PHENOLOGICAL AND AGRONOMIC STUDIES OF *BRASSICA NAPUS* L.

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by

© Malcolm J. Morrison

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ABSTRACT

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The study examined the effects of temperature and plant density on the phenological, agronomic and morphological characteristics of spring rapeseed (Brassica napus L.) cv. Westar.

Rapeseed was grown under different temperature regimes in controlled environment chambers. A 5°C baseline temperature (b_o) was calculated from the relationship between percent development to physiological maturity (%DPM) and temperature. In the field, the growing degree day (GDD) equation using the 5°C bo was superior to calendar days in predicting phenological development. An equation was developed relating %DPM to GDD enabling researchers and producers to predict the phenological development of the crop from accumulated temperature.

Rapeseed was sown in the field in 15 and 30 cm row widths at seeding rates of 1.5, 3.0, 6.0 and 12 kg ha^{-1}. Plants seeded in 15 cm rows yielded more per area than those in 30 cm wide rows. The higher yields per unit area were the result of more pods $plant^{-1}$ and a greater number of seeds pod^{-1}. There were no significant differences in harvest index, lodging and protein, oil and chlorophyll concentration due to row widths. The highest yields per unit area were achieved with the 1.5 and 3.0 kg ha^{-1} seeding rates. Rapeseed plants compensated for lower densities by the production of more branch racemes. Plants seeded at the 1.5 kg ha^{-1} rate produced significantly more pods $plant^{-1}$ and seeds pod^{-1} than those seeded at 12 kg ha^{-1} rates. As seeding rate increased,

lodging increased. There were no significant differences for harvest index and protein and oil concentrations due to seeding rate. Generally, as seeding rate increased, seed chlorophyll concentrations decreased. The returns to producers achieved by higher yields at lower seeding rates may be reduced due to grade reduction from high seed chlorophyll concentrations (exceeding 22 ppm).

Rapeseed seeded in 15 cm wide rows produced a greater dry weight m^{-2} (W), leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR) and net assimilation rate (NAR) than rapeseed grown in 30 cm wide rows. In general, plants seeded at 6 and 12 kg ha^{-1} had higher W and LAI at the early growth stages than those seeded at 1.5 and 3.0 kg ha^{-1} rates. However, as the plants grew, the differences between the seeding rates decreased until they were negligible or greater for the plants seeded at the low seeding rates. At flowering, the CGR and NAR of rapeseed seeded at the 1.5 and 3.0 kg ha^{-1} rates were greater for the plants at the 6.0 and 12.0 kg ha^{-1} rates, indicating that canopies formed at the low seeding rates were more photosynthetically efficient in terms of carbon fixed per unit leaf area than those established at high rates.

The results from these experiments indicate that agronomic and morphological characteristics can be affected by seeding rates and row widths. Narrow rows are superior to wide rows and low seeding rates are superior to high rates. Producers should be encouraged to experiment with lower than recommended seeding rates under their own environmental and management conditions.

1.0 INTRODUCTION

Rapeseed (*Brassica napus* L. and *B. campestris* L.) is the major oilseed crop in Canada and ranks fourth on the prairies in terms of land area after wheat, barley and oats . In 1987, 2.7 million ha of rapeseed were grown on the prairies (Prairie Pools 1987). More than 50 percent of that area was sown to the high yielding *B. napus* type rapeseed with Westar the predominate cultivar grown.

Rapeseed research in Canada initially focused on quality and yield improvement. Plant breeders have successfully improved the oil and meal quality by reducing the concentration of erucic acid and glucosinolates in the crop, setting the standard of 'canola' quality. To remain competitive in the world market, it is desirable to improve the yield of rapeseed through plant breeding accompanied by improved agronomic management practices.

Altering the seeding rate and row width influences rapeseed growth through changes in plant density. Studies in Alberta determined that higher yields were obtained using narrow row compared to wide rows while there were no effects due to seeding rates (Kondra 1975, 1977; Degenhardt and Kondra 1981b and Christensen and Drabble 1984). Seeding rate studies in Saskatchewan using 2.5, 5.0, 10 and 20 kg ha^{-1} have reported that significantly higher yields were achieved using seeding rates as high of 20 kg ha^{-1} (Clarke and Simpson 1978b). Recently in Saskatchewan, McGregor (1987) observed that plant density could be reduced from current recommendation of 200 to 250 plants m^{-2} to as low as 40 plants m^{-2} with less than a 20 percent loss in yield.

Growth analysis can be used to examine the effects of agronomic treatments on the net photosynthetic production, development and morphology of field crops (Radford 1967). In Alberta, Major (1977) used growth analysis in rapeseed to examine the role of leaves in seed development. Kasa and Kondra (1986) examined growth analysis characters for their use in a rapeseed breeding program. In Saskatchewan, Clarke and Simpson (1978a) reported that the seeding rate of rapeseed affected several growth analysis characters.

There is a need for research on the effects of the environment on the phenological, morphological and agronomic characteristics of rapeseed in Manitoba. Accordingly, the objectives of this thesis were to: 1) examine the relationship between the rate of phenological development and temperature to determine a baseline temperature for use in an accumulated thermal unit model; 2) study the effects of plant density on agronomic characteristics and yield; and 3) determine the effects of plant density on growth analysis characteristics.

2.0 LITERATURE REVIEW

2.1 Accumulated Heat Units:

2.1.1 History and types of heat unit models.

Crop development is a function of both genetic and environmental parameters. Temperature, flux and duration of photosynthetically active radiation and soil moisture and fertility conditions markedly influence most biological processes within a plant. Of these factors, temperature and photoperiod appear to have the greatest influence on plant development rate (Daughtry et al. 1984).

Reamur (1735) was the first to suggest that the sum of the mean daily shade air temperature, between one stage of development and another, for a particular species of plant, was more constant than the number of calendar days (CD). Boussingault (1834), used a method similar to Reamur's to calculate the total quantity of heat required to ripen grain. The product of mean daily temperature above $0^{o}C$ for a day was termed a degree day (DD) i.e. the number of degrees above $0^{o}C$ multiplied by the time period of one day. Degree days or growing degree days (GDD) can be defined as the amount of heat in one day available for use in physiological development. Heat units, day degrees, degree days and growing degree days are synonymous.

Numerous methods have been developed for predicting plant development based on the principle of accumulated heat units above a minimum temperature for growth, referred to as a baseline temperature, as outlined in the following equation:

$$DD = \sum_{S1}^{S2} (Tm - b_o) \qquad (2.1)$$

where S1 and S2 = stage 1 and stage 2
b_o = baseline temperature in ^oC.
Tm = mean daily temperature.
(Davidson and Campbell 1983).

Results from this model can differ depending upon the selection of a minimum baseline temperature, and/or the use of a maximum temperature beyond which temperature is detrimental to further growth.

Heat unit models assume that: 1) photoperiod does not influence crop development, 2) there is only one baseline temperature throughout the life cycle of the plant, 3) day and night temperatures are of equal value and 4) developmental response to temperature is linear over the normal seasonal temperature range (Wang 1960).

Researchers have developed several methods of predicting crop development using other environmental variables in addition to temperature. Nuttonson (1953) incorporated the effect of daylength as well as temperature in his predictive equation. He showed that photothermal units (PTU) were more precise in predicting growth responses of wheat than degree days.

$$PTU = \sum_{S1}^{S2} L\ (Tm - bo) \qquad (2.2)$$

where L = daylength in hours.
(Nuttonson 1953)

Brown (1964, 1969) developed the corn heat unit (CHU) method based on the assumptions that a plant responded differently to temperature in the daytime than in the night. Two baseline temperatures were incorporated into the model. A temperature of 4.4^oC was used as a nightime, or respiration baseline temperature, while 10.0^oC was used as

a daytime or photosynthesis baseline temperature. The maximum temperature expression was a quadratic equation with a maximum temperature beyond which development was retarded.

$$CHU = 0.9[(Tmin-4.4) + 1.665\ (Tmax - 10) -0.042(Tmax - 10)^2] \quad (2.3)$$

where Tmin = minimum night temperature in ^oC
Tmax = maximum day temperature in ^oC
(Brown 1964)

Robertson (1968) developed a biophotothermal model which was superior to the simple heat unit equation and photothermal units for determining the influence of temperature and photoperiod on wheat (Triticum aestivum L.) development. His model consisted of three quadratic terms, one for photoperiod, one for maximum temperature and one for minimum temperature.

$$r = \frac{dm}{dt} = F1(L) \times F2(T) \quad (2.4)$$

where r = daily rate of development
m = degree of maturity
T = temperature in ^oC
t = time (days)
L = length of photoperiod (hours)
F1 and F2 = appropriate nonlinear functions of photoperiod and daily temperature, respectively.
(Robertson 1968)

Sierra (1977) took Robertson's (1968) model one step further by formulating a model describing the combined effects of solar radiation intensity and duration with air temperature to predict soybean (Glycine max (L) Merr.) development in Argentina.

Davidson and Campbell (1983) developed a phenological index based upon average daily temperature which accurately described the development of wheat. A time scale was derived relating phenological development to percent soft dough (%SD) defined as ((number of days to a

selected phenological stage)/(number of days to soft dough)) x 100, as follows:

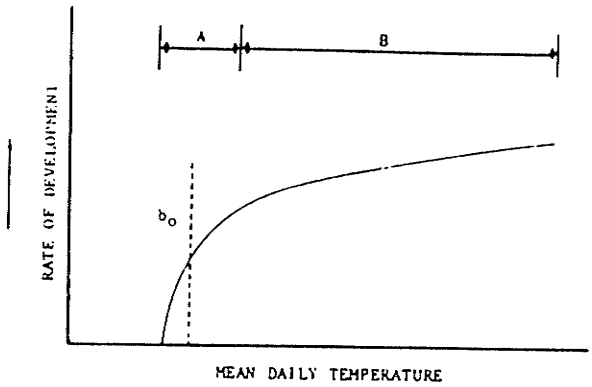
$$\%SD = K1 \sum_{S1}^{S2} (Tm - b_o) \qquad (2.5)$$

where K1 = rate constant with units %SD/^{o}C/day.
(Davidson and Campbell 1983)

All heat unit accumulation models were developed largely to overcome the inadequacies of calendar days for predicting crop development (Warrington and Kanemasu 1983). Greater precision is sometimes achieved using methods that take into consideration other environmental variables as well as temperature. However, for most field crops, models based on temperature alone can often explain over 95% of the variability in phenological development (Russelle et al. 1984). Simple accumulated heat unit models are used most frequently because they satisfy practical needs and are readily derived from air temperature, which is an easily and often measured parameter (Bauer et al. 1984).

2.1.2 Determination of a baseline temperature.

The baseline temperature (b_o) is the temperature at which physiological development ceases. The baseline temperature is also a convenient mathematical concept. It permits the calculation of a linear relationship between rate of crop development and mean temperature in the normal temperature range without using nonlinear functions (Davidson and Campbell 1983). If in Figure 2.1 the baseline temperature was not included, the relationship between mean daily temperature and rate of crop development would be curvilinear and would require a complex



A = Low temperature range. Rate of development decreases rapidly

B = Normal growing temperature range. Rate of development is linearly related to temperature.

Figure 2.1 The theoretical relationship between mean daily temperature and rate of development.

(Davidson and Campbell 1983)

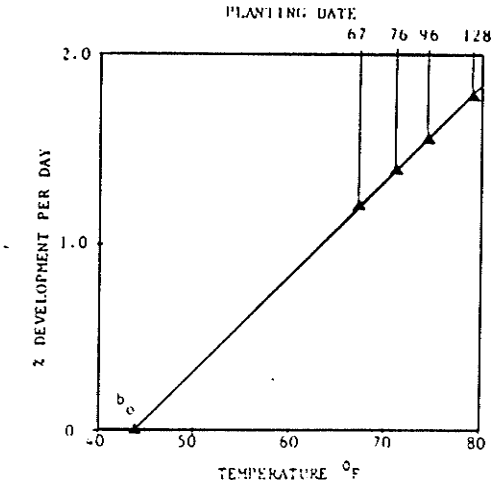


Figure 2.2 A plot of temperature vs. % development per day for field corn.

(Arnold 1959)

regression equation to describe the shape of the curve. Establishing a baseline temperature reduces the degree of curvature and permits the use of linear regression. Some accuracy is lost at temperatures approaching the baseline temperature, however accuracy is gained in the normal growing temperature range.

The precision with which a heat unit model can predict crop development is often dependent upon the baseline temperature. When the selected baseline temperature is too high, the heat unit summation for a specific plant growth phase (e.g. planting to first flower) will be too high in regions of higher temperature. If the baseline temperature is too low the reverse will occur (Arnold 1959).

Arnold (1959) described two methods of determining the baseline temperature. In the first method, a range of baseline temperatures were tested in a heat unit formula for a series of plantings. The baseline temperature resulting in the lowest coefficient of variation of heat unit summations over all planting dates was determined to be the appropriate baseline temperature. The second method used regression analysis to determine the relationship between temperature and rate of development.

Arnold (1959) calculated phenological rate of development for a particular growing period as a percent development per day (%DPD) to that particular stage .

$$\%DPD = \frac{100}{\text{number of days between growth stages}} \quad (2.6).$$

A series of planting dates were used to obtain variation in mean %DPD and mean daily temperature i.e. averaged over the entire growing period,

for corn (Zea mays L.). The mean daily temperature, x, was the independent variable and the mean %DPD, y, was the dependent variable. The resulting equation was solved for x when y equals zero to obtain the baseline temperature (Figure 2.2).

Although the relationship between temperature and %DPD has been assumed to be linear, the evidence in the literature suggests that it is actually curvilinear. Brown (1960) plotted soybean rate of development against temperature and compared linear, quadratic and logarithmic regression equations to determine the best fitting line. He found that the equation that best described the relationship between rate of development and temperature was derived from the $\log_{10}$ of the mean daily temperature vs %DPD. The $\log_{10}$ transformation of the temperature axis linearizes the curve and permits simple linear regression analysis.

Canadian climatic conditions restrict the length of the growing season, thus reducing the variation available to determine the relationship between development and temperature. Therefore, controlled environment cabinets provide the best method of obtaining basic information on environment-plant development relationships. In growth cabinets, microclimatic variations can be minimized, and a constant photoperiod can be maintained (Davidson and Campbell 1983). This allows the investigator to develop a heat unit model based on controlled environmental conditions. However, since these conditions are different from actual field conditions, a baseline temperature or heat unit equation that has been determined in the growth cabinet must be verified using field experiments.

2.1.3 Field verification of heat unit models.

Heat unit models have been developed for many major field crops. These models were verified for use in the field using data from several years and/or geographic locations and/or planting dates (Davidson and Campbell 1983).

The precision of a particular heat unit model in describing phenological development of a crop can be determined by comparison with other heat unit models and/or calendar days (CD). Gilmore and Rogers (1958) compared 15 methods of computing heat units in corn. Data from several geographic sites and/or years, were collected on the number of calendar days and heat units, (calculated using the 15 different formulas) to specific phenological stages of development. Means, variances and coefficients of variation (CV) were calculated across environments for each method, at each specific stage of development. The particular heat unit model resulting in the lowest CV was assumed to be the most precise method for that particular growth stage. Major et al. (1975a) used this method to compare CVs of 11 heat unit methods developed for predicting soybean development.

Major et al. (1983) conducted a study at 11 locations across Canada to determine if the corn heat unit method was superior to growing degree days and calendar days. Since the magnitude of the CV can be affected by the size of the mean, they converted GDD and CHU into days using a correction factor before comparing the CVs from the three methods. The correction factor was derived by dividing the grand mean number of accumulated GDD and CHU by the grand mean number of days. Mean CVs ranged from 8.7 to 25.8% depending upon the heat unit method used

and/or the growth phase used for their determination. They determined that no one thermal GDD equation had sufficient advantage over the CHU system to warrant its adoption in Canada.

Robertson (1968) used regression analysis to determine the most precise heat unit model in wheat. The number of actual days to a specific growth stage and the number of days predicted by heat unit models were used as x and y variables, respectively, in a regression equation. Theoretically, the most precise model was the one with the slope and y intercept closest to one and zero, respectively and a low standard error of estimate. Robertson (1968) used data collected over four years from nine sites across Canada to determine the most precise model. The mean number of observed days were compared to the mean number of days predicted from growing degree days, photothermal units and biophotothermal units. From planting to the soft dough stage, slope and y-intercept values were 0.58 and 34.6, 0.76 and 20.3, and 0.92 and 7.6 for GDD, PTU and biophotothermal units, respectively. Robertson did not statistically determine if these slopes and y-intercept values were significantly different from one or zero, respectively, but concluded that biophotothermal units were more precise than PTU and GDD.

2.1.4 Uses for heat unit models.

Numerous studies have demonstrated the usefulness of temperature based developmental models such as GDD or CHU for predicting crop growth and development, classifying crop species, hybrids and varieties or evaluating geographic regions for crop adaptation (Russelle et al. 1984). The disadvantages of using calendar day maturity ratings becomes

obvious when corn hybrids are grown under different environmental conditions, since environmental variation between years and locations may alter the number of days elapsed between planting and grain maturity. Mederski et al. (1973) grew three corn hybrids for two years at six widely spaced locations in Ohio. The number of days from planting to 25 percent kernel moisture varied by as much as 29 days for one hybrid between 1969 and 1970, while corn heat units varied from 2158 to 1966. Using an average accumulation of 13 CHU per day, this would result in a difference of only 15 days between the two years. Corn heat units are used across Canada to develop heat unit maps and recommend corn hybrids suitable to the growing conditions (Major et al. 1983).

Accumulated heat units are used in the scheduling of planting and harvesting vegetable crops such as sweet corn, (Zea mays L.) canning peas (Pisum sativum L.) and tomatoes (Lycopersicon esculentum L.) (Cross and Zuber 1972). Plant breeders often use heat unit models to schedule the planting of parental lines to ensure synchrony of flowering of male and female lines (Coligado and Brown 1975).

Russelle et al. (1984) used modified GDDs instead of days as the divisor in a classical growth analysis. This facilitated treatment comparisons within experiments and reduced the effects of differing temperature regimes among experiments.

