of these problems, Hardwick and Milbourn (1967) turned
their attention instead to component yield analysis, that is, analysis of
the number and size of the "sinks" at which photosynthates and proteins
are stored as the final product. This approach is based on an

extension of the method of Engledow and Wadham (1923) in which final yield for the whole plant is factorized into components at each node separately:

yield = number of podding nodes x number of pods per node x
number of peas per pod x weight per pea

The contribution of each component is the result of a number of physiological processes. By analysing the yield from crops grown under a range of conditions, one can assess the contribution of each component and process to final yield. The question remains of how this knowledge is to be used. Because of lags between nodes the detailed picture is very complex and its dynamics are further complicated by interactions between components.

1.8 Yield - Tenderometer Relationship

To interpolate yields for a given maturity, a knowledge of the form of the yield - tenderometer relationship is necessary. The relationship between the yield of shelled peas per plant (W) and the tenderometer value (T) is generally a curvilinear relationship in which the increase of W per unit increase in T declines with T, particularly for higher values of T (Berry 1966).

A model for this relationship of the form

$$\left(\frac{T - T_o}{W}\right)^{\theta} = A + B \ (T - T_o)$$

where θ, T_o, A and B are constants, was given by Berry (1963), together with a method of fitting. The relationship described by the equation is such that the yield at tenderometer value T_o is zero and for $\theta = 1$ the yield approaches an upper limit for increasing values of T. For $\theta < 1$ the yield reaches a maximum and then declines for higher values of T.

Experience in fitting the relationship has shown that the fit is
not very sensitive to variations in $\theta = 1$ (Berry 1966). In so far as
the tenderometer value is only obtainable in a range of the order of
60 to 180 it may be argued that the behaviour of the relationship out-
side this range is of no consequence. Berry (1966) found that the
relationship given by the equation with $\theta = 1$ and $T_o = 70$ fitted
his data satisfactorily in the majority of cases. Pollard, Wilcox
and Peterson (1947) gave data which showed no sign of approaching an
upper limit to yield for a tenderometer value as high as 160. There-
fore, the model with $\theta = 1$ and $T_o = 70$ values between 70 and 180 is
suggested in best relating the yield of shelled peas to maturity.

In 1981 Martin tested six methods used to relate yield and
tenderometer reading and he found that whatever method he used there
was little variation between results. Martin stated that linear
interpolation has the advantage of not being based on any preconceived
idea of yield-tenderometer relationships and is simple to use.
Berry's (1966) method was better because of the curvilinear relation-
ship between yield and tenderometer reading especially if there is
a wide range in tenderometer values or if upper tenderometer readings
are high.

1.9 AIS - Tenderometer Relationship

The correlation of tenderometer and AIS (alcohol insoluble solids)
on raw peas has been studied extensively by Adam (1958). Adam observed
that the relationship between tenderometer reading and AIS was constant
in seven years of trial. From these studies, he arrived at regression
lines as follows; where y is the tenderometer reading and x the AIS
constant.

$$y = 7.42x + 19$$
$$x = 0.122y - 1.1$$

Thus for an AIS content (x) of 15% the most probable tenderometer reading (y) would be 131; or for a tenderometer reading (y) of 120 the AIS content (x) would be 13.5%. From these equations, AIS maturity results can be converted to tenderometer readings and vice versa.

1.10 Harvest Index

Component analysis of yield begins with the expression of yield into two major components, namely accumulation of assimilate and partitioning of assimilate. Assimilate accumulation is most easily measured as total plant dry weight or biological yield (Donald 1962; Wallace 1973). Biological yield is a direct outcome of the extent and duration of photosynthesis, subject only to the addition of minerals and losses by respiration. Environmental factors which influence total yield such as temperature, do so because it influences either directly or indirectly the rate of duration of photosynthesis. The highest photosynthetic rates occur when growth and sink demand are high (Donald 1962; Blenkinsop and Pate 1974; Pate 1975). Therefore, total plant dry weight (biological yield) is a measure of overall photosynthetic efficiency (Wallace 1973).

Partitioning of assimilates is a physiological component of yield, little is known concerning the mechanisms controlling the partitioning. The partitioning of assimilates as seed weight is defined as economic yield (Donald 1962; Wallace 1973). The ratio of economic yield to biological yield is commonly called the harvest index (Donald 1962). Hardwick (1970) defined harvest index in peas as:

$$\text{harvest index} = \frac{\text{dry weight pod + peas}}{\text{dry weight stem + leaves}}$$

CHAPTER 2

Greenhouse Experiment: The Effect of Temperature on the Growth and
                         Development of Four Pea Cultivars

2.1   Introduction

Temperature has a large influence on the growth and development of
the pea plant (Reath and Wittwer 1952; Lambert et al 1958; Karr et al
1959; Ormrod et al 1970; Nonnecke et al 1971). As reports are lack-
ing on a comparative response to temperature of cvs with different
node-podding characteristics, this experiment was designed to study the
effect of temperature on four pea cvs representing single, double and
triple node-podding habits. Growth analysis techniques as well as yield
component analysis were used to assess cv response to temperature.

2.2   Materials and Methods

There were four cvs grown in three temperature treatments. Cvs
grown were:

Cultivar	Node-Podding Type	Code
Puget	triple-pod	Tp
Puke	double-pod	Dp
William Massey	single-pod	Sp
Aft1 (semi-leafless)	single-pod	Sp1

Sp1 is an unnamed semi-leafless type with normal stipules and small
    leaflets on the tendril.

Three greenhouses were maintained at the following base temperatures,

one house at 30 C (high), a second house at 20 C (medium) and a third house at 10 C (low). Fan ventilation came into operation at 3 C above the base temperature, however, temperatures exceeded the base temperature particularly during periods of high radiation. All three 6 m x 6 m greenhouses were adjacent to each other and were identical in design and orientation.

The seed was sown on April 2, 1978 in 12 cm plastic pots (6 seeds per pot) containing a 50:50 (by volume) sand : soil compost media (see appendix 2). Each greenhouse contained 2 replications of each cv arranged in a randomized block design. Seedlings were thinned to 2 per pot to approximate a commercial field population of 100 plants/m^2. A weekly feeding of 25 ml North Carolina State University nutrient solution (appendix 3) was applied to each pot commencing May 2, four weeks after sowing. A regular hand watering programme was followed to maintain good soil moisture conditions. Plants were trained to bamboo canes and sprayed in the fifth week of growth with one application of gusathion 50 WP at 1 g per litre of water to control pests. Weekly harvests of 6 plants (3 pots) in each temperature treatment began April 14 (2 weeks after sowing) and continued for each cv until visual signs of over-maturity such as wrinkling and colour loss of the pod was evident.

The following data were recorded at each harvest:
1. root, stem, leaf and pod dry weight
2. leaf area (measured by leaf area meter, Lambda Instruments LI-3000)
3. internode length
4. position of first podding node
5. number of podding nodes
6. number of pods at each podding node
7. number of peas at each podding node
8. fresh and dry weight of peas at each podding node
9. maturity, alcohol insoluble solids (%AIS) of peas at each podding

node at each pea harvest (refer to appendix 1 for procedures).

All plant parts were dried in a forced-air oven at 80 C for 72 hours and then weighed.

2.2.1 Growth Analysis

The functional approach to growth analysis, the method devised by Hughes and Freeman (1967) was used to derive new data points from quadratic equations:

$$\log_e W = a + bx + cx^2$$
$$\log_e A = a^1 + b^1 x + c^1 x^2$$
$$\log_e W_L = a^{11} + b^{11} x + c^{11} x^2$$

Data were analysed at each harvest as a factorial and appropriate standard error of means (SE) were derived. The block effect was added to the error term as temperature treatments were not replicated.

2.2.2 Maturity Estimations

Torfason, Nonnecke and Strachan (1956) and Scheltma, Sykes and Last (1961) defined the optimum harvest date (OHD) as the moment the average AIS of a crop is 12% (approximately 110 tenderometer). An adjusted % AIS was calculated on a per plant basis at each pea harvest based on the %AIS and the fresh weight of peas at each podding node (n):

$$\frac{\%AIS_{n1} \times FW\ peas_{n1} + \%AIS_{n2} \times FW\ peas_{n2} \cdots}{\Sigma\ FW\ peas}$$

As the OHD did not occur on most occasions on a scheduled harvest, a linear regression of harvest (independent variable) on adjusted %AIS (dependent variable) were used to predict the OHD.

The %AIS at each pea harvest was plotted and the slope of the line between the %AIS (dependent variable) and harvest (independent variable) was used as a measure of the rate of pea maturity.

2.2.3 Components of Yield

At each pea harvest, the actual total number of pods and peas per plant were counted (sum overall podding nodes). The components of yield were then derived in the following manner:

a. number of podding nodes per plant was the actual number counted.

b. number of pods per node per plant.

$$\frac{\text{total number of pods per plant}}{\text{number of podding nodes per plant}}$$

c. number of peas per pod per plant.

$$\frac{\text{total number of peas per plant}}{\text{total number of pods per plant}}$$

The number of podding nodes, pods per node and peas per pod at each pea (seed) harvest were then averaged over the number of pea harvests to arrive at the actual number at the OHD.

The fresh weight (FW) per pea at each harvest was derived from the number (#) of peas and the FW of peas at each podding node (n).

$$(2) \quad FW/pea = \frac{\#peas_{n1} \times FW\,peas_{n1} + \#peas_{n2} \times FW\,peas_{n2} \cdots}{\Sigma\,\#peas}$$

A linear regression of the adjusted %AIS (independent variable) and weight per pea (dependent variable) at each pea harvest was used to derive the actual weight per pea at the OHD.

A stepwise multiple regression technique was used to assess the contribution of each component to yield variability and the nature of the relationship between components and final yield. This technique assumes a linear and additive relationship among the variables (Nie 1975). A further assumption that an orderly sequence of development of yield components occurs was made, namely that the components appear in the order set out in the Hardwick and Milbourn (1967) yield equation (equation 3).

2.2.4 Yield Estimations

The fresh weight at each pea harvest was then determined by two methods:

a. The Hardwick and Milbourn (1967) yield component equation.

(3) Yield = number of podding nodes x number of pods per node
x number of peas per pod x fresh weight per pea

By linear regression, adjusted %AIS (independent variable) and yield (dependent variable), the fresh weight pea yield at the OHD was determined.

b. Berry's (1966) yield-tenderometer relationship

(4) $(\frac{T-To}{W})^{\theta} = A + B$ (T-To) where T (tenderometer) = 70, $\theta = 1$,
W = yield per plant, A and B are constants.

%AIS was converted to tenderometer values using Adam's (1958) equation (refer to section 1.9 for details). By linear regression, values obtained by equation (1), adjusted %AIS (independent variable) and yield derived by equation (4) (dependent variable), the fresh weight pea yield at the OHD was obtained.

2.2.5 Dry Matter Distribution

Distribution of dry weight at the OHD was derived by linear regression, dry weight of plant part (dependent variable) and harvest (independent variable). Data is plotted on a percentage basis of total plant dry weight but was statistically analysed as arcsine transformed data. The harvest index at the OHD was determined by the Hardwick (1970) equation.

(5) harvest index = $\frac{\text{pod weight + pea weight}}{\text{stem weight + leaf weight}}$

Yield component data, fresh weight yield, rate of pea maturity, distribution of dry weight and harvest index were analysed as a factorial and appropriate standard error of means (SE) were derived.

All data is expressed on a per plant basis. Level of significance is noted as follows:

* p<0.05   ** p<0.01   *** p<0.001   NS   not significant

2.3 Results

2.3.1 Growth Analysis

RGR decreased with time at all temperatures, the rate of decline being most rapid at 30 C (Fig. 2.1). Despite an initially higher RGR at 30 C, RGR was generally lower at higher temperatures. NAR also decreased with time and was lower as temperature increased. LAR at all temperatures initially rose then fell. The peak in LAR occurred earlier at high temperatures. The SLA was initially higher at high temperature and there was some indication that SLA was lower at low temperature. This was particularly evident at 10 C. The LWR like the LAR increased then declined with time. The peak in LWR also occurred earlier and was higher as temperature increased. No significant cv differences were observed in any of the growth parameters.

2.3.2 Growth and Development

2.3.2.1 Internode Length

High temperature caused a reduction in internode length in all cvs (Table 2.1). Dp consistently had the longest internode at all temperatures and Sp the shortest internode at all temperatures except at 30 C where the Sp1 cv had the shortest internode. Internode length in Sp did not change appreciably whereas in all other cvs it was reduced by 2 to 3 cm at 30 C from the length at 10 C.

TEMPERATURE
———— 10 C
━━━━━ 20 C
– – – – 30 C

RGR

g/g

.5
.4
.3
.2
.1

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
HARVEST (WEEK)

SE± .037 .063 .023 .016 .010 .082 .009 .017 .015 .011 .020 .027 .011 .011 .012

NAR

$\frac{g}{cm^2}$ X 10^{-2}

.5
.4
.3
.2
.1

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
HARVEST (WEEK)

SE± .016 .018 .018 .018 .010 .010 .015 .018 .028 .009 .038 .013 .018 .018 .026

cm^2/g

200
150
100
50

LAR

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
HARVEST (WEEK)

SE± 6.24 5.86 5.65 12.08 4.63 4.69 4.58 4.35 5.74 3.46 3.60 4.47 6.93 7.81 8.37

Fig. 2.1 Growth curves derived from a quadratic equation

	TEMPERATURE
	10 C
	20 C
	30 C

SE± 38.30	21.30	16.94	68.40	9.48	8.71	7.87	3.00	18.49	10.19	11.18	14.17	14.32	12.63	13.56

SE±.043	.011	.003	.004	.006	.008	.008	.005	.005	.004	.003	.006	.010	.011	.016

Table 2.1: Effect of Temperature on Internode Length in Four Pea Cvs

Temperature (C)	Internode Length (cm) of Cultivars[1]				Mean[2]
	Tp	Dp	Sp	Sp1	
10	3.65	4.09	1.72	3.18	3.16
20	2.72	3.03	1.47	1.86	2.27
30	1.78	1.81	1.28	1.16	1.50
Mean[3]	2.71	2.97	1.49	2.06	

12 DF 1. interaction SE ± .072*** 2. temperature SE ± .036***
3. cv SE ± .041***

2.3.2.2 Position of First Podding Node

The node at which the first pod(s) developed occurred at an earlier (lower) node in all cvs at lower temperatures.

Table 2.2: Effect of Temperature on the Position of the First Podding Node in Four Pea Cvs

Temperature (C)	Position of First Podding Node in Cultivars[1]				Mean[2]
	Tp	Dp	Sp	Sp1	
10	16.6	12.4	7.8	8.7	11.3
20	18.5	15.8	8.1	11.5	13.4
30	19.5	16.7	8.3	14.6	14.7
Mean[3]	18.2	14.9	8.0	11.6	

12 DF 1. interaction SE ± .156*** 2. temperature SE ± .078***
3. cv SE ± .090***

The first pod(s) in Sp was on the earliest node at all temperatures and in Tp on the latest (highest) node. From 30 to 10 C, position of the first pod(s) in Sp did not change appreciably. The largest change was in the Sp1 cv, a difference of 6 nodes.

2.3.3 Components of Yield

The effect of temperature on the components of yield in pea cvs is shown in table 2.3. Results of the cv x temperature interaction appear in the upper half of the table, cv and temperature means appear in the lower half of the table.

2.3.3.1 Number of Podding Nodes

All cvs produced fewer podding nodes at 30 C. Only the Tp and Sp1 cvs produced more podding nodes at 20 C than at 10 C. Dp had the highest number of podding nodes of all cvs at 10 C and Tp at both 20 and 30 C. Sp had the fewest number of podding nodes at all temperatures. The largest decrease in number of podding nodes with an increase in temperature occurred in the Dp cv yet the number of podding nodes did not change appreciably in Sp.

2.3.3.2 Number of Pods per Node and Total Number of Pods

The number of pods per node decreased as temperature increased except in the Sp cv. No consistent trend was evident in Sp. Tp had the largest reduction in the number of pods per node as temperature increased, pod number per node was least affected in both the Sp and Dp cvs. Of all the cvs, Tp produced the most number of pods per node at all three temperatures, Sp and Dp cvs produced the fewest at 10 C, Dp and Sp1 cvs at 20 and 30 C.

Table 2.3 Effect of Cv and Temperature on the Components of Yield in Four Pea Cvs at the OHD

Cultivar/ Temperature (C)	Number			Fresh Weight(g) / Pea[4]	Total No.	
	Podding Nodes[1]	Pods per Node[2]	Peas per Pod[3]		Pods[5]	Peas[6]
Tp 10	3.1	2.12	2.57	.227	6.57	16.89
20	4.3	1.06	2.14	.247	4.55	9.75
30	1.6	.85	1.83	.165	1.36	2.49
Dp 10	5.1	.88	4.27	.364	4.48	19.16
20	3.5	.76	4.56	.245	2.66	12.12
30	1.3	.66	2.44	.174	.86	2.09
Sp 10	1.8	.89	3.53	.382	1.60	5.65
20	1.0	1.04	2.80	.250	1.04	2.91
30	1.0	.79	1.59	.268	.79	1.25
Spl 10	3.3	.96	2.68	.502	3.16	8.49
20	3.5	.82	2.51	.373	2.87	7.20
30	1.1	.61	2.07	.287	.67	1.38

interaction 12 DF 1. SE ± .13*** 2. SE ± .067*** 3. Se ± .313***
4. SE ± .0431 NS 5. SE ± .099*** 6. Se ± .784***

Tp	3.0	1.34	2.18	.213	4.16	9.70
Dp	3.3	.76	3.76	.261	2.66	11.12
Sp	1.2	.90	2.64	.300	1.14	3.27
Spl	2.6	.79	2.42	.387	2.23	5.69
10	3.3	1.21	3.26	.368	3.95	12.54
20	3.0	.92	3.00	.278	2.78	7.99
30	1.2	.72	1.98	.223	.93	1.80

mean 12 DF 1. cv SE ± .07*** temperature SE ± .06***
2. cv SE ± .012*** temperature SE ± .010***
3. cv SE ± .180*** temperature SE ± .156***
4. cv SE ± .0249** temperature SE ± .0215**
5. cv SE ± .057*** temperature SE ± .049***
6. cv SE ± .452*** temperature SE ± .392***

Total pod numbers decreased in all cvs as temperature increased. Pod number was most reduced in Tp and was least affected in Sp. The Tp cv consistently produced the highest total number of pods at all temperatures, Sp the fewest except at 30 C where the Sp1 cv produced the lowest total pod number.

2.3.3.3 Number of Peas per Pod and Total Number of Peas

The number of peas per pod decreased in all cvs as temperature increased except in Dp where the highest number of peas per pod occurred at 20 C. The Dp and Sp cvs had the largest reduction in the number of peas per pod, pea number per pod was least affected in the Sp1 cv. Of all four cvs, Dp consistently produced the highest number of peas per pod at all temperatures, Tp the least except at 30 C where the Sp cv produced the fewest.

Total pea numbers decreased in all cvs as temperature increased, Dp had the largest decrease and Sp the smallest reduction. Dp consistently produced the largest total number of peas at all temperatures except at 30 C where Tp produced more. Sp produced the fewest total number of peas at all temperatures except at 30 C where the Sp1 cv produced the lowest total pea number.

2.3.3.4 Fresh Weight per Pea

The cv x temperature interaction was not significant, however the mean fresh weight per pea was significantly reduced as temperature increased. The Sp1 and Sp cvs produced the heaviest, Tp the lightest mean pea weight.

2.3.4 Fresh Weight Yield

The fresh weight yield was derived by the: a. yield component

Table 2.4:   Effect of Temperature on the Fresh Weight Yield of Four Pea cvs at the OHD

| Temperature (C) | Fresh Weight Yield (g) at the OHD[1] | | | | | | | | Mean[2] | |
| | Tp | | Dp | | Sp | | Spl | | | |
	a	b	a	b	a	b	a	b	a	b
10	3.834	3.717	6.975	5.138	2.160	1.826	4.262	5.202	4.307	3.970
20	2.409	2.350	2.971	3.048	.728	.822	2.686	2.663	2.198	2.220
30	.410	.405	.364	.431	.336	.395	.398	.388	.377	.404
Mean[3]	2.217	2.157	3.436	2.872	1.074	1.014	2.448	2.751		

12 DF   1. interaction a. SE ± .4841* b. SE ± .2314*** 2. temperature a. SE ± .2420***
        b. SE ± .1157*** 3. cv a. SE ± .2795*** b. SE ± .1336***

Calculated by a. Harwick and Milbourn (1967) equation b. yield-tenderometer relationship

equation (3) and b. yield-tenderometer relationship (4), (table 2.4).

The fresh weight yield in all cvs decreased as temperature increased. All cvs yielded similarly at 30 C, however, Dp out-yielded all other cvs at 10 C and had the most variable yield with temperature change. The yield of Sp varied the least with temperature and Sp also had generally the lowest yield at all three temperatures.

2.3.5 Interaction of Yield Components and Their Relationship to Yield

Stepwise multiple regression was used to measure the relative magnitude of the contribution of each component to yield variability.

Table 2.5: Relative Contribution of Yield Components to Variability in Fresh Weight Yield of Four Pea Cvs (yield based on the Hardwick and Milbourn, 1967 equation)

| Component | Contribution to R^2 [1] | | | |
| | Cultivars | | | |
	Tp	Dp	Sp	Spl
Number of podding nodes	.012	.896	.901	.043
Number of pods per node	.834	.019	.001	.003
Number of peas per pod	.005	.043	.081	.001
Weight per pea	.146	.037	.017	.944

1. The coefficient of determination (R^2) measures increments in the variability of a single yield component, taken as a dependent variable and accounted for after including each preceding yield component sequentially (as listed in the table) in a stepwise multiple regression.

Yield variability in Tp was largely attributed to the number of pods per node, in Dp and Sp cvs to the number of podding nodes and in the Sp1 cv to the weight per pea. The number of peas per pod in Tp and Sp1 cvs and the number of pods per node in Dp and Sp cvs contributed the least to yield variability.

The interaction between components of yield is measured directly by the correlation coefficient. Negative correlations suggest compensation of one component by another. Positive correlations suggest that environmental factors can improve two yield components at the same time without compensatory losses in yield (Table 2.6).

There was a significant positive correlation in the Tp cv with yield and the number of pods per node and number of peas per pod. Yield in the Dp cv was positively correlated with the number of podding nodes and number of pods per node. Yield in both the Sp and Sp1 cvs was positively correlated with the number of podding nodes, number of peas per pod and weight per pea. The Tp cv also had significant positive interactions between the number of podding nodes and weight per pea and between the number of pods per node and number of peas per pod. Dp had significant positive interactions between the number of podding nodes and number of pods per node, also between the number of podding nodes and number of peas per pod and finally between the number of pods per node and number of peas per pod. The Sp1 cv had significant positive interaction between the number of podding nodes and number of peas per pod, between the number of podding nodes and weight per pea and was the only cv with a significant positive interaction between the number of peas per pod and weight per pea. The Sp cv had a positive interaction between the number of podding nodes and weight per pea. Sp was the only cv with negative correlations indicating component compensation. Sp had significant negative correlations between the number of podding nodes and number of pods per node and between the number of pods per node and weight per pea.

Table 2.6: Correlation Coefficients as a Measure of Interaction Between Yield Components and Component Relationship to Fresh Weight Yield in Four Pea Cvs (yield based on the Hardwick and Milbourn 1967 equation)

Dependent Variable	Independent Variable															
	Podding Nodes				Pods per Node				Peas per Pod				Weight per Pea			
	Tp	Dp	Sp	Spl	Tp	Dp	Sp	Spl	Tp	Dp	Sp	Spl	Tp	Dp	Sp	Spl
Podding Nodes		1.0														
Pods per Node	.21	.85*	-.78*	.38	1.0											
Peas per Pod	.34	.79*	.74	.91**	.80*	.81*	-.23	.38	1.0							
Weight per Pea	.76*	.25	.98***	.80*	.39	.01	-.80*	.64	.40	-.27	.67	.78*	1.0			
Yield	.55	.94**	.95***	.90**	.91**	.85*	-.58	.62	.83*	.73	.89**	.84*	.71	.42	.93**	.97***

5 DF

2.3.6 Maturity Assessment

2.3.6.1 Weeks to Optimum Harvest Date (OHD)

High temperature reduced the number of weeks from sowing to optimum harvest in all cvs.