There is recent interest in the development and refinement of crop growth models. A crop development model based on easily obtainable meteorological parameters would be a useful tool for agricultural researchers since it would permit them to compare processes such as crop growth, nutrient uptake and water use on a normalized time scale

(Davidson and Campbell 1983). Researchers modeling crop growth and yield often use a heat unit component as the driver of their model (Bauer et al. 1985; Ingram and McCloud 1984). A model incorporating environmental variables such as temperature that accurately describes the rate and duration of development processes can be of great use to all aspects of agriculture.

2.1.5 Effect of temperature on rapeseed phenology.

There are few reports on the effects of temperature on the phenology of rapeseed. Kondra et al. (1983) examined the effect of temperature on rapeseed germinated on moist sand in petri dishes. There was no significant difference in final percent germination over the air temperature range of 2 to 25 ^{o}C. However, time to germination increased as temperature decreased.

Seeding date studies are frequently used to observe the effects of environment on crop phenology. As the growing season progresses the average daily temperature and photoperiod increase to a midseason high and then decrease. The seasonal variation in the average daily temperature can be described by a simple sine function (Charles-Edwards 1982). Varying planting dates can produce variation in the average temperature and the stage of crop growth subjected to that temperature. Degenhardt and Kondra (1981a, 1981b) reported the effects of seeding date on the phenology and resulting yield of rapeseed. They observed that a delay in seeding from May 3 to May 31 resulted in a decrease in the number of days to first flower and a decrease in the number of days to maturity. They also found that a delay of 28 days resulted in a

significant reduction in yield. Thurling (1974b) postulated that a reduction in the number of days in the vegetative period, prior to first flower, resulted in a reduction in total yield. Using this argument, Degenhardt and Kondra (1981b) proposed that a reduction in the number of days to first flower, caused by a delay in seeding, resulted in lower yields. Perhaps if growing degree days had been used instead of days as a measure of time, there would have been no significant differences in time to first flower between seeding dates.

In Australia, Hodgson (1978), used Arnold's (1959) methods to calculate baseline temperatures for specific phases of crop development for the western Canadian B. napus and B. campestris cultivars Midas and Torch. He showed that the baseline temperatures varied widely depending upon the phase of growth (Table 2.1). A baseline temperature for the duration from seeding to maturity was not reported.

Rapeseed, a long-day photoperiod species, is relatively insensitive to photoperiods between 12 to 18 hours (Major 1980). Photoperiods of less than 12 hours will delay flowering. Under Canadian prairie conditions planting is usually done within the first three weeks of May, by which time the photoperiod exceeds 12 hours. Therefore, one expects that the influence of photoperiod on rapeseed development would be minor.

2.1.6 The growth stage key.

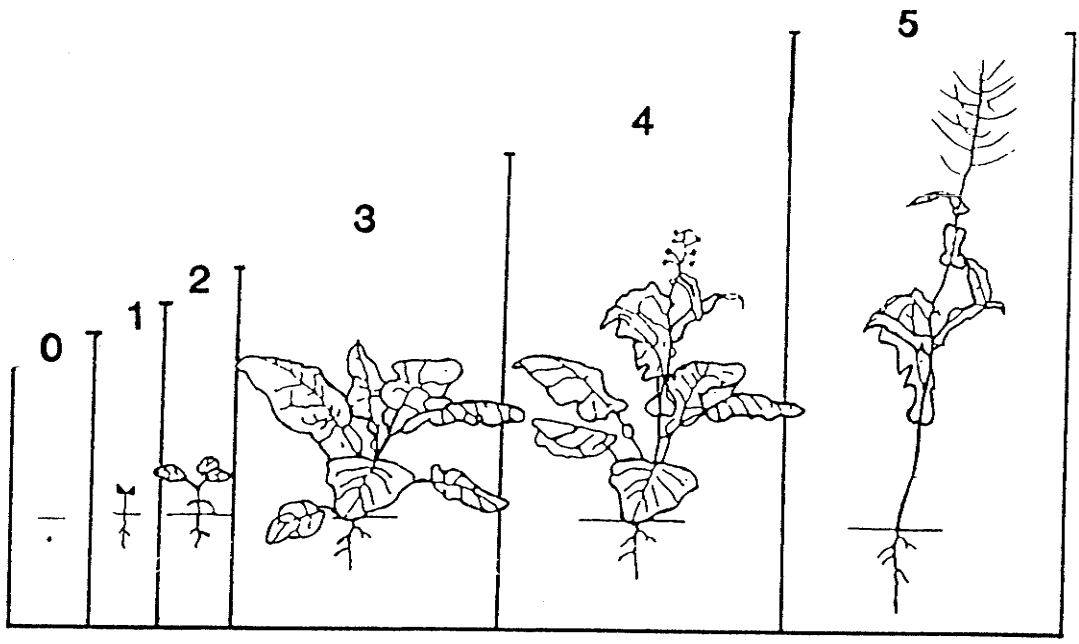
Harper and Berkenkamp (1975) developed a growth stage key for B. campestris and B. napus. The life cycle is divided into six distinct stages which are further subdivided (Figure 2.3). They noted that the

first and sometimes the second formed true leaves would partially expand and quickly senesce and advise not to count these leaves when determining substage. In order to avoid confusion while observing phenology the first and second true leaves were designated as seedling leaves and numbered 1.1 and 1.2, respectively.

Table 2.1 Baseline temperatures for B. campestris and B.napus for four phases of growth.

Cultivar	Growth phase	Baseline Temperature (°C)
Torch	planting to bolting	7.26
B. campestris	bolting to first flower	2.78
	first flower to pod fill	2.80
	pod fill to maturity	3.93
Midas	planting to bolting	0.45
B.napus	bolting to first flower	1.44
	first flower to pod fill	6.07
	pod fill to maturity	1.14

(Hodgson 1978)



Descriptions are based on the main stem

Stage

0 Seed

1 Seedling
- 1.1 First true leaf (senesces).
- 1.2 Second true leaf (senesces).

2 Rosette
- 2.1 Third true leaf expanded.
- 2.2 Fourth true leaf expanded.
  (add 0.1 for each additional leaf).

3 Bud
- 3.1 Inflorescence visable at centre of rosette.
- 3.2 Inflorescence raised above level of rosette.
- 3.3 Lower buds yellowing.

4 Flower
- 4.1 First flower opens.
- 4.2 Many flowers opened, lower pods elongating.
- 4.3 Raceme still flowering, lower pods starting to fill.
- 4.4 Flowering complete, seeds enlarging in lower pods.

5 Ripening
- 5.1 Seeds in lower pods full size, translucent.
- 5.2 Seeds in lower pods deep green.
- 5.3 Seeds in lower pods green-brown mottled.
- 5.4 Seeds in lower pods brown
- 5.5 Seeds in all pods brown, plant senescent.

Figure 2.1.3 A growth stage key for rapeseed (B. campestris and B. napus).

(Harper and Berkenkamp 1975)

2.2 The Effect of Plant Density on the Agronomic Characteristics of Rapeseed.

2.2.1 Planting density and its effects on competition.

A field crop consists of a population of genetically similar plants. Usually, in the early stages of development, these plants are sufficiently separated so that they do not interact with each other. As the plants grow, they influence the environment of the neighboring plants. This modification can be termed competition (Milthorpe and Moorby 1974).

Competition occurs when two or more plants need a particular factor necessary for growth, or when the immediate supply of that factor is below the combined demand of the plants. Two plants, no matter how close together, do not compete so long as the supply of the necessary factors are in excess of the needs of both. Among these necessary factors are water, nutrients, light, carbon dioxide and oxygen (Donald 1963). Competition for physical space rarely occurs, since even within a very dense crop, only about one percent of the total canopy volume is occupied by plant parts, and in the soil, only two percent of the volume is occupied by roots (Milthorpe and Moorby 1974).

If the collection of factors necessary for growth and reproduction can be considered to be a pool from which plants draw their supplies, then a successful competitor is a plant which draws most rapidly or can continue to draw from the pool when the contents are limiting (Donald 1963). In a field crop situation, where all plants have equal value, strong competition and the crowding out of neighboring plants is highly

undesirable (Duncan 1969). According to Donald (1968) ideal crop plants should be as intraspecifically noncompetitive as possible. However, the regime under which man grows most of his crops is usually one of intense intraspecific competition.

Plants can exhibit extreme plasticity by responding in size and form to the available environmental conditions (Donald 1963). By altering the seeding rate and the row width, the plant density within the rows is changed. Conventional spacing practices for crops have developed through experience with their effects on yield and with mechanical husbandry. Generally, field crop planting patterns are arranged in either a square grid or an elongated rectangle. For a given plant density, increasing the row width decreases the distance between the plants within the row, thereby, increasing the competition among the plants within the rows. Alternatively, as row width decreases for a given plant density the distribution of plants becomes more uniform. Experimenting with corn, Duncan (1969) observed that the higher the plant density the greater the advantage of narrow rows over wide rows.

2.2.2 Effect of plant density on the phenology of rapeseed.

Clarke and Simpson (1978a) observed that maturity was delayed as density decreased. Degenhardt and Kondra (1981b) demonstrated that increasing the seeding rate from 3 to 6 to 12 kg ha^{-1} resulted in slight reductions in the duration of some growth stages after first flower. Increasing the seeding rate resulted in a significant decrease in days to maturity of the first pod on the main raceme. The seed formation period was also significantly reduced by increased seeding

rates. Degenhardt and Kondra (1981b) proposed that time to maturity could be delayed by decreasing seeding rate. McGregor (1987) reported no significant differences in days to first flower as affected by plant densities ranging from 3.6 to 186.3 plants m^{-2}, while time to maturity at the lower densities was delayed by as much as 16 days. At high densities, the plants were small had few branches and matured rapidly, while plants at low densities produced a greater number of lateral branches and pods $plant^{-1}$.

2.2.3 Effect of plant density on yield.

In Britain, Helps (1971) seeded rapeseed at rates of 3.4, 6.6 and 10 kg ha^{-1} either in drilled rows 56 cm apart or broadcast. In the drilled rows the 6.6 and 10 kg ha^{-1} seeding rates yielded significantly more than the 3.4 kg ha^{-1} seeding rate. Broadcast seeding produced a significantly higher yield than the 56 cm drilled rows.

Further work in Britain by Mendham et al. (1981) on winter rapeseed, showed that plant densities as low as 8 plants m^{-2} still produced adequate seed yields. They proposed that at low seeding rates, sparse crops could compensate by increasing the number of pods per plant. The authors noted however, that low seeding rates may result yield losses from increased weed infestation and other pests.

Scarisbrick et al. (1982) conducted three experiments in Britain on the effect of seeding rate on the yields of winter and spring cultivars of rapeseed. Experiments one and two consisted of seeding rates of 4.5, 9.0, and 13.5 kg ha^{-1} applied to winter and spring cultivars. Experiment three used winter rapeseed seeded at rates of 2.25, 4.5, 9.0,

18.0 and 36.0 kg ha^{-1}. Row width remained constant throughout the three experiments. Results from experiments one and two indicated that yields increased significantly in both winter and spring rapeseeds when the seeding rate was increased from 4.5 to 9.0 kg ha^{-1}. However, no significant further increase in yield occurred when the seeding rate increased to 13.5 kg ha^{-1}. In experiment three, yields were not significantly different for winter rapeseed sown at 4.5, 9.0, and 18.0 kg ha^{-1}. However, significant reductions in yield occurred using the extreme low and high rates of 2.25 and 36.0 kg ha^{-1}, respectively.

Jenkins and Leitch (1986) examined the effects of 15 and 20 cm row widths on the yield of winter rapeseed. Seeding rate was constant for both row widths resulting in differences in the distance between plants within the row. Row widths of 15 and 20 cm produced distances of 3.0 and 5.0 cm between plants within the row, respectively. There were no significant differences in seed yield resulting from the variation in row width.

In Canada, Downey et al. (1974) recommended seeding rates of 4.5 to 6.5 kg ha^{-1} for spring rapeseed. Kondra (1975) studied the effects of row widths of 15, 23, 31 and 61 cm and seeding rates of 3, 6 and 12 kg ha^{-1} on the seed yield of rapeseed. The 15 cm row width produced a significantly higher yield than all other row widths and there was a consistent trend towards higher yields as the row width decreased from 61 to 15 cm. The effects of seeding rate were quite variable and strongly influenced by the environment. On average the 6 kg ha^{-1} rate produced the highest yields. Additional work by Kondra (1977) also compared seeding rates of 3, 6, and 12 kg ha^{-1} at 30 cm row widths.

Seeding rate had a significant but variable effect on rapeseed yield. The average yield from four sites indicated that the 6 kg ha^{-1} rate produced the highest yield.

Clarke and Simpson (1978b) investigated the effects of seeding rates of 2.5, 5, 10 and 20 kg ha^{-1} and irrigation treatments on the yield of rapeseed. Under both rainfed and irrigated conditions, the 20 kg ha^{-1} seeding rate produced the highest yields. Under rainfed conditions there were no significant differences between the 2.5, 5 and 10 kg ha^{-1} rates. In a related study Clarke et al. (1978) compared broadcast to 30 cm drilled rows treatments at seeding rates of 2.5, 5, 10 and 20 kg ha^{-1}. With both seeding methods, each increase in seeding rate resulted in a significant increase in yield.

Degenhardt and Kondra (1981a) seeded five rapeseed genotypes at 3, 6 and 12 kg ha^{-1} seeding rates in 23 cm row widths. There were no significant differences in yield between seeding rates across four station years, but the highest genotypic mean yield occurred consistently with the 6 kg ha^{-1} rate. Seeding rate effects were inconsistent for the different genotypes.

Christensen and Drabble (1984) examined the effects of row widths of 23, 15 and 7.5 cm and seeding rates of 7 and 14 kg ha^{-1} on the yield of rapeseed in northwestern Alberta. There were no significant yield differences due to seeding rates. The highest yields were consistently achieved with the 7.5 cm row width. Average yield increases of 36 percent occurred when row widths were decreased from 15 to 7.5 cm. There were no significant yield differences between row widths of 15 and

23 cm. They proposed that a more uniform distribution was obtained within the row by decreasing the row width.

McGregor (1987) seeded rapeseed in 15 cm rows, then thinned to obtain densities varying from 3.6 to 186.3 plants m^{-2}. Yield was not directly proportional to plant density over the range of densities examined. Density could be reduced to as little as 40 plants m^{-2} with less than a 20 percent loss in yield. The plants that remained after thinning were able to compensate for the plants that were removed. Yield decreased rapidly with less than 8 plants m^{-2} indicating that there was no appreciable interplant competition limiting individual plant growth at that density and no further potential for yield compensation.

2.2.4 Effect of plant density on the components of yield.

Adams (1967) identified three main components of yield in field bean (Phaseolus vulgaris L.). These were: the number of pods $area^{-1}$ (x), the number of seeds pod^{-1} (y) and the weight of seeds (z). These components were negatively correlated with each other, competed for the same source of nutrients and metabolites and when multiplied together, produced total seed yield. Adams and Grafius (1971) proposed that there is a balance among the components of seed yield in a crop plant, which is achieved through the sequential response of these components to limited resources. If for example, the number of pods $area^{-1}$ is reduced, the number of seeds pod^{-1} or seed weight may increase. If however, limited input were to constrain the number of pods that formed, even an abundant input to components y and z at a later stage may be

insufficient to overcome the depressing effect on seed yield of a low pod number.

Olsson (1960) reported that the seed yield of an individual rapeseed plant was determined by the number of pods plant^{-1}, seeds pod^{-1} and seed weight. Among these components, the number of pods plant^{-1} had the greatest influence on yield. The number of pods plant^{-1} was largely controlled by the plants response to its environment. When the environmental factors limiting growth and reproduction were abundant, rapeseed produced a larger number of branches, more pods and a higher yield plant^{-1}. The number of seeds pod^{-1} and seed size were influenced to a lesser degree by the environment.

Thurling (1974b) observed that yield component compensation, as outlined by Adams (1967), was prevalent in rapeseed grown in Australia. In a seeding date study, reductions in the number of pods plant^{-1} were compensated for by an increase in the number of seeds pod^{-1}. Thurling (1974b) concluded that yield component relationships in rapeseed were characterized by the type and degree of stress imposed upon the plants by the environment.

British researchers determined that winter rapeseed compensated for low plant density by increased numbers of pods plant^{-1} (Mendham et al. 1981; Scarisbrick et al. 1982 and Jenkins and Leitch 1986). As density increased pods plant^{-1} decreased, while there was no effect on seed weight. When yield components were analysed on a per area basis few significant differences were observed.

In Canada, Clarke et al. (1978) broadcast and drilled rapeseed in 30 cm rows at seeding rates of 2.5, 5, 10, and 20 kg ha^{-1}. Broadcast

seeded rapeseed had more branches plant^{-1} and pods plant^{-1} than drill seeded rapeseed at the same rate. In both seeding methods, the number of branches plant^{-1} and pods plant^{-1} were reduced significantly with each increase in seeding rate. Seeding method did not affect the number of seeds pod^{-1} or the seed weight. As seeding rate increased, the number of seeds pod^{-1} and the seed weight tended to decrease and increase, respectively. In a related study Clarke and Simpson (1978b) seeded rapeseed at 2.5, 5, 10, and 20 kg ha^{-1} in 30 cm rows. The number of branches plant^{-1} and pods plant^{-1} decreased significantly with each increase in seeding rate. However, the number of pods m^{-2} increased with increased seeding rate. The number of seeds pod^{-1} and the seed weight increased significantly when seeding rate was increased from 5 to 10 kg ha^{-1}. Contrary to the results reported by Olsson (1960) and Thurling (1974b), Clarke and Simpson (1978b) determined that the number of branches plant^{-1} and pods plant^{-1} were negatively correlated with yield, while seed weight was positively correlated with yield. There was no compensation between the number of pods plant^{-1} and the number of seeds pod^{-1}, although a decrease in seeds pod^{-1} resulted in an increase in seed weight.

Degenhardt and Kondra (1981a) seeded rapeseed in 23 cm rows at 3, 6 and 12 kg ha^{-1}. An increase in seeding rate resulted in a significant decrease in the number of racemes plant^{-1} but a significant increase in racemes m^{-2}. An increase in seeding rate did not result in an increase in seed weight. They concluded that yield components evaluated on a single plant basis did not have a direct relationship to yield on an area basis.

McGregor (1987) thinned rapeseed to produce plant densities of 3.6, 7.2, 21.7 and 186.3 plants m^{-2}. A decrease from 186.3 to 3.6 plants m^{-2} resulted in an increase in branches $plant^{-1}$ from 3.4 to 21.5, respectively and pods $plant^{-1}$ increased from 29 to 214, respectively. Plants at low densities had the greatest number of pods, more seeds pod^{-1} and the highest seed weight.

2.2.5 Effect of plant density on harvest index.

Donald (1962) originally defined harvest index as the ratio of seed yield to biological yield. Biological yield was defined as the total above ground dry matter produced by the plant. In soybeans, apparent harvest index has been defined as the ratio of seed yield to mature plant weight. While in some crops the two ratios are the same, they are different in crops that drop their leaves before maturity, (Schapaugh and Wilcox 1980).

Thurling (1974a) found harvest indices ranging from 0.16 to 0.23 in rapeseed grown in Australia. Harvest index was not significantly correlated with yield and varied with the environment. He concluded that selection for yield in rapeseed based on harvest index would offer little advantage in breeding for yield.

In Canada, Clarke (1977) reported no significant differences in rapeseed harvest index among seeding rates of 2.5, 5, 10, and 20 kg ha^{-1} in 30 cm wide rows. Campbell and Kondra (1978) observed significant positive correlations between harvest index and yield of several rapeseed cultivars. Degenhardt and Kondra (1981a) seeded five genotypes in rows 23 cm apart at seeding rates of 3, 6 and 12 kg ha^{-1}. Increasing

seeding rates from 3 to 6 kg ha^{-1} resulted in no significant differences in harvest index. There was a significant decrease in harvest index from 0.28 to 0.27 when seeding rates increased from 6 to 12 kg ha^{-1}. They concluded that harvest index could be a useful breeding tool if seeding rate and date were kept constant.

In Britain, Scarisbrick et al. (1982) seeded winter and spring rapeseed at rates of 4.5, 9.0 and 13.5 kg ha^{-1}. Harvest index values for winter rapeseed (0.34) were higher than for spring rapeseed (0.24). There were no significant differences in harvest index between the 4.5 and 9.0 kg ha^{-1} rates. In a similar experiment Jenkins and Leitch (1986) reported that within the same row width, plants 5.0 cm apart had significantly higher harvest indices than plants 3.0 cm apart.

2.2.6 Effect of plant density on quality characteristics.

2.2.6.1 Oil and protein concentration

The value of an oilseed crop is generally determined by the yield and quality of its oil and protein (Fowler and Downey 1970). The oil and protein concentration of the seed are modified by the environment and by the degree of ripening at harvest (Olsson 1960). The oil is largely formed in the last stages of ripening and early harvest of unripened rapeseed may result in lower oil concentration in the seed.

Bechyne and Kondra (1970) tested the effect of pod position on the plant on fatty acid composition of the oil. There were no significant differences in the proportions of fatty acids in seeds from pods on the lower and the upper main raceme or from the lowest pod on the lowest branch raceme.

Kondra (1975, 1977) seeded rapeseed in 15, 23, 31 and 61 cm row widths at 3, 6 and 12 kg ha^{-1}. Row widths and seeding rates had no effect on the protein and oil concentration of the seed.

Clarke (1977) compared rapeseed in broadcast-seeded plots with 30 cm drilled rows at 2.5, 5, 10 and 20 kg ha^{-1}. There were no significant differences in oil concentration among broadcast-seeded treatments. However, rapeseed seeded in 30 cm drilled rows at 2.5 and 5.0 kg ha^{-1} rates had significantly higher oil concentration than the 20 kg ha^{-1} seeding rate in the drilled rows.

Diepenbrock and Geisler (1979) examined the growth and composition of rapeseed seeds from pods on the main and branch racemes at regular time intervals from flowering. They observed that seeds from the branch racemes developed more rapidly than those from the main raceme. However, main raceme seeds were found to have a higher seed weight and slightly higher oil concentration than branch raceme seeds.

2.2.6.2 Chlorophyll concentration.

Seed immaturity or greeness is a major degrading factor in Canadian rapeseed (Daun 1982). The green colour in immature rapeseed is caused by chlorophyll. Chlorophyll in the seeds becomes a problem when it is extracted into the oil in such quantities that it is difficult and expensive to remove by traditional bleaching techniques. Chlorophyll has also been implicated as a pro-oxidant in the formation of oxidative rancidity in the oil. Daun (1982) found nonsignificant correlations between green seed percentage and chlorophyll concentration. The spectrophotometric procedures which measure

chlorophyll actually measure the group of compounds which include both chlorophyll 'a' and 'b' and their respective pheophytins. Pheophytins, which act as a primary electron acceptors in photosystem II, are colourless chlorophyll that lack Mg^{2+} (Salisbury and Ross 1985).

Canadian Trading Rules for canola oil have established 25 ppm chlorophyll as a maximum for top grade crude oil. Daun (1987) determined that oil chlorophyll levels of 25 and 30 ppm were equivalent to a seed chlorophyll levels of 22 and 24 ppm. On average, Canadian rapeseed seed chlorophyll levels have varied from a high of 28 ppm in 1982 to a low of 11 ppm in 1984. In 1982 a severe early frost stopped the seed development and chlorophyll concentration was high (Daun 1985). In 1984 drought conditions resulted in low chlorophyll concentrations. Chlorophyll concentration is a useful measure of seed maturity, since it will decrease with decreasing seed moisture levels.

When crop maturity is uneven and the ripening delayed, the chlorophyll concentration can be high (Loof 1972). Clarke (1977) proposed that low seeding rates decreased the uniformity of crop maturity since these plants produced more branches and pods $plant^{-1}$. Low seeding rates may result in higher seed chlorophyll concentrations than high seeding rates.

2.3. Growth Analysis.

2.3.1 Concepts and uses.

The concepts and techniques of growth analysis have been developed as a means of determining the effects of climate and agronomic treatments on the rate of development and morphology of the plant or crop under investigation. Growth analysis has become a standard technique for estimating the net photosynthetic production of individual plants and crop stands. Two assessments of plant growth are used for a growth analysis; a measure of plant dry weight and a measure of the size of the photosynthetic assimilatory mechanism (Radford 1967). These characters are measured over the lifespan of several similar plants through successive destructive samples at key growth stages (Kvet et al. 1971). Advanced growth analysis characters are calculated from these measurements (Clarke 1977).

Two methods of calculating growth analysis characters of a plant or crop are used. These have been referred to as the classical and functional approaches (Hunt 1978). In classical growth analysis, mean values of the growth analysis characters are calculated for a specific time interval of plant growth. In the functional approach, growth analysis characters are calculated from fitted curves of the relationship of weight (W) and leaf area (LA) with time. The functional approach allows the investigation of general trends while the classical approach provides more specific insight into separate phases of crop growth. Both methods of growth analysis involve destructive sampling of plant material at various intervals of development. A homogeneous set

of plants or sample plots permits destructive harvesting at several growth stages (Kvet et al. 1971).

2.3.2 Growth character equations.

The equations for determining the various growth characters have been reviewed by Kvet et al. (1971) and Hunt (1978, 1982). The following equations can be found in these reviews.

The absolute growth rate (G) of a plant is the slope of the weight (W) versus time (t) curve. Since changes in dry weight over a season can be large, the natural logarithm ($\log_e$) of weight is often used. When weight of the plants within a crop covering an area of land (P) is determined the crop growth rate (CGR) can be calculated. The CGR represents an increase in crop dry weight per area of land per unit time and provides an indication of the dry weight production efficiency of a crop (Equation 2.7).

$$CGR = \frac{dw}{dt} \quad [\text{weight} \times \text{area}^{-1} \times \text{time}^{-1}] \quad (2.7).$$

where W = weight per area.

The leaf area of a plant (LA) describes the size of the photosynthetic assimilatory apparatus. The natural logarithm of LA can be plotted against time. Leaf area index (LAI) reflects the actual productive capacity of a crop per unit area of land and is a dimensionless value that represents the ratio of leaf area per land area (Equation 2.8)

$$LAI = \frac{LA}{P} \quad [\text{leaf area} \times \text{land area}^{-1}] \quad (2.8).$$

where P = land area.

Theoretically, at the optimum LAI, the lowest leaves maintain a positive carbon balance. Thus, net respiration of the lower leaves will not exceed net photosynthesis. Below this point these leaves can become an unproductive burden on the plant. The maximum LAI that a crop achieves can be influenced by environmental conditions as well as by plant density (Kvet et al. 1971). When LAI is plotted against time, the area under the curve provides an estimate of the leaf area duration (LAD) (Equation 2.9).

$$LAD = \int_{t1}^{t2} LAI \; dt \qquad [time] \qquad (2.9)$$

LAD expresses in quantitative terms the magnitude and duration of the assimilatory surface of a plant or crop. Usually crops with similar LAI but longer LAD are more efficient producers of assimilate and result in higher yields (Kvet et al. 1971).

The net assimilation rate (NAR) of a crop represents the increase of plant weight per unit leaf area (Equation 2.10).

$$NAR = \frac{1}{LA} \times \frac{dw}{dt} \qquad [weight \times area^{-1} \times time^{-1}] \quad (2.10).$$

where LA is the size of the assimilatory apparatus. NAR provides an index of the functional efficiency of a crop as a producer of dry weight per unit land area (Hunt 1982).

2.3.3 Growth characters from growth curves.

In many growth analysis experiments, it is the general trend of a growth function that is of major interest rather than its short term fluctuations (Kvet 1971). Radford (1967) outlined procedures for

calculating growth characters from the fitted curves of plant dry weight (W) and leaf area index (LAI) with time. Least squares regression analysis was used to fit the growth analysis data to an appropriate polynomial equation. Hunt (1982) warned that the accuracy in the fit of the curve achieved should not become the primary aim of the research, especially when the identity of the empirical model itself becomes of lesser importance. Higher order polynomials become more difficult to interpret biologically with each additional parameter. Usually, the simplest model possible that adequately fits the curve and has a low standard error is used.

Crop growth rate and net assimilation rate can be calculated from the appropriate regression equations of W and LAI over time (Equations 2.11 and 2.12, respectively).

$$CGR = \frac{1}{P} \times \frac{dw}{dt} = f'W(t) \times \exp[fW(t)] \qquad (2.11)$$

$$NAR = \frac{1}{LAI} \times \frac{dw}{dt} = f'W(t) \times \exp[fW(t)-fLAI(t)] \qquad (2.12)$$

where f(W) and f(LAI) are appropriate functions of dry weight and leaf area over time.

Values of time (t) are substituted into the above equations to develop instantaneous values for the growth characters.

2.3.4 The use of growing degree days in growth character determination.

Numerous studies have found that accumulated thermal unit indices are more accurate at describing plant growth and development than accumulated time as measured in days (Gilmore and Rodgers 1958; Cross and Zuber 1972; Major et al. 1975a; Major et al. 1983 and Daughtry et al. 1984). Despite the general acceptance of the relationship between

temperature and the rate of plant development, temperature indices have rarely been used in growth analysis (Russelle et al. 1984). Growing degree days are a measure of biological time and can be used in both classical and functional growth analysis. It is important to use an accumulated heat unit index which describes growth to a greater degree of accuracy than calendar days. The use of GDD in growth character determination should make the comparisons among and within growth analyses more universal.

2.3.5 The effect of competition on growth characters.

The maximum yield of a crop is a result of the competitive stresses among and between the plants within the crop. Growth analysis provides an indication of these competitive relationships and may grant some insight into what determines the optimum density for crop production. Donald (1963) reviewed the combined effects of competition on several growth analysis characters. Shortly after crop emergence there is a linear relationship between plant density and dry weight. Competition for light initially occurs at the highest density and with growth, manifests at lower and lower densities. Competition at the highest density becomes more intense until plant growth is retarded. As the plants grow, the dry weight yield at lower densities will progressively approach that of the higher densities until dry weight per area of land is fairly uniform among all plant densities. The linear relationship that initially occurred is replaced by a curve in which dry weight yield rises sharply with increasing density and remains constant over a wide range of densities.

Crop growth rate (CGR) is calculated on a land area basis. Therefore, CGR early in the growing season will be higher at high plant densities than at low densities. The response of LAI to plant density is much the same as it is for dry weight and CGR. Leaf area duration (LAD) may be greater at lower plant densities (Donald 1963).

2.3.6 Rapeseed growth analysis.

In a series of publications, Allen et al. (1972) and Allen and Morgan (1973, 1975) characterized the growth of spring rapeseed in Britain and compared cultivars using growth analysis. Rapeseed growth was divided into three phases (Allen and Morgan 1975). Phase one occurred from seeding to bolting and was dominated by a rapid increase in biomass and leaf area. Phase two occurred during flowering when LAI and CGR decreased. Phase three occurred during seed ripening and was characterized by a slight increase in CGR and a further increase in dry weight, mainly from the seeds. Allen and Morgan (1973) proposed that since there was an increase in dry weight after the leaves began to senesce, that the developing pods provided their own assimilates for growth. Leaves were responsible for the early establishment of the number of pods and seeds. Allen and Morgan (1975) proposed that a cultivar with a large LAI and LAD would result in the highest yield.

Mendham and Scott (1975) used growth analysis to investigate the effect of dry weight before flowering on the yield of winter rapeseed. They determined that delayed autumn sowing resulted in slower spring growth and a diminished yield. Further research indicated that plants

with the largest LAI before flowering produced the highest yields (Mendham et al. 1981).

Jenkins and Leitch (1986) examined the effect of plant densities of 35 and 78 plants m^{-2} on the yield and growth characters of winter rapeseed. LAI and dry weight were lower in the fall and spring at the lower density. However, due to morphological compensation there were no significant differences in dry weight after flowering. No significant yield differences occurred between the two plant densities.

Thurling (1974a) used growth analysis of spring rapeseed to study morphological characters associated with higher yields in Australia. There were no significant differences between cultivars for CGR. All cultivars produced about 50 percent of their dry weight before flowering. Total dry weight production was closely correlated with yield. Cultivars with relatively high LAI at flowering and greater LAD after flowering tended to produce the highest yields. In a similar experiment, Richards and Thurling (1978) used growth analysis to investigate the morphological response of rapeseed to drought conditions. The highest yielding cultivars produced the most W and LA at anthesis.

In Canada, Major (1977) studied the seasonal distribution of rapeseed dry weight and the relationship between CGR and LAI to assess the role of leaves in seed development. Sixty to seventy percent of the total dry weight of the plant was obtained after the maximum LAI was attained. The CGR was greatest near the time of maximum LAI and decreased as LAI decreased indicating that leaf tissue was an important source of photosynthate. Major (1977) concluded, that although pods

have the capability to produce their own assimilates, the leaves were still the most important source of assimilates. Translocation of assimilates from the leaves may account for the increase in dry weight after senescence.

Clarke and Simpson (1978a) investigated rapeseed growth characters in response to seeding rates of 2.5, 5, 10 and 20 kg ha^{-1}. The highest seeding rate produced the most dry weight and the greatest LAI before flowering. The 20 kg ha^{-1} rate also produced the greatest LAD, pod area and CGR. The 2.5 kg ha^{-1} rate produced the highest mean NAR, however, these plants could not compensate for the lower LAI, thus the CGR remained the lowest of the four rates. Yield was significantly correlated with LAI at anthesis and LAD after anthesis.

Kasa and Kondra (1986) examined eight rapeseed cultivars to determine if differences in growth characters affected yield. The earlier maturing genotypes had the highest mean relative growth rate. Although there were no significant differences in yield among the eight cultivars, the higher yielding cultivars did have a larger LAI before anthesis and a larger LAD after anthesis.

McGregor (1987) studied the effect of densities ranging from 186 to 3.6 plants m^{-2} on dry weight accumulation per plant. On a per plant basis, as density increased, the dry weight decreased. While on an area basis, dry weight increased as density increased. Leaf dry weight peaked later and persisted longer as density decreased.

3.0 THE DETERMINATION AND VERIFICATION OF A BASELINE TEMPERATURE FOR RAPESEED.

3.1 Introduction.

Numerous models have been proposed to describe the phenological development of a plant as a function of environmental variables (Daughtry et al. 1984). These models were developed to overcome the inadequacies of calendar days for predicting crop development (Warrington and Kanemasu 1983). Greater accuracy has sometimes been achieved using models that incorporate other environmental variables as well as temperature (Nuttonson 1953; Robertson 1968; Sierra 1977). For most field crops, models based on temperature alone can often explain over 95 % of the variability in phenological development (Russelle et al. 1984). Simple accumulated heat units have most frequently been used because they satisfy practical needs and are readily derived from air temperature, which is an easily and often measured parameter (Bauer et al. 1984). Numerous names have been assigned to accumulated heat units. Among the most common are degree days (DD) and growing degree days (GDD). Both represent the accumulated heat over a particular growing period that is available for crop growth. The standard GDD formula can be summarized as follows:

$$GDD = \sum_{S1}^{S2} (Tm - b_o) \qquad \text{(Eq. 3.1)}$$

where Tm is the mean daily temperature and b_o the baseline temperature. GDD are summed daily from stage 1 to stage 2 (S1, S2) to obtain a measure of accumulated heat.

Physiologically, the baseline temperature (b_o) is the temperature at which plant development ceases. The precision with which a GDD model can predict crop development is dependent upon the baseline temperature. When the selected baseline temperature is too high, the GDD summation will be higher in environments with high temperatures. When b_o is too low the reverse trend will occur (Arnold 1959).

In Urbana Illinois, Arnold (1959) used regression analysis to determine the baseline temperature and the relationship between temperature and rate of development of field corn (Zea mays L). He used a series of planting dates to obtain variation in mean daily temperature and mean daily development rate. Controlled environment cabinets provide a means of obtaining information on temperature-plant development relationships. Baseline temperatures and heat unit equations established in the growth cabinet must be verified with field observations (Davidson and Campbell 1983).

Hodgson (1978b) determined baseline temperatures for field grown rapeseed (Brassica napus) for successive development phases. Baseline temperatures ranged from 0.45 to 6.07°C for vegetative and floral development, respectively. He did not determine a baseline for the entire development period. Rood et al. (1984) used a 5°C b_o to determine GDD for B. campestris. In their research no references were cited or reasons provided why 5°C was chosen as a baseline temperature.