Table 2.7: Effect of Temperature on the Number of Weeks From Sowing to the OHD in Four Pea Cvs

Temperature (C)	Number of Weeks to the OHD[1]				Mean[2]
	Tp	Dp	Sp	Sp1	
10	15.65	14.79	10.40	16.99	14.45
20	11.10	10.02	6.04	10.63	9.44
30	8.72	9.66	4.36	8.88	7.90
Mean[3]	11.82	11.49	6.93	12.16	

12 DF 1. interaction SE ± .229*** 2. temperature SE ± .114***
3. cv SE ± .132***

Sp was the earliest maturing cv at all three temperatures. Of the four cvs, Sp1 and Tp required the longest time to reach optimum harvest at 10 C and 20 C, Dp the longest at 30 C. The Dp and Sp cvs were least affected by temperature in number of weeks to optimum harvest, Sp1 was the most sensitive cv to temperature change.

2.3.6.2 Rate of Pea Maturity

The increase in pea maturity as measured by the slope in %AIS with successive harvest indicates the rate at which peas (seeds) matured (Fig. 2.2). Means of cv and temperature treatments appear in Appendix 5.
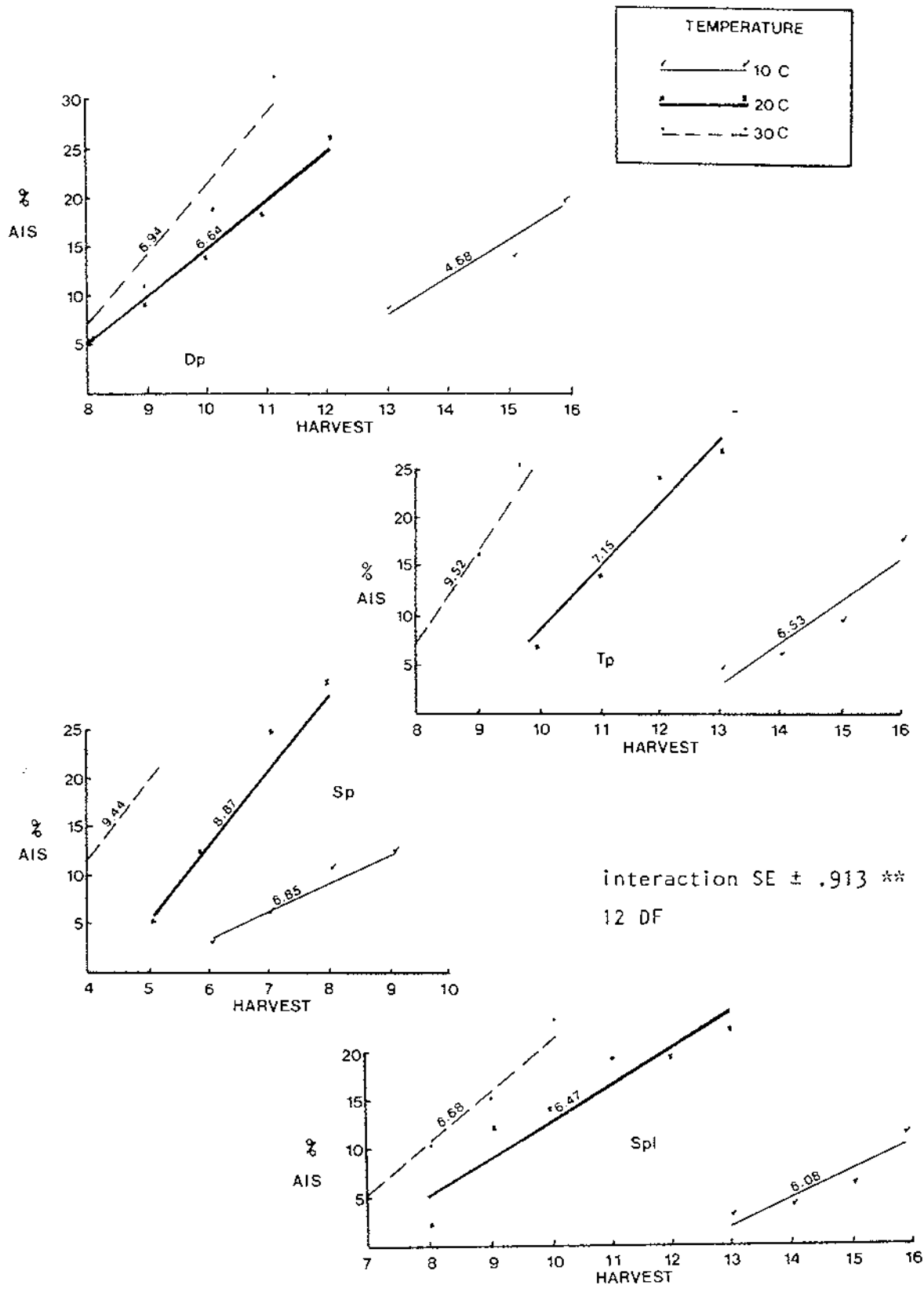
Fig. 2.2 Rate of crop maturity as indicated by slope of line

High temperature increased the rate of pea maturity in all cvs. Peas in the Sp cv generally matured most rapidly and peas generally matured the slowest in Dp at all temperatures. The slow pea maturity rate of Dp was most evident at 10 C.

2.3.7 Dry Weight Distribution

The dry weight distribution at the OHD is shown to vary considerably between cvs and temperature (Fig 2.3). Means of cv and temperature treatments appear in table 2.8.

Table 2.8:   Effect of Temperature on the Distribution of Dry Weight in Four Pea Cvs at the OHD

Temperature (C)	% of Total Plant Dry Weight				
	Root	Stem	Leaf	Pod	Pea
10	9.42	30.36	23.48	25.28	11.46
20	11.45	29.53	32.58	17.48	8.96
30	14.39	30.08	29.42	9.06	17.05
SE	±.489	±.488	±.420	±.816	±.697
Cultivar					
Tp	12.49	37.08	28.30	13.77	8.36
Dp	9.46	33.21	31.25	15.03	11.25
Sp	12.66	16.84	24.79	27.41	18.30
Spl	12.40	36.21	30.55	10.64	10.20
SE	±.565	±.564	±.485	±.942	±.805

12 DF   Statistical analysis based on arcsine transformed data

1.   Root. Percent total dry weight in root increased in all cvs as temperature increased, particularly in the Spl cv. Of the four cvs, Dp generally
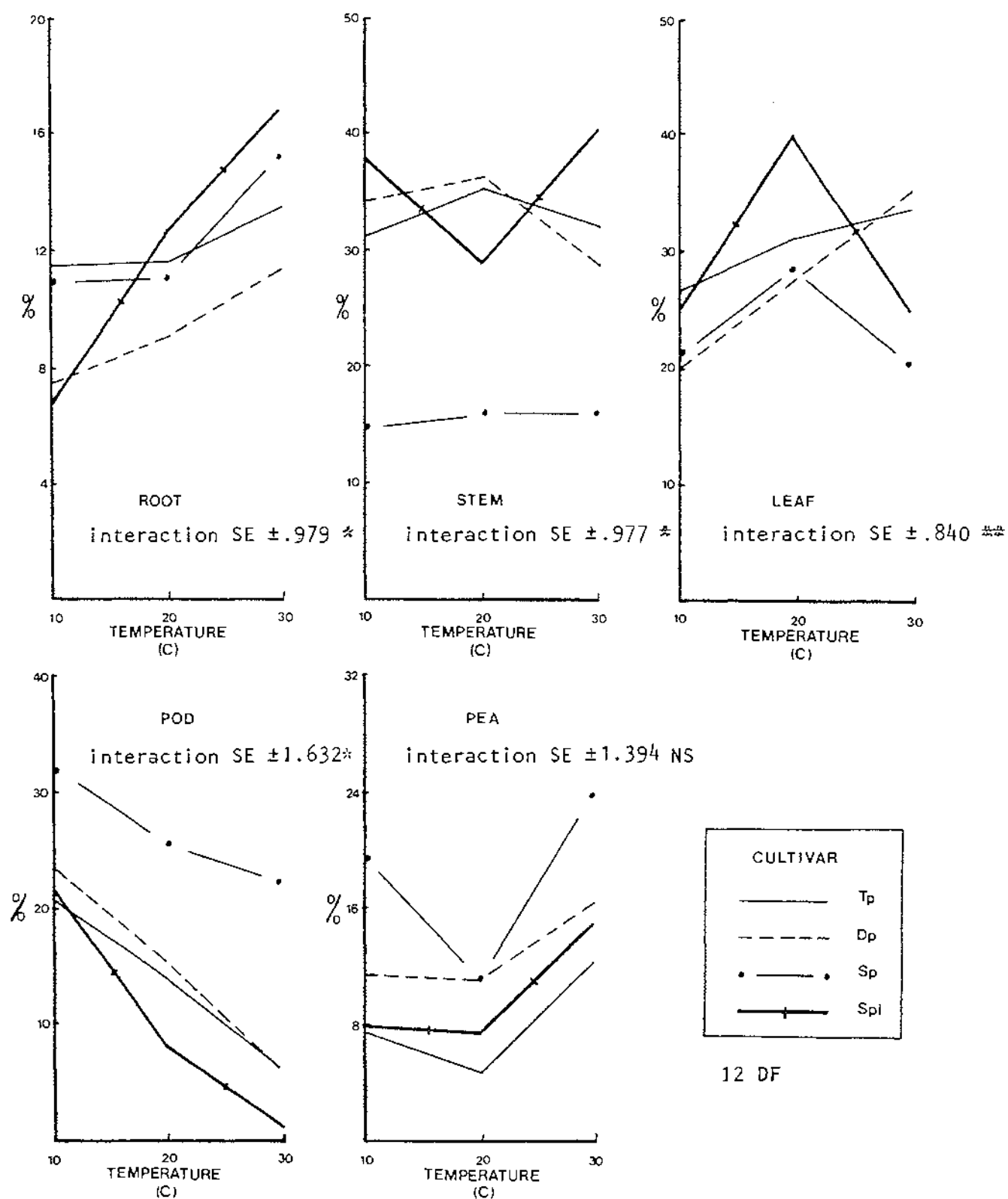
Fig. 2.3 Distribution of dry weight (%) at the OHD. Statistical analysis based on arcsine transformed data

produced the smallest percent in root at all temperatures, Tp the highest at 10 C and Spl the highest at 20 and 30 C.

2. Stem. The percentage dry weight in stem in Sp did not differ greatly between temperature treatments, however, the Tp and Sp cvs did produce a smaller percentage in stem at 30 C and Spl at 20 C. At all temperatures, stem comprised the largest percent of total dry weight in both Tp and Dp cvs.

3. Leaf. Percent total dry weight in leaf increased in the Tp and Dp cvs as temperature increased, particularly in the Dp cv. Leaf percentage in the Sp and Spl cvs increased at 20 C and then fell sharply at 30 C.

4. Pod. Percent total dry weight in pod decreased in all cvs as temperature increased, particularly in the Spl cv. Percent in pod was most stable in the Sp cv.

5. Pea. The cv x temperature interaction was not significant, however, the mean percent total dry weight in pea increased as temperature increased. The highest mean percentage in pod was in the Sp cv and the lowest in the Tp cv.

6. Total Plant Dry Weight. High temperatures produced smaller plants in all cvs (Table 2.9). Sp was the least affected by temperature and was consistently the smallest cv at all temperatures. Tp and Spl cvs were the largest plants at 10 and 20 C, Dp at 30 C. The largest high temperature reduction in plant size occurred in Spl followed closely by Tp.

Table 2.9: Effect of Temperature on Total Plant Dry Weight in Four
Pea Cvs at OHD

Temperature (C)	Total Plant Dry Weight (g) at the OHD[1]				Mean[2]
	Tp	Dp	Sp	Spl	
10	6.115	4.867	1.644	6.540	4.791
20	3.121	2.815	.965	2.030	2.233
30	1.561	1.563	.697	1.057	1.219
Mean[3]	3.599	3.081	1.102	3.209	

12 DF   1. interaction SE ±.1932***   2. temperature   SE ±.0966***
3. cv   SE ±.1115***

2.3.8 Harvest Index

Harvest index measured the distribution of dry weight between vegetative and reproductive growth. Hardwick (1970) used the following equation to derive harvest index in peas:

$$\text{harvest index} = \frac{\text{pod weight} + \text{pea weight}}{\text{stem weight} + \text{leaf weight}}$$

Table 2.10:   Effect of Temperature on Harvest Index in Four Pea Cvs
at the OHD

Temperature (C)	Harvest Index at the OHD[1]				Mean[2]
	Tp	Dp	Sp	Spl	
10	.50	.64	1.43	.48	.76
20	.42	.28	.97	.22	.47
30	.27	.34	1.25	.24	.59
Mean[3]	.39	.42	1.21	.31	

12   DF   1. interaction SE ±.089 NS   2. temperature SE ±.044***
         3. cv SE ±.051***

The cv x temperature interaction was not significant.   Harvest index was
highest at 10 C and the lowest at 20 C.   Sp had the largest harvest
index, Spl the smallest.

2.4 Discussion

2.4.1 Growth and Development

The main effects of high temperature on pea growth and development were earlier maturity and lower fresh weight yields. Earlier maturity was evident in all cvs in the reduction of the number of weeks from sowing to the OHD (Table 2.7). High temperature shortened the period of development without giving sufficient compensation by faster growth, the result was that plants remained smaller (Van Dobben 1962) (Table 2.9). The shortened phase of growth and the smaller plant that resulted was evident in growth analysis.

Growth analysis showed that the growth rate was reduced at high temperature (Fig. 2.1). The higher the temperature regime, the lower were both RGR and NAR, and the greater their decline with time. RGR fell due to the decrease in NAR and LAR. NAR decreased at high temperature possibly due to the increase in respiration and possibly due to a decreased photosynthetic rate (Yoshida 1972; Evans 1975). Also, earlier peaks in LAR were observed as temperature increased, evidence of a more rapid and selective development in plants where growth of leaves was promoted to a greater extent than growth of stems and roots (higher LAR). Leaves also became thinner (higher SLA). LAR decreased more quickly at high temperature due to decreases in SLA and LWR. The size of the LAR was not sufficient to compensate for the lower NAR at high temperature and therefore smaller plants resulted with a lower RGR. LWR also peaked earlier and was higher as temperature increased due to a more rapid development. At high temperature, leaves comprised a greater proportion of the total plant dry weight and LWR decreased more quickly due to a rapid senescence of these leaves and possibly due to the effect of pod development on increasing total plant dry weight.

The smaller plants resulting from a lower NAR at high temperature entered the reproductive phase with a lower rate of assimilate accumulation than plants at lower temperature where a higher NAR provided for more vegetative and reproductive growth. Fresh weight pea yield decreased at high temperature in all cvs probably as a result of a lower rate of assimilate supply (NAR) in the smaller plant (Table 2.4). A shortening of the growth phase in most crop plants, whether directly associated with NAR or not, results in lower yields (Van Dobben 1962; Yoshida 1972). The reduced yields observed in this experiment appear to support a relationship of NAR and growth duration to yield in peas.

Harvest index also decreased as temperature increased possibly as a result of the lower NAR and possibly also due to some internal hormonal mechanisms which could have determined fresh weight yield (Yoshida 1972). In a cv such as Sp, the high harvest index indicated that the distribution of assimilates to pods and peas was favoured over leaves and stems. This was somewhat evident in the pattern of dry weight distribution within the plant (Fig. 2.3). The Dp cv had a better balanced distribution of assimilates between vegetative and reproductive growth (lower harvest index). Harvest index has been used, rightly or wrongly as a selection criterion for high yield and earliness in many crops (Wallace 1973). In this experiment, Sp was the earliest maturing cv and also had the highest harvest index but the lowest fresh weight yield. Dp, with an average sized harvest index compared to the other cvs was later maturing and had the highest fresh weight yield. To use harvest index as a selection tool for high yield and earliness in peas is an over-simplification and it should therefore be used with caution. Nevertheless, harvest index like LAR indicated that there is a selective distribution of assimilates within the plant which is apparently under some influence by temperature.

With an increase in temperature, the internode length decreased in all cvs (Table 2.1). The decrease was most evident in later maturing

cvs such as Tp and Sp1. Temperature affected internode length through
its effect on cell division and cell elongation in the subapical region.
Differences in length between temperature treatment may have been brought
about by rate rather than period of development and the roles of GA_3 and
IAA in their combined effects on elongation (Sachs 1965). Late maturing
cvs developed more quickly at high temperature and were therefore most
affected. The number of nodes to the first pod(s) was also later (higher)
as temperature increased, particularly in later maturing cvs (table 2.2).
The delay in podding may have been due to destruction of a flower-
promoting substance at high temperature (Moore 1964), destruction of a
flower inhibiting substance at low temperature (Barber 1959) or the
balance or interaction between auxin and some other plant constituent
(Leopold and Guernsey 1954). As flower initiation occurs only a few
days after inhibition (Haupt 1969), the results of this experiment have
indicated that the temperature during germination and early growth is an
important influence on the position of the first pod(s).

2.4.2 Components of Yield

Component analysis revealed that at high temperature, the number of
yield components decreased (table 2.3) along with fresh weight pea yield
(Table 2.4). These results were in agreement with reports by Boswell
(1926); Reath and Wittwer (1952); Karr et al (1959); Ibarbia and Bienz
(1970); Ormrod et al (1970) and Nonnecke et al (1971) that pea yield
decreased at high temperature. The number of podding nodes and number
of pods per node generally decreased most in the high frequency podding
cv, Tp, a result largely of environment and genetic differences (Yarnell
1962; Ibarbia and Bienz 1970). The number of pods per node decreased at
high temperature possibly due to non-initiation of floral primordia in
the shoot apex (Ormrod et al 1970) and possibly due to high temperature
stress causing flower and pod abortion (Meadley and Milbourn 1970; Hole
and Harwick 1974; Hole 1977). Both flower and pod abortion were observed

during the course of the experiment. The number of pods retained may be directly associated with NAR (a measure of the rate of assimilate accumulation). The results of this experiment suggest that there is a direct relationship between the number of yield components and fresh weight pea yield. NAR was lower at high temperature and the number of yield components decreased resulting in lower fresh pea weight yields. The total number of pods decreased as temperature increased as a direct result of the reduced numbers of podding nodes and pods per node. The number of peas per pod and fresh weight per pea also decreased as temperature increased possibly due to a reduced translocation of assimilates and nutrients into pods and peas (Lambert and Linck 1958). Fewer peas per pod may also have resulted from ovule abortion due to a low NAR and high temperature stress (Linck 1961). Seeds are reported to produce growth regulating substances which mediate the movement of assimilates and nutrients to pods (Audus 1963; Cathey 1964; Ishag 1973). The number of peas per pod were most reduced in Dp and Sp cvs and least reduced in Tp, a direct response to the degree of reduction in the number of podding nodes and number of pods per node. Sp produced the heaviest pea, Tp the lightest pea. Pea weight was a result of the dry weight (assimilate) distribution mechanism within the plant. Sp had the highest harvest index indicating reproductive growth was favoured in the amount of assimilates received, therefore a heavier pea was produced. The opposite was observed in the Tp cv. Growth analysis failed to indicate significant cv differences which may have supported assimilate distribution patterns that were suggested by harvest index data.

This experiment failed to identify one component in all cvs as the main contributor to fresh weight pea yield variability (Table 2.5). Yield variability in Tp was largely due to the number of pods per node, in Dp and Sp the number of podding nodes and in the Sp1 cv it was the weight per pea. The hypothesis linking variation in pea yield with variation in the number of pods per node was rejected in part in this experiment

(although yield in Tp varied largely due to the number of podding nodes) as was total pod number rejected by Hardwick, Andrews, Hole and Salter (1979). Neither was Hardwick's hypothesis suggesting that the weight of peas per pod (weight per pea) was the main cause of variation in pea yield supported.

All four cvs in this experiment recorded high positive correlations with pea yield and a number of yield components (Table 2.6). Pea yield decreased in the Sp and Sp1 cvs as the number of podding nodes, peas per pod and weight per pea decreased, in Tp pea yield decreased as the number of pods per node decreased and in Dp pea yield decreased as the number of podding nodes and pods per node decreased. If high temperature reduced pea yield by decreasing the number of yield components, an increase in the number of yield components through positive interactions between components can be expected to result in a fresh weight pea yield increase. In fact component numbers increased at low temperature through positive component interactions, the result was a yield increase. However, when one component was favoured, for any reason, over the other in the amounts of assimilates received, a negative correlation arose between them (Adams 1967). Component compensation was evident only in the Dp and Sp cvs, with significance only in the Sp cv. Component compensation in Sp resulted in the most stable yield between temperature treatments (Table 2.4). The Dp cv, with the highest incidence of significant position interactions yielded very low at high temperature and had the highest yield at low temperature emphasizing that potentials are available for both low and high pea yield when positive interactions between components exist but where negative interactions would maintain a yield stabilizing effect. This compensatory growth behaviour in Sp was also evident in its consistently high harvest index at all temperatures (Table 2.10).

CHAPTER 3

Field Experiment: The Effect of Sowing Date on the Growth and
                     Development of Four Pea Cultivars

3.1   Introduction

The greenhouse experiment (Chapter 2) indicated that the growth,
development and yield of the pea plant is markedly influenced by
temperature.   This experiment was designed to use successional sowings
in the field to further examine the growth and development of single,
double and triple node-podding cvs in natural conditions.   Growth
analysis techniques as well as yield component analysis were used to
assess cv response to sowing date.

3.2   Materials and Methods

The field experiment was conducted during the 1978-79 growing
season at Massey University.   Four successive sowings were made at six-
week intervals.

Table 3.1:   Sowing Dates During the 1978-79 Growing Season and Mean
             Temperature (From Date of Sowing to Final Harvest) for
             Each Sowing.

Sowing	Sowing Date	Mean Temperature (C)
1	11 October	13
2	1 December	15
3	18 January	18
4	2 March	14

At the beginning of the season, in October, temperatures were relatively cool. As the season advanced, the temperature rose and then declined rapidly in late April. Fig. 3.1 gives the pattern of the weekly sum of heat unit (day degrees) accumulation above 5C during the growing season beginning with the week the first sowing was made and ending with the week in which the last harvest of the fourth sowing was made. The method given by Anon (1977) was used to calculate daily heat units.

$$\text{daily heat units} = \frac{\text{maximum temperature (C) + minimum temperature (C)}}{2} - 5C$$

Along with the higher mid summer temperatures, rainfall during the late December through February period was lowest (Fig. 3.2). Both earlier and later in the season rainfall was considerably higher and combined with low temperatures during May plant growth was slow and vines began to rot, bringing an end to the trial. Hours of sunshine and solar radiation were most intense during the December through January period (Figs. 3.3 and 3.4). Long intense hours of sunlight combined with optimum moisture conditions which were achieved through irrigation provided for rapid plant growth and high potential pea yield, particularly for sowings 1 and 2. Temperature was selected as the subject of study in this experiment because of its major impact on pea growth and close relationship with hours of sunlight, daylength and natural rainfall patterns at the location of this field trial.

Four cvs representing three common podding types commercially available were grown.