There has been very little research examining the relationship between temperature and phenological development in rapeseed. The objectives of this research were to: examine the relationship between temperature and rapeseed (B. napus) phenological development; determine

a baseline temperature for rapeseed; and use the baseline temperature in simple models, which can be utilized by producers and researchers to describe phenological development.

3.2 Materials and Methods

3.2.1 Growth cabinet studies.

In order to determine a baseline temperature for spring rapeseed, the cultivar Westar was grown from seed to maturity in walk-in growth cabinets (Econaire GRW-36) set at different daily mean temperatures of 10, 13.5, 15, 17, 20, 22, and 25°C. These mean temperatures were established by setting the minimum and maximum temperatures five degrees lower and higher respectively, than the desired mean. The cabinets were programmed to increase and decrease the temperature 1°C per hour in a stepwise manner and to hold the maximimum and minimum temperatures for two hours. This was done in order to simulate outdoor diurnal fluctuations in temperature. Temperature was measured and logged every half hour by a data logger (Omega Engineering OM205) equipped with copper-constantan thermocouple probes shielded from direct light and mounted at plant height in the cabinet.

Westar plants were grown under a 16 h photoperiod. Photosynthetically active radiation of 45-50 W m^{-2}, measured 60 cm below the lights, was provided by a 3:1 combination of cool white fluorescent and 'GRO LUX' wide spectrum tubes. Relative humidity was maintained between 70-90%. Plants were watered to field capacity daily and fertilized at each growth stage with a modified Hoaglands nutrient solution (Downs and Helmers 1975; Appendix I Table 1).

Three seeds were planted into one litre milk cartons (pots) containing a 1:1:1, peat:vermiculite:perlite soil-less mixture. Four holes were punched in the bottom of each pot. Five cm of coarse sand

was placed in the bottom of each pot to facilitate drainage and add stability. Plants were uniformly thinned to one plant per pot at the first true leaf stage. One hundred and fifty plants, placed in a completely random design were grown from seed to maturity at each temperature regime. Pots were rotated every two weeks until flowering.

Observations on phenological development were made daily using the Harper-Berkenkamp (1975) growth stage key, here after abrviated as HB. The number of days to each growth stage were noted. The population was said to be at a particular stage when 50 percent of the plants had achieved that stage.

3.2.2 Baseline temperature determination.

The number of days from seeding to physiological maturity (PM) was determined for each temperature regime. The percent development to physiological maturity (%DPM) per day was calculated using the following equation:

$$\%DPM\ day^{-1} = \frac{100}{\text{number of days to PM}} \qquad (3.2)$$

(Arnold 1959)

The values from the different temperature regimes were used to calculate a regression equation in which the $\log_{10}$ of the mean cabinet temperature was the independent variable and the %DPM day^{-1} the dependent one. The X intercept became the baseline temperature. The regression equation established a model of %DPM day^{-1} as influenced by temperature.

3.2.3 Field studies.

Phenological observations on the number of days from seeding to successive growth stages of Westar canola were made at several sites from 1984 to 1986 using the Harper and Berkenkamp (1975) key (Figure 2.3). Trials were located at the Point and the Arboretum locations at the University of Manitoba. The Point soil is a Riverdale silty loam and the Arboretum a Red River clay. Trials at the Point were seeded on May 17, 1984; May 7, 15, 21 and 27, 1985 and May 13, 21 and June 4, 1986. Trials at the Arboretum were seeded on May 27, 1985 and May 21, 1986. Individual sites were treated as one treatment. Mean days to each phenological stage were determined by visual observation of the plots regardless of seeding rate, planting pattern or the number of replications in each test. Continuous recording thermographs, mounted in Stevenson screens one m above the ground, recorded daily maximum and minimum air temperatures. Specific growth stages chosen represented key physiological stages throughout the development of the plant. These stages were easily identifiable when observing the plants phenological development in the growth cabinet and the field. These stages were; HB1.0 (emergence), HB2.1 (start of the vegetative stage), HB2.4 (late vegetative stage), HB3.1 (start of bolting stage), HB4.1 (start of flowering stage), HB5.1 (start of ripening stage), and HB5.3 (physiological maturity) (Harper and Berkenkamp 1975).

3.2.4 Field verification of growth cabinet determined values.

Two methods were used to verify the growth cabinet determined baseline temperature and the %DPM regression equation. The first

procedure involved direct comparison of GDD from the field and the growth cabinet. The second procedure involved using the growth cabinet determined regression equation for %DPM with field measured temperatures to predict field values for %DPM which were then compared to observed field results.

3.2.4.1 Comparison of growth cabinet and field growing degree days.

Growing degree days at each field site were calculated daily using on site meterological data and Equation 3.1 with a 5°C baseline temperature. Growing degree days were successively summed from seeding to seven key development stages on the Harper and Berkenkamp (1975) scale HB(1.0, 2.1, 2.4, 3.1, 4.1, 5.1, and 5.3). A daily mean air temperature from seeding to physiological maturity was determined at each field site and a grand mean daily temperature calculated from all 10 field sites. Mean GDD to each growth stage were determined from the 10 field sites. Growth cabinet GDD were calculated from seeding to physiological maturity for each cabinet temperature regime using Equation 3.1 and a 5°C b_o. A data set representing GDD from the growth cabinet was developed through interpolation between GDD from the 17 and 20°C average temperature cabinets for the same temperature as the grand mean seasonal air temperature from all 10 field sites. Therefore, cabinet and field GDD were compared at the same mean temperature.

Regression analysis was used to determine how well the growth cabinet GDD reflected field GDD. A linear regression equation was calculated using the interpolated cabinet GDD for the seven phenological stages as the abscissa and the 10 field site mean GDD as the ordinate.

The resulting regression line was tested for a slope of one and an intercept of zero (Kleinbaum and Kupper 1978). Theoretically, if cabinet and field GDD were identical the regression line would have a slope of one and a y-intercept of zero.

3.2.4.2 Comparison of predicted and observed percent development.

The regression equation, describing percent development to physiological maturity per day, determined in the growth cabinets was tested using the field data. At each site, daily mean air temperatures were used with the cabinet derived equation to determine a predicted %DPM per day. These values were successively summed from seeding to each specific growth stage.

Observations on the number of days to a specific growth stage were made at each field site. The observed %DPM to each selected growth stage were determined by Equation 3.3.

$$\%DPM = \frac{\text{number of days to a growth stage}}{\text{number of days to PM.}} \times 100 \qquad (3.3)$$

Regression analysis at each site was used to compare the observed field %DPM with the %DPM predicted from the growth cabinet equation. Observed %DPM was used as the abscissa and predicted %DPM as the ordinate. The slope of the resulting line was compared to one and the y-intercepts to zero, for each site separately.

To determine if the data from all ten field sites could be combined, a test of homogeneity of slopes was performed on the regression equations (Gomez and Gomez 1984). Regression analysis was done on the mean observed and predicted %DPM for all ten sites. To determine how well the predicted %DPM described observed %DPM, the

slope and y-intercept from the regression equation for the combined data were compared to one and zero, respectively. As previously stated, if the slope was not significantly different from one and the y-intercept not significantly different from zero, the predicted values accurately represented the observed values.

3.2.5 Evaluation of prediction methods.

Predicted %DPM, calendar days and GDD with a $5^{o}C$ b_{o} were compared in order to determine which system provided the most accurate description of rapeseed phenological development in the field. Variances and means were determined from all field locations and the coefficient of variation (CV) calculated. The CVs of the three methods were compared at key growth stages. The method with the lowest CV was determined to be the most accurate method of estimating phenological development.

3.3 Results and Discussion.

3.3.1 Growth cabinet observations.

The effect of temperature on phenological development of Westar rapeseed was similar for growth cabinet temperature regimes ranging from 10 to 20°C. As cabinet mean temperature increased from 10 to 20°C, the number of days required to reach a particular growth stage decreased (Table 3.1). Physiological maturity was assumed to have occurred when the seeds within the lower developing pods on the main raceme were just starting to turn from green to brown. Fowler and Downey (1970) determined that rapeseed was physiologically mature when the seed had obtained its maximum dry matter and the oil content, and the proportions of fatty acids constituting that oil stabilized. They found that this occurred about 42 days after pollination. In the growth cabinet experiments, under the 17°C mean temperature treatment, it took 43 days from first flower to the HB5.3 growth stage. In the Harper and Berkenkamp (1975) scale physiological maturity is represented by the HB5.3 growth stage.

According to the Harper and Berkenkamp (1975) growth stage key, vegetative development is judged on the number of expanded leaves. Plants grown in the 10 and 13.5°C cabinets did not possess the same number of expanded leaves as those grown at 15, 17 and 20°C. Closer inspection of plants grown in the 10 and 13.5°C temperature regimes revealed that the leaves were present but not expanded. This indicated that at least seven true leaves must be present on Westar rapeseed

TABLE 3.1 Number of days (Day) and growing degree days (GDD) from seeding to phenological growth stages (GS HB) for the cabinet mean temperatures.

Cabinet mean temperature (°C)														
	10.0		13.5		15.0		17.0		20.0		22.0		25.0	
GS (HB)	Day	GDD	Day	GDD	Day	GDD	Day	GDD	Day	GDD	Day	GDD	Day	GDD
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	9	45	7	60	5	50	5	60	4	60	4	68	3	60
1.1	25	125	17	144	14	140	15	180	12	180	12	204	10	200
1.2	34	170	22	187	20	200	23	276	17	255	17	289	15	300
2.1	42	210	28	238	26	260	26	312	21	315	20	340	19	380
2.2	51	255	33	280	31	310	30	360	26	390	22	374	22	440
2.3	--†	--	37	314	35	350	35	420	30	450	25	425	25	550
2.4	--	--	40	340	39	390	39	468	34	510	27	459	30	600
2.5	--	--	--	--	42	420	40	480	37	555	--	--	32	640
3.1	56	280	44	374	44	440	41	492	39	585	28	476	41	820
3.2	62	310	49	416	49	490	43	516	42	630	30	510	44	880
3.3	67	335	51	434	51	510	49	588	43	645	32	544	46	920
4.1	71	355	53	450	55	550	53	636	46	690	35	595	47	940
4.2	81	405	59	502	60	600	56	672	50	750	‡			
4.3	84	420	64	544	65	650	63	756	53	795				
4.4	112	560	72	612	77	770	74	888	60	900				
5.1	118	590	75	638	79	790	76	912	62	930				
5.2	132	660	94	799	88	880	85	1020	68	1020				
5.3§	156	780	107	910	99	990	96	1152	78	1170				
5.4	166	830	119	1012	109	1090	106	1272	87	1305				
%DPM day^{-1}														
	0.641		0.935		1.010		1.042		1.282					

† = leaves present but not expanded.
‡ = pod aborted, abnormal phenological development.
§ = HB5.3 = physiological maturity.

before bolting. However, all seven of these leaves need not be fully expanded.

Plants grown at the 22 and 25°C mean temperature regimes did not produce pods or seeds, while those plants grown at the 20°C and lower mean temperatures did. The phenological development of the sterile plants was altered and as a consequence the data from these cabinets was not used in the analysis. Mean temperatures of 20, 22 and 25°C were established with temperature ranges of 15-25, 17-27 and 20-30°C, respectively. Therefore, it appeared that cabinet maximum temperatures greater than 25°C resulted in sterility.

The cause of whole plant rapeseed sterility was not determined. Sterility could have resulted from pollen inviability, or ovule abortion after fertilization as found by Halterlein et al. (1980) in field bean (Phaseolus vulgaris) and Barrow (1983) in cotton (Gossypium hirsutum). In contrast, Fan and Stefansson (1986) observed a reversion of some cytoplasmic male sterile (CMS) rapeseed plants to fertile plants when they were grown at temperatures greater than 26°C. They determined that temperature operated on the buds at a very early stage in the archesporial development to promote normal stamen development. It is not known whether the mechanism involved in restoring fertility in a CMS rapeseed plant under high temperatures is in any way related to the mechanism for eliminating fertility in a fertile rapeseed plant. It is interesting to note that both processes are triggered by similar high temperatures.

Seeding date experiments with rapeseed indicated that a delay in seeding resulted in a reduction in seed yield (Degenhardt and Kondra

1981b). Delayed seeding would have resulted in delayed flowering. Under western Canadian conditions, rapeseed seeded in early May will flower in mid to late June, while a delay in seeding of 28 days would delay flowering to mid July, the hottest period of the growing season. Delayed seeding increases the stress on the plant during the sensitive flowering period. Potential gains in rapeseed yields could be obtained if genotypic tolerance to high temperatures during flowering could be found and incorporated into current cultivars.

3.3.2 Determination of a baseline temperature.

The number of days from seeding to physiological maturity (HB0 to HB5.3) from Table 3.1 were used with Equation 3.2 to calculate the percent development to physiological maturity per day (%DPM day^{-1}).

$$\%DPM\ day^{-1} = \frac{100}{\text{number of days to PM}} \qquad (3.2)$$

(Arnold 1959)

The %DPM day^{-1} of Westar rapeseed versus temperature was best described by the relationship of %DPM day^{-1} versus the $\log_{10}$ of temperature as found by Katz (1952) for canning peas and Brown (1960) for soybeans. When %DPM day^{-1} and the $\log_{10}$ of the mean cabinet temperature were used in regression analysis a baseline temperature for Westar rapeseed was calculated by solving the resulting equation for temperature when %DPM day^{-1} equalled zero (Arnold 1959). A baseline temperature of 4.77 +/- 1.5°C (the antilog of 0.678) was calculated for Westar rapeseed (Figure 3.1). A baseline temperature of 4.77, or for practical purposes, 5°C is very convienient. This is recognized as a baseline temperature for many

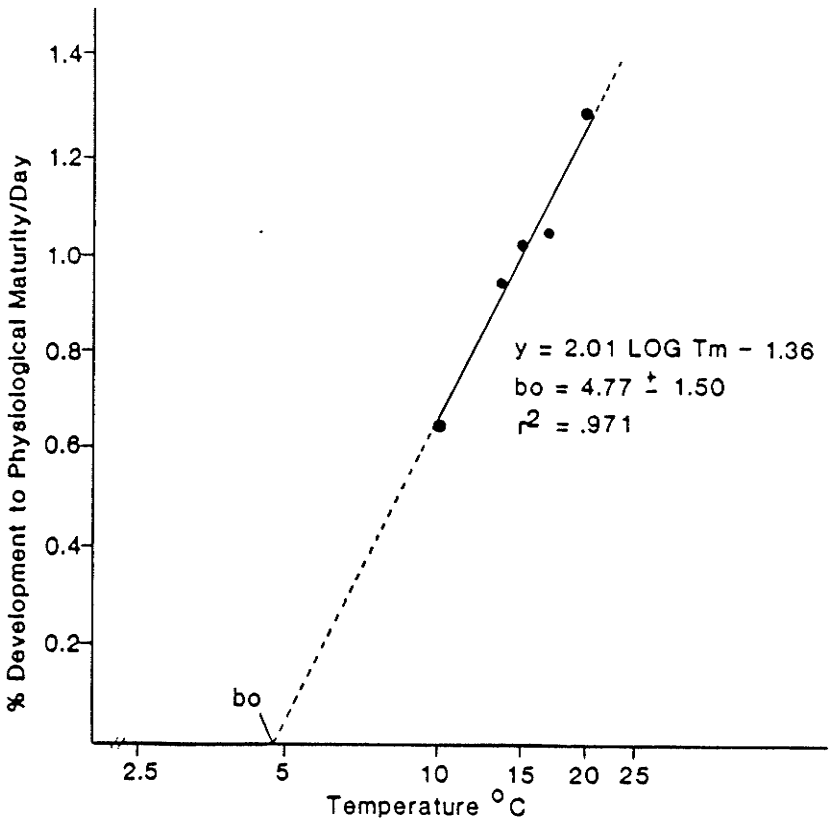


Figure 3.1 LOG_{10} temperature (°C) versus percent development to physiological maturity per day (%DPM day^{-1}). The determination of a baseline temperature.

crop species, therefore the GDD maps have already been developed (Edey 1977; Dunlop and Shaykewich 1982).

Rood et al. (1984) used a 5°C baseline temperature to determine GDD for B. campestris cv. Span. No reason was supplied or reference cited as to why 5°C was chosen as the baseline temperature.

Baseline temperatures for spring rapeseed, determined by Hodgson (1978) in Australia, ranged from 0.45 to 6.07°C for vegetative development and flowering, respectively (Table 2.1). There are several reasons why the Australian results were different from those of the current study: 1) Hodgson (1978) determined a baseline temperature for successive developmental phases instead of from seeding to physiological maturity. 2) Hodgson (1978) used simple linear regression rather than using an appropriate transformation, thus, potentially underestimating the baseline temperatures. 3) Hodgson (1978) planted spring rapeseed during the Australian winter. The shortened winter photoperiod increased the vegetative phase by delaying flowering, thus confounding baseline temperature determinations. In the current study, the photoperiod was maintained at a constant 16 hours in the growth cabinets. 4) There may have been differences in cultivar response to temperature, since Hodgson (1978) used Midas while Westar was used in the present study.

A maximum temperature, beyond which a further increase in temperature is detrimental to growth, for rate of development of rapeseed could not be obtained due to the sterility in the 22 and 25°C mean temperature cabinets. Further research to investigate a maximum temperature for rapeseed development would require that plants be grown

in cabinets set at a single temperature between 25 and 30°C. The maximum temperature would correspond to a maximum point on a response curve of temperature and %DPM day^{-1}. Table 3.1 indicates that a maximum temperature for vegetative development would be different than that for reproductive development. Vegetative development was not affected as much by high temperatures as was reproductive development.

The equation for %DPM day^{-1} vs temperature was determined to be $y = 2.01 \log_{10} Tm - 1.36$, where Tm is the mean temperature. This equation can be used to predict %DPM day^{-1} which can be used as a time scale to predict phenological development.

3.3.3 Field studies.

A field data base of phenological observations of Westar was developed from ten sites, over three years and two locations. The number of days to each HB growth stage were recorded (Table 3.2).

The environments of 1984, 1985 and 1986 were quite different from each other and bracketed the 30 year average (Table 3.3, Appendix I, Figure 1). The three growing seasons represented a fairly wide range of southern Manitoba growing conditions, yet phenological development of rapeseed was similar in each year. Potentially, severe drought, extremes in temperature and other climatic abnormalities may alter phenological development rates. Phenological developmental observations in other rapeseed growing regions of Canada should be conducted to obtain a broader picture of the response of development to climate.