Cultivar	Node-Podding Type	Code
* Puget	triple-pod	Tp
Victory Freezer	double-pod	Dp(Vf)
* Puke	double-pod	Dp(Pk)
* William Massey	single-pod	Sp

*
 Cvs also grown in the greenhouse experiment (Chapter 2).

$$\text{Daily heat units} = \frac{\text{minimum (C)} + \text{maximum (C)}}{2} - 5\text{ C}$$
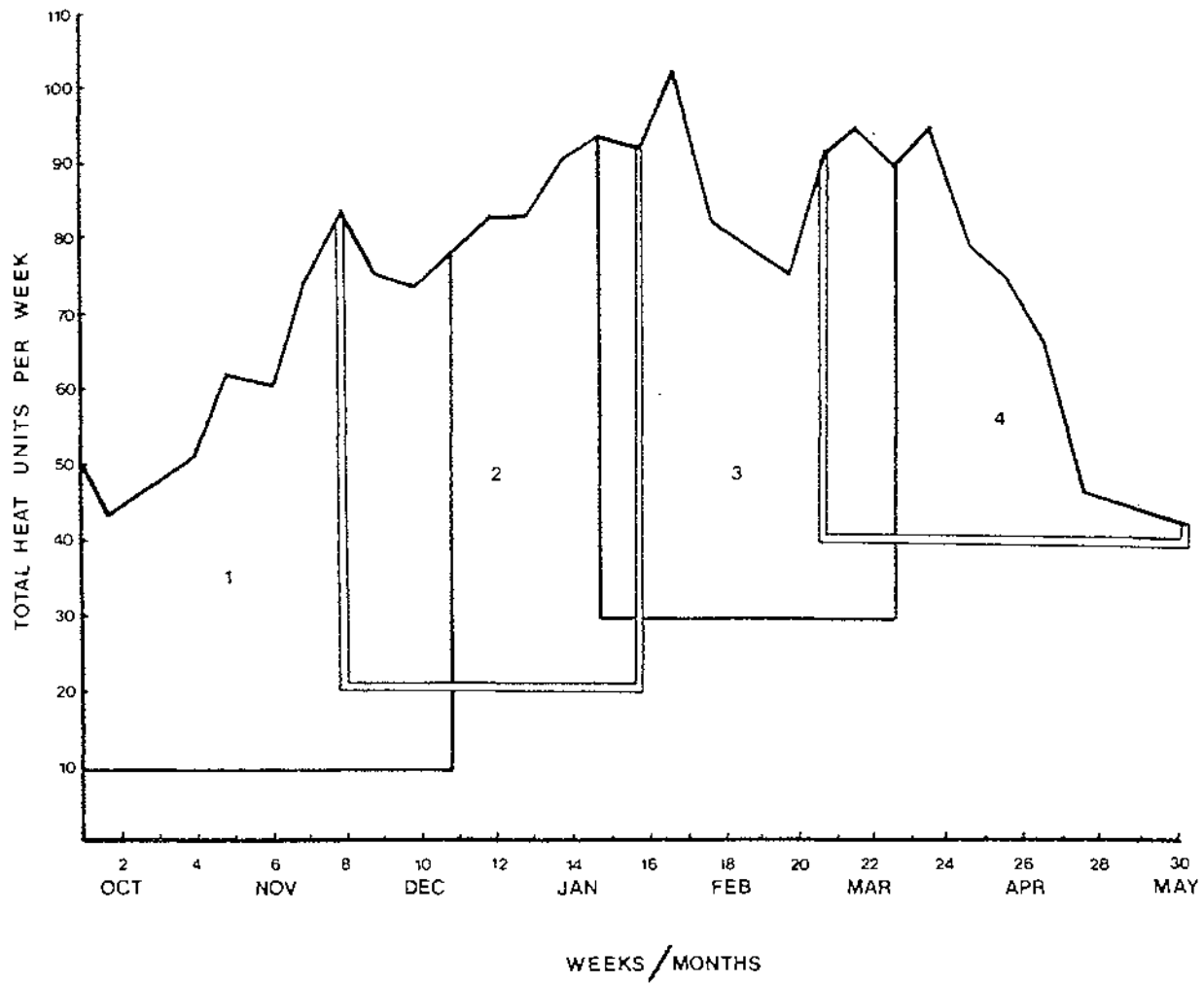
Fig. 3.1 Weekly heat unit accumulation (day degrees) over
four successive field sowings of peas
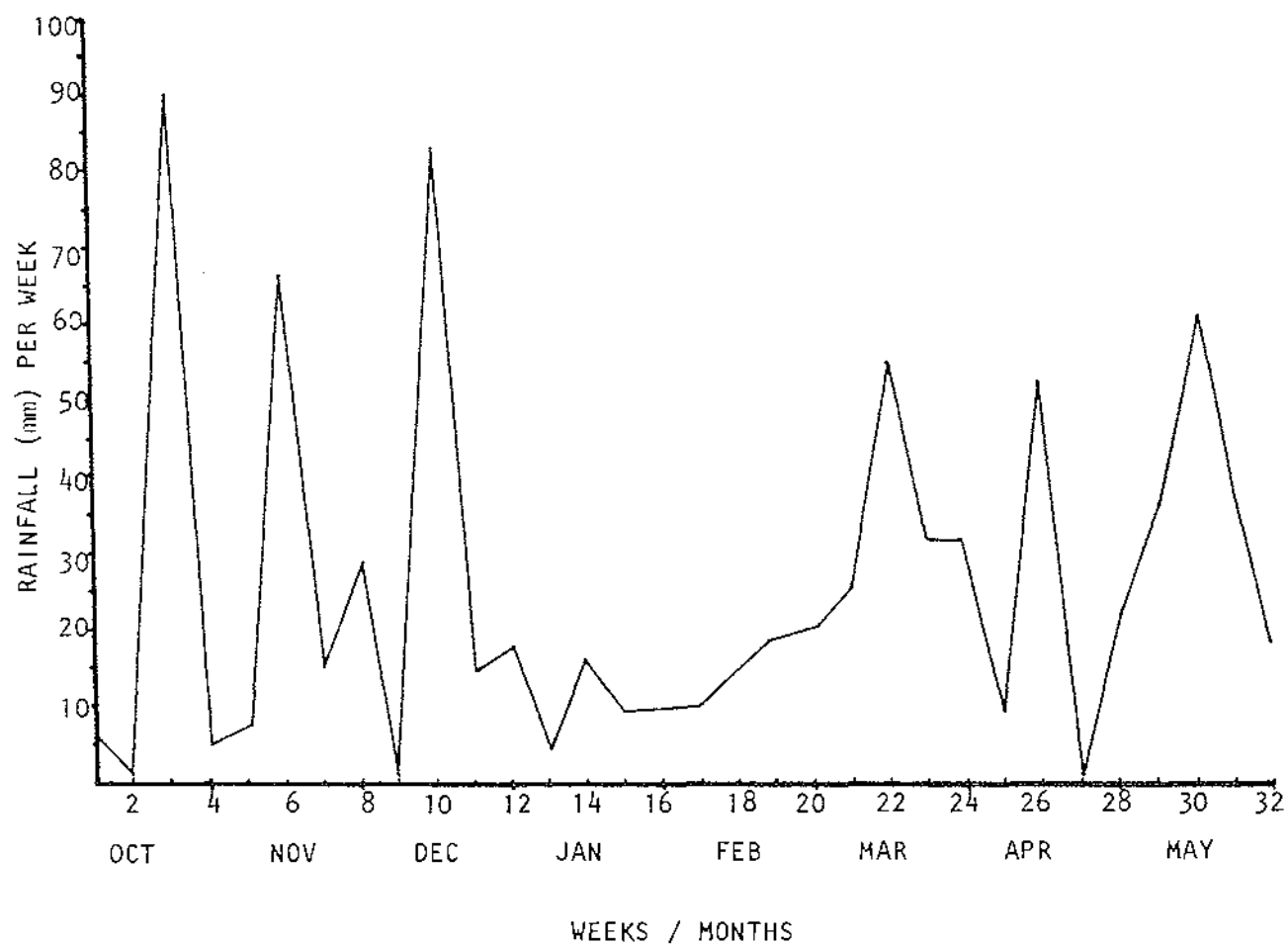
Fig. 3.2 Weekly rainfall (mm) over four successive field sowings of peas
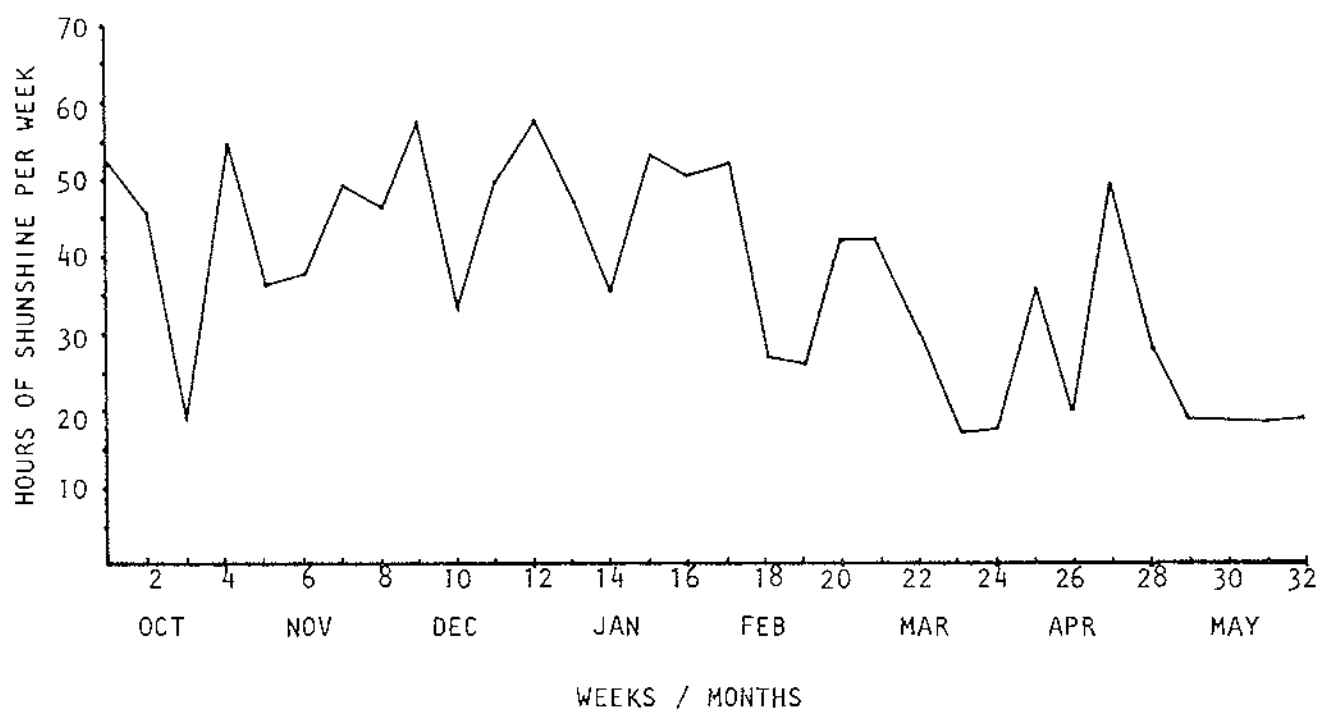
Fig. 3.3 Weekly hours of sunshine over four successive field sowings
of peas
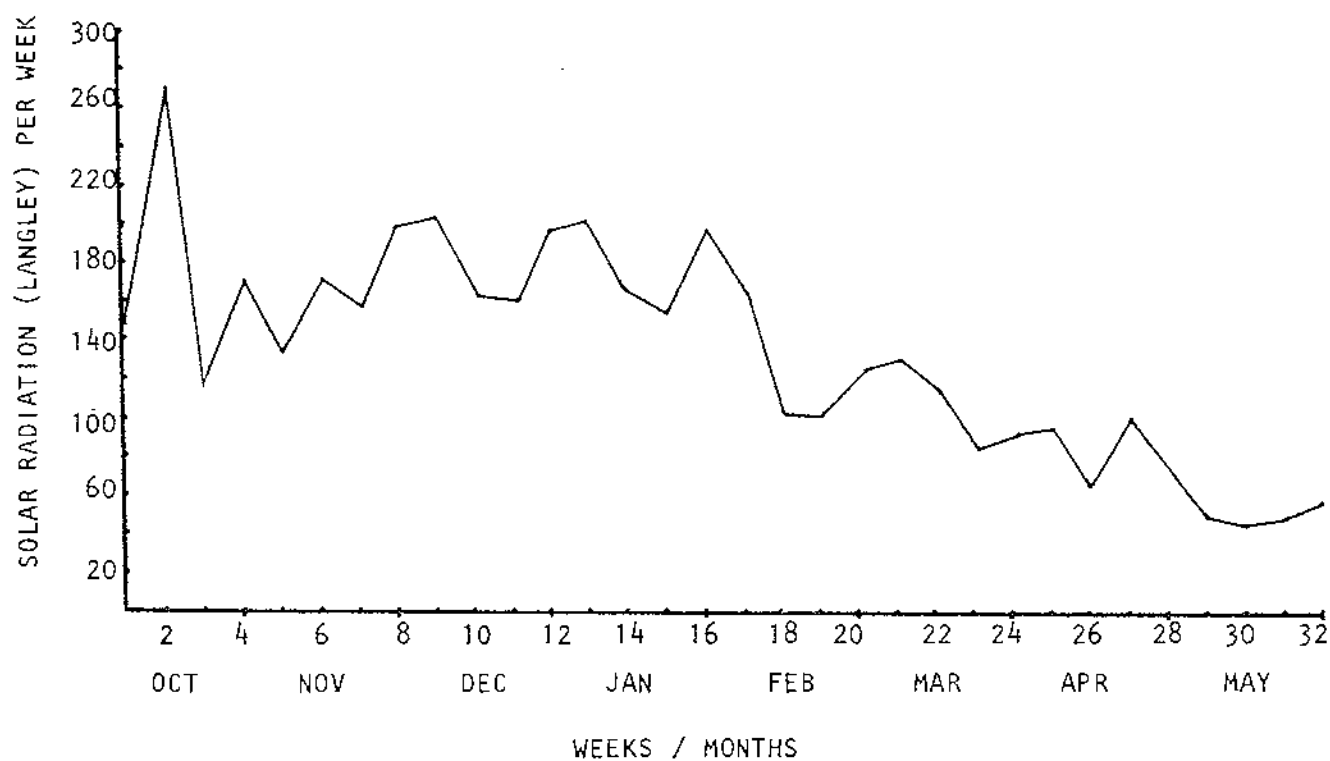
Fig. 3.4 Weekly solar radiation (langley) over four successive
field sowings of peas

The field (in grass) was fall ploughed and rotovated in the spring as soon as conditions permitted. Soil at the site was classified as Karapoti brown sandy loam (see Appendix 6). The experimental design was a randomized complete block consisting of each cv replicated 3 times at each sowing. Prior to sowing, beds were treated with a broadcast application of 450 kg/ha 30% potassic superphosphate and rotovated in. No herbicides were used.

A Stanhay Mark 11 precision drill was calibrated to sow 125 seeds /m^2 to approximate 100 plants/m^2. Rows were spaced 20 cm apart with 5 rows to a bed. Each bed consisted of one cv and measured 10 m in length. Irrigation water was applied as required by an overhead square pattern system immediately after sowing and approximately once every week during dry periods at a rate of approximately 25mm per irrigation.

Along the center row of each bed, harvest sampling sites were marked at 40 cm intervals. Weekly harvests of 10 plants from one sampling site was randomly chosen and plants from the center three rows were dug up, roots washed clean and the following data were recorded:

1. root, stem, leaf and pod dry weight
2. leaf area (measured by leaf area meter), Lambda instrument, LI 3000
3. number of podding nodes
4. number of pods per podding node
5. number of peas at each podding node
6. fresh and dry weight of peas at each podding node
7. maturity, alcohol insoluble solids (% AIS) of peas at each podding node at each pea harvest (refer to Appendix 1 for procedures).

All plant parts were dried in a forced-air oven at 80 C for 72 hours and then weighed.

Growth curves were fitted to quadratic equations as outlined in the greenhouse experiment (Section 2.2). Component analysis techniques were used to examine changes in the number of yield components in the four successive sowings of peas. This was not possible in the fourth sowing as this crop failed to reach the podding phase due to adverse weather conditions. All component data was adjusted to coincide with the Optimum Harvest Date (OHD), details of which are outlined in Section 2.2 of the greenhouse experiment. The block effect was retained in the factorial analysis and standard errors of means (SE) were derived.

3.3 Results

3.3.1 Growth Analysis (Fig. 3.5)

Low temperature and very damp conditions prevented the fourth sowing from making good growth to support pod and pea development. As the fourth sowing failed to reach the podding stage, the growth curves were considered to be anomalous and therefore the results are discussed only in terms of the first three sowings.

RGR was initially higher at sowing 2 and 3 and also declined more rapidly with later sowing. NAR was initially lower at the second sowing and also decreased more rapidly at later sowings. The highest point in LAR occurred at the second sowing and the peak in LAR also occurred earlier at this sowing. Sowing one generally had the lowest LAR. There was a general rise in LAR then a rapid decrease with time particularly at the second sowing. SLA changed little with time and was not clearly affected by sowing date. LWR like LAR peaked earliest at the second sowing and was also the lowest in sowing one. LWR initially rose and then declined with time in all sowings, particularly in the first sowing. LWR declined most rapidly at the second sowing. No significant cv differences were observed in any of the growth parameters.

3.3.2 Components of Yield

The effect of sowing date on the components of yield in pea cvs is shown in Table 3.2. Results of the cv x sowing interaction appear in the upper half of the table. Cv and sowing treatment means appear in the lower half of the table.

3.3.2.1 Number of Podding Nodes

There was a reduction in number of podding nodes in all cvs with later sowing. The number of podding nodes decreased most in Tp and

Fig. 3.5 Growth curves derived from a quadratic equation

SOWING
1
2
3
4

400

300

200

100

cm²/g

SLA

1 2 3 4 5 6 7 8 9 10
HARVEST (WEEK)

SE ±   .023 .017 .015 .052 .012 .012 .014 .019 .015 .017

6

5

4

3

2

1

g/g

LWR

1 2 3 4 5 6 7 8 9 10
HARVEST (WEEK)

SE ±   .023 .017 .015 .052 .012 .019 .014 .015 .019 .017
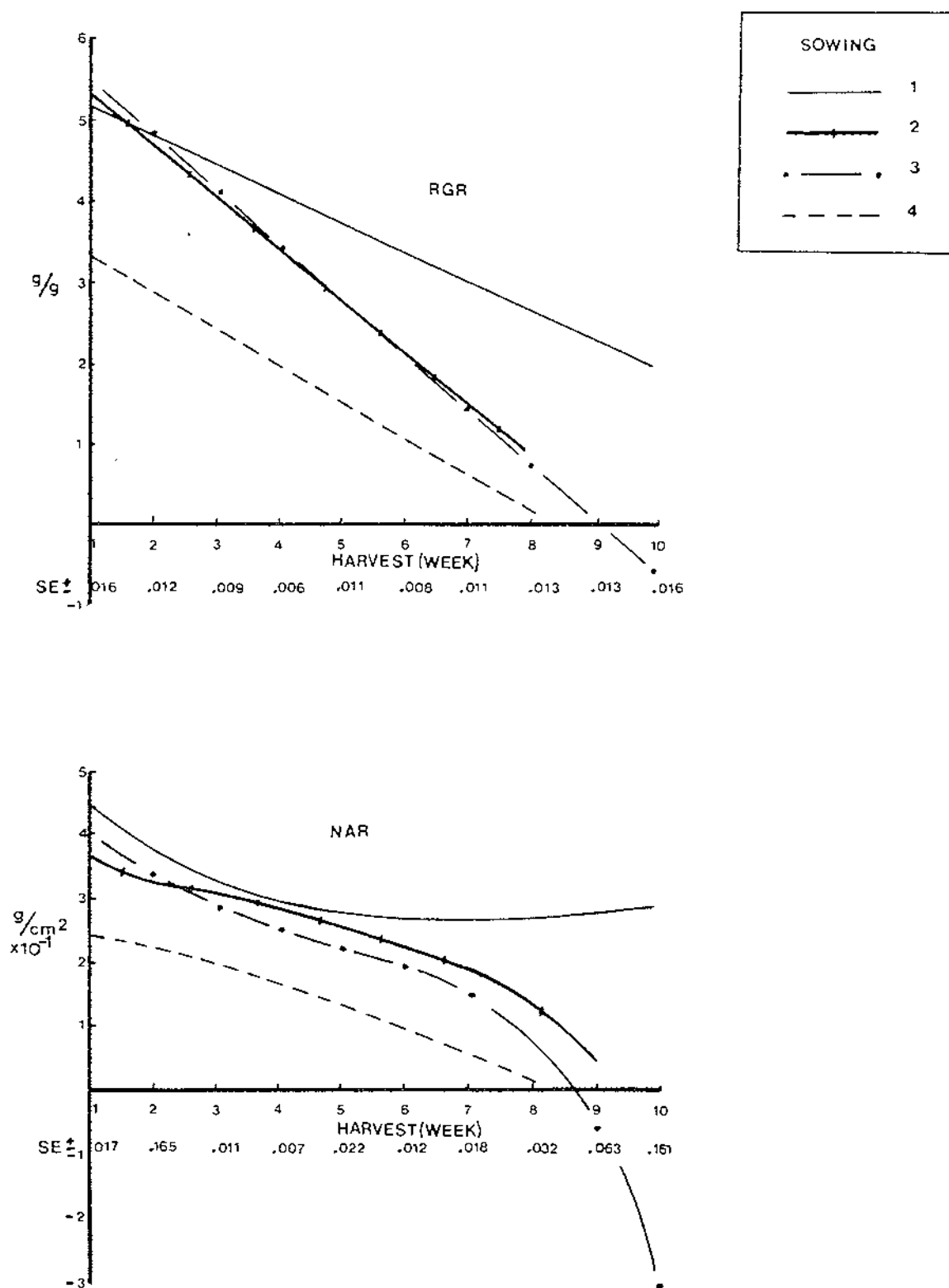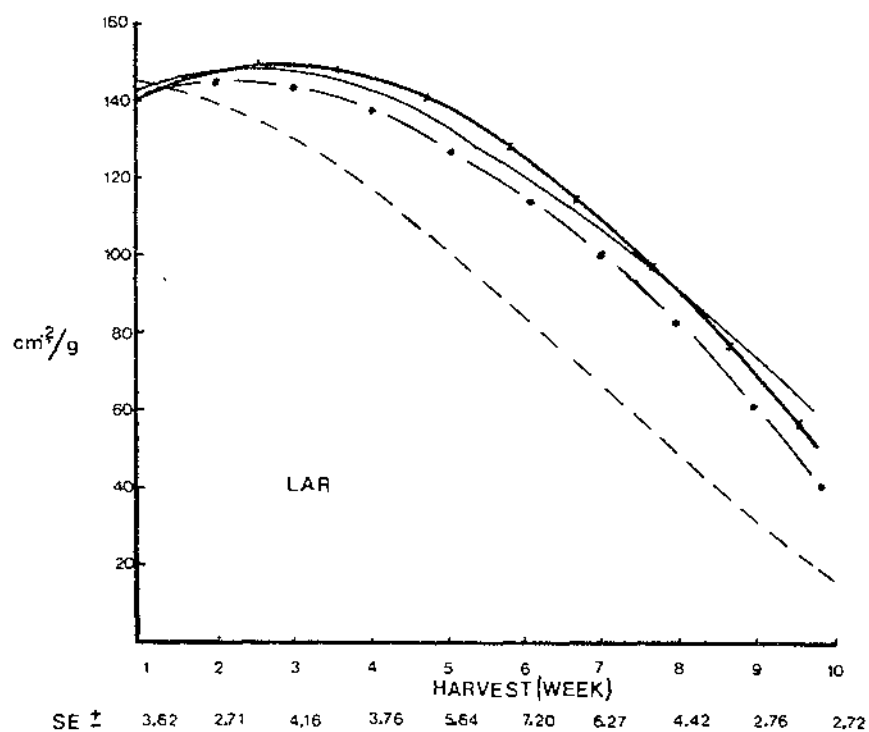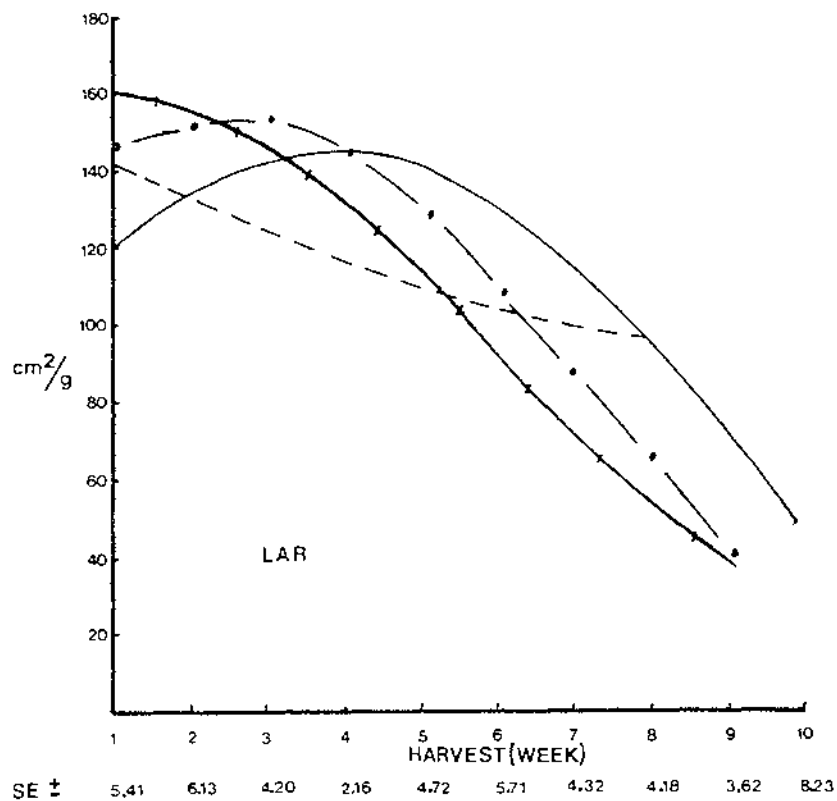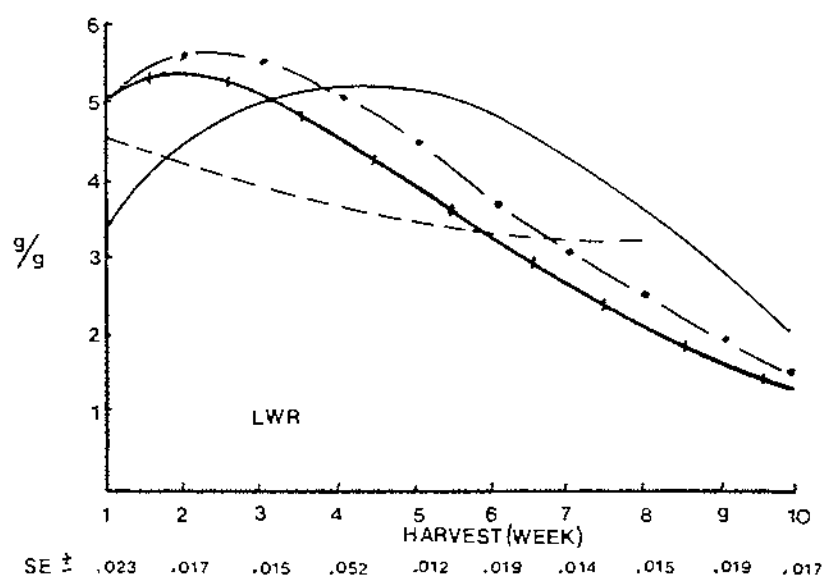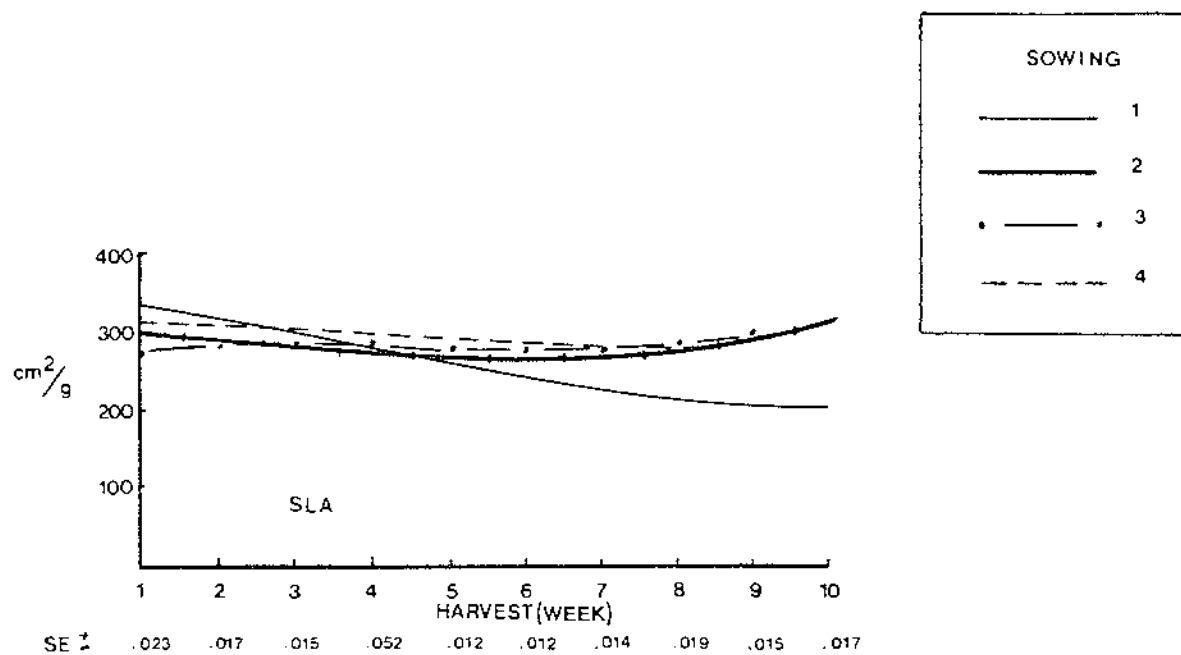
Table 3.2: Effect of Cv and Sowing Date on the Components of Yield in Four Pea Cvs (First Three Sowings [+]) at the OHD

Cultivar	Sowing	Number			Fresh Weight (g) per Pea[4]	Total Number	
		Podding Node[1]	Pods per Node[2]	Peas per Pod[3]		Pods[5]	Peas[6]
Tp	1	4.1	1.85	5.60	.318	7.58	42.47
	2	3.6	1.51	4.64	.375	5.43	25.22
	3	2.0	2.02	3.29	.373	4.04	13.29
Dp (Vf)	1	4.0	2.14	4.47	.298	8.56	38.26
	2	3.6	1.49	4.63	.320	5.36	24.83
	3	1.2	1.84	2.66	.296	2.21	5.87
Dp (Pk)	1	4.0	1.36	6.97	.227	5.44	37.91
	2	3.1	1.47	6.14	.344	4.55	27.97
	3	3.0	2.12	5.50	.315	6.36	34.98
Sp	1	4.0	.76	5.22	.482	3.04	15.86
	2	3.5	.96	5.38	.390	3.36	18.07
	3	3.2	1.79	5.21	.427	5.72	29.84

interaction 22 DF
1. SE ± .15*** 2. SE ± .302 NS
3. SE ± .275** 4. SE ± .0172**
5. SE ± .457*** 6. SE ± 3.065***

Tp		3.2	1.79	4.51	.355	5.68	26.99
Dp (Vf)		2.9	1.82	3.92	.304	5.37	22.98
Dp (Pk)		3.3	1.65	6.20	.295	5.45	33.62
Sp		3.5	1.17	5.27	.433	4.04	21.25
	1	4.0	1.53	5.56	.331	6.15	33.62
	2	3.4	1.36	5.19	.357	4.67	24.02
	3	2.3	1.94	4.16	.352	4.58	20.99

mean 22 DF
1. cv SE ± .07*** sowing SE ± .06***
2. cv SE ± .174* sowing SE ± .151*
3. cv SE ± .159*** sowing SE ± .137***
4. cv SE ± .0099*** sowing SE ± .0086 NS
5. cv SE ± .264*** sowing SE ± .228***
6. cv SE ± 1.769*** sowing SE ± 1.532***

+ sowing four failed to reach the podding stage

Dp (Vf) cvs. Both Dp (Pk) and Sp maintained the number of podding nodes in the third sowing at about the same level as at the second sowing. The number of podding nodes in Tp and Dp (Vf) at the third sowing fell sharply.

3.3.2.2 Number of Pods per Node and Total Number of Pods

The cv x sowing date interaction in the number of pods per node was not significant. The Tp and Dp (Vf) cvs produced the highest mean number of pods per node, Sp the smallest number. The mean number of pods per node was the lowest at the second sowing and the highest at the third sowing.

Tp and Dp (Vf) had fewer total pod numbers at later sowings whereas total pod number increased in Dp (Pk) and Sp with later sowing. Dp (Vf) had the largest decrease in pod number; pod number changed least in Dp (Pk). Tp and Dp (Vf) cvs produced the largest total number of pods at sowings 1 and 2, Sp the least. Dp (Pk) produced the most number of pods at sowing 3, Dp (Vf) the least.

3.3.2.3 Number of Peas per Pod and Total Number of Peas

The number of peas per pod decreased in all cvs with later sowings except in Sp where pea number per pod did not change appreciably. Dp (Pk) had the highest number of peas per pod at all sowings, Dp (Vf) the least. The number of peas per pod decreased most in Tp and Dp (Vf) with later sowings as did the total number of peas. Total pea number changed least in Dp (Pk) and Sp and actually increased in Sp at later sowings, particularly in sowing 3. Tp produced the highest total number of peas at the first sowing, Dp (Pk) at sowings 2 and 3. Sp produced the lowest total number of peas at the first and second sowing, Dp (Vf) at the third sowing.

3.3.2.4 Fresh Weight Per Pea

The fresh weight per pea was the lowest at the first sowing in all cvs except in Sp where pea weight was the highest. The Sp cv produced the heaviest pea at all sowings. Dp (Pk) produced the lightest pea at sowing 1, Dp (Vf) at sowing 2 and 3. Pea weight changed the most in Dp (Pk) and the least in Tp between sowings.

3.3.3. Fresh Weight Yield

The fresh weight yield was derived by the a. yield component equation (3) and b. yield-tenderometer relationship (4) as outlined in Section 2.2. The fresh weight yields are shown in Table 3.3.

The fresh weight yield of cvs varied considerably between sowings, decreasing with later sowing in Tp and Dp (Vf) cvs and increasing in Dp (Pk) and Sp cvs. Dp (Pk) maintained a high yield that changed the least between sowings. Yield in Dp (Vf) and Tp cvs was most variable, dropping off sharply in sowing 3.

3.3.4 Interaction of Yield Components and Their Relationship to Yield

Step-wise multiple regression was used to measure the relative magnitude of the contribution of each component to yield variability. (Table 3.4).

The yield of the Tp and Dp (Vf) cvs varied largely due to the number of peas per pod whereas in Sp it was the number of pods per node that was the largest contributor to yield variability. In the Dp (Pk) cv yield variability arose largely due to the number of pods per node, however there was a large contribution to yield variability from the number of podding nodes. In all cvs except Tp, the weight per pea contributed the least to yield variability. The number of podding nodes contributed the least to yield variabiltiy in Tp.

Table 3.3: Effect of Sowing Date on the Fresh Weight Yield of Four Pea Cvs at the OHD

| Sowing | Fresh Weight Yield (g) at the OHD | | | | | | | | | |
| | Tp | | Dp (Vf) | | Dp (Pk) | | Sp | | Mean[2] | |
	a	b	a	b	a	b	a	b	a	b
1	13.507[1]	12.258	11.402	11.372	8.607	9.832	7.648	6.482	10.291	9.986
2	9.458	9.250	7.947	9.321	9.625	11.261	7.049	8.182	8.530	9.503
3	4.957	6.872	1.738	2.247	11.018	12.323	12.742	13.345	7.609	8.696
Mean[3]	9.307	9.460	7.029	7.646	9.750	11.138	9.146	9.336		

22 DF
1. interaction a. SE ± .0044***   b. SE ± .2292***
2. sowing a. SE ± .5022*   b. SE ± .1146***
3. cv a. SE ± .5799 NS   b. SE ± .1323***

Calculated by a. Hardwick and Milbourn (1967) equation, b. yield-tenderometer relationship

Table 3.4: Relative Contribution of Yield Components to Variability in Fresh Weight Yield of Four Pea Cvs (yield based on the Hardwick and Milbourn, 1967 equation)

| Component | Contribution to R^2 [1] | | | |
| | Cultivars | | | |
	Tp	Dp (Vf)	Dp (Pk)	Sp
Number of podding nodes	.039	.073	.162	.040
Number of pods per node	.046	.089	.704	.873
Number of peas per pod	.803	.818	.076	.068
Weight per pea	.099	.014	.052	.013

[1] The coefficient of determination (R^2) measures increments in the variability of a single yield component, taken as a dependent variable and accounted for after including each preceding yield component sequentially (as listed in the table) in a step-wise multiple regression.

The interaction between components of yield is measured directly by the correlation coefficient. Negative correlations suggest compensation of one component by another. Positive correlations suggest that environmental factors can improve two yield components at the same time without compensatory losses in yield, (Table 3.5).

There was a significant positive correlation in both Tp and Dp (Vf) cvs between yield and the number of podding nodes and the number of peas per pod. Dp (Vf) also had a significant negative correlation between yield and the weight per pea. Yield in Dp (Pk) was significantly correlated with the number of pods per node as was yield in Sp, however, the significance was at a higher level in Sp. Sp also had a significant negative correlation between yield and the number of podding nodes.

The only significant component interaction in Tp was a positive relationship between the number of podding nodes and number of peas per

Table 3.5: Correlation Coefficients as a Measure of Interaction Between Components and Component Relationship to Fresh Weight Yield in Four Pea Cvs (yield based on the Hardwick and Milbourn, 1967 equation)

Dependent Variable	Independent Variable															
	Podding Nodes				Pods per Node				Peas per Pod				Weight per Pea			
	Tp	Dp(Vf)	Dp(Pk)	Sp	Tp	Dp(Vf)	Dp(Pk)	Sp	Tp	Dp(Vf)	Dp(Pk)	Sp	Tp	Dp(Vf)	Dp(Pk)	Sp
Podding Nodes		1.0														
Pods per Node	-.54	-.01	-.44	-.92**		1.0										
Peas per Pod	.90**	.84**	.88**	.01	-.25	.16	.03	-.15		1.0						
Weight per Pea	-.28	-.70*	-.72*	.49	-.28	-.38	-.37	-.19	-.53	.41	-.67*	-.39		1.0		
Yield	.81**	.89**	-.24	-.78**	-.02	.32	.67*	.93**	.89**	.90**	-.17	.03	-.34	-.72*	.12	-.01

8 DF

pod. There was also a significant positive interaction between the number of podding nodes and number of peas per pod in Dp (Vf), however, the number of podding nodes and weight per pea were negatively corre- lated indicating a degree of component compensation. The number of podding nodes and number of peas per pod in Dp (Pk) were positively correlated, however both the number of podding nodes and number of peas per pod were negatively correlated to weight per pea indicating some compensation between components was occurring. The only significant component interaction in Sp was a negative correlation between the number of podding nodes and number of pods per node. All cvs indicated some degree of component compensation, however only the Dp (Vf), Dp (Pk) and Sp cvs had significant negative interactions, the highest frequency occurred in Dp (Pk).

3.3.5 Maturity Assessment

3.3.5.1 Weeks to Optimum Harvest Date (OHD)

The interaction of cv x sowing was not significant (Table 3.6). The mean number of weeks from sowing to optimum harvest was the most in the first sowing and the least in the second sowing.

The Sp cv was the earliest, Tp and Dp (Vf) the latest maturing cvs. There was an increase in the number of heat units in all cvs with later sowing.

Table 3.6:   Effect of Sowing Date on the Number of Weeks (Total Heat
             Units) to the OHD in Four Pea Cvs

| Sowing | Number of Weeks (heat units) to OHD | | | | |
	Tp	Dp (Vf)	Dp (Pk)	Sp	Mean[2]
1	9.86 (879)	9.70 (818)	9.20 (769)	8.29 (668)	9.26
2	7.50 (918)	7.50 (918)	6.92 (817)	6.07 (690)	6.99
3	8.64 (1124)	8.48 (1065)	7.86 (868)	6.32 (728)	7.82
Mean[3]	8.66	8.56	7.99	6.89	

22 DF   1. interaction SE ± ..190 NS   2. sowing SE ± .095***
        3. cv SE ± .109***

3.3.5.2 Rate of Pea Maturity

The increase in pea maturity as measured by the slope in %AIS with successive harvests indicates the rate at which the peas (seeds) matured (Fig. 3.6). Means of cv and sowing dates appear in Appendix 5.

Peas generally matured more quickly at later sowings, except in Tp where peas in the first sowing matured more quickly. Peas in Dp (Pk) matured most quickly at the first and second sowing, Sp at the third. Tp had the slowest maturing peas in the first and second sowing, Dp (Pk) at the third sowing.

3.3.6 Dry Weight Distribution

The distribution of dry weight at the OHD in each sowing is plotted in Fig. 3.7. Means of cv and sowing date appear in Table 3.7.

1. Root. The cv x sowing interaction was not significant. Mean percent total dry weight in root was significantly smaller at later sowings.

interaction SE ±.647*

22 DF
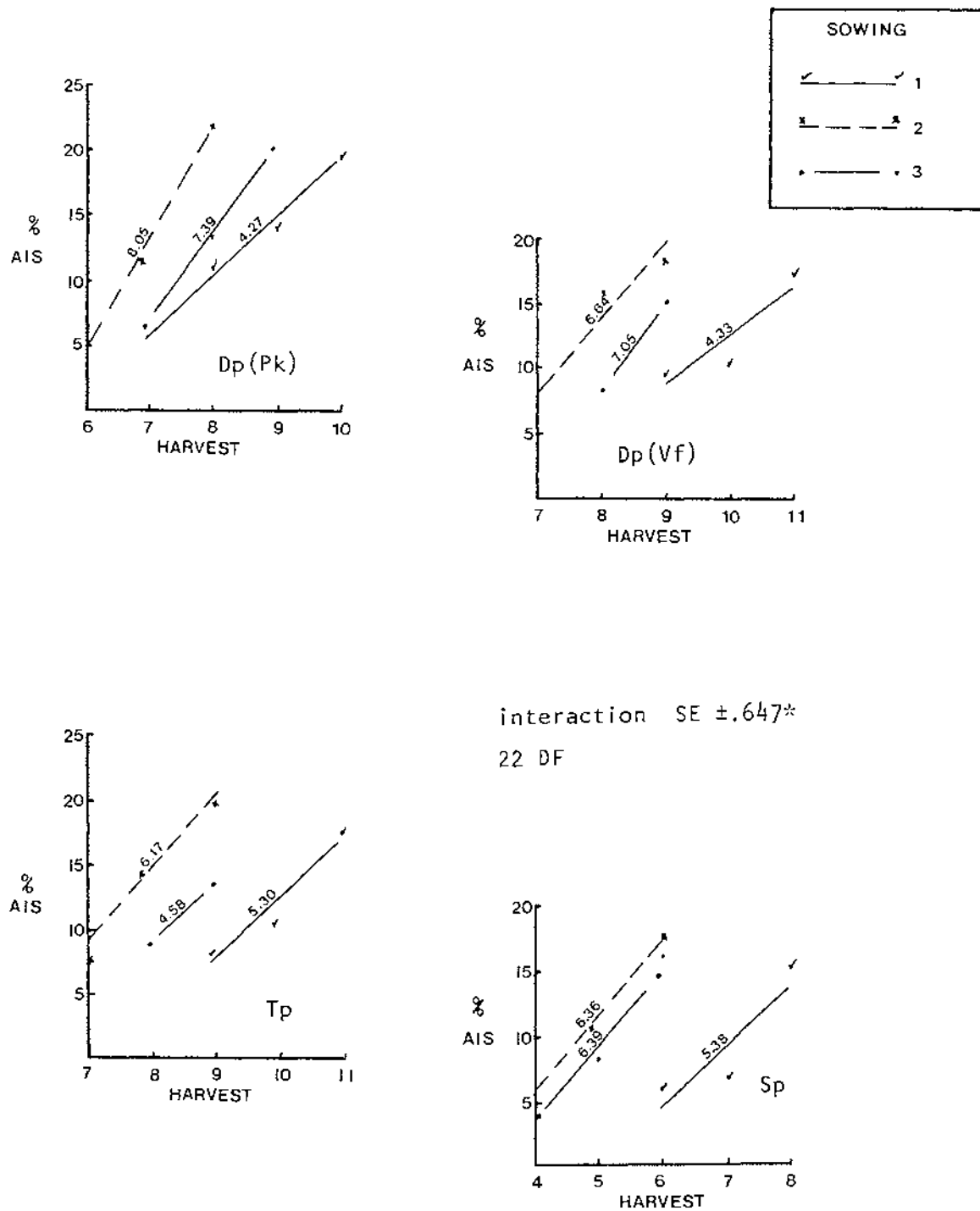
Fig. 3.6 Rate of crop maturity as indicated by slope of line
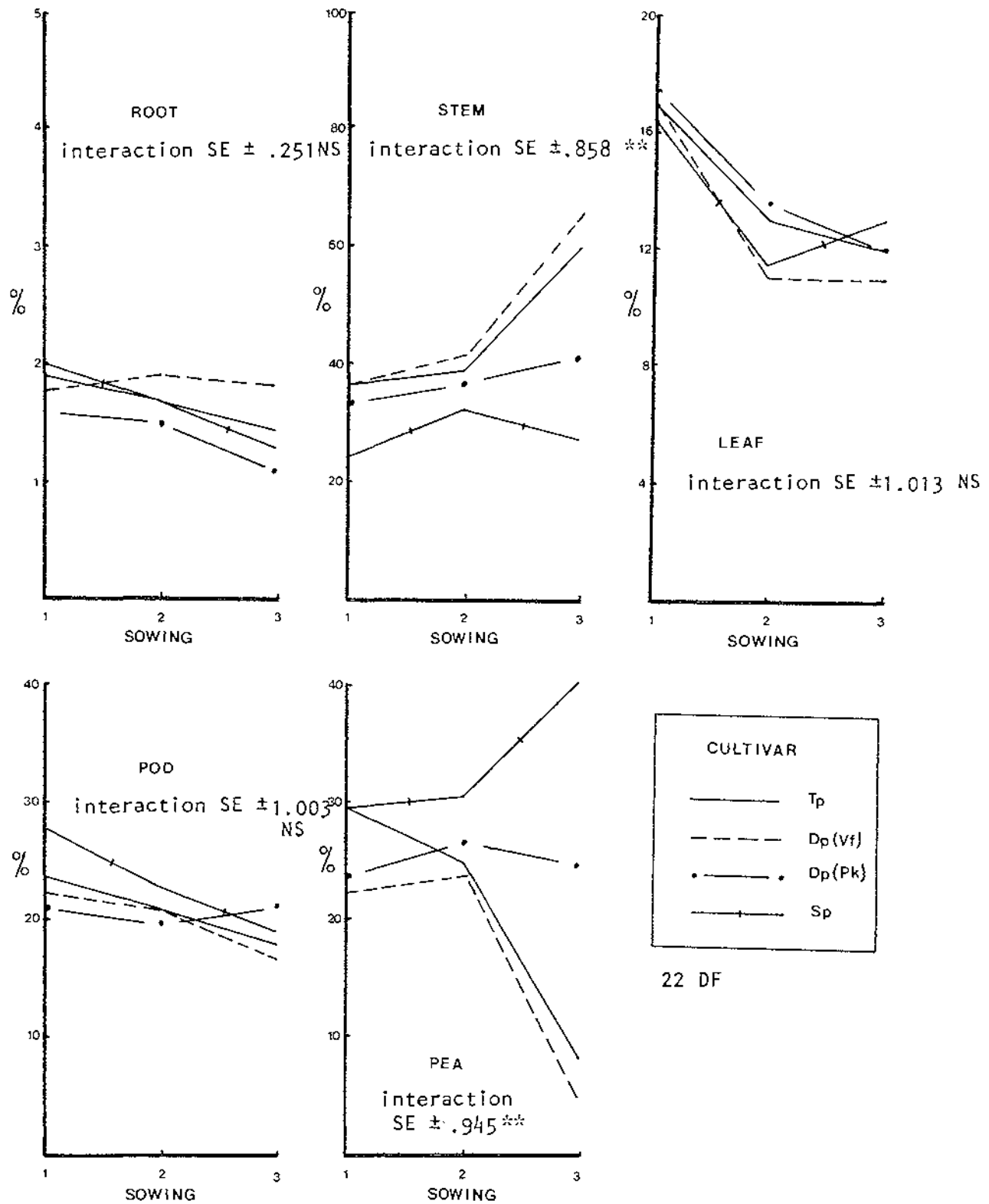
Fig 3.7 Distribution of dry weight (%) at the OHD. Statistical
analysis based on arcsine transformed data

The Dp (Vf) cv produced the largest mean percent in root, Dp (Pk) the smallest.