TABLE 3.2 Days from seeding to individual growth stages for ten field sites.

Year	1984	1985	1985	1985	1985	1985	1986	1986	1986	1986		
Seeding Date	5/17	5/07	5/15	5/21	5/27	5/17	5/13	5/13	5/21	6/05		
Growth Stage (HB)	Location P†	P	P	P	P	A	P	P	A	P	AVE	S.D.
1.0	12	9	9	8	--	10	9	8	9	7	9	1.41
1.1	--	--	14	15	--	--	14	15	14	12	14	1.10
1.2	--	17	19	17	--	--	17	17	--	14	17	1.60
2.1	18	23	25	22	--	28	20	20	18	19	21	3.40
2.2	34	28	28	27	30	33	24	22	23	21	27	4.50
2.3	--	31	31	31	--	37	27	27	27	23	29	4.20
2.4	34	34	34	34	37	38	30	29	--	26	33	3.86
2.5	--	36	38	36	--	40	34	31	33	28	34	3.85
3.1	36	41	40	38	41	44	36	36	36	--	39	2.96
3.2	40	45	46	--	43	46	39	41	41	33	42	4.13
3.3	--	49	48	41	45	--	42	43	43	--	44	3.05
4.1	--	54	50	48	47	49	44	45	45	40	47	4.01
4.2	44	--	53	--	49	53	48	--	48	42	48	4.14
4.3	48	57	58	50	57	58	54	55	54	49	54	3.77
4.4	--	60	64	60	64	65	61	62	61	56	61	2.74
5.1	60	69	67	71	66	67	65	64	--	64	66	3.18
5.2	69	76	78	84	74	77	72	71	74	77	75	4.24
5.3	79	91	88	95	88	87	86	86	82	84	87	4.48

† P = Point, A = Arboretum

TABLE 3.3 Mean daily temperature (TEMP ^{o}C) and precipitation (PPTN mm) for 1984 to 1986 and a long term average (1951 to 1980).

Year	1984		1985		1986		Long term Average	
Month	TEMP	PPTN	TEMP	PPTN	TEMP	PPTN	TEMP	PPTN
May	12.0	29.8	15.1	64.0	13.9	25.2	11.3	65.7
June	18.8	227.9	16.1	67.4	17.3	109.3	16.8	80.1
July	22.2	38.3	20.7	34.0	20.2	136.8	19.6	75.9
August	22.8	21.6	16.7	218.0	18.4	19.4	18.3	75.0
mean/total	19.0	317.6	17.2	383.0	17.5	290.7	16.5	296.7

3.3.4 Field verification of growth cabinet determined values.

It is necessary to verify growth cabinet determined results with field material before equations and the baseline temperature derived from cabinet experiments can be used in the field.

3.3.4.1 Comparison of growth cabinet and field GDD.

The phenology of rapeseed plants grown in growth cabinets must be similar to those grown in the field in order for the baseline temperature to be valid. At each field site, on-site daily mean temperatures were used with Equation 3.1 and a 5°C b_o to calculate field GDD from seeding to seven specific phenological stages HB(1.0, 2.1, 2.4, 3.1, 4.1, 5.1 and 5.3), respectively throughout the rapeseed plants development. Mean GDD to each stage were determined from all 10 field sites. A seasonal mean temperature, from seeding to physiological maturity, was determined from daily meteorological data at each field site and the grand mean seasonal temperature from all field sites was found to be 18.3°C. Cabinet GDD to the same growth stages were determined for 18.3°C through interpolation between results from the 17 and 20°C mean temperature cabinets (Table 3.1). Regression of mean field GDD on growth cabinet GDD was used to determine how well growth cabinet GDD reflected field GDD (Figure 3.2). The resulting regression line was not significantly different from the 1:1 line. The slope and y-intercept were not significantly different from one and zero, respectively. Therefore, the phenological development, in response to temperature, of plants in the growth cabinet was not significantly different from plants in the field.

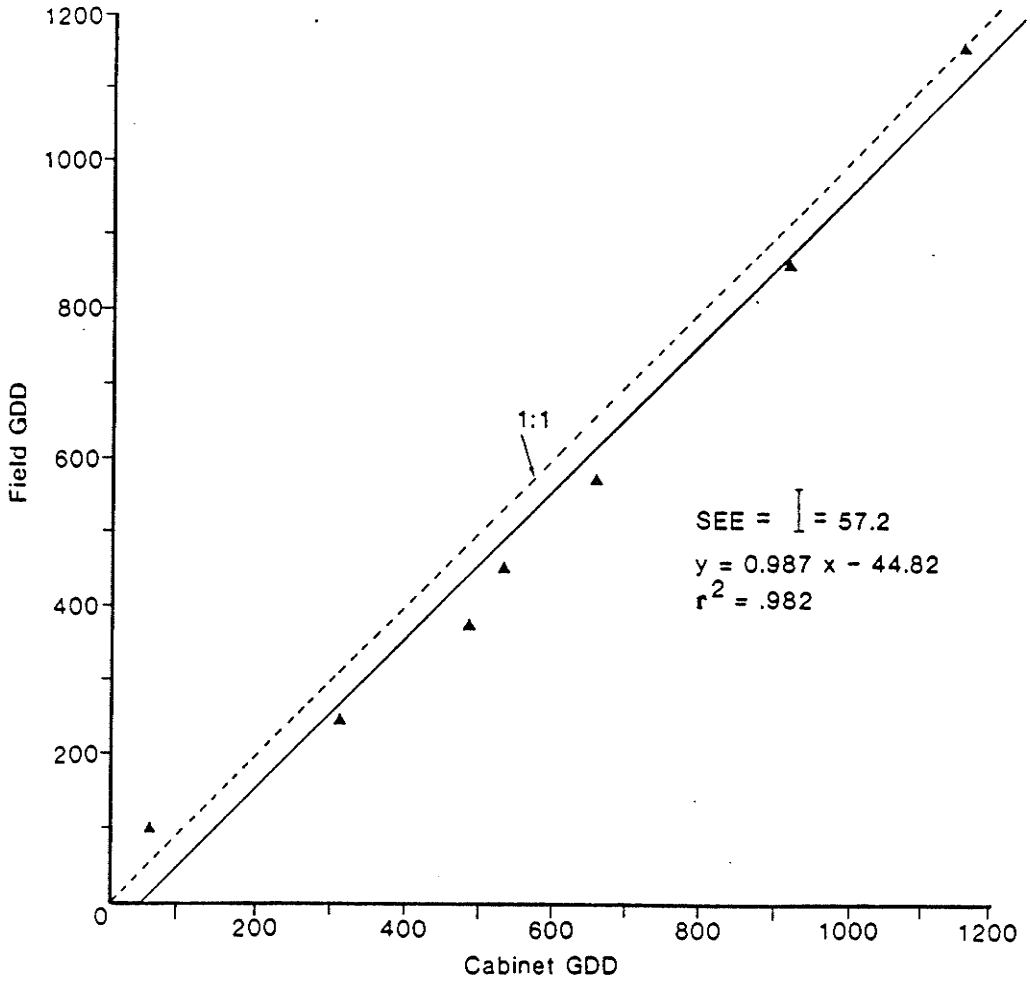


Figure 3.2 Comparison of cabinet growing degree days (GDD) and field GDD at seven phenological stages.

Cabinet GDD were greater in magnitude than the field GDD from early vegetative (HB2.1) to flowering (HB4.1) (Figure 3.2). More heat was required by the plants in the cabinets than in the field to reach the same growth stage. This may have resulted from a lower light intensity in the growth cabinet (45-50 growth cabinet, 150-200 W m^{-2} field). Lower light intensities can result in lower photosynthetic rates which can influence plant growth and development. Light intensity differences could also have resulted in higher leaf temperatures in the field than in the growth cabinet (Salisbury and Ross 1985). Baier (1973) concluded that it was extremely difficult to simulate in the growth cabinet all the variation and interacting effects of all environmental elements, particularly radiation, to which field grown crops are exposed.

Phenological development and response to temperature observed in the growth cabinet reflect the phenology of rapeseed in the field. The agreement between field and cabinet supports the 5°C baseline temperature as determined in the growth cabinet.

3.3.4.2 Comparison of predicted and observed %DPM

The regression equation developed to establish the baseline temperature can be used to predict %DPM day^{-1} in the field.

$$\%DPM\ day^{-1} = 2.10\ Log_{10}\ Tm - 1.36 \qquad (3.4)$$

where Tm = mean daily temperature

Daily mean air temperatures at each field site were used to calculate values of %DPM day^{-1} for the duration from seeding to physiological maturity. These values were successively summed from planting to each

specific growth stage to calculate predicted values for %DPM at each site. The number of observed days to each specific stage were used with Equation 3.3 to calculate the observed %DPM at each site.

$$\%DPM = \frac{\text{number of days to a specific stage}}{\text{number of days to physiological maturity}} \times 100 \qquad (3.3)$$

Regression analysis at each site showed that there were no significant differences between the predicted and observed %DPM. A homogeneity of slope test revealed that the data from all sites were homogeneous and could be combined. Regression analysis on the means from observed and predicted %DPM showed that the predicted %DPM was not significantly different from the observed %DPM (Figure 3.3). The slope and y-intercept of the resulting line were not significantly different from one and zero, respectively. The standard error of the estimate (SEE) was 1.42 %DPM and the r^2 was 0.99.

The equation determined in the growth cabinet to describe %DPM accurately estimates %DPM in the field. The equation used to determine %DPM was also the equation used to determine the 5°C baseline temperature. Since the predicted and observed %DPM were statistically the same, then the baseline temperature of 5°C, determined in the growth cabinet can be used for field grown Westar rapeseed.

Baier (1973) used the regression of the estimated wheat yield versus the observed wheat yield to test a wheat yield-weather analysis model over eight geographic locations. The data points were compared to a 1:1 line but a regression line was not determined. Baier (1973) was satisfied when the estimated yields were "reasonably close" to the 1:1

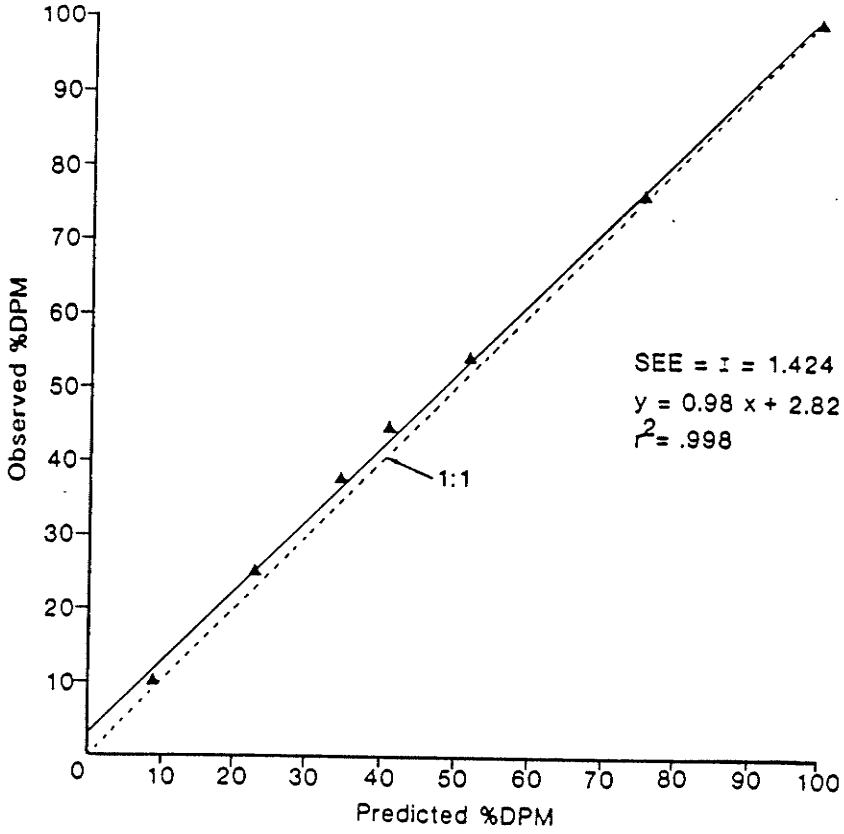


Figure 3.3 Comparison of predicted percent development to Physiological maturity (%DPM) with observed %DPM.

line. Shouse et al. (1982) used this technique to test the fit between predicted and measured evapotranspiration in cowpea (Vigna unguiculata).

While not significantly different from the 1:1 line, the data points and the determined regression line were above the 1:1 line in the mid developmental stages (Figure 3.3). The equation was less accurate in describing phenological development during the early and mid phases of crop growth and more accurate when the plant was maturing. During emergence soil temperature and moisture may have had more influence on plant development then air temperature (Kondra et al. 1983). Accuracy during the vegetative phase may have been sacrificed at the expense of increased accuracy in predicting physiological maturity. The importance of the inaccuracy of the model depends upon its use. If the model is used to predict maturity and the suitability of an environment to the growth of the crop, the model is sufficient. However, the model will slightly underestimate time to bolting and first flower.

3.3.5 Evaluation of phenological prediction methods

Variances and means were determined from all ten field sites for calendar days (CD), GDD and %DPM. GDD and %DPM were determined daily using on-site meteorological data and Equations 3.1 and 3.4, respectively. The coefficient of variation (CV) was calculated for each specific growth stage (Table 3.4). The method with the lowest CV was the most precise method (Gilmore and Rodgers 1958). If development was controlled only by temperature, then thermal units would sum to a constant value in all environments. The deviations about this constant would be minimal resulting in a low CV (Major et al. 1975b).

TABLE 3.4 Means ($\bar{x}$) and coefficients of variation (CV%) from ten field sites for calendar days, growing degree days and percent development to physiological maturity (%DPM).

Seeding to:	Growth stage key (HB)	Calendar days $\bar{x}$	Calendar days CV	Growing degree days $\bar{x}$	Growing degree days CV	Predicted %DPM $\bar{x}$	Predicted %DPM CV
Emergence	1.0	8.7	(19.5)+	97.9	32.2	9.3	23.0
Early vegetative	2.1	21.6	15.3	245.8	11.3	22.7	(11.0)
Late vegetative	2.4	32.9	11.9	373.5	(10.4)	34.5	10.5
Bolting	3.1	38.7	7.8	449.0	9.9	40.6	(6.4)
Flowering	4.1	46.9	8.5	576.0	6.7	51.4	(5.5)
Pod fill	5.1	65.9	4.9	859.7	5.2	74.8	(4.3)
Physiological maturity	5.3	86.6	5.2	1157.2	(2.2)	100.0	2.3

+ Brackets indicate method with the lowest coefficient of variation.

The CVs of all three methods used to predict growth stage were highest at emergence and lowest at maturity (Table 3.4). Since these methods were all measured from seeding, the differences between sites would be of lesser magnitude as the growth of the crop progressed from seeding to maturity.

Calendar days were the most accurate method of predicting time from seeding to emergence (Table 3.4). During emergence the plant may not have been as affected by air temperature as much as it was during the rest of its growth. Emergence may have largely depended upon the soil temperature and the soil moisture content. Major et al. (1983) also determined that CD were superior to corn heat units and GDD for predicting the emergence of corn.

Over all growth stages, %DPM was the most precise method of predicting phenological development, having the lowest CV at four out of seven growth stages, and having a lower CV than CD at all of the growth stages except emergence (Table 3.4). GDD with a $5^{o}C$ b_{o} was the second best method having the lowest CV in two out of seven growth stages and having a lower CV than CD at four of the growth stages. At some growth stages the %DPM and GDD CVs were very similar. Accumulated thermal unit equations were found to be superior to CD in describing phenological development in a number of agricultural crops (Gilmore and Rodgers 1958; Cross and Zuber 1972; Major et al. 1975a; Major et al. 1975b; Major et al. 1983 and Daughtry et al. 1984).

3.3.6 Temperature-growth stage response curve.

The growth stage key does not represent a linear progression of growth for rapeseed. The intervals for phenological development between stages in the vegetative phase of development are not the same as between stages within the reproductive phases. As a consequence, an equation relating GDD to growth stage could not be developed since it would produce results on a linear time scale which would not always correspond to the growth stage key. For example, values of 3.5 may be predicted by the equation when in fact HB3.5 does not exist in the growth stage key. Since %DPM was a function of temperature, and can also be used to describe phenological development, an equation was developed relating GDD to the phenological rate of development.

A test for homogeneity of GDD and %DPM variances indicated that data from all ten field sites were homogeneous and could be combined, resulting in mean values for GDD and %DPM to each growth stage (Appendix I, Table 2.)

Mean %DPM was plotted against mean GDD for each growth stage (Figure 3.4). Simple linear regression was found to account for greater then 99 % of the total variation indicating that the relationship between development and temperature is largely linear in nature. In Figure 3.4, growth stage corresponding to %DPM was plotted on the right side of the figure. This figure demonstrates that the growth stage key is not linear in nature since the intervals between growth stages are variable. Plotting the growth stages in such a way would allow the user to determine the growth stage corresponding to GDD.