Table 3.7: Effect of Sowing Date on the Distribution of Dry Weight in Four Pea Cvs at the OHD.

Sowing	% of Total Plant Dry Weight				
	Root	Stem	Leaf	Pod	Pea
1	1.87	30.30	17.17	24.39	26.27
2	1.70	37.49	12.35	21.57	26.89
3	1.43	48.41	12.04	18.40	19.72
SE	±.125***	±.429***	±.506***	±.501***	±.472***
Cultivar					
Tp	1.27	42.20	14.22	21.04	21.27
Dp (Vf)	1.84	47.15	13.04	20.40	17.57
Dp (Pk)	1.43	37.41	14.43	21.14	25.29
Sp	1.71	27.83	13.67	23.59	33.20
SE	±.145***	±.495***	±.584 NS	±.579 NS	±.545***

22 DF Statistical analysis based on arcsine transformed data.

2. Stem. Percent total dry weight in stem increased with later sowing in all cvs except in Sp where a slight decrease occurred at the third sowing. The Dp (Vf) and Tp cvs produced the largest percent in stem, Sp the smallest at all sowings. The percent in stem of Dp (Pk) and Sp cvs did not differ greatly between sowings, however, Dp (Vf) and Tp cvs produced an approximate 20 to 30% higher percentage in stem with later sowing.

3. Leaf. The cv x sowing interaction was not significant. Mean percent total dry weight in leaf decreased with later sowing. No significant differences between cvs was obtained.

4. Pod. The cv x sowing interaction was not significant. Mean percent total dry weight in pod decreased with later sowing. No significant differences between cvs was obtained.

5. Pea. Percent total dry weight in pea decreased with later sowing in all cvs except in Sp where percent dry weight in pea increased particularly in the third sowing. Percent dry weight in pea decreased most with later sowing in the Tp cv and did not change appreciably in the Dp (Pk) cv.

6. Total Plant Dry Weight. Total plant dry weight in all cvs was the lowest at the second sowing. Generally, all cvs except Sp were the largest at the first sowing.

Table 3.8: Effect of Sowing Date on Total Plant Dry Weight in Four Pea Cvs at the OHD.

Sowing	Total Plant Dry Weight (g) at the OHD[1]				Mean[2]
	Tp	Dp (Vf)	Dp (Pk)	Sp	
1	12.285	13.062	12.838	7.437	11.405
2	9.514	8.063	9.330	6.703	8.402
3	10.006	8.540	10.850	8.190	9.397
Mean[3]	10.601	9.888	11.006	7.443	

22 DF   1. interaction SE ± .1967***   2. sowing SE ±.0983 ***
        2. cv SE ± .1135***

Sp was consistently the smallest cv at all sowings and plant size increased in this cv at the third sowing above that of earlier sowings.

3.3.7 Harvest Index

Harvest index measures on a dry weight basis the distribution of dry weight between vegetative and reproductive growth. Hardwick (1970) used the following equation to derive harvest index in peas:

$$\text{harvest index} = \frac{\text{pod weight} + \text{pea weight}}{\text{stem weight} + \text{leaf weight}}$$

Table 3.9: Effect of Sowing Date on Harvest Index in Four Pea Cvs at the OHD.

Sowing	Harvest Index at the OHD[1]				Mean[2]
	Tp	Dp (Vf)	Dp (Pk)	Sp	
1	1.01	.88	.91	1.42	1.05
2	.87	.89	.93	1.25	.98
3	.36	.29	.84	1.45	.74
Mean[3]	.75	.68	.89	1.37	

22 DF 1. interaction SE ±.068 **   2. sowing SE ±.034 ***
       3. cv SE ±.039 ***

Both Sp and Dp (Pk) cvs had a harvest index that did not change appreciably between sowings whereas the harvest index in Tp and Dp (Vf) cvs fell sharply particularly at the third sowing. Sp produced the largest harvest index at all sowings, Dp (Vf) generally the smallest.

3.4 Discussion

3.4.1 Growth and Development

The effects of sowing date on pea growth and development were not consistent in all cvs and were also quite different to results observed in the greenhouse experiment. The earliest maturity occurred at the second sowing, the latest at the first as shown in the number of weeks from sowing to the OHD (Table 3.6). Earliest maturity at the second rather than the third sowing occurred possibly due to the longer photo-period (day length) of mid December, higher light intensities and lower moisture conditions which usually accompany high temperatures. The earlier maturity at the second sowing resulted in smaller plants (Table 3.8), because the period of development was shortened without giving sufficient compensation by faster growth (Van Dobben 1962). This was also observed in the greenhouse experiment that high temperatures reduced total plant weight.

Growth analysis showed that generally, both RGR and NAR were lower and decreased more rapidly with time and with later sowing. RGR fell due to the decrease in NAR and LAR. NAR decreased possibly due to increased respiration at the higher temperatures which prevailed (Table 3.1) and a decreased photosynthetic rate (Yoshida 1972). The lower NAR and faster rate of development (as measured by the time to the OHD) at the second sowing resulted in smaller plants. SLA was not clearly affected by sowing date. LWR peaked earlier and was higher at the second sowing due to a more rapid plant development. This resulted in the earlier and higher peak in LAR at the second sowing. The earlier and higher peak in LAR in the second sowing was evidence of a more rapid development in plants where growth of leaves was promoted to a greater extent than growth of stems and roots. LAR was lower at the first and third sowing where plant size increased due to a lower rate of development.

At sowings 2 and 3, leaves comprised a greater proportion of the total plant dry weight and decreased more quickly due to a more rapid senescence of leaves and possibly due to the effect of pod development on total plant dry weight where developing pea seed competed for assimilates.

The fresh weight pea yield at each sowing was dependent upon good growing conditions. Pea yields were high in all cvs at the first sowing, particularly in Tp and Dp (Vf) due to a high NAR and favourable environment (Table 3.3). The lower NAR in the second sowing saw decreased yields only in the Tp and Dp (Vf) cvs. Dp (Pk) and Sp maintained a high yield despite the lower NAR probably due to a higher rate of translocation of assimilates to pods and peas where an adequate supply of assimilates existed to maintain yield. A more rapid rate of assimilate translocation from leaves into "sinks" (pods and peas) has been shown to increase photosynthesis (Vernon and Allison 1963; Thorne and Evans 1964; Sweet and Wareing 1966). Despite a possible higher photosynthetic rate, NAR did not increase probably due to an overall higher respiration rate. The use of a curve fitting technique may have "smoothed over" any effect on NAR. The higher mean temperatures of sowing 2 and 3 (Table 3.1) would have increased respiration which could account for the lower NAR. Yields of Dp (Pk) and Sp increased further and were the highest at the third sowing despite a still lower NAR and higher mean temperature. Because yield increased at the second and third sowings despite a decreasing NAR, assimilate supply must not have been limiting yield as it appeared to limit yield at high temperature in the greenhouse experiment. Yield in Tp and Dp (Vf) fell sharply in the third sowing because these later maturing cvs were exposed to warm and damp conditions which caused excessive leaf rot with flower and pod abortion, therefore overshadowing any effect due to NAR. Both Sp and Dp (Pk) were mature by this time.

Although fresh weight yield estimations derived by the Hardwick and Milbourn (1967) equation and the yield-tenderometer relationship

are quite similar, some differences arose (Table 3.3). Hardwick and Milbourn's derivation is based on a product of the number and weight of yield components. Berry's (1966) yield-tenderometer derivation assumes a curvilinear relationship between yield and maturity (in this study %AIS). This method derives a fresh weight yield taking into account the maturity of the peas at the time of harvest and their yield (weight) which is a direct result of the yield component contribution. These methods of derivation therefore arrive at differing estimations of fresh weight yield.

Changes in the harvest index with sowing like changes in fresh weight yield were also not only a result of NAR. Sp had consistently the highest harvest index which indicated that in the distribution of assimilates, pods and peas were favoured over leaves and stems. This was also evident in the pattern of dry weight distribution within the plant (Fig. 3.7). The Dp (Vf) cv had the lowest harvest index at all sowings indicating vegetative growth was favoured over reproductive growth in the amount of assimilates received. Both Dp (Pk) and Sp maintained a high harvest index at all sowings which decreased slightly in Dp (Pk) with later sowing probably due to the decrease in NAR. The harvest index in Tp and Dp (Vf) decreased at the second sowing most likely due to the decrease in NAR. The sharp drop these cvs had in both harvest index and fresh weight yield at the following third sowing was due largely to adverse weather conditions and not the low NAR. Flower and pod abortion was very evident. In this experiment, Sp was the earliest maturing cv with the lowest yield in general and the highest harvest index. Tp had the smallest harvest index and yielded the highest under favourable conditions as a later maturing cv. A cv like Sp in which reproductive growth is preferred in the amount of assimilates received resulted in low yields in comparison to other cvs. Harvest index has been emphasized as a possible selection criterion for high yield and earliness in many crops (Wallace 1973). To use harvest index as a selection tool for high yield and earliness in peas may be an oversimplification and should therefore be used with caution. This

possible error was also noted in the greenhouse experiment. Some consideration should be given to yield component behavior in combination with harvest index in peas as a yield selection criterion.

3.4.2 Components of Yield

Component analysis revealed that decreases in fresh weight yield were closely paralleled by a decreased number of yield components which is very closely related to harvest index. In three successive sowings, yield was the lowest in the second sowing (Table 3.3). This was in partial agreement with reports by Boswell (1926) and Wang (1962) who observed that yield in peas decreased with later sowing. All cvs, particularly Tp and Dp (Vf), had a reduced number of podding nodes with later sowing. The number of pods per node was the lowest in the second sowing and increased to the highest number in sowing 3. Total pod numbers decreased with later sowing in the high frequency podding cv, Tp and also the Dp (Vf) cv due to the large decrease in the number of podding nodes. This may have been a result of unfavorable environment in the third sowing which caused severe flower and pod abortion and also due to genetic differences (Yarnell 1962). The number of pods per node decreased at the second sowing possibly due to non-initiation of floral primordia in the shoot apex at high temperature conditions (Ormrod et al 1970) and possibly due to high temperature stress causing flower and pod abortion (Meadley and Milbourn 1970; Hole and Hardwick 1974; Hole 1977). It is also likely that developing pea seeds in competition for assimilates enhanced the senescence of the apical meristem, thereby reducing yield (Hedley 1979). Flower and pod abortion was evident in the Tp and Dp (Vf) cvs at the third sowing where total pod number and fresh weight yield were the lowest. However, in Dp (Pk) and Sp, the number of podding nodes decreased with later sowing and with an increase in the number of pods per node at the third sowing, the overall effect was an increase in total pod number. The number of pods retained may

have been controlled by the NAR (a measure of the amount of assimilate).
This was postulated in the greenhouse experiment. The number of peas
per pod decreased in all cvs with later sowing except in Sp where the
number of peas per pod did not change appreciably. The high harvest
index of Sp was the basis of this stability. Pea number decreased
possibly due to the lower NAR and also possibly due to reduced trans-
location of assimilates to pods and peas (Lambert and Linck 1958) and
also ovule abortion due to intra-pod competition for assimilates (Linck
1961). The weight per pea increased in response to a lessening of the
intra-pod competition from a reduced number of peas in each pod. Pea
number changed most in Dp (Pk) and least in Sp, a response attributed
to harvest index and intra-pod competition. Sp produced the heaviest
pea as it also did in the greenhouse experiment. Sp produced the heaviest
pea because in its distribution of assimilates, reproductive growth was
favoured over vegetative growth as indicated by the high harvest index.
The total number of peas decreased in Tp and Dp (Vf) because of the
reduction in number of peas per pod and podding nodes with later sowing.
Total pea number increased slightly at the third sowing in Sp due to an
increase in the number of pods per node. Total pea number in Dp (Pk)
remained steady because of an increase in the number of pods per node
at the third sowing and a decrease in the number of peas per pod with
later sowing.

This experiment like the greenhouse experiment failed to identify
one component as the major contributor to fresh weight yield variability
in all pea cvs (Table 3.4). Both Tp and Dp (Vf) attributed yield
variability largely to the number of peas per pod and both Dp (Pk) and
Sp to the number of pods per node. The number of podding nodes in Dp (Pk)
also contributed greatly to the variability in yield. As in the green-
house experiment, the hypothesis linking variation in pea yield with
the number of pods per node was rejected in part in this experiment as
was total pod number rejected by Hardwick et al (1979). The weight per

pea generally contributed least to yield variability in all cvs and
therefore did not support Hardwick's second hypothesis that the weight
of peas per plant was the main cause of yield variability. It appears
that yield variability in pea cvs of different podding habits is not
attributed to one component of yield alone, but rather the influence of
environment on pea growth and development and the interaction between
components.

All four cvs in this experiment recorded high correlations between
yield and a number of yield components (Table 3.5). Adverse environmental
conditions with possibly the lower NAR reduced yield in Tp and Dp (Vf)
largely through a reduced number of podding nodes and peas per pod,
particularly in Dp (Vf). Yield in Dp (Vf) did not decrease further
because of the compensatory effect by the increase in pea weight. Yield
in both Dp (Pk) and Sp increased at later sowings because the number of
pods per node was the only component to decrease signficantly. Yield
was maintained by component compensation. Component compensation, or
compensatory growth behavior, was observed in all cvs with significance
occurring in all but the Tp cv. If one component is favoured, for any
reason, over the other in the amount of assimilates received, a negative
correlation (component compensation) may arise between them (Adams 1967).
In Dp (Vf), the number of peas per pod decreased as the number of podding
nodes decreased but the weight per pea increased in response. In Dp (Pk),
a decrease in the number of podding nodes brought about a decrease in
the number of peas per pod but an increase in the weight per pea. In Sp,
as the number of podding nodes increased the number of pods per node
decreased. However, in a favourable environment where assimilate supply
is adequate, the potentials for high yield are seen in terms of positive
interactions, for yield increases through an increase in the number of
yield components. The reverse is true in an unfavourable environment as
was seen during the third sowing. Negative interactions contribute to
yield stability as occurred in both Dp (Pk) and Sp. The yield of these

early maturing cvs increased further in sowings 2 and 3 because of a net increase in component numbers which were supplied with sufficient amounts of assimilates. Because of the yield increases in these cvs, the lower NAR in sowings 2 and 3 did not appear to limit yield potential to the extent as did low NAR at high temperature in the greenhouse experiment. This was evident in the very much lower NAR $(x10^{-2})$ in the greenhouse experiment (Fig. 2.1) as compared to that in the field experiment (NAR $x10^{-1})$ (Fig. 3.5).

CHAPTER 4

Climate Room Experiment: The Effect of Temperature Treatments during
the Vegetative and Reproductive Growth Phases
on the Development of Three Pea Cultivars

4.1 Introduction

The two preceding experiments indicated that temperature markedly
influenced the growth and development of the pea plant. This experiment
was designed to investigate differences in development of three podding
types of pea cvs using high and low temperature treatments during both
the vegetative and reproductive growth phases.

4.2 Materials and Methods

Three cvs used in the previous two experiments were selected for
their node-podding habit: Puget, triple-podded (Tp), Puke, double-
podded (Dp) and William Massey, single-podded (Sp). Code designations
are the same as those used in the previous experiments.

Seeds were sown February 26, 1979 in 15 cm (1 liter) plastic pots
(6 seeds per pot) and thinned to three seedlings per pot to give a density
of approximately 100 plants/m^2. Growing medium consisted of a 50:50 (by
volume) sand:peat mix (appendix 2). Plants were initially grown for 14
days at 20 C in 6 m x 6 m greenhouses at Massey University and then moved
(when the facilities became available) to the climate rooms, Plant Physiology
Division, D.S.I.R. Refer to appendix 4 for details on the climate rooms.

Plants were divided between two climate rooms and randomly arranged
into 2 replications with the three cvs in each replicate. Each climate
room operated on a 12 hour day (160 ± 5 w/m^2 photosynthetic irradiance)
and a constant day-night temperature, one room at 15 C (low) and the
second at 25 C (high). Relative humidities were 58 and 77%, respectively,
to provide the same vapour pressure deficit. Carbon dioxide levels were

at 300 ppm. A manual weekly feeding of 200 ml North Carolina State University nutrient solution (appendix 3) was applied to each pot plus a daily watering. Plants were trained to bamboo canes and sprayed 5 weeks after sowing with one application of guthion (asinphosmethyl) 50 WP at 1 g per liter of water to control pests.

As each cv approached full bloom at the first podding node, approximately 50% of the pots were removed from the 25 C (high temperature) room and placed in the 15 C (low temperature) room and vice versa. The result was four treatments:

1. 15-15   a constant 15 C temperature

2. 25-25   a constant 25 C temperature

3. 25-15   25 C during the vegetative phase (V) and 15 C during the reproductive phase (R)

4. 15-25   15 C during the vegetative phase (V) and 25 C during the reproductive phase (R).

Harvest began when sizable peas (seeds) were evident and successive harvests continued every 3 days until peas showed visual signs of over-maturity such as wrinkling and color loss of the pod. One pot (3 plants) from each replicate was taken at each harvest.

The following data were recorded at each harvest:

1. stem, leaf and pod dry weight

2. number of podding nodes

3. number of pods at each podding node

4. number of peas at each podding node

5. fresh and dry weight of peas at each podding node

6. maturity, alcohol insoluble solids (%AIS) of peas at each podding node (refer to appendix 1 for procedures).

All plant parts were dried in a forced-air oven at 80 C for 72 hours and then weighed.

At each harvest, the number of podding nodes and the actual total number of pods and peas per plant were counted (sum over all podding nodes). The components of yield were derived by the procedures outlined in Section 2.2. Data were analysed as a. 3 x 4 (cv x temperature) and b. 2 x 2 x 3 (vegetative x reproductive x cv) factorial and appropriate standard error of means (SE) derived. The replicate effect was added to the error term as temperature treatments were not replicated. All data are expressed on a per plant basis. Level of significance is noted as follows:

not significant	NS
$p < 0.05$	*
$p < 0.01$	**
$p < 0.001$	***

4.3 Results

4.3.1 Components of Yield

The effect of temperature treatments on the components of yield in pea cvs is shown in Table 4.1a. Results of the cv x temperature treatment interactions appear in the upper half of the table while treatment means appear in the lower half of table 4.1a. Results of the vegetative x reproductive x cv (V x R x Cv) treatment interactions with means appear in tables 4.1b.

4.3.1.1 Number of Podding Nodes

There was a significant cv x temperature interaction indicating that high temperature (25 C) reduced the number of pod bearing nodes in all cvs. The V x R x Cv interaction was not significant. High temperature during the vegetative phase had a significant effect on the reduction of podding nodes in all cvs whereas high temperature during the reproductive phase did not. The number of podding nodes was reduced most in Tp. Dp had the lowest mean number of podding nodes, Tp the highest.

Table 4.1a: Effect of cv and temperature treatment during the vegetative and reproductive phase on components of yield in three pea cvs at the OHD

Cultivar/ Temperature (C)		Number			Fresh Weight (g) per Pea[4]	Total Number	
		Podding Nodes[1]	Pods/ Node[2]	Peas/ Pod[3]		Pods[5]	Peas[6]
Tp	15-15	3.1	1.36	3.93	.414	4.21	16.56
	25-25	2.0	.93	3.16	.394	1.86	5.87
	15-25	2.1	1.61	3.48	.324	3.38	11.76
	25-15	2.1	1.02	3.25	.404	2.14	6.96
Dp	15-15	3.0	1.14	4.80	.406	3.43	16.41
	25-25	1.5	.82	2.86	.427	1.24	3.51
	15-25	2.0	1.43	3.98	.419	2.86	11.38
	25-15	1.7	.59	3.92	.373	1.00	3.93
Sp	15-15	3.0	.76	5.39	.516	2.29	12.28
	25-25	2.0	.93	3.19	.463	1.86	5.93
	15-25	2.0	.87	2.84	.470	1.75	4.94
	25-15	2.0	.78	3.97	.516	1.56	6.19

interaction 12 DF 1. SE ± .10   *   2. SE ± .155 **   3. SE ± .298 ***
4. SE ± .0282 NS   5. SE ± .343 *   6. SE ± 1.769 NS

Tp		2.3	1.23	3.45	.384	2.89	10.28
Dp		2.0	.99	3.89	.406	2.13	8.80
Sp		2.2	.83	3.85	.491	1.86	7.33
	15-15	3.0	1.09	4.70	.445	3.31	15.08
	25-25	1.8	.89	3.07	.428	1.65	5.10
	15-25	2.0	1.30	3.43	.404	2.66	9.36
	25-15	1.9	.79	3.71	.431	1.56	5.69

mean 12 DF 1. cv SE ± .05   **   temperature SE ± .05   ***
2. cv SE ± .077   **   temperature SE ± .090   **
3. cv SE ± .149   *   temperature SE ± .172   NS
4. cv SE ± .0141 *** temperature SE ± .0163 NS
5. cv SE ± .172   **   temperature SE ± .198   ***
6. cv SE ± .885   NS   temperature SE ± 1.021 ***

Table 4.1b: Effect of high (25 C) and low (15 C) temperature during the vegetative and reproductive growth phase of peas on the number of yield components in three pea cvs at the OHD.

number of podding nodes

Growth Phase	Number of Podding Nodes			Mean
	Tp	Dp	Sp	
Vegetative 15 C	2.6	2.5	2.5	2.5
25 C	2.0	1.6	2.0	1.8
Reproductive 15 C	2.6	2.3	2.5	2.4
25 C	2.0	1.7	2.0	1.9
Mean	2.3	2.0	2.2	

12 DF   vegetative SE ± .04 ***   reproductive SE ± .04 ***
        V x R   SE ± .05 ***   V x Cv   SE ± .07 **
        R x Cv   SE ± .07 NS   cultivar   SE ± .05 **
        V x R x Cv SE ± .10 NS

number of pods per node

Growth Phase	Number of Pods per Node			Mean
	Tp	Dp	Sp	
Vegetative 15 C	1.48	1.28	.81	1.19
25 C	.97	.70	.85	.84
Reproductive 15 C	1.19	.86	.77	.94
25 C	1.27	1.12	.90	1.09
Mean	1.23	.99	.83	

12 DF   vegetative SE ± .063 ***   reproductive SE ± .063 NS
        V x R   SE ± .090 NS   V x Cv   SE ± .110 *
        R x Cv   SE ± .110 NS   cultivar   SE ± .077 **
        V x R x Cv SE ± .155 NS

total number of pods

Growth Phase	Total Number of Pods			Mean
	Tp	Dp	Sp	
Vegetative 15 C	3.79	3.14	2.02	2.98
25 C	2.00	1.12	1.71	1.61
Reproductive 15 C	3.17	2.21	1.92	2.43
25 C	2.62	2.05	1.80	2.15
Mean	2.89	2.13	1.86	

12 DF vegetative SE ± .140 *** reproductive SE ± .140 NS
       V x R   SE ± .198 *   V x Cv   SE ± .242 **
       R x Cv   SE ± .242 NS cultivar   SE ± .172 **
       V x R x Cv SE ± .343 NS

number of peas per pod

Growth Phase	Number of Peas per Pod			Mean
	Tp	Dp	Sp	
Vegetative 15 C	3.70	4.39	4.11	4.06
25 C	3.20	3.39	3.58	3.39
Reproductive 15 C	3.59	4.36	4.68	4.21
25 C	3.32	3.42	3.01	3.25
Mean	3.45	3.89	3.85	

12 DF vegetative SE ± .121 *** reproductive SE ± .121 ***
       V x R   SE ± .172 *   V x Cv   SE ± .211 NS
       R x Cv   SE ± .211 ** cultivar   SE ± .149 *
       V x R x Cv SE ± .298 *

total number of peas

Growth Phase	Total Number of Peas			Mean
	Tp	Dp	Sp	
Vegetative 15 C	14.16	13.89	8.61	12.22
25 C	6.41	3.72	6.06	5.39
Reproductive 15 C	11.76	10.17	9.23	10.38
25 C	8.81	7.44	5.43	7.23
Mean	10.28	8.80	7.33	

12 DF   vegetative SE ± .722 ***   reproductive SE ± .722 **
        V x R   SE ± 1.021 **   V x Cv   SE ± 1.251 **
        R x Cv   SE ± 1.251 NS   cultivar   SE ± .885 NS
        V x R x Cv SE ± 1.769 NS

fresh weight per pea

Growth Phase	Fresh Weight (g) per Pea			Mean
	Tp	Dp	Sp	
Vegetative 15 C	.369	.412	.493	.424
25 C	.399	.400	.489	.429
Reproductive 15 C	.409	.389	.516	.438
25 C	.359	.423	.466	.416
Mean	.384	.406	.491	

12 DF   vegetative SE ± .0115 NS   reproductive SE ± .0115 NS
        V x R   SE ± .0163 NS   V x Cv   SE ± .0200 NS
        R x Cv   SE ± .0200 NS   cultivar   SE ± .0141 ***
        V x R x Cv SE ± .0282 NS

4.3.1.2 Number of Pods per Node and Total Number of Pods

High temperature (25 C) reduced the number of pods per node in all cvs. This reduction was significant when high temperature occurred during the vegetative phase. Tp produced significantly more pods per node than either Dp or Sp and also had generally the highest reduction of pods per node when high temperature occurred.