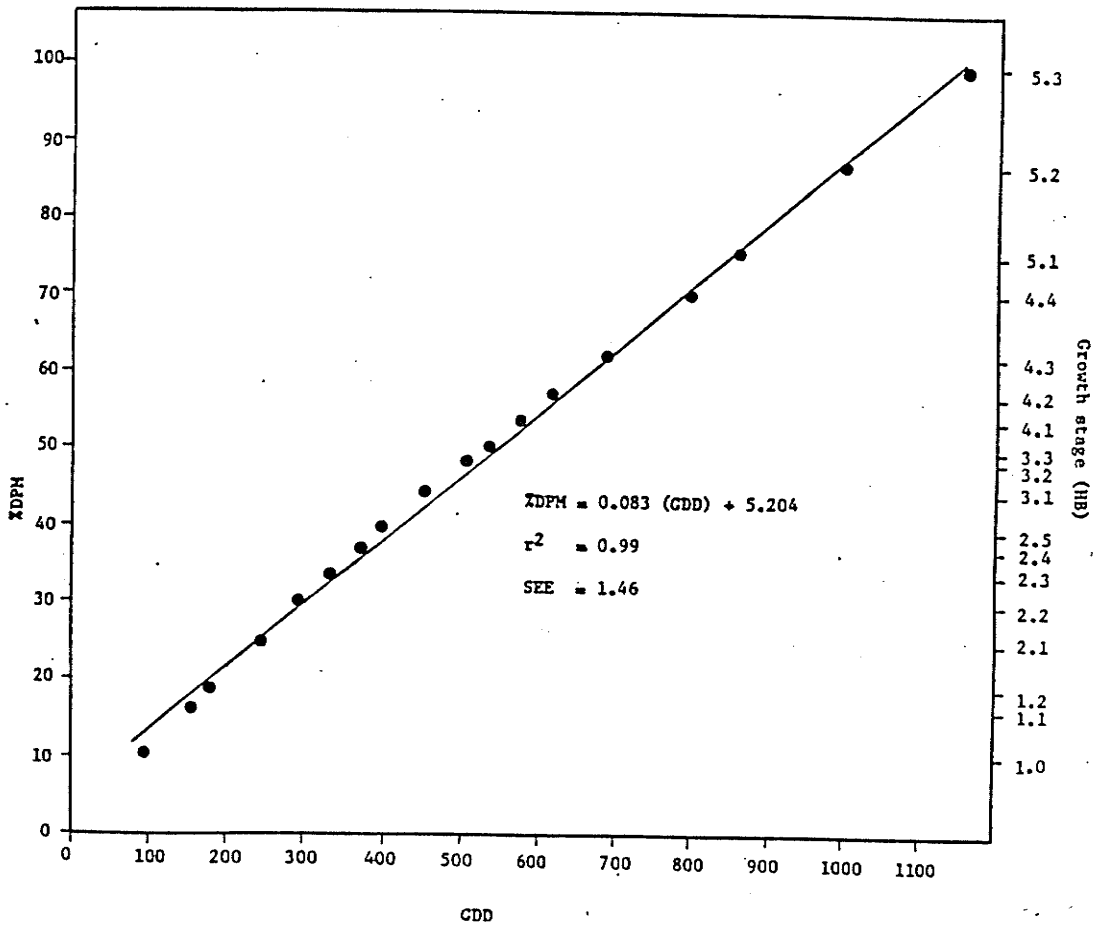


Figure 3.4 Temperature-growth stage response curve. Growing degree days (GDD) versus predicted percent development to physiological maturity (%DPM).

The equation relating growth stage to GDD (%DPM = 0.083(GDD) + 5.204) would be of practical use to producers as well as researchers, since it would permit them to predict stage of development of rapeseed with greater accuracy. Producers could use this equation for scheduling the deployment of fungicides, herbicides and other agronomic applications, as well as predicting maturity and harvest times for the crop. Plant breeders could use this equation to compare the phenological response of new cultivars and hybrids (Eskridge and Stevens 1987). Plant physiologists could use the equation to compare such dynamic processes as crop growth rate, nutrient uptake and water use, on a normalized time base. Researchers modelling crop growth and yield should particularly benefit from such an equation, since the evaluation of phenological development is a primary input into any model that attempts to describe the dynamic process of plant growth (Davidson and Campbell 1983).

3.4 Summary and Conclusions

Growth cabinets set at different mean temperatures were used to determine a baseline temperature of 5°C for Westar rapeseed. Temperature in excess of 25°C caused whole plant sterility; the mechanism of this sterility was not determined. Response to temperature was found to be logarithmic in nature. The equation used to determine the baseline temperature could also be used to describe the phenological development in the field.

Phenological development as measured by growing degree days from the growth cabinet was found to accurately reflect results from the ten field sites. The equation for %DPM day^{-1} established to find the b_o was used to determine predicted %DPM in the field. Predicted and observed %DPM were not statistically different indicating that the 5°C baseline temperature determined in the growth cabinet can be used in the field in a growing degree day formula. %DPM can be used as a phenological index describing the development from seed to physiological maturity in rapeseed. Temperature was the only environmental variable altered in the growth cabinet. The agreement between field and cabinet and between predicted and observed %DPM indicates that temperature exerts a very strong influence on rapeseed phenology.

%DPM and GDD were found to be superior to CD in predicting phenological development. However, these methods were not 100% accurate in their predictions. Improvements in these models may be made by including the influence of daylength or light intensity. %DPM and GDD models can be used as time scales against which other crop responses such as dry weight gain can be plotted. This allows results from a

variety of environments to be compared on a common time base. A simple linear model relating %DPM to GDD was developed. With this model producers and researchers can predict the phenological stage of development of Westar rapeseed from accumulated daily temperature. Potential uses of this equation are numerous in all areas of rapeseed related agriculture.

4.0 THE EFFECT OF PLANT DENSITY ON THE AGRONOMIC CHARACTERISTICS OF RAPESEED

4.1 Introduction.

Over the past 15, years the response of Brassica napus to varying row width and seeding rates has been studied in several rapeseed growing regions in western Canada. Few studies have been conducted in southern Manitoba. The region receives more accumulated heat and on average more precipitation than other prairie regions (Edey 1977, Environment Canada 1980).

Generally, rapeseed is planted in rows in a pattern that can be described by an elongated rectangle. For a given plant population, increasing the row width decreases the distance between the plants within the row, thereby increasing intrarow competition for available resources. Alternatively, as row width decreases for a given plant density, the distribution of plants becomes more uniform (Donald 1963). In Alberta, Kondra (1975) found that rapeseed sown in 15 cm rows significantly outyielded rapeseed sown in 23, 31 or 61 cm rows. Christensen and Drabble (1984) determined that a yield increase of 36 percent occurred when row width decreased from 15 to 7.5 cm, while there were no significant yield differences between 15 and 23 cm row widths. They proposed that a more uniform plant distribution, obtained from the narrower rows, resulted in less competiton for available resources and higher yields. However, Clarke et al. (1978) in Saskatchewan reported that 30 cm wide drilled rows produced a higher plant density and a greater yield than broadcast seeded rapeseed at the same rate.

Donald (1963) observed that in many crops there was a wide range of seeding rates that resulted in the same yields. He attributed this response to the extreme plasticity in size and form that plants can exhibit in response to their environment. Kondra (1975, 1977) and Degenhardt and Kondra (1981b) observed no significant yield differences between seeding rates of 3, 6 and 12 kg ha^{-1}. Christensen and Drabble (1984) found no significant yield differences between seeding rates of 7 and 14 kg ha^{-1} in northwestern Alberta. In Saskatchewan, Clarke and Simpson (1978b) and Clarke et al. (1978) experimented with seeding rates of 2.5, 5, 10 and 20 kg ha^{-1}. In both studies, they found that yield increased with increasing seeding rates. McGregor (1987) seeded and thinned rapeseed to obtain populations varying from 3.6 to 186.3 plants m^{-2}. He determined that the plant density could be reduced to as little as 40 plants m^{-2} with less than a 20 percent yield loss. The plants compensated for increased area by increasing the number of branches and the pods and seeds borne on those branches.

The objectives of this present study was to examine the effects of 15 and 30 cm row widths and seeding rates of 1.5, 3, 6 and 12 kg ha^{-1} on the yield and other agronomic characteristics of rapeseed grown in southern Manitoba.

4.2. Materials and Methods.

A field experiment was designed to determine the effects of manipulating seeding rates and row widths on several agronomic and quality characteristics of Westar rapeseed.

4.2.1 Experimental design and field observations.

Westar rapeseed was planted in a split-plot design. Row widths of 15 and 30 cm were used as main plot effects, while seeding rates of 1.5, 3, 6, and 12 kg ha^{-1} were subplot effects. Each plot was replicated six times and consisted of 16 rows, 5.5 m long. The two exterior rows were used as guard rows. The two center rows were harvested for yield and were bordered by guard rows. Five rows on either side of the center four rows were used to sample for growth analysis, yield components and harvest index. Row widths of 30 and 15 cm resulted in plots 4.8 and 2.4 m wide, respectively. Plots were seeded to a depth of 2 cm with a double disc eight-row belt cone seeder equipped with packing wheels. An eight row drill strip bordered the sides of the test.

Two field sites were used. The Point and Arboretum sites were both located at the University of Manitoba. The Point soil is a Riverdale silty loam, while the Arboretum is a Red River clay. The Point site is sheltered near the Red river, while the Arboretum site is exposed to wind, and further away from the river. The experiment was seeded at the Point on May 15 in 1985 and on May 13 and 21 at the Point and Arboretum, respectively, in 1986.

Land at both sites was fall prepared. The Point sites in 1985 and 1986 were treated with fall applied granular trifluralin (a,a,a-triflouro-2, 6-dinitro-N-N-dipropyl-p-toluidine) at recommended rates. No trifluralin was applied at the Arboretum. The plots were hand weeded throughout the growing season. At the Point 110 kg ha^{-1} of 34-0-0 and 15 kg ha^{-1} S was broadcast and incorporated in the fall. No fertilizer was applied at the Arboretum. Furadan 10 G (carbofuran) insecticide was applied with the seed at 5 kg ha^{-1} to prevent damage from Flea beetles (Phyllotera cruciferae (Goeze) and Psylliodes punctulatas (Melsheimer)).

Visual observations of phenological development were made every second day using the modified Harper and Berkenkamp (1975) growth stage key (Figure 2.3). The number of days from seeding was recorded at each growth stage. Growing degree days (GDD) were calculated to the corresponding growth stage using locally collected daily mean temperatures (Tm) and a five degree baseline temperature (b_o) (Equation 4.1).

$$GDD = \sum_{S1}^{S2} (Tm - b_o) \qquad (4.1)$$

Plants m^{-2} were determined at the early vegetative stage (HB2.1) and at physiological maturity (HB5.3) by counting the number of plants in a 0.5 m length from two rows per plot and multiplying the results by appropriate area factors (6.67 for 15 cm and 3.34 for 30 cm wide rows). Percent seeded stand was calculated as the (number of plants m^{-2}/number of seeds planted m^{-2}) x 100. Two measurements of plant height from the soil surface to the tip of the main raceme at each growth stage were taken from the innermost rows and averaged for each plot.

A split plot analysis of variance was used to analyse data from each location. The nature of the seeding rate effects were determined using orthogonal contrasts (Gomez and Gomez 1984). When appropriate, Bartlett's test for homogeneity of error variance was conducted on both main and split plot error mean squares. When data from the three locations was combined the analysis was treated as a split-split plot. Least significant difference (LSD) values at the 0.05 level of probability were used to separate means.

4.2.2 Yield.

The two center rows from each plot were trimmed to five m and harvested for yield at the HB5.4 growth stage. The rows were harvested by hand and air dried to constant weight in burlap sacks before being threshed with a stationary thresher. The threshed seeds were cleaned using a fanning machine and weighed. Seed weights per plot were transformed to yield in kg ha^{-1} before analysis.

4.2.3 Yield components.

Yield components in rapeseed consist of the number of pods $plant^{-1}$ the number of seeds pod^{-1} and the 1000 seed weight. Five representative plants from each plot were chosen from 1 m of the sampling rows. Plants were bundled and hung in a drying room before separation. Branches, defined as fruit bearing racemes arising from the main stem, were removed and counted. Main raceme and branch raceme pods were counted, placed in bags and dried for three days at 35°C before weighing. Pods were threshed using a de-awning machine and the seed cleaned with a

fanning mill. Seed was weighed and the 1000 seed weight determined. The number of seeds per plot was calculated from ((total seed weight per plot)/(1000 seed weight) x 1000). The number of seeds per pod was calculated from (total number of seeds)/(number of pods).

4.2.4 Apparent harvest index.

Plants from 1 m of row were removed from the sampling rows in each plot at the HB5.4 growth stage. Plants were cut at the soil surface, counted and placed in bags. The plants in the bags were dried to a constant weight, weighed and then threshed by a stationary thresher. The seed was cleaned and weighed. Since the leaves senesce and drop off after the beginning of flowering, an apparent harvest index was calculated from (seed weight)/(total biomass weight) (Schapaugh and Wilcox 1980). Apparent harvest index will hereafter be referred to simply as harvest index.

4.2.5 Lodging.

Lodging ratings were conducted at the HB5.4 growth stage prior to harvest. Ratings were conducted on a 0 to 5 scale with 0 representing an erect, nonlodged plot and 5 a completely lodged plot.

4.2.6 Quality characteristics.

Seeds harvested for yield were used to determine the concentration of oil and protein. Oil concentration was determined by Nuclear Magnetic Resonance technique (Robertson and Morrison 1979) using 25 g seed samples. Protein concentration was determined using the standard

Kjeldahl procedure using 1 g samples and a titanium dioxide cataylist in the digestion procedure.

Seeds from the yield component study were used to determine the apparent chlorophyll concentration of main and branch seeds. Seed chlorophyll was determined using the absorbance spectrophotometric method (Daun 1976). A Beckmann M 25 Spectrophotometer with a 0.5 mm band width was used to determine seed chlorophyll concentration in ppm. Seed samples, supplied by the Canadian Grain Commission, containing a wide range of predetermined chlorophyll concentrations were used to establish a standard curve. Chlorophyll concentration was determined for seeds on the branches and main racemes. Total chlorophyll was determined from a weighted average calculated from the proportional seed weight from the branch and main racemes.

4.3 Results and Discussion.

4.3.1 Field observations.

4.3.1.1 Plant density.

The stand density (plants m^{-2}) was determined at the beginning of the vegetative period (HB2.1) and at physiological maturity (HB5.3). Significant row width effects occurred at the HB5.3 stage at the Point 1985 and at the Arboretum 1986 (Appendix II, Table 1). Significant seeding rate effects occurred at both growth stages at all locations. The response of plant density to seeding rate was linear in nature. An analysis of variance of density at each location indicated that there were significant differences between growth stages at all locations (Appendix II, Table 2.).

The 15 cm row width resulted in significantly higher densities than the 30 cm row width at the HB5.3 stage, at the Point in 1985 and Arboretum in 1986 (Table 4.1). While these differences were not always significant the 15 cm row width resulted in higher densities than the 30 cm row width for both growth stages and locations, a confirmation of reports by Allen and Morgan (1972), Christensen and Drabble (1984) and Clarke et al. (1978). The more even plant distribution obtained through reduced row spacing or broadcast seeding resulted in lower interplant competition and greater plant survival to maturity.

Average plant densities were quite different at each location. Certified Westar seed size varied considerably between the 1985 and 1986 seed lots. This resulted in more seeds planted m^{-2} in 1986. Soil textural differences between the Point and the Arboretum resulted in

TABLE 4.1 Effect of row width (cm) and seeding rate (kg ha^{-1}) on the plants m^{-2} and percent seeded stand.

Growth Stage	Plants m^{-2} HB2.1	Plants m^{-2} HB5.3	Percent seeded stand HB2.1	Percent seeded stand HB5.3
		Point 1985		
Row width				
15	101.7 a	88.7 a	81.7 a	74.9 a
30	90.7 a	72.5 b	75.9 b	55.0 b
Seeding rate				
1.5	33.8 d	29.3 d	92.6 a	75.8 a
3.0	64.1 c	52.0 c	88.0 a	70.5 ab
6.0	106.1 b	90.7 b	72.9 b	62.3 bc
12.0	179.5 a	150.2 a	61.6 c	51.0 c
Growth Stage mean	95.9 A	80.6 B	78.8 A	64.9 B
		Point 1986		
Row width				
15	192.7 a	150.4 a	83.4 b	74.8 a
30	165.5 a	128.6 a	93.4 a	69.0 a
Seeding rate				
1.5	51.3 d	54.2 c	87.7 a	86.3 a
3.0	101.4 c	75.9 c	93.1 a	69.5 ab
6.0	192.4 b	173.1 b	87.9 a	73.8 ab
12.0	371.3 a	254.9 a	92.8 a	58.1 b
Growth Stage mean	179.1 A	139.5 B	88.3 A	71.9 B
		Arboretum 1986		
Row width				
15	62.5 a	54.6 a	40.1 a	33.5 a
30	57.0 a	41.1 b	36.5 a	31.7 a
Seeding rate				
1.5	24.6 c	21.2 d	49.3 a	42.6 a
3.0	46.3 b	34.6 c	46.4 a	34.6 ab
6.0	62.6 b	53.0 b	31.3 b	26.6 b
12.0	105.5 a	82.6 a	26.4 b	26.5 b
Growth Stage mean	59.8 A	47.8 B	38.3 A	32.5 B

a-d means within growth stage, row width, seeding rate and location followed by the same letter are not significantly different at the LSD = 0.05 probability level.

A,B means between growth stages for either parameter followed by the same letter are not significantly different at the LSD = 0.05 probability level.

more crusting and rapeseed loss at emergence at the Arboretum. Nutall (1982) reported that rapeseed was susceptible to crusting and that some soils with a high silt and low organic matter content crust more than others. Rapeseed was irrigated shortly after seeding at the Point but not at the Arboretum. Additional soil moisture may have increased the germination, emergence and success of the seedlings. The disparity in plant density resulting from the same row width and seeding rate treatments makes the combination of data over locations and years difficult.

A clearer understanding of seeding efficiency and plant loss as influenced by row width and seeding rate was obtained by examining the plant stand as expressed as a percent of the seeded stand (%SS). There were a significant row width effect at the HB5.3 and HB2.1 stage at the Point in 1985 and 1986, respectively (Appendix II, Table 1). Significant seeding rate effects occurred at all stages and locations except the HB2.1 stage at the Point 1986. An analysis of variance at each location indicated that significant differences existed between growth stages for %SS (Appendix, II, Table 2.).

At both growth stages the 15 cm row width generally resulted in a greater number of plants than in the 30 cm wide rows (Table 4.1). The 15 cm row width consistently had a greater %SS than the 30 cm row width.

As seeding rate increased the %SS decreased (Table 4.1). This effect was more prominent at physiological maturity (HB5.3) than at early vegetative development (HB2.1). As the intrarow density increased, competition between plants increased resulting in fewer plants surviving to maturity. These results are in agreement with those

of Clarke and Simpson (1978a) and Scarisbrick et al. (1982) but in contrast to Degenhardt and Kondra (1981a) who reported that seeding rate did not effect competitive mortality rates. However, if they had calculated competitive mortality on a %SS basis they would have determined that the lowest seeding rate resulted in the highest %SS, leading to the conclusion that seeding rates did affect competitive mortality rates.