Total pod number in all cvs was also reduced by high temperature when it occurred during the vegetative phase. The highest frequency podding cvs, Tp and Dp, had the highest mean number of pods per node and also the highest reduction or loss of pods when high temperature occurred. The opposite was true for Sp.

4.3.1.3 Number of Peas per Pod and Total Number of Peas

The number of peas per pod significantly decreased in all cvs when high temperature (25 C) occurred during the reproductive phase. The number of peas per pod decreased most in Sp in the presence of high temperature, whereas pea number per pod decreased only slightly in Dp and Tp cvs.

Total number of peas was significantly reduced in all cvs when high temperature occurred during the vegetative phase. Tp and Dp cvs had the highest reduction in total number of peas. This was earlier observed to occur in both cvs as high temperature also reduced total pod number in these two cvs. The mean total number of peas was also reduced by high temperature during the reproductive phase, but the reduction was not as highly significant as it was during the vegetative phase.

4.3.1.4 Fresh Weight per Pea

There was no significant effect of temperature or any of the interactions on the fresh weight per pea. The only significant difference found was between the cvs with Sp producing the heaviest and Tp the lightest pea weight when harvested at the OHD.

4.3.2 Fresh Weight Yield

The fresh weight yield was derived by the : a. yield component equation (3) and b. yield-tenderometer relationship (4). For details as to application of these equations, refer to Section 2.2.

Table 4.2a: Effect of temperature treatment on the fresh weight yield of three pea cvs at OHD where "a" denotes yields derived by the yield component equation, "b" denotes yields derived by the yield-tenderometer relationship.

| Temperature (C) | Fresh Weight Yield (g) at the OHD[1] | | | | | | | |
| | Tp | | Dp | | Sp | | Mean[2] | |
	a	b	a	b	a	b	a	b
15-15	6.855	8.798	6.662	8.516	6.363	8.269	6.626	8.527
25-25	2.312	2.619	1.498	1.977	2.745	2.757	2.185	2.451
15-25	3.810	3.625	4.768	5.217	2.321	2.668	3.633	3.836
25-15	2.811	2.871	1.465	2.182	3.194	3.843	2.490	2.965
Mean[3]	3.947	4.478	3.598	4.473	3.655	4.384		

12 DF
1. interaction a. SE ± .6541 * b. SE ± .8359 NS
2. temperature a. SE ± .3776 *** b. SE ± .4826 ***
3. cv a. SE ± .3270 NS b. SE ± .4179 NS

Only the interaction of cv x temperature (Table 4.2a) in the yield component (a) fresh weight yield derivation was significant. In all cvs, a constant low temperature (15-15 C) produced the highest yield whereas high temperature (25 C) whenever present always reduced yield. The V x R x Cv interaction (Table 4.2b) resulted in no significant effect on fresh weight yield. Mean fresh weight yield was significantly reduced by high temperature (25 C) during both growth phases with the vegetative phase being most sensitive to high temperature. Fresh weight yield in all cvs was significantly reduced when high temperature occurred during

the vegetative growth phase. This was particularly evident in both Tp and Dp cvs. No significant differences in mean fresh weight yield at OHD was observed between cvs in either method of yield derivation.

Table 4.2b: Effect of high (25 C) and low (15 C) temperature during the vegetative and reproductive growth phase of peas on fresh weight yield of three pea cvs at OHD where yield has been derived by the yield component equation (a) and Berry's yield-tenderometer relationship (b).

a. fresh weight yield (yield component)

		Fresh Weight Yield (g) at the OHD			
Growth Phase		Tp	Dp	Sp	Mean
Vegetative	15 C	5.332	5.715	4.342	5.129
	25 C	2.561	1.481	2.969	2.337
Reproductive	15 C	4.833	4.063	4.778	4.558
	25 C	3.061	3.133	2.533	2.909
Mean		3.947	3.598	3.655	

12 DF vegetative SE ± .2670 *** reproductive SE ± .2670 ***
       V x R   SE ± .3776 *** V x Cv   SE ± .4625 **
       R x Cv   SE ± .4625 NS   cultivar   SE ± .3270 NS
       V x R x Cv SE ± .6541 NS

b. fresh weight yield (Berry equation)

Growth Phase		Fresh Weight Yield (g) at the OHD			
		Tp	Dp	Sp	Mean
Vegetative	15 C	6.211	6.866	5.468	6.181
	25 C	2.745	2.079	3.300	2.708
Reproductive	15 C	5.834	5.349	6.056	5.746
	25 C	3.122	3.597	2.712	3.143
Mean		4.478	4.473	4.384	

```
12 DF   vegetative SE ± .3412 ***   reproductive SE ± .3412 ***
        V x R      SE ± .4826 ***   V x Cv       SE ± .5911 *
        R x Cv     SE ± .5911 NS    cultivar     SE ± .4179 NS
        V x R x Cv SE ± .8359 NS
```

In nearly every case, method b, the yield-tenderometer relationship derived higher yield estimations. The largest differences occurred in the 15-15 treatment whereas at all other temperatures the differences in the two yield derivations (Table 4.2a) were very slight.

4.3.3   Interaction of Yield Components and Their Relationship to Yield

Step-wise multiple regression was used to measure the relative magnitude of the contribution of each component to yield variability.

The number of podding nodes in all cvs contributed the most to variability in yield, weight per pea the least. Yield variability in Sp was almost entirely due to the number of podding nodes, whereas in the Sp cv a large contribution was also attributed to the number of pods per node.

Table 4.3: Relative contribution of yield components to variablility in
fresh weight yield of three pea cvs (yield based on the
Hardwick & Milbourn, 1967 equation)

| Component | Contribution to R^2 [1] | | |
| | Cultivars | | |
	Tp	Dp	Sp
number of podding nodes	.880	.762	.934
number of pods per node	.096	.189	.011
number of peas per pod	.007	.037	.045
weight per pea	.008	.015	.005

1. the coefficient of determination (R^2) measure increments in the vari-
ability of a single yield component, taken as a dependent variable
and accounted for after including each preceding yield component seqent-
ially (as listed in the table) in a step-wise multiple regression.

The interaction between components of yield is measured directly by
the correlation coefficient. Negative correlations suggest compensation
of one component by another. Positive correlations suggest that environ-
mental factors can improve two yield components at the same time without
compensatory losses in yield, (Table 4.4).

Yield in all three cvs had a significant positive correlation with
the number of podding nodes and number of peas per pod. The Dp cv also
had a significant positive correlation between the number of pods per
node and yield. The weight per peas was not significantly correlated with
yield in any cv. There was only one positive interaction between yield
components in Tp and Dp cvs and that was between the number of podding
nodes and the number of peas per pod. Dp had the higher level of
significance. Sp had positive interactions between the number of podding
nodes and number of peas per pod, as well as between the number of peas

Table 4.4: Correlation coefficients as a measure of interaction between yield components and component relationship to fresh weight yield in three pea cvs.

Dependent Variable	Independent Variable											
	Podding Nodes			Pods per Node			Peas per Pod			Weight per Pea		
	Tp	Dp	Sp	Tp	Dp	Sp	Tp	Dp	Sp	Tp	Dp	Sp
Podding Nodes		1.0										
Pods per Node	.26	.36	-.57		1.0							
Peas per Pod	.75*	.79**	.90**	.41	.24	-.71*		1.0				
Weight per Pea	.45	-.17	.48	-.55	.10	-.83**	.16	-.12	.68*		1.0	
Yield	.94**	.86**	.97**	.54	.71*	-.58	.82**	.78**	.97**	.26	.05	.57

7 DF

per pod and weight per pea. All cvs showed some degree of component compensation, however, only the Sp cv had significant negative interactions between components. These were between the number of pods per node and number of peas per pod and between the number of pods per node and weight per pea.

4.3.4 Maturity Assessment

4.3.4.1 Weeks to Optimum Harvest Date (OHD)

All interactions were highly significant. High temperature (25 C) significantly reduced the mean number of weeks from sowing to optimum harvest whether it occurred during either the vegetative or reproductive growth phase. At a constant low temperature (15-15 treatment) the longest period to maturity was required (Table 4.5a).

Table 4.5a: Effect of temperature treatment on the number of weeks from sowing to the OHD in three pea cvs.

Temperature (C)	Number of Weeks to the OHD[1]			Mean[2]
	Tp	Dp	Sp	
15-15	16.80	16.22	10.35	14.45
25-25	10.20	8.93	5.65	8.26
15-25	11.43	10.44	7.78	9.88
25-15	16.66	10.42	8.65	11.91
Mean[3]	13.77	11.50	8.10	

12 DF   1. interaction SE ± .131 ***   2. temperature SE ± .075 ***
        3. cv   SE ± .065 ***

High temperature during both vegetative and reproductive growth phases enhanced the rate of pea growth and development whereas low temperature delayed growth and development. Though both were highly

significant, high temperature during the reproductive phase rather than the vegetative phase had a greater effect on reducing the mean number of weeks required to reach OHD in peas (Table 4.5b). Tp was consistently the latest maturing and Sp the earliest maturing cv.

Table 4.5b: Effect of high (25 C) and low (15 C) temperature during the vegetative and reproductive growth phase of three pea cvs on the number of weeks to the OHD.

| Growth Phase | Number of Weeks to the OHD | | | |
	Tp	Dp	Sp	Mean
Vegetative 15 C	14.11	13.33	9.06	12.16
25 C	13.43	9.67	7.15	10.08
Reproductive 15 C	16.73	13.32	9.50	13.18
25 C	10.81	9.68	6.71	9.07
Mean	13.77	11.50	8.10	

12 DF   vegetative SE ± .053 ***   reproductive SE ± .053 ***
        V x R   SE ± .075 ***   V x Cv   SE ± .092 ***
        R x Cv   SE ± .092 ***   cultivar   SE ± .065 ***
        V x R x Cv SE ± .131 ***

4.3.4.2 Rate of Pea Maturity

The increase in pea maturity as measured by the slope in %AIS with successive harvests can indicate the rate at which peas (seeds) matured (Fig. 4.1). Means of cv and temperature treatments in the cv x temperature analysis appear in appendix 5. Values for both analyses were adjusted to correspond to a seven day interval.

The cv x temperature interaction was not significant with only mean temperature differences showing significance. Constant low temperature (15-15 treatment) delayed maturity rate of peas the most and a constant high temperature (25-25) increased maturity most rapidly (Fig. 4.1).
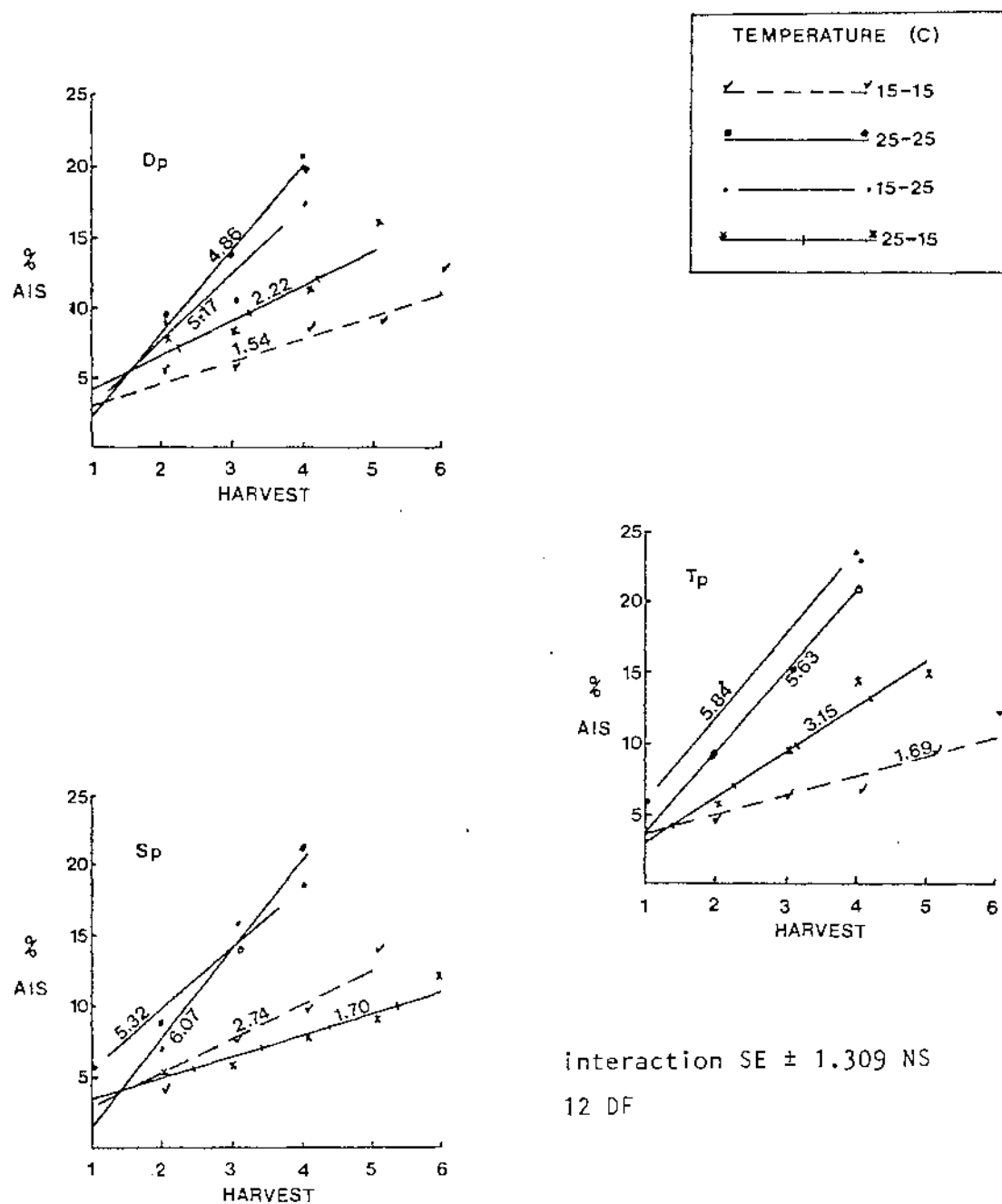
Fig. 4.1 Rate of crop maturity as indicated by slope of line

The only significance observed in the V x R x Cv analysis was between reproductive treatment means (Table 4.6). High temperature during the reproductive growth phase increased the mean rate of pea maturity significantly over low temperature during the same phase. The rate of increase was over twice that of low temperature.

Table 4.6: Effect of high (25 C) and low (15 C) temperature during the vegetative and reproductive growth phase of three pea cvs on the rate of pea maturity.

Growth Phase		Rate of Pea Maturity			Mean
		Tp	Dp	Sp	
Vegetative	15 C	3.76	3.36	4.03	3.71
	25 C	4.39	3.54	3.88	3.93
Reproductive	15 C	2.42	1.88	2.22	2.17
	25 C	5.73	5.02	5.69	5.48
Mean		4.07	3.45	3.95	

12 DF	vegetative	SE ±	.534 NS	reproductive	SE ± .5345 ***
	V x R	SE ±	.755 NS	V x Cv	SE ± .925 NS
	R x Cv	SE ±	.925 NS	cultivar	SE ± .654 NS
	V x R x Cv	SE ±	1.309 NS		

4.3.5 Dry Weight Distribution

The distribution of dry weight at the OHD is illustrated in Fig. 4.2 with interaction standard errors of means as derived in the temperature x cv analysis of data. Means for the temperature x cv analysis appear in Table 4.7a, and Table 4.7b for the V x R x Cv analysis.

No roots were collected in this study.

Table 4.7a: Effect of temperature treatment on the distribution of dry weight in three pea cvs at the OHD.

Temperature (C)	% of Total Plant Dry Weight			
	Stem	Leaf	Pod	Pea
15-15	36.60	17.90	21.50	24.00
25-25	46.08	17.66	19.53	16.73
15-25	44.79	13.30	19.64	20.27
25-15	42.58	19.04	21.59	16.79
SE	±1.360 **	±2.072 NS	±1.933 NS	±1.120 **
Cultivar				
Tp	53.24	15.09	18.36	13.31
Dp	51.81	16.39	16.30	15.50
Sp	22.45	20.95	27.04	29.56
SE	±1.178 ***	±1.794 *	±1.674 ***	±.969 ***

12 DF   Statistical analyses based on arcsine transformed data.

1.   Stem.   Percent total dry weight in stem was similar in Tp and Dp cvs, but was consistently the lowest in the Sp cv at all temperature treatments (Fig. 4.2).   The Dp and Sp cvs responded by increasing and decreasing, respectively, percent weight in stem at high temperature during the vegetative phase (Table 4.7b).   Sp had signficantly the lowest mean percent stem weight.

2.   Leaf.   None of the interactions in either analysis were significant. Only cvs were significantly different in percent leaf dry weight.   Both Tp and Dp cvs were similar in leaf percent of total dry weight, but were significantly less than was recorded for Sp.

3.   Pod.   Percent total dry weight in pod was consistently the highest in Sp at all temperature treatments (Fig. 4.2).   Sp maintained stability in percent total dry weight in pod with high and low temperature exposure, however, in Tp pod weight increased significantly with high temperature
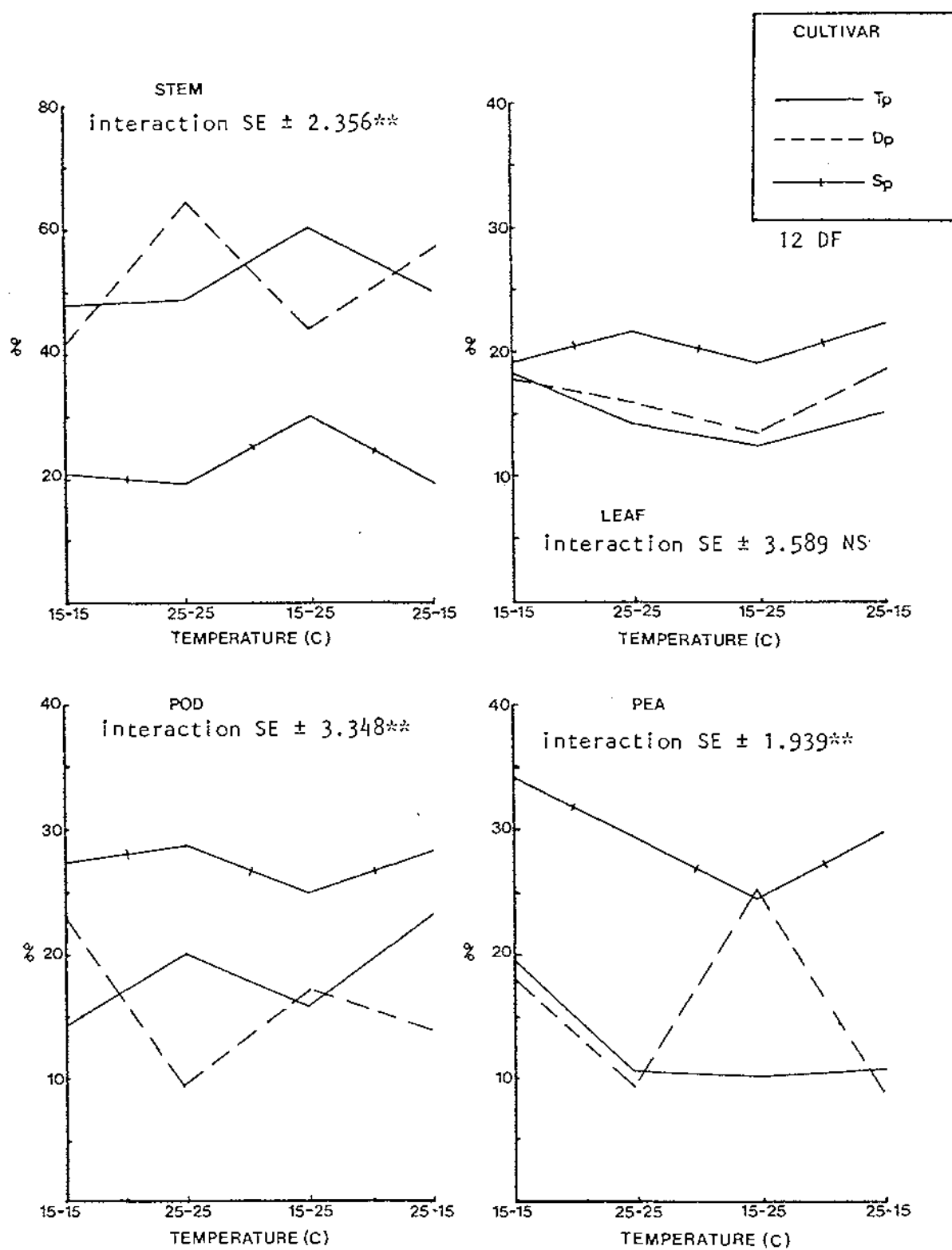
Fig. 4.2   Distribution of dry weight (%) at the OHD.   Statistical
analysis based on arcsine transformed data.