The number of plants lost between seeding and the HB2.1 stage increased as seeding rate increased while at low seeding rates the majority of the plants were lost between the HB2.1 and HB5.3 stage (Table 4.1). At the Arboretum the majority of plants were lost at emergence, probably due to soil surface crusting.

As interplant competition increased, either due to increased row width or increased seeding rate, the plant mortality increased. In terms of the number of plants produced per seeds sown, the 1.5 kg ha^{-1} seeding rate sown in 15 cm wide rows was the most efficient.

4.3.1.2 Phenological development.

The 15 cm row width produced plants requiring significantly more GDD to reach first flower (HB4.1) and physiological maturity (HB5.3) than the 30 cm row width at the Arboretum (Table 4.2; Appendix II, Table 3). This trend was not evident at the other locations. As seeding rate increased the plant required fewer GDD to reach the HB5.1 stage at the Point 1985 and fewer GDD to reach the HB4.1 and HB5.3 stages at the Arboretum 1986. No conclusion can be made on the effect of row widths and seeding rates on the phenological development of Westar rapeseed

TABLE 4.2 Effect of row width (cm) and seeding rates (kg ha^{-1}) on the number of growing degree days to phenological growth stages.

Growth stage	1.0			2.1			3.1		
Location	P85†	P86	A86	P85	P86	A86	P85	P86	A86
Row width									
15	106.3	51.3	154.6	264.2	207.2	283.8	428.9	417.1	473.4
30	106.3	51.3	152.6	264.2	207.2	283.8	428.9	420.4	473.4
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.6	0.0
Seeding rate									
1.5	106.3	51.3	154.6	264.2	207.2	283.8	427.3	415.7	473.4
3.0	106.3	51.3	154.6	264.2	207.2	283.8	428.1	417.1	473.4
6.0	106.3	51.3	151.1	264.2	207.2	283.8	429.7	421.2	473.4
12.0	106.3	51.3	151.1	264.2	207.2	283.8	429.7	421.2	473.4
SE	0.0	0.0	2.1	0.0	0.0	0.0	0.8	1.9	0.0

Growth stage	4.1			5.1			5.3		
Location	P85	P86	A86	P85	P86	A86	P85	P86	A86
Row width									
15	579.2	533.8	640.0	849.6	801.1	--	1134.8	1141.6	1171.8
30	580.1	583.6	630.0	849.6	814.4	--	1133.2	1147.8	1163.4
SE	2.7	1.0	1.0	2.3	8.3		2.8	3.5	2.0
Seeding rate									
1.5	577.4	536.6	659.8	865.8	806.4	--	1132.6	1151.3	1178.1
3.0	579.2	536.6	636.5	853.7	817.5	--	1142.4	1144.5	1171.2
6.0	579.2	536.6	627.0	842.8	805.2	--	1127.1	1141.9	1163.5
12.0	582.8	535.6	617.3	836.5	802.2	--	1133.6	1141.7	1157.4
SE	2.6	1.9	3.0	2.9	13.8		3.8	4.3	3.0

† P85 = Point 1985, P86 = Point 1986 and A86 = Arboretum 1986.
-- Data not collected at this stage.

since there were no consistent differences between treatments noted on the main racemes. In contrast Degenhardt and Kondra (1981b) proposed that rapeseed maturity could be hastened by high seeding rates. However, in their study a difference of only 1.7 days occurred when the seeding rate was increased from 3 to 12 kg ha^{-1}. While this difference was statistically significant, in a practical context it was not great enough to change seeding rate recommendations. Under Manitoba conditions, seeding rates can not be used reliably to decrease the time to maturity.

4.3.1.3 Plant height

Plant height was measured from the soil surface to the growing point of the main raceme at each growth stage from emergence to the end of flowering (terminal plant height). Analyses of variance were done at each growth stage for each location (Appendix II, Table 4).

The 15 cm row width resulted in significantly taller plants than the 30 cm row width at the mid-vegetative stage (HB2.3) at the Point 1985 (Table 4.3). However, at the 30 cm row width, plants were significantly taller at the end of bolting (HB3.3) and at terminal plant height (HB4.4) at the Arboretum 1986 location. These height differences did not occur at the other locations, therefore little can be concluded about the effect of row width on plant height.

While significant differences in plant height existed between all seeding rates at bolting, these differences decreased as the plants grew (Table 4.3). Similar to the results of Degenhardt and Kondra (1981a)

TABLE 4.3 Effect of row width (cm) and seeding rate (kg ha^{-1}) on plant height (cm) at key growth stages.

Growth stage	1.0	2.1	2.3	2.5	3.1	3.3	4.1	4.4
				Point 1985				
Row width								
15	1.0 a	2.0 a	4.0 a	15.3 a	16.8 a	70.3 a	86.3 a	133.2 a
30	1.0 a	2.0 a	4.0 a	14.1 a	17.8 a	73.3 a	89.8 a	133.3 a
Seeding rate								
1.5	1.0 a	2.0 a	4.0 a	9.0 d	10.9 d	66.5 b	84.3 b	133.1 a
3.0	1.0 a	2.0 a	4.0 a	11.9 c	13.9 c	71.2 ab	86.7 ab	134.2 a
6.0	1.0 a	2.0 a	4.0 a	17.4 b	20.5 b	73.8 a	90.7 a	134.8 a
12.0	1.0 a	2.0 a	4.0 a	20.3 a	24.0 a	75.8 a	90.6 a	130.8 a
				Point 1986				
Row width								
15	0.5 a	1.5 a	4.9 a	10.4 a	25.2 a	72.4 a	83.8 a	128.3 a
30	0.5 a	1.5 a	4.2 b	9.9 a	23.4 a	70.6 a	82.2 a	127.9 a
Seeding rate								
1.5	0.5 a	1.5 a	4.0 b	6.8 b	18.8 d	69.2 b	82.8 a	132.8 a
3.0	0.5 a	1.5 a	4.0 b	8.4 b	22.8 c	71.6 ab	84.0 a	129.5 b
6.0	0.5 a	1.5 a	4.9 a	11.7 a	25.9 a	73.8 a	83.5 a	128.2 b
12.0	0.5 a	1.5 a	5.3 a	13.7 a	29.7 a	71.3 ab	81.7 a	122.0 c
				Arboretum 1986				
Row width								
15	0.5 a	1.5 a	3.3 a	10.5 a	17.4 a	58.8 b	--	122.9 b
30	0.5 a	1.5 a	3.3 a	10.5 a	19.1 a	64.8 a	--	128.3 a
Seeding rate								
1.5	0.5 a	1.5 a	3.2 a	8.7 b	13.9 c	49.5 c	--	125.9 ab
3.0	0.5 a	1.5 a	3.0 a	8.8 b	17.2 cb	62.6 b	--	126.6 ab
6.0	0.5 a	1.5 a	3.5 a	11.6 a	22.1 a	67.6 a	--	130.3 a
12.0	0.5 a	1.5 a	3.5 a	12.9 a	19.9 ab	67.3 ab	--	121.5 b

-- no observation at this growth stage.

a-d means within growth stage, location, row width and seeding rate followed by the same letter are not significantly different at the LSD = 0.05 probability level.

the tallest plants in the current research at bolting were the shortest plants at the end of flowering at all locations .

Plants produced at the high seeding rates were subjected to a higher degree of intrarow competition which resulted in taller, etiolated plants at bolting. This difference was maintained until the end of flowering. Duncan (1969) proposed that corn plants grown at high densities expended a greater part of their photosynthate production on height. As a consequence there was less photosynthate available for root development, resulting in a smaller shallower root system. Rood and Major (1984) found that increased rapeseed plant density lead to decreased root mass. These facts and the results from the current research suggest that lower planting densities should be used in areas subject to periodic moisture stress since the plants may expend less photosynthate increasing their height and more on root development.

4.3.2 Effect on yield.

Significant row width and seeding rate effects on yield occurred at all locations (Appendix II, Table 5). The response of yield to seeding rate was largely linear in nature at the Point 1985 and 1986 and cubic in nature at the Arboretum 1986. A significant row by rate interaction occurred at the Point 1985. Bartlett's test for homogeneity of error variance indicated that while subplot error mean squares were homogeneous, main plot errors were not. Heterogeneity of error mean squares usually precludes combined analysis. However, when the F-ratios are large, confidence can be placed in their proof of significance (Cochran and Cox 1957). Significant yield differences existed between

all locations. The Point in 1985 produced the highest average yield followed by the Point 1986 and the Arboretum 1986. Weed control and soil fertility were better at the Point locations than at the Arboretum. Soil crusting was greater at the Arboretum than at the Point.

At all locations the 15 cm row width produced significantly greater yields than the 30 cm row width (Table 4.4). These results are consistent with those previously reported in the literature (Kondra 1975 and Christensen and Drabble 1984). However, the magnitude and significance of the yield differences among 15, 23, 31 and 61 cm row widths was quite variable among locations and years. In the current experiment decreasing the row width while maintaining the same seeding rate decreased the distance between the plants within the row, thereby reducing intrarow competition which resulted in a higher yield.

At the Point in 1985 and 1986 the lowest seeding rate produced the highest yields while at the Arboretum the second lowest seeding rate produced the highest yield (Table 4.4). There were no significant differences among seeding rates at the Point locations for the 30 cm row width (Figure 4.1). At the Arboretum the 3.0 kg ha^{-1} seeding rate significantly outyielded the 1.5 and 12.0 kg ha^{-1} seeding rates for the 30 cm wide rows. At the Point in 1985 and 1986, yields decreased as seeding rate increased from 1.5 to 12 kg ha^{-1} in the 15 cm rows. At the Point in 1985 there were significant differences in yield among the 1.5, 3, and 6 kg ha^{-1} treatments, while the 12 kg ha^{-1} treatment was not significantly different from the 3 or 6 kg ha^{-1} rates. At the Point in 1986, significant yield differences occurred between the 1.5 and 12 kg

TABLE 4.4 Effect of row width (cm) and seeding rate (kg ha^{-1}) on yield (kg ha^{-1})

	Point 1985	Point 1986	Arboretum 1986
Row width			
15	3514.9 a	3027.8 a	2368.9 a
30	2920.0 b	2480.8 b	1880.0 b
Seeding Rate			
1.5	3533.8 a	3009.5 a	1981.8 b
3.0	3271.2 b	2859.8 a	2443.2 a
6.0	3041.2 bc	2818.1 a	2177.5 ab
12.0	3023.7 c	2396.6 b	1895.7 b

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 probability level.

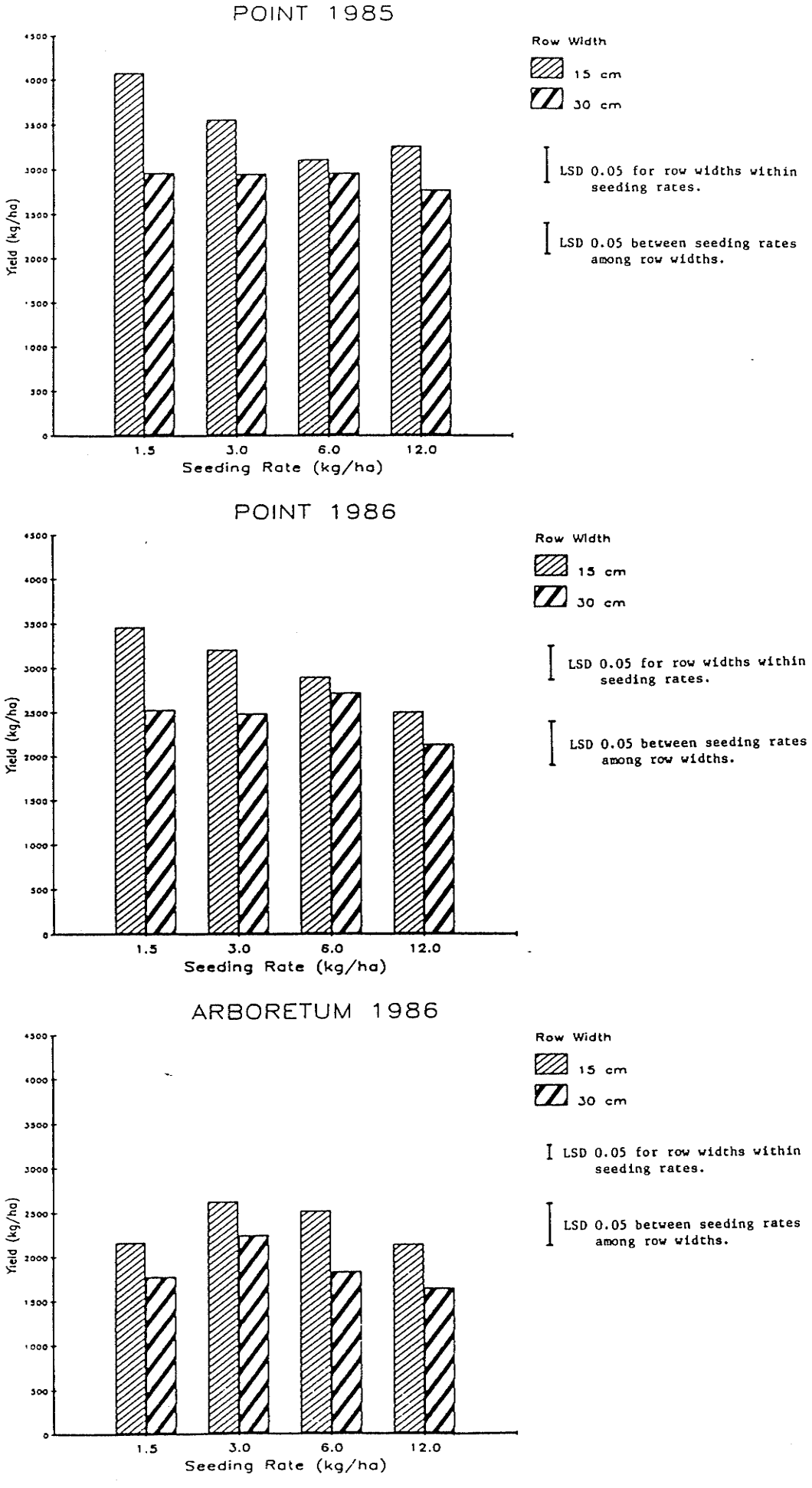


Figure 4.1 Effect of row width (cm) and seeding rate (kg ha^{-1}) on yield (kg ha^{-1}).

ha^{-1} seeding rates. At the Arboretum the 3.0 kg ha^{-1} seeding rate resulted in a significantly higher yield than the 1.5 and 12 kg ha^{-1} rate.

Donald (1963) concluded that in studies where the objective was to find the optimum seeding rate to produce the highest yield, rarely was a wide enough range of rates used to permit the expression of the relationship of plant density to yield. He found that as seeding rate increased, seed yield in many crops increased rapidly, reached a plateau and then slowly declined. There was a considerable range of seeding rates which resulted in similar yields. Donald (1963) attributed this response to the extreme plasticity in size and form that certain plants exhibit in response to their spatial environment.

It is apparent from the past research that seeding rates from 3 to 12 kg ha^{-1} result in nearly the same yield (Kondra 1975, 1977; Degenhardt and Kondra 1981a; Clarke and Simpson 1978b; Christensen and Drabble 1984 and McGregor 1987). The results of the past and current research follow Donald's (1963) density yield response relationship. The highest yields were achieved at the Point 1985 under the 1.5 kg ha^{-1} rate seeded at 15 cm row widths. Mean plant density at harvest for this treatment was 30 plants m^{-2}. The 3 and 6 kg ha^{-1} rates were similar, corresponding to the density-yield plateau. At the Point 1986 location there were no significant differences among the 1.5, 3 and 6 kg ha^{-1} seeding rates. The 1.5 kg ha^{-1} rate in 1986 produced 54.2 plants m^{-2} indicating that under those environmental conditions higher yields may have been obtained with an even lower seeding rate. Under the poorer conditions that prevailed at the Arboretum in 1986 the yield of

the 1.5 kg ha^{-1} rate was significantly lower than the 3.0 kg ha^{-1} rates but there were no differences among the 6 and 12 kg ha^{-1} rates. The 3.0 and 1.5 kg ha^{-1} rates resulted in densities of 34.2 and 21.2 plants m^{-2}, respectively.

Recommended seeding rates for rapeseed (B. napus) grown in Manitoba are currently set at 6-8 kg ha^{-1} (Manitoba Agriculture 1987). Under good growing conditions this rate can be reduced to as low as 1.5 to 3.0 kg ha^{-1} which should establish a density of at least 30 plants m^{-2}. This study was conducted under relatively weed free conditions. On a field scale, competition from weeds can result in dramatic yield losses at low rapeseed densities. It will be necessary to examine the interaction between rapeseed density and weed competition before the current seeding rate recommendations are changed.

4.3.3 Effect on yield components.

The yield components $plant^{-1}$ were determined arithmetically either by summing branch and main raceme components, as with the total number of pods $plant^{-1}$, or by calculating a weighted mean based on the percent contributed by the branch and main raceme components, as with seeds pod^{-1} and 1000 seed weight. Yield components were analysed on a total plant basis, and the relationship between the main and branch racemes was also examined.

An analysis of variance was conducted on each yield component at each location (Appendix II, Table 7). Bartlett's test for homogeneity of error variance indicated that while main and sub plot error variances

were homogeneous for seeds pod^{-1} and 1000 seed weight, they were heterogeneous for pods plant^{-1}. Therefore, locations were not combined.

Expected yields plant^{-1} were determined by multiplying the yield component values together (ie. pods plant^{-1} x seeds pod^{-1} x 1000 seed weight)/(1000). Observed yields plant^{-1} were determined from the harvested yield m^{-2}/number of plants m^{-2}. While expected yields plant^{-1} were 1.6 times greater on average than observed yields plant^{-1}, the response to row width and seeding rates were very similar (Table 4.5). This indicates that the yield components on a per plant basis represent the general trend accurately, even though the values are exaggerated.

The 15 cm row width resulted in significantly more pods plant^{-1} than the 30 cm wide rows at the Point locations (Table 4.5). While not significant, the same trend was evident at the Arboretum 1986 locations. Significant seeding rate differences in pods plant^{-1} occurred at all locations. As seeding rate increased, the number of pods plant^{-1} decreased. There were significant differences in pods plant^{-1} between all four seeding rates at the Point 1985. However, there were no significant differences between the 6 and 12 kg ha^{-1} rates or the 1.5 and 3 and 6 and 12 kg ha^{-1} rates at the Point and Arboretum in 1986, respectively.