Table 4.7b: Effect of high (25 C) and low (15 C) temperature during the
vegetative and reproductive growth phase of three pea cvs
on the percent dry weight distribution of stem, leaves,
pods and peas at the OHD (statistical analyses based on
arcsine transformed data).

stem

| Growth Phase | % Stem of Total Dry Weight | | | |
	Tp	Dp	Sp	Mean
Vegetative 15 C	54.16	42.60	25.19	40.65
25 C	52.28	60.99	19.72	44.33
Reproductive 15 C	49.23	49.51	20.04	39.59
25 C	57.21	54.23	24.87	45.43
Mean	53.22	51.83	22.45	

12 DF   vegetative SE ± .962 NS   reproductive SE ± .962 **
        V x R   SE ± 1.360 NS   V x Cv   SE ± 1.666 ***
        R x Cv   SE ± 1.666 NS   cultivar   SE ± 1.178 ***
        V x R x Cv SE ± 2.356 NS

leaf

| Growth Phase | % Leaf of Total Dry Weight | | | |
	Tp	Dp	Sp	Mean
Vegetative 15 C	15.42	15.44	19.01	16.62
25 C	14.76	17.34	22.90	18.33
Reproductive 15 C	16.44	18.16	20.83	18.47
25 C	13.74	14.62	21.07	16.47
Mean	15.09	16.39	20.95	

12 DF   vegetative SE ± 1.465 NS   reproductive SE ± 1.465 NS
        V x R   SE ± 2.072 NS   V x Cv   SE ± 2.537 NS
        R x Cv   SE ± 2.537 NS   cultivar   SE ± 1.794 *
        V x R x Cv SE ± 3.589 NS

pod

	% Pod of Total Dry Weight			
Growth Phase	Tp	Dp	Sp	Mean
Vegetative 15 C	15.15	20.44	26.14	20.57
25 C	21.59	12.18	27.94	20.57
Reproductive 15 C	18.62	18.88	27.18	21.56
25 C	18.09	13.72	26.90	19.57
Mean	18.36	16.30	27.04	

```
12 DF   vegetative  SE ± 1.367 NS   reproductive SE ± 1.367 NS
        V x R       SE ± 1.933 NS   V x Cv       SE ± 2.367 **
        R x Cv      SE ± 2.367 NS   cultivar     SE ± 1.674 ***
        V x R x Cv  SE ± 3.348 NS
```

pea

	% Peas of Total Dry Weight			
Growth Phase	Tp	Dp	Sp	Mean
Vegetative 15 C	15.27	21.52	29.66	22.15
25 C	11.37	9.49	29.44	16.76
Reproductive 15 C	15.66	13.45	31.95	20.35
25 C	10.96	17.43	27.16	18.51
Mean	13.31	15.47	29.55	

```
12 DF   vegetative  SE ±  .791 ***   reproductive SE ±  .791 NS
        V x R       SE ± 1.120 NS    V x Cv       SE ± 1.371 **
        R x Cv      SE ± 1.371 *     cultivar     SE ±  .969 ***
        V x R x Cv  SE ± 1.939 NS
```

(25 C) during the vegetative phase and in Dp pod weight decreased with exposure to high temperature during the vegetative phase (Table 4.7b). Temperature had no significant effect on percent pod weight in cvs during the reproductive phase. The Sp cv had the highest mean percent total dry weight in pod of all the cvs.

4. Pea. Percent total dry weight in peas was generally the highest in Sp at all temperature treatments (Fig. 4.2). Though both were significant, high temperature (25 C) during the vegetative phase reduced the percent weight in peas in all cvs more than during the reproductive phase (Table 4.7b). Dp was particularly sensitive to high temperature during the vegetative phase; Tp was sensitive to high temperature during both phases whereas Sp was least sensitive to V x Cv and R x Cv interactions.

5. Total Plant Dry Weight. Total plant dry weight decreased in the presence of high temperature (25 C) in all cvs, and particularly in Dp when high temperature occurred during the vegetative phase (Tables 4.8a and 4.8b). There was no significant R x Cv interaction. Mean total plant dry weight was reduced significantly whether high temperature occurred during the vegetative or reproductive growth phase. Sp produced the smallest total plant dry weight that varied the least between temperature treatments. Tp was the largest plant almost consistently.

Table 4.8a: Effect of temperature treatment on total plant dry weight
in three pea cvs at the OHD.

| Temperature (C) | Total Plant Dry Weight(g) at the OHD[1] | | | Mean[2] |
	Tp	Dp	Sp	
15-15	13.200	13.126	6.829	11.051
25-25	4.991	3.792	2.171	3.651
15-25	5.791	6.658	2.773	5.074
25-15	5.401	4.426	2.856	4.227
Mean[3]	7.345	7.001	3.657	

12 DF   1.   interaction SE ± .7487 **   2.   temperature SE ± .4322 ***
3.   cv SE ± .3743 ***

Table 4.8b: Effect of high (25 C) and low (15 C) temperature during the
vegetative and reproductive growth phase of three pea cvs
on total plant dry weight at the OHD.

| Growth Phase | | Total Plant Dry Weight at the OHD | | | Mean |
		Tp	Dp	Sp	
Vegetative	15 C	9.495	9.892	4.801	8.062
	25 C	5.196	4.109	2.513	3.939
Reproductive	15 C	9.300	8.776	4.842	7.639
	25 C	5.391	5.225	2.472	4.362
Mean		7.345	7.001	3.657	

12 DF   vegetative SE ± .3056 ***   reproductive SE ± .3056 ***
V x R   SE ± .4322 ***   V x Cv   SE ± .5294 **
R x Cv   SE ± .5294 NS   cultivar   SE ± .3743 ***
V x R x Cv SE ± .7487 NS

4.3.6 Harvest Index

Harvest index measures on a dry weight basis the distribution of dry weight between vegetative and reproductive growth. Hardwick (1970) used the following equation to derive harvest index in peas:

$$\text{harvest index} = \frac{\text{pod weight + pea weight}}{\text{stem weight + leaf weight}}$$

Table 4.9a: Effect of temperature treatment on the harvest index in three pea cvs at the OHD.

Temperature (C)	Harvest Index at the OHD[1]			Mean[2]
	Tp	Dp	Sp	
15-15	.51	.70	1.60	.93
25-25	.46	.24	1.37	.69
15-25	.37	.74	1.03	.71
25-15	.53	.31	1.30	.71
Mean[3]	.47	.50	1.32	

12 DF 1. interaction SE ± .147 **   2. temperature SE ± .085 *
       3. cv SE ± .073 ***

Treatment interactions were significant in both analyses (Tables 4.9a and 4.9b). The presence of high temperature reduced harvest index in all cvs. High temperature during the vegetative phase severely reduced harvest index in the Dp cv, harvest index in the Tp and Sp cvs remained relatively stable, increasing slightly. High temperature during the reproductive phase had no significant effect on harvest index in cvs. Mean harvest index in Tp and Dp cvs was the lowest with that of Sp higher by more than double that of the other two cvs. Harvest index in Sp was also the highest in all temperature x cv interactions.

Table 4.9b: Effect of high (25 C) and low (15 C) temperature during
the vegetative and reproductive growth phase of three pea
cvs on harvest index at the OHD.

| Growth Phase | Harvest Index at the OHD | | | Mean |
	Tp	Dp	Sp	
Vegetative 15 C	.44	.72	1.31	.82
25 C	.49	.27	1.33	.70
Reproductive 15 C	.52	.50	1.45	.82
25 C	.41	.49	1.20	.70
Mean	.47	.50	1.32	

```
12 DF   vegetative SE ± .060 *    reproductive SE ± .060 *
        V x R      SE ± .085 NS   V x Cv       SE ± .104 **
        R x Cv     SE ± .104 NS   cultivar     SE ± .073 ***
        V x R x Cv SE ± .147 *
```

4.4 Discussion

4.4.1 Growth and Development

The effects of high (25 C) and low (15 C) temperature treatments during the vegetative and reproductive growth phase on peas indicated that earlier maturity and lower fresh weight yields were due to high temperature's effect on the growth and development of the pea plant. High temperature reduced total plant dry weight and also generally reduced the number of yield components, which in the three cvs was shown to vary depending on the growth phase in which high temperature occurred.

The presence of high temperature during either growth phase reduced the number of weeks required for all cvs to reach the optimum harvest date. The most significant mean reduction was observed when high temperature occurred during the reproductive phase of growth (Tables 4.5a and b). A constant low temperature (15-15) delayed pea growth and development the most. High temperature accelerated pea growth and development, however, increased respiration may have reduced the assimilate level which resulted in the observed earlier maturity and consequent reduction in fresh weight yield (Van Dobben 1962). Similar observations related to high temperature and the rate of pea maturity indicated that the mean rate of pea maturity increased significantly only when high temperature occurred during the reproductive growth phase (Table 4.6, Fig. 4.1). Low temperature delayed pea maturity. It appears that high temperature accelerated the transport of assimilates to the developing peas (seeds), the reproductive phase which was marked by the development of strong sinks (Lovell et al, 1972). Earlier maturity characterized by the onset of the reproductive phase resulted in reduced total plant dry weight.

Total plant dry weight in all cvs was significantly lower when high temperature occurred during the vegetative phase (Table 4.8a and 4.8b).

High temperature during the reproductive phase had no significant cv effect on total plant dry weight. Largest plants were produced at a constant low temperature (15-15 C) where more assimilates may have been available for plant growth because a lower respiration rate may have utilized fewer assimilates. Total plant dry weight in Sp was consistently the lowest in all temperature treatments and it decreased the most in Tp whenever high temperature occurred.

Distribution of assimilates within the plant showed that stem weight as a percent of total dry weight was lowest in Sp at all temperature treatments (Table 4.7a, Fig. 4.2). Stem weight decreased significantly when high temperature occurred during the vegetative phase in Sp, but increased in Dp. There was little change in Tp (Table 4.7b). Mean leaf weight was highest in Sp. Both Dp and Tp cvs were larger and later maturing than Sp, yet Sp directed more assimilates to pods and peas (reproductive structures) than did either of the other two cvs. Total pod dry weight was consistently highest in Sp at all temperature treatments and also varied little between temperature treatments. Only during the vegetative phase did high temperature significantly increase pod weight in Tp and decrease pod weight in Dp. Total pea dry weight in Tp and Sp cvs was reduced significantly by high temperature during the reproductive phase and in both Tp and Dp cvs it was reduced by high temperature during the vegetative phase. The Tp cv appeared to yield a lighter pea in either growth phase that high temperature occurred. Based on dry matter distribution patterns, Dp appeared to be a high temperature vegetative phase sensitive cv and Sp showed some sensitivity to high temperature in the reproductive phase. Tp was an overall high temperature sensitive cv. This response in dry weight distribution due to temperature was effective in determining fresh weight yield.

Fresh weight yield differences between treatments showed that yield was reduced significantly in all cvs by high temperature when it occurred during the vegetative phase (Table 4.2b). The R x Cv interaction

was not significant. The Dp cv had the most significant yield reduction when high temperature occurred during the vegetative phase and Tp followed closely behind. Yield in Sp decreased to a much lesser extent. Higher yields in all cvs occurred at low temperature where a higher NAR due possibly to a reduced respiration rate may have resulted in a larger assimilate supply and more rapid translocation of assimilates into pods and peas (Lambert and Linck 1958). Larger plants at low temperature had greater yield potential due to a larger photosynthetic area (seen in a higher percent leaf dry weight), hence assimilate supply. The yield-tenderometer derivation method given by Berry (1966) quite consistently arrived at slightly higher yield estimates than did Hardwick and Milbourn's yield component equation. The differences may have arisen from the curvilinear approach using maturity to determine yield (Berry) and the product of yield components at a specific point in pea maturity to determine yield (Hardwick). Fitting data to a curve tends to smooth-over fluctuations in data and therefore the results may be a compromise.

Harvest index in all cvs decreased in the presence of high temperature probably due to reduced total plant dry weights from a lower NAR (Tables 4.9a and b). It was most clearly evident in Dp that harvest index was reduced most by high temperature during the vegetative phase, earlier noted in dry weight distribution patterns. This cv's sensitivity to high temperature during the vegetative phase was shown in a reduced distribution of dry weight to pods and peas and also reduced fresh weight yield. Harvest index in Tp and Sp cvs appeared to show no consistent behavior under variable temperature treatments. Sp consistently produced the highest harvest index indicating that this cv favored pods and peas (reproductive growth) over stems and leaves (vegetative growth) to the amount of assimilates received. Sp was also the earliest maturing cv. Harvest index can be used to measure the amount of assimilates distributed between vegetative and reproductive growth in a plant and the high harvest index in Sp may indicate a selective distribution of assimilates occurs

in peas which is regulated by temperature. High temperature in the
previous two experiments was shown to reduce NAR probably due to an
increase in respiration. Fewer assimilates means a lowering of harvest
index values, lower total plant dry weights and a reduction in fresh
weight pea yield. Under stress, survival of a species may induce a
selective distribution of assimilates to reproductive structures. The
Sp cv in particular exhibited such behavior. The danger exists that
harvest index may be used as a selection criterion for high yield and
earliness in some crops (Wallace 1973). This experiment showed that this
method of selection can overlook the effect temperature has on distribution
of assimilates within the plant and the plant's sensitivity to temperature
variation during vegetative and reproductive growth phases. Sp was the
earliest maturing cv, had consistently the highest harvest index yet
this cv was shown to be very sensitive to high temperature during the
reproductive phase and as a result fresh weight yield rose and fell
according to temperature's influence. A high harvest index in peas
does not appear to guarantee earliness and high yield in all cvs.

4.4.2 Components of Yield

The number of podding nodes in all cvs was reduced when high temperature
occurred during vegetative and reproductive growth phases, but was
significant only when high temperature occurred during the vegetative
phase (Tables 4.1a and b). The Tp cv had the highest reduction in number
of podding nodes. The number of pods per node in all cvs was also
reduced by high temperature when it occurred during the vegetative phase.
The R x Cv interaction was not significant. The reduction of podding
nodes and number of pods per node under high temperature was possibly
due to flower and pod abortion caused by stress and also intrapod
competition for assimilates (Linck 1961). The first pod set may have had
an advantage over later pods in the amount of assimilates received
(Clay 1935; Lamprecht 1952; Ibarbia & Bienz 1970), particularly at
high temperatures. Although not recorded, flower and pod abortion

was seen to occur at 25 C treatments. The number of pods per node and total pod number was highest in Tp, a cv capable of a multiple podding habit. It was high temperature during the vegetative phase and not the reproductive phase that reduced pod number in all cvs. Total pod number decreased as a result of fewer podding nodes and pods per node at high temperature where smaller plants were less able to supply more assimilates. The high frequency podding cv, Tp, appeared to have more pods per plant which aborted or failed to develop in high temperature treatments. The number of peas per pod decreased significantly in all cvs when high temperature occurred during the reproductive phase and this was possibly due to ovule abortion caused by competition between ovules for assimilates and possibly due to a reduced supply of assimilates (lower NAR) and nutrients for pods and peas (Lambert and Linck 1958). The number of peas per pod was most reduced in Sp, a cv that maintained pod number at a fairly stable level under high temperature conditions. At the expense of maintaining pods, a low assimilate supply may have cause pea ovule abortion. The Tp cv had severe pod losses at high temperature and unlike Sp, pea number per pod was reduced the least due to more assimilates that were not committed to supporting pod development. Total pea numbers were reduced in all cvs at high temperature as a result of fewer number of pods and peas at each node. Total pea numbers were reduced significantly by high temperature during the vegetative growth phase when the number of podding nodes and peas per pod were also significantly reduced. The R x Cv interaction was not significant. The only significant difference in fresh weight per pea was between cvs. Sp produced the heaviest pea and Tp the lightest. This was reflected in harvest index where Sp consistently produced the highest harvest index, favoring reproductive over vegetative growth in the amount of assimilates received. It appears that high temperature during the vegetative phase reduced plant growth, decreasing the plant's photosynthetic area needed to produce assimilates. During the reproductive phase, competition between yield components for a limited assimilate supply (source/sink competition) resulted in a

reduced number of yield components and ultimately a reduced fresh weight yield. Competition for assimilates within the plant may have caused abortion in upper nodes (Lockhart and Gottschall 1961) and a resulting loss of yield components (pods capable of producing peas) needed to increase fresh weight yield.

This experiment identified the number of podding nodes as the main component contributing most to yield variability in all cvs (Table 4.3). Hardwick's (1979) hypothesis linking variation in pea yield with variation in the number of pods per node was rejected in this experiment as it was in the two previous experiments. The weight per pea, as in the field experiment, generally contributed least to yield variability and did not support Hardwick's second hypothesis. Yield variability in Sp arose largely due to the number of podding nodes, however, the number of pods per node contributed approximately 20% of the variability. A similar observation in Sp was noted in the field experiment. It appears that fresh weight pea yield variability cannot be seen in terms of only one yield component, but rather the interaction between these yield components and how they respond to temperature's effect on assimilate supply.

Yield of all four cvs in this experiment decreased significantly as the number of podding nodes and number of peas per pod decreased (Table 4.4). Yield in Dp also decreased slightly as the number of pods per node decreased. In the presence of high temperature, the number of yield components decreased and fresh weight yield was lower, however, yield increased as did the number of yield components at the constant 15 C treatment. The positive interactions between the number of podding nodes and number of peas per pod and between the number of peas per pod and weight per pea in Sp reflected component response to temperature treatment, increasing as yield increased and decreasing as yield decreased. Both Tp and Dp had positive interactions between the number of podding nodes and number of peas per pod. However, when one component if favored, for any reason, over the other in the amount of assimilates received, a

negative correlation or component compensation, may arise (Adams 1967).
Component compensation was evident in all cvs, with significance only
in the Sp cv, between the number of peas per pod and the number of pods
per node and between weight per pea and number of pods per node. Sp was
the only cv with compensatory growth behavior in all three experiments.
Component compensation did appear to contribute to yield stability in
this experiment as it did in both the greenhouse and field experiments
but not to such a degree probably due to the sharp temperature change
between vegetative and reproductive growth phases and a high incidence
of no significant change in component numbers between temperature
treatments. However, the compensatory growth behavior of Sp in this
experiment was evident in the consistently high harvest index of this
cv at all temperature treatments and the consistently high fresh weight
yield as compared to other cvs.

CHAPTER 5

Summary

Three experiments investigating the effects of temperature on growth and development of peas have shown that high temperature reduced fresh weight yield by complex responses observed through growth analysis and yield component analysis. Single, double and triple podding cultivars exhibited some differing behavioral responses to temperature.

Growth analysis showed that in both the greenhouse (Chapter 2, Fig. 2.1) and field experiments (Chapter 3, Fig. 3.5) net assimilation rate was lower under high temperature and the rate of decline in net assimilation rate also occurred more rapidly as temperature increased. Net assimilation rate was lower and decreased more quickly at high temperature possibly due to an increased respiration rate and a decrease in photosynthetic rate (Yoshida 1972, Evans 1975). The higher net assimilation rate of the field experiment (10^{-1}) as opposed to the greenhouse experiment (10^{-2}) probably arose due to the more severe temperature stress (therefore high respiration) experienced under greenhouse conditions. With a decline in net assimilation rate, relative growth rate also declined at high temperature and the rate of decline increased as temperature increased. Later sowings where mean temperatures increased (Chapter 3, Fig. 3.1) showed this trend in decline of relative growth rate. Leaf area ratio was higher as temperature increased indicating leaf growth was higher in relation to other plant parts. True leaf area was difficult to estimate because of simultaneous leaf production and leaf loss and which was further complicated by photosynthetic area of stems and chlorophyllus pods (Smillie 1962). However, the size of the leaf area ratio was most likely not sufficient to compensate for the lower net assimilation rate at high temperatures and therefore smaller plants resulted from a lower relative growth rate. Leaf weight ratio was also higher as temperature increased and the rapid senescence of leaves at high temperature resulted in a rapid

decline of leaf weight ratio which added to the fall in leaf area ratio. Thinner leaves shown by a higher specific leaf area at high temperature may not have been as photosynthetically efficient and further added to the decline in net assimilation rate and therefore relative growth rate (Yoshida 1972; Evans 1975).

The lower net assimilation rate at high temperature (measured only in the greenhouse and field experiments) and lower relative growth rate produced a smaller plant as indicated by total plant dry weight and this smaller plant was also earlier maturing. Total plant dry weight in all cultivars was significantly lower when high temperature occurred during the vegetative phase (Chapter 4, Table 4.8a and 4.8b). High temperature as opposed to low temperature during the vegetative phase must have shortened the period of development without giving sufficient compensation by faster growth (Van Dobben 1962). When comparing cultivars, single-pod cultivar, William Massey, was consistently the smallest plant and was generally also the earliest maturing. Puget, the triple-pod cultivar was the largest plant and generally the latest maturing. Plant size and rate of maturity appeared to be indirectly related to each other as far as pea cultivars tested in this study were concerned.

The shortened period of growth at high temperature was indicated by earlier pea maturity (weeks to optimum harvest date) (Chapter 2, Table 2.7; Chapter 3, Table 3.6). Whether high temperature occurred during the vegetative or reproductive growth phase, a significantly earlier optimum harvest date was observed particularly when high temperature occurred during the reproductive phase (Chapter 4, Table 4.5a and b). In other words, growth and development during the reproductive phase concentrated on pod and pea (seed) development at the expense of additional vegetative growth. Transport of assimilates to peas (seeds) may have increased due to high temperature (Evans 1975) and this may have resulted from a strong sink demand for assimilates. Pods and peas may have acted as dominate sinks for assimilates. This observation was partially supported by data in all three experiments which showed that the rate of

pea maturity (measured by change in percent AIS) increased significantly at high temperature (Chapter 2, Fig. 2.2; Chapter 3, Fig. 3.6). The mean rate increase was significant only during the reproductive phase (Chapter 4, Table 4.6), when pods and peas were developing.

In addition to earlier maturity and a lower total plant dry weight under high temperature, internode length decreased and this was more pronounced in later maturing cultivars (Chapter 2, Table 2.1). Temperature must have affected internode length through its effect on cell elongation in the subapical region. Differences in internode length may have been brought about by rate rather than period of development and the roles of GA_3 and IAA in their combined effects on elongation (Sachs 1965). Later maturing cultivars developed more quickly at high temperature and were therefore most affected. The number of nodes to the first pod(s) was also later (higher) as temperatures increased, particularly in later maturing cultivars (Chapter 2, Table 2.2). The delay in podding may have been due to destruction of flower promoting/inhibiting substance (Moore 1964, Barber 1959) or control by growth regulators (Leopold and Guernsey 1954). Whatever the cause, temperature during germination and early growth was shown to have an influence on the position of the first pod(s).

High temperature's effect on reducing total plant dry weight indicated that there was some selective distribution of assimilates occuring within the pea plant. Harvest index was used in all three experiments to measure this distribution of assimilates between vegetative and reproductive growth structures. In all three experiments, harvest index like net assimilation rate decreased as temperature increased (Chapter 2, Table 2.10; Chapter 3, Table 3.9; Chapter 4, Table 4.9a and b). In other words, at high temperature, a lower total assimilate supply was available and therefore further growth and development of the pea plant was hindered. With the development of strong sinks such as pods and peas a greater demand on assimilates probably occurred, largely deterring further vegetative growth which could have provided the source for more photosynthates,

hence assimilate supply. The early maturing single-pod cultivar, William Massey, almost consistently produced the highest harvest index whereas later maturing cultivars tended to have lower harvest indexes. Only the double-podded cultivar, Puke, showed a vegetative growth phase sensitivity to high temperature reduction of harvest index, other cultivars showed little temperature response to harvest index (Chapter 4, Table 4.9a and b). Despite the use of harvest index as a selection criterion for earliness and high yield in some crops (Donald 1962), this selection criterion should only be used with great care when applied to peas. William Massey was not always the highest yielding cultivar even though it was generally the earliest maturing cultivar tested in these experiments. When using harvest index as a selection criterion in pea cultivars, more consideration should be given as to how an individual pea cultivar responds to temperature (environment) in growth and development characteristics because such behavior provides some insight into fresh weight yield x temperature response in peas.

In peas, fresh weight yield response to temperature is most clearly seen in terms of yield component behavior and response. The number of yield components in all three experiments generally decreased in the presence of high temperature (Chapter 2, Table 2.3; Chapter 3, Table 3.2; Chapter 4, Table 4.1a and b). It was shown that the net assimilation rate was lower at high temperatures, therefore, the number of yield components retained must have been due to net assimilation rate and possible environmental stress. A reduced number of yield components generally resulted in a reduced fresh weight yield. Beginning with the number of podding nodes and the number of pods per node, both components generally decreased in all cultivars at high temperature with the highest reduction occurring in the high frequency podding cultivar, Puget, followed by Puke, the double-podding cultivar. High frequency podding cultivars appeared to be less tolerant to environmental stress largely due to a genetic weakness (Yarnell 1962; Ibarbia and Bienz 1970). The

number of pods decreased at high temperature possibly due to non-initiation of floral primordia in the shoot apex (Ormrod et al 1970) and possibly due to high temperature stress causing flower and pod abortion (Meadly and Milbourn 1970; Hole and Hardwick 1974; Hole 1977). Both flower and pod abortion were observed during the course of all three experiments though not recorded. Only high temperature during the vegetative growth phase reduced the number of pods in all cultivars; high temperature during the reproductive phase had no significant effect (Chapter 4, Tables 4.1a and b). Lower net assimilation rate indicative of fewer available assimilates combined with temperature stress during the vegetative phase causing abortion must have limited pod number. Fluctuation in pod number was the outcome of differences in either the number of pods produced or the number of pods lost. Lower or earlier set pods may have had an advantage over later (higher) set pods in the amount of assimilates received (Clay 1935; Lamprecht 1952; Ibarbia and Bienz 1970). Such competition for assimilates may have caused abortion in upper nodes. The number of peas per pod and total number of peas also decreased as temperature increased possibly due to a reduction in assimilate supply and movement of nutrients into pods and peas (Lambert and Linck 1958). The number of peas per pod in all cultivars was reduced significantly during the reproductive phase when high temperature occurred. Fewer total number of peas in all cultivars decreased during the vegetative phase due to reduced number of podding nodes and pods per node. Fewer peas per pod and total pea numbers may have also resulted from ovule abortion due to inter pod/pea competition for the limited assimilate supply and high temperature stress (Linck 1961). The developing seeds in pods may have been in competition for assimilates, therefore some ovules aborted and growth of the apical meristem (production of more pods and peas) may have been hindered which lead to a reduction in fresh weight yield (Headley 1979). William Massey showed some sensitivity to reduced pea numbers by high temperature during the reproductive phase and Puke to high temperature during the vegetative

phase. The single-pod cultivar, William Massey, quite consistently produced the heaviest pea weight and Puget, the triple-pod cultivar, the lightest pea weight. Pea weight, pea and pod number were seen to be in direct relationship to harvest index where a high harvest index resulted in a heavier pea weight, but only when pea and pod numbers were reduced. William Massey yielded the fewest number of peas and pods yet had the heaviest mean pea weight. Puget was observed to respond in sharp contrast. It appeared that fewer competing sinks (pods and peas) for assimilates allowed for a heavier pea weight.

No single component of yield was shown to be the major source of fresh weight yield variability in all pea cultivars (Chapter 2, Table 2.5; Chapter 3, Table 3.4). Only in the climate room experiment (Chapter 4, Table 4.3) was the number of podding nodes shown to be the major source of yield variability in all cultivars. There was also no single component for each cultivar in all three experiments identified as the major source of variability in yield. The hypothesis linking variation in yield with variation in the number of pods per node and total pod number was rejected in this study as it was by Hardwick et al (1979). Neither was weight per pea (Hardwick's second hypothesis) supported because to use pea weight as a component of yield is an oversimplification due to the range in pea weights at each succeeding node. Nevertheless, in all three experiments, there was a high degree of both positive and negative correlations between the number of yield components and fresh weight yield. Under suitable temperature conditions, positive correlations were shown to indicate an increase in fresh weight yield whereas when high temperature occurred, a decrease in fresh weight yield occurred which was shown by a negative correlation (Chapter 2, Table 2.6; Chapter 3, Table 3.5; Chapter 4, Table 4.4). Interaction between yield components showed that negative correlations could be interpreted as one component being favored over others in the amount of assimilates received, in other words, component compensation (Adams 1967). The single-pod cultivar,

William Massey, consistently exhibited in all three experiments some degree of component compensation and this cultivar was shown to have the most stability in terms of fresh weight yield between temperature (sowing) treatments. The double-pod cultivar, Puke, also exhibited some degree of component compensation. Component compensation must have influenced harvest index where reproductive growth was favored over vegetative growth and this behavior gave William Massey its consistently high harvest index, heaviest weight per pea and high fresh weight yield. It is not one component alone that contributes to yield variability in peas, but rather the genetic capability of a cultivar to exhibit both positive and negative interactions between components of yield. The degree to which a cultivar responds through component compensation and direction of component interaction (positive or negative) will determine yield response to temperature.

Fresh weight yield in economic terms is an important criterion to use in pea cultivar selection. In all three experiments, high temperature reduced fresh weight yield (Chapter 2, Table 2.4; Chapter 3, Table 3.3; Chapter 4, Table 4.2a and b). Yield decreased probably due to a reduced assimilate supply (lower net assimilation rate) in a smaller plant (lower relative growth rate) that had thinner, less photosynthetically efficient leaves (higher specific leaf area). These effects on growth parameters resulted in earlier plant maturity measured in fewer weeks needed to reach optimum harvest date. The shortening of the growth phase in most crop plants whether directly associated with net assimilation rate or not resulted in lower yields (Van Dobben 1962; Yoshida 1972) by temperature's influence on the rate of duration of photosynthesis (Donald 1962; Wallace 1973). It was high temperature during the vegetative growth phase that most significantly reduced fresh weight yield in all pea cultivars (Chapter 4, Table 4.2b), a growth phase during which a high and extended net assimilation rate was needed to boost fresh weight yield. The earlier onset of the reproductive phase set in motion an

increased demand for assimilates by pods and peas in a plant requiring more assimilates to develop additional yield components and thereby increase fresh weight yield. The reduction of assimilate supply (net assimilation rate) at high temperature reduced the number of yield components in all cultivars which was characterized by intrapod competition for assimilates and pod and pea abortion. Yield component interaction helped to stabilize fresh weight yield, particularly in the single-pod cultivar, William Massey. Positive interactions between fresh weight yield and yield components were indicative of potential yield increases and vice versa for negative interactions. Component interaction behavior appeared to be directly controlled by the assimilate supply position, positive if unlimiting and negative if limiting.

CHAPTER 6

Conclusion

The development of pea yield as illustrated in Figure 6.1 is determined to a large extent by the environment through direct intervention and also by the assimilate supply which is a product of the environment. The environment as investigated in this study was temperature.

If one were to follow the growth and development of the pea plant from the time of seeding through to harvest, the effects temperature has on a pea seedling and its subsequent growth and development showed that the node position on which the first pod sets is delayed by high temperature and that the delay is more dramatic in later maturing cultivars. Where the first flowering node occurs on the plant appears to be temperature dependent. A spring sown crop has the advantage of cooler temperatures and earlier pod set is anticipated as opposed to a summer sown crop where higher temperatures prevail. The period of vegetative growth if subjected to high temperature stress will result in a smaller plant with a lower net assimilation rate, hence, assimilate supply capacity. Once in the flowering stage pollination and pod set is also temperature (environment) dependent, but assimilate supply plays an even more important role. High temperature stress will cause flower and pod abortion and this was observed to occur in all three experiments. However, an aborted pod could enable pod set to occur on higher nodes only if assimilate supply is adequate. A flower that has set pod and does not abort may inhibit further pod set if assimilate supply is limiting and therefore reach the stop point on the diagram. If the temperature is low so as not to cause any stress and assimilate supply is adequate, other nodes further up the plant may set pods leading to a potentially higher fresh weight yield. Also, in cultivars which have the genetic capability of setting more than one pod per node, an adequate assimilate supply will permit multiple podding. It is at this point that the role of assimilate supply
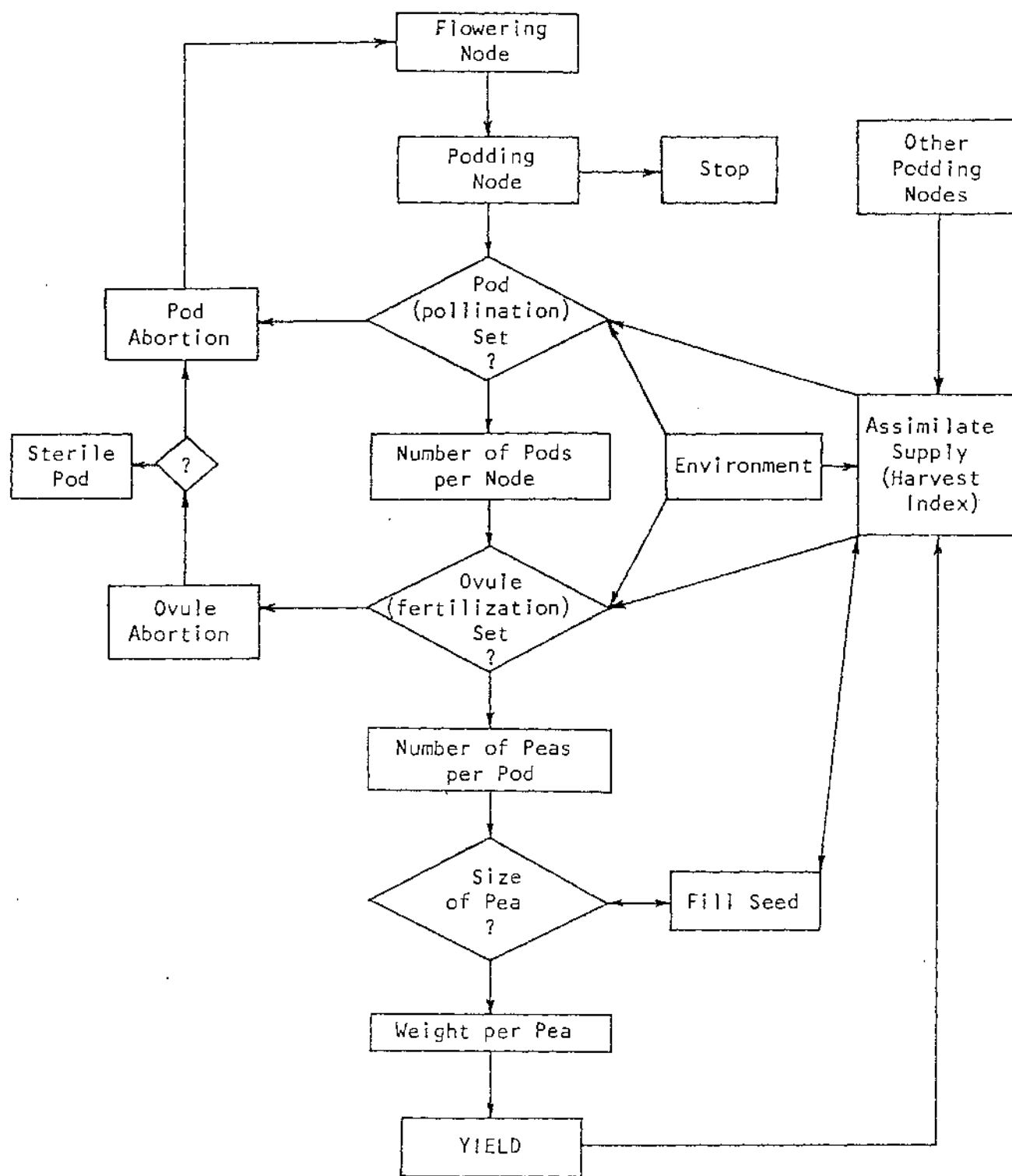
Fig. 6.1   The development of pea yield

becomes so important. Competition between sinks (pods and peas) occurs with the lower most sinks on the plant inhibiting later pod set if a tight assimilate supply situation exists.

As previously mentioned, the potential of a pea plant to supply a sufficient amount of assimilates so as not to hinder potential fresh weight yield is largely determined by temperature during the vegetative growth phase. High temperature during the reproductive phase has more influence on rate of pea maturity than on fresh weight yield. High temperature during the vegetative growth phase produces a smaller plant (lower relative growth rate) with thinner leaves (higher specific leaf area) which are less efficient photosynthetically (Yoshida 1972; Evans 1975). Earlier maturity occurs and the overall effect of a reduced net assimilation rate is a lower fresh weight yield. With a lower assimilate supply, harvest index decreases as vegetative growth competes with sinks (pods and peas) for the limited supply of assimilates.

Once a pod has set, the fertilization if complete will lead to ovule set provided both the environment (temperature) and assimilate supply are favorable. The first pod set acts as the dominant sink for assimilates and may hinder further pod set if assimilates become limited. High temperature stress and/or inadequate assimilate supply could cause ovule abortion in that pod leading to pod sterility or worse, pod abortion. An aborted pod would act as no sink whereas a sterile pod would draw on assimilates. A sterile pod in a tight assimilate supply situation could limit further pod set. The number of peas per pod is also dependent on assimilate supply and competition between peas (seeds) for assimilates begins soon after pollination. To what extent the pea fills (sizes) will be determined by the volume of assimilates available and harvest index. A good supply of assimilates may produce large, heavy peas giving a high yield. Even if assimilate supply is adequate, a cultivar like Puget with a low harvest index will produce a small, light pea because large growth of vegetative plant parts competes for assimilates hindering pods and peas, the reproductive structures, which develop later. On the other

hand, a cultivar like William Massey will produce a heavy pea because reproductive growth is favored over vegetative growth (high harvest index) in the amount of assimilates received.

In the breeding and selection of pea cultivars, results of this study have indicated that one of the important selection criteria to be looked for in a breeding program is cultivars which possess a high harvest index in which a more favorable balance between vegetative and reproductive growth exists. If such a balance were possible it may be via simultaneous flowering between reproductive nodes and increasing the period during which acceptable edible quality is retained. Any improvement in the uniformity of flowering and pod filling to a more synchronous reproductive habit will obviously increase the profitability of the crop. Therefore, selection should be made for more synchronous flowering with simultaneous fruit maturation among an increased number of pods per node and more seeds (peas) per pod. The ideal plant type should not only exhibit an almost simultaneous maturation of its early pods, but also once the set of these pods (ovules) has taken place further apical growth of the shoot should cease in order to prevent the formation of further vegetative growth and flowers. Younger pods (ovules) are likely to have no useful purpose and might then be inhibiting to the filling of the already formed pods. The remaining leaves must remain photosynthetically efficent to produce a high pea yield as when vegetative growth ceases upon flowering there will not be additional leaf growth available to add to photsynthetic leaf area and no doubt further yield increases.

For the time it takes a pea crop to reach and maintain an acceptable stage of maturity depends on how many pods there are on the plant and their distribution on the plant along with the biochemistry of individual peas (seeds). Therefore, peas should be bred for more determinate growth habit thereby minimize wasteful distribution of assimilates to plant parts that will not add to economic yield. Maximum

productivity lies within a restricted number of reproductive nodes.

In order to arrive at a more accurate measure of economic yield potential in peas, the Hardwick (1970) formula for harvest index derivation should be altered to read as

$$\text{harvest index} = \frac{\text{peas (seed) dry weight}}{\text{stem + leaf + pod dry weight}}$$

because pea (seed) weight is the only yield criterion important in economic terms. The Hardwick (1970) formula included pod dry weight in the numerator and such a harvest index in peas hould not be used unless one were only interested in a ratio between vegetative and reproductive growth.

It is well if the plant breeder develops all these desirable plant characteristics, however, for the producer the environment, over which he has little if any control, can greatly alter plant structure and thereby alter yield. Environmental factors such as water deficit, decreasing or increasing photoperiod and extremes of temperature en-hance abscission of plant parts. In this study, the effects of temperature were studied and showed that leaf area or photosynthetic area generally increased as temperature rose (also with later sowings) and this should have led to higher pea yields. However, this did not happen and to the producer high temperatures, particularly during the reproductive growth phase, can reduce yield through abscission of reproductive structures. Sowings in which cool temperatures pre-vail especially during the reproductive growth phase are recommended. Sowing dates demonstrated the vulnerability of this crop to adverse weather. What the plant breeder needs to develop is pea plants with still higher photosynthetic areas in which supply of assimilates to developing reproductive structures results in better pod and ovule survival. In other words, peas must maintain a much higher

and efficient photosynthetic area throughout pod swelling to reduce flower, pod and ovule abortion.

Assimilate supply can be limited by an insufficiently sized or active photosynthetic area (tissue) capable of producing adequate supplies of assimilates and/or by competition between both vegetative and reproductive growth for the available assimilates. This competition for available assimilates between yield components was shown to exist in all cultivars tested. No one yield component was consistently shown to be the main source of yield variability in any of the cultivars tested. However, a redistribution of assimilates between yield components (component compensation) was shown to exist in all cultivars, particularly in the high yielding cultivar, William Massey. Component compensation was shown to contribute to yield stability in peas under variable temperatures and successive sowing dates. Surely such a characteristic as component compensation in a pea breeding program should be considered as another step toward yield stabilization in a variable environment.

To the producer, cultivar selection becomes critical in his operation. Taking the general increase in temperature as the season advances, the pea crop will yield the highest and hold optimum maturity the longest under relatively cool temperatures. Plant growth will be more vigorous and yield as a consequence will be high. The duration of this ideal cool, spring like weather will determine if an early or late maturing cultivar should be selected. As the season advances and higher temperatures prevail, plant vigor will decline and yield will drop as a consequence which may be compounded by high temperature stress causing reproductive structures to abort. From this study early maturing cultivars appeared to maintain a higher yield under such conditions largely due to component compensation (redistribution

of assimilates between reproductive structures) and therefore may be a good choice for the producer. This study showed all cultivars as having high temperature sensitivity during the reproductive phase and therefore earlier maturing or very late maturing cultivars would be a good choice so that the reproductive phase does not coincide with highest summer temperatures. It should be remembered too that high temperature accelerates seed filling and optimum maturity under such conditions may be difficult to control. As the growing season approaches late summer, crop maturity under cooler temperatures would permit higher yield production provided very low temperatures (like high temperatures) did not cause flower and pod abscission. Higher temperatures during the vegetative vs the reproductive growth phase did reduce yield somewhat, however, not as much as did high temperature during both growth phases.

Cultivar response to the general rise then decline of temperature characteristic of the growing season in the production area will have a strong bearing on producer selection of pea cultivars and sowing date. To the plant breeder, the number of yield components are subject to genetic control, however, their ultimate number and value to the producer are subject to abortion under high temperature stress and unless the pea plant's sensitivity to temperature can be controlled genetically, cultivar selection by the producer becomes even more critical.

APPENDIX 1

Maturation in Peas: A Chemical Method of Maturity Assessment - the
Alcohol Insoluble Solids (AIS) Test

Since in green peas quality attributes such as tenderness and
flavour are strongly dependent on the maturity of the peas, the
determination of quality is generally used as a method to assess quality.
Common methods to obtain a reliable indication of maturity are to measure
their average tenderness with the help of various instruments. Although
many more or less satisfactory instruments have been developed (Christel
1938, Makower 1950; Kramer, Burkhart and Rogers 1951) only a few are in
general use. The most important are the tenderometer (Martin 1937) and
the maturometer (Lynch and Mitchell 1950; Mitchell and Lynch 1954;
Mitchell, Casimir and Lynch 1961). A less common method to obtain a
reliable indication of maturity is the determination of the average
alcohol-insoluble solids of the peas (Kerbesz 1935).

The validity of this AIS method is based on the degree of correla-
tion between their results and the results of a sensorial assessment of
quality. Reported correlation coefficients between alcohol-insoluble
solids and quality are ±0.90 or higher (Kerbesz 1935; Kramer, Scott
and Guyer 1950; Kramer 1954; Lee, Whitecombe and Henning 1954).
Correlation coefficients between tenderometer values and quality reported
by Kramer et al (1950); Kramer (1954); Lee et al (1954) and Torfason,
Nonnecke, and Strachan (1956)are of the same magnitude.

Although both methods give good results in most scientific work,
relatively large samples of peas are required for mechanical maturity
assessments. The AIS method has the advantage of adaptation to small
samples, fresh or processed. The only shortcomings are that the method
is time consuming and can be expensive. The AIS method was used in this
study because pea samples were small and held-over in a frozen state.

The method required the maseration of the pea sample and an extraction for half an hour in 200 ml of boiling 80% ethanol. The alcohol was filtered under suction through a weighed filter paper and the residue (insoluble solids) dried overnight at 70-80 C in a forced-air oven. The samples were cooled in a desicator and weighed.

Peas are suitable for processing when the AIS is 12-14% (Saray 1969; Schippers 1969).

Results of the technique used in this study were tested against samples of peas supplied by J. Wattie Canneries in which the maturity was tested by a tenderometer. Three AIS tests were made on each cv supplied of known tenderometer reading. The mean % AIS of the 3 replications is given below:

Cultivar	Tenderometer Reading	%AIS
Puke *	103	8.7
Puget *	100	9.8
Kuru	100	10.8
Piri	104	12.1
Pateu	107	11.8
C 39	105	11.2

* cvs grown in this study

The results indicate the technique used was good.

APPENDIX 2

Growing Media

The two growing media used in the experiments were a modification of the "U.C. - type Soil Mix" and comprised of:

1. Glasshouse - equal parts coarse sand (1.0 - 0.25 mm diameter) and soil (Karapoti silt loam).

2. Climate rooms - equal parts moss peat and coarse sand.

Lime and nutrients were added in the following quantities:

Material	g/m^3
dolomite limestone	3000
single superphosphate	1500
osmocote[a]	1500
frit 503[b]	150

a encapsulated fertilizer with formula 18 N 2.6 P 10 K

b fritted trace elements comprising 8% Fe, 7.5% Mn, 7.0% Zn, 3.0% Cu, 3.0% B, 0.2% Mo.

APPENDIX 3

N.C.S.U. Nutrient Solution

2 ml : g/l

Stock Section A

Ammonium nitrate
NH_4NO_3 80.05

Calcium nitrate
$Ca(NO_3)_2 \cdot H_2O$ 132.40

Sequestrene 330
NaFe   29.80

Stock Solution B

Potassium dihydrogen phosphate
KH_2PO_4 12.50

Potassium monohydrogen phosphate
K_2HPO_4 5.50

Potassium nitrate
KNO_3 63.90

Magnesium sulfate
$MgSO_4 \cdot 7H_2O$ 30.81

Sodium sulphate
Na_2SO_4 35.50

Micronutrients   400 ml NCSU micronutrient con-
                                        centrate per 100 l stock solu-
                                        tion B

Zinc sulphate
$ZnSO_4 \cdot 7H_2O$ 0.25

Manganese chloride
$MnCl_2$ 0.26

Cupric sulfate
$CuSO_4 \cdot 5H_2O$ 0.01

Boric acid
H_3BO_3 0.35

Sodium molybdate
$Na_2MoO_4 \cdot 2H_2O$ 0.0034

4 ml of each stock solution + 4 ml of acid solution (200 ml/100

l water) mixed with 1 litre of water = final solution

APPENDIX 4

The Climate Rooms

Each climate room measured 2.75 x 2.75 x 2.75 meters, with an effective growing area of 2 x 2 meters. The plants were wheeled into the room on trolleys. Conditioned air from ducting along the top of each side wall was passed over the plant trolleys and was recycled, via a false floor to the machinery chamber at the rear of each room. The artificial light was supplied from each source in the light rig located in the loft region above each room. Radiation from the rig was passed through a temperature controlled 2.5 cm waterscreen heat-barrier supported on a sheet of plate glass. Mirroring on the walls of each room gave a more even spread of light over the plant growing area and decreased the light gradient from the light loft.

APPENDIX 5

Rate (slope) of Pea Maturity

1. Greenhouse Experiment (chapter 2)

Temperature (C)	Mean	Cultivar	Mean
10	6.03	Tp	7.73
20	7.28	Dp	6.08
30	8.19	Sp	8.38
		Spl	6.41
SE	± .456***		
12 DF		SE	± .527**

2. Field Experiment (chapter 3)

Sowing	Mean	Cultivar	Mean
1	4.82	Tp	5.35
2	6.80	Dp (Vf)	6.01
3	6.35	Dp (Pk)	6.57
		Sp	6.04
SE	± .323		
22 DF		SE	± .374 NS

3. Climate Room Experiment (chapter 4)

Temperature (C)	Mean	Cultivar	Mean
15-15	1.99	Tp	4.07
25-25	5.52	Dp	3.45
15-25	5.44	Sp	3.95
25-15	2.35		
		SE	± .654 NS
SE	± .755***		
12 DF			

APPENDIX 6

Soil Classification : Karapoti Sandy Loam

    parent material or rock - medium textured alluvium

    description of representative soil profile:

        A1 0-18 cm greyish brown sandy loam; friable; moderate nut
                                  structure

        B1 18-25 cm greyish brown silt loam; friable weak nut structure

        B2 25-64 cm olive brown and olive grey heavy lilt loam; few
                              yellowish brown mottles; friable weak
                              blocky sturcture

        B6 64-97 cm olive brown fine sandy loam; friable; structureless

        C   on olive brown sand; loose, single-grained

    drainage class - well drained

Source: New Zealand Soil Bureau, 1974. Soils of Palmerston North and
        Environs, New Zealand. N.Z.D.S.I.R. Soil Survey Report 24/1:6

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