The 15 cm row width resulted in significantly more seeds pod^{-1} than the 30 cm wide rows at the Point in 1986. This trend was not evident at the other locations. There were significant differences in seeds pod^{-1} due to seeding rates at the Point 1985 and Arboretum 1986. These differences were significantly linear in nature. The 1.5 and 3.0 kg ha^{-1} rate produced significantly more seeds pod^{-1} than the 6 and 12 kg

TABLE 4.5 Effect of row width (cm) and seeding rate (kg ha^{-1}) on yield components and expected and observed yield $plant^{-1}$ (g).

	Pods $plant^{-1}$	Seeds pod^{-1}	1000 seed weight (g)	Ex yield $plant^{-1}$	Obs yield $plant^{-1}$
			Point 1985		
Row width					
15	122.4 a	23.5 a	3.73 a	11.1 a	5.7 a
30	114.6 a	24.1 a	3.71 a	10.3 a	6.8 a
Seeding rate					
1.5	202.7 a	24.8 a	3.74 a	18.8 a	12.9 a
3.0	145.3 b	24.9 a	3.62 a	13.2 b	6.8 b
6.0	78.2 c	22.8 b	3.75 a	6.6 c	3.5 c
12.0	47.6 d	22.6 b	3.78 a	4.0 d	2.0 d
			Point 1986		
Row width					
15	88.1 a	19.4 a	3.85 a	6.6 a	3.3 a
30	72.5 b	18.4 b	3.92 a	5.2 b	2.8 b
Seeding rate					
1.5	130.6 a	19.3 a	3.84 a	9.7 a	5.7 a
3.0	90.1 b	19.5 a	3.78 a	6.7 b	3.8 b
6.0	57.8 c	18.1 a	3.85 a	4.0 c	1.8 c
12.0	42.7 c	18.5 a	4.06 a	3.2 c	1.0 d
			Arboretum 1986		
Row width					
15	136.3 a	18.5 a	3.29 a	8.5 a	6.5 a
30	126.4 a	19.1 a	3.35 a	8.1 a	5.7 a
Seeding rate					
1.5	187.6 a	20.8 a	3.18 a	12.2 a	9.8 a
3.0	160.8 a	18.9 b	3.38 a	10.3 a	7.9 a
6.0	97.7 b	18.5 bc	3.35 a	6.1 b	4.3 b
12.0	79.3 b	17.0 c	3.39 a	4.6 b	2.4 b

a-d means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

ha^{-1} rates and the 1.5 kg ha^{-1} rate produced significantly more seeds pod^{-1} than the other rates at the Point 1985 and Arboretum 1986 locations, respectively (Table 4.5). There were no significant differences between row widths or seeding rates for the 1000 seed weight at any location.

The results from the current experiment and the literature (Olsson 1960; Kondra 1975; Clarke and Simpson 1978a; Degenhardt and Kondra 1981a; Scarisbrick et al. 1982 and McGregor 1987) show that the primary yield component affected by the spatial environment (row width and seeding rate) is the number of pods $plant^{-1}$. Seeds pod^{-1} and seed weight are least affected by the environment. Narrow row widths and low seeding rates resulted in more pods $plant^{-1}$ than wide rows and higher seeding rates.

4.3.3.1 Distribution of yield and yield components

Seeding rate and row width influence the distribution of yield and yield components within a rapeseed plant. Yield component branch/main raceme ratios were calculated. The percent of the total yield contributed by branch and main racemes was determined and a branch/main raceme yield ratio calculated. Analyses of variance were conducted on the yield components arising from the branch and main racemes and on the derived ratios (Appendix II, Table 8 and 9). Bartlett's homogeneity of error variance test indicated that main plot and subplot yield component errors were not homogeneous, therefore, the locations were not combined.

At the Point 1986 the 15 cm row width resulted in a significantly higher branch/main raceme pods $plant^{-1}$ ratio than the 30 cm wide rows

(Appendix II, Table 9; Table 4.6). A similar trend was evident at the other locations. The lowest seeding rate resulted in the highest branch/main pod ratio. As seeding rate increased this ratio decreased. Both the number of branch pods and main pods plant^{-1} decreased as seeding rate increased, although the difference was greater for branch pods (Table 4.7).

There were no significant row width differences in branch/main raceme seeds pod^{-1} ratios (Appendix II, Table 9). The ratios were all less than one indicating that more seeds pod^{-1} were produced on the main racemes (Table 4.6). Significant differences due to seeding rate in branch/main raceme seeds pod^{-1} occurred only at the Arboretum 1986. (Appendix II, Table 9). The number of seeds produced in both branch and main raceme pods decreased as seeding rate increased (Table 4.7). However, the decrease was more pronounced in the branch pods.

There were no significant row width differences in branch/main raceme ratios for seed weight (Appendix II Table 9). The ratios were less than one at all locations indicating that larger seeds were produced on the main raceme (Table 4.6). Significant seeding rate differences in the branch/main raceme ratio for seed weight occurred only at the Point in 1985 (Appendix II, Table 9). Generally as seeding rate increased branch raceme seed weights increased slightly while main raceme seed weights remained relatively constant (Table 4.7).

The percent of the total yield plant^{-1} contributed by the branch and main racemes was determined by multiplying branch or main raceme yield components together and dividing by the total yield plant^{-1}. There were no significant row width differences for branch/main raceme

TABLE 4.6 Effect of row width (cm) and seeding rate (kg ha^{-1}) on the ratios of branch/main raceme yield components and branch/main raceme percent yield.

	Pods $plant^{-1}$	Seeds pod^{-1}	1000 Seed weight	Percent Yield ratio
		Point 1985		
Row width				
15	2.03 a	0.90 a	0.94 a	1.67 a
30	1.93 a	0.87 a	0.96 a	1.61 a
Seeding rate				
1.5	3.56 a	0.90 a	0.92 a	2.89 a
3.0	2.40 b	0.92 a	0.93 bc	2.04 b
6.0	1.30 c	0.83 a	0.97 ab	1.06 c
12.0	0.66 d	0.88 a	0.99 a	0.57 d
		Point 1986		
Row width				
15	1.41 a	0.80 a	0.96 a	1.06 a
30	1.27 b	0.78 b	0.96 a	0.85 a
Seeding rate				
1.5	2.14 a	0.78 a	0.95 a	1.56 a
3.0	1.41 b	0.84 a	0.95 a	1.10 b
6.0	0.85 c	0.84 a	0.97 a	0.70 c
12.0	0.67 c	0.70 a	0.97 a	0.45 d
		Arboretum 1986		
Row width				
15	2.83 a	0.86 a	0.89 a	2.17 a
30	2.49 a	0.83 a	0.93 a	1.87 a
Seeding rate				
1.5	3.73 a	1.01 a	0.90 a	3.16 a
3.0	3.60 a	0.77 b	0.90 a	2.43 a
6.0	1.79 b	0.84 b	0.94 a	1.42 b
12.0	1.53 b	0.76 b	0.90 a	1.07 b

a-d means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

TABLE 4.7 Effect of row width (cm) and seeding rate (kg ha^{-1}) on branch and main raceme yield components and percent total yield.

	BNPD	MNPD	BSEP	MSEP	BSWT	MSWT	B%YLD	M%YLD
				Point 1985				
Row width								
15	84.5a	37.9a	22.4a	25.1a	3.62a	3.85a	56.7a	43.3a
30	77.4a	37.2a	22.6a	26.1a	3.64a	3.77a	56.1a	43.9a
Seeding rate								
1.5	158.2a	44.6a	24.2a	27.2a	3.59ba	3.89a	72.9a	27.1d
3.0	102.8b	42.8a	24.2a	26.6a	3.48b	3.75a	66.2b	33.8c
6.0	44.2c	34.1b	20.8b	25.1ab	3.69ab	3.79a	49.5c	50.5b
12.0	18.7d	28.8c	21.0b	23.6b	3.76a	3.80a	34.9d	65.1a
				Point 1986				
Row width								
15	53.0a	35.2a	17.3a	21.9a	3.76a	3.94a	46.3a	51.8a
30	40.6b	31.9b	16.3a	20.2a	3.84a	3.98a	43.9a	55.8a
Seeding rate								
1.5	89.1a	41.6a	17.7a	22.7a	3.76a	3.98a	59.4a	40.6c
3.0	53.3b	37.8b	18.0a	21.8a	3.69a	3.88a	50.0ab	50.0bc
6.0	27.3c	32.1b	17.0a	18.7a	3.78a	3.89a	43.7b	56.0b
12.0	17.4c	36.0b	14.6b	21.0a	3.96a	4.09a	29.5c	70.5a
				Arboretum 1986				
Row width								
15	100.7a	35.6a	17.6a	20.3a	3.26a	3.56a	63.5a	36.0a
30	91.2a	35.2a	17.5a	21.1a	3.16a	3.53a	59.9a	39.7a
Seeding rate								
1.5	148.7a	38.9a	21.1a	20.9ab	3.09a	3.49a	73.9a	26.1c
3.0	123.9a	36.8a	16.8b	21.7a	3.29a	3.65a	67.2a	32.8c
6.0	62.3b	35.4a	17.2b	20.4ab	3.25a	3.48a	57.4b	42.6b
12.0	48.9b	30.4a	14.9b	19.7b	3.19a	3.56a	48.7c	51.3a

a-d means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

B = branch raceme, M=main raceme.

NPD = number of pods $plant^{-1}$, SEP = number of seeds pod^{-1}

SWT = 1000 seed weight, %YLD = percent total yield.

percent total yield. Significant differences for branch/main raceme percent total yield occurred at all locations due to varying seeding rate. As seeding rate increased, the branch/main raceme ratios for percent of total yield decreased (Table 4.6). At low seeding rates a large portion of the total yield was produced on the branches and as seeding rate increased the yield from the branches decreased (Figure 4.2). The main raceme produced more pods containing more and larger seeds than the branch racemes, confirming earlier reports by Clarke (1979). The number of pods produced on the branch racemes served to buffer the effect of a reduced plant density and maintain the yield. The branch/main raceme ratio for the number of pods plant^{-1} was similar to the ratio for total yield, confirming earlier observations that yield plant^{-1} was most strongly influenced by the number of pods plant^{-1}.

4.3.4 Effect on harvest index.

There were no significant differences in harvest index due to row width or seeding rate effects at any location (Appendix II, Table 10). A significant row width by seeding rate interaction occurred at the Point 1986 location.

While the differences were not statistically significant the harvest indices resulting from the 30 cm wide rows were slightly larger than the ones from the 15 cm wide rows at all locations (Table 4.8). The 12 kg ha^{-1} seeding rate resulted in the lowest harvest index at all locations. There were no other trends evident among the other seeding rates.

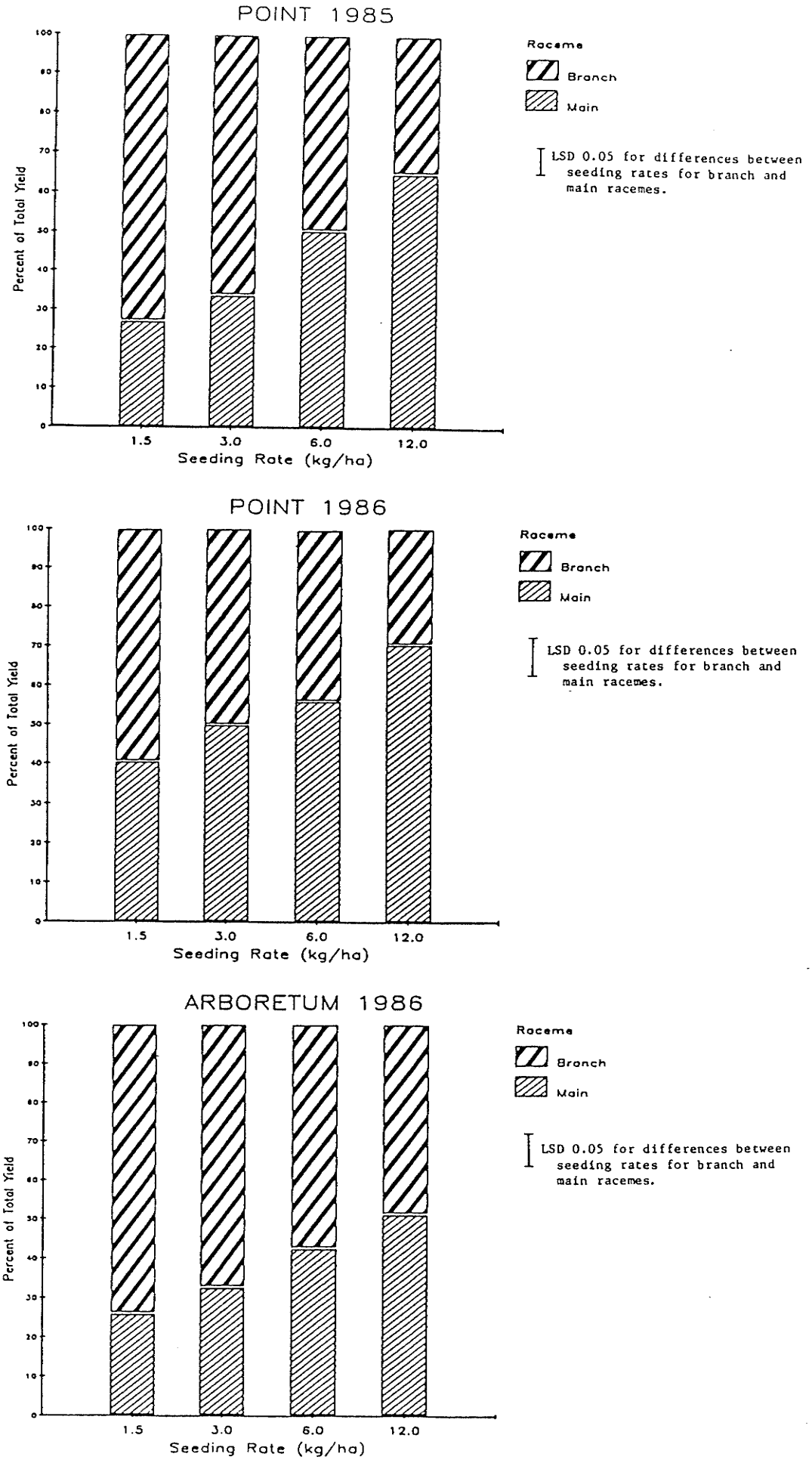


Figure 4.2 Effect of seeding rate (kg ha^{-1}) on the percent of total yield contributed by the branch and main racemes.

Harvest index was not affected by either row width or seeding rate, similar to the results reported by Clarke (1977), but in contrast to Kondra (1981a) and Scarisbrick et al. (1982) who observed that as seeding rate increased harvest index decreased. Since harvest index in rapeseed has been found to be very responsive to environmental variation it is not be a useful tool for yield selection (Thurling 1974b).

The ability of the rapeseed plant to compensate for its spatial environment resulted in similar harvest indices from different plant densities. Harvest index is not a useful tool to use to account for yield differences between the row width and seeding rate treatments.

TABLE 4.8 Effect of row width (cm) and seeding rate (kg ha^{-1}) on harvest index (percent).

Location	Point 1985	Point 1986	Arboretum 1986
Row width			
15	17.9 a	22.7 a	22.0 a
30	20.0 a	23.1 a	23.8 a
Seeding rate			
1.5	21.0 a	23.4 a	21.6 a
3.0	18.4 a	23.8 a	24.6 a
6.0	19.5 a	22.8 a	23.3 a
12.0	16.8 a	21.4 a	22.1 a

4.3.5 Effect of row width and seeding rate on lodging.

Lodging was rated on a scale from 0 to 5 with 0 representing no lodging and 5 complete lodging. There were no significant differences in lodging due to row width (Appendix II, Table 11; Table 4.9). There were significant differences in lodging due to seeding rate. A significant row width by seeding rate interaction occurred at the Point 1985 location. Bartlett's test indicated that subplot error mean squares were heterogeneous.

As seeding rate increased from 1.5 to 12 kg ha^{-1}, lodging increased significantly (Table 4.9, Figure 4.3). Similar results were reported by Loof (1972) and Kondra (1975). Lodging at all locations was greatest at the highest seeding rate. The plants appeared to lodge from the base of the stem. Therefore, a weak stem or a shallow root system may have caused lodging. High plant densities produced plants with thinner stems which were less able to support the weight of the pods and seeds. This resulted in a reduction in yield. Under a lodged rapeseed canopy, the movement of air is impaired and the rate of drying of the crop is reduced (Daniels et al. 1986). This creates a favorable microclimate for the initiation and spread of disease (Thompson and Hughes 1984). At the Point in 1986 the percentage of the crop infected by Sclerotinia (Sclerotinia sclerotiorum) seeded at 1.5, 3 and 6 kg ha^{-1} was significantly lower than at the 12 kg ha^{-1} rate (Table 4.10).

Few studies have been conducted on the effect of lodging on rapeseed, therefore it is difficult to determine if a lodging rating of 2.5 results in a greater yield loss than one of 1.5 or 3.5. A more

TABLE 4.9 Effect of row width (cm) and seeding rate (kg ha^{-1}) on lodging (0-5).

	Point 1985	Point 1986	Arboretum 1986
Row width			
15	2.3 a	1.6 a	1.8 a
30	3.0 a	2.0 a	1.5 a
Seeding rate			
1.5	1.2 c	0.2 d	0.8 c
3.0	2.1 b	1.0 c	1.0 c
6.0	3.3 a	2.3 b	1.9 b
12.0	3.9 a	3.8 a	3.0 a

a-d means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 probability level.

TABLE 4.10 Effect of row width (cm) and seeding rate (kg ha^{-1}) on Sclerotinia infection (percent) at the Point 1986.

	Percent infection
Row width	
15	18.5 a
30	18.3 a
Seeding rate	
1.5	16.1 b
3.0	15.3 b
6.0	15.8 b
12.0	26.2 a

a,b means within row widths and seeding rates followed by the same letter are not significantly different at the LSD = 0.05 probability level.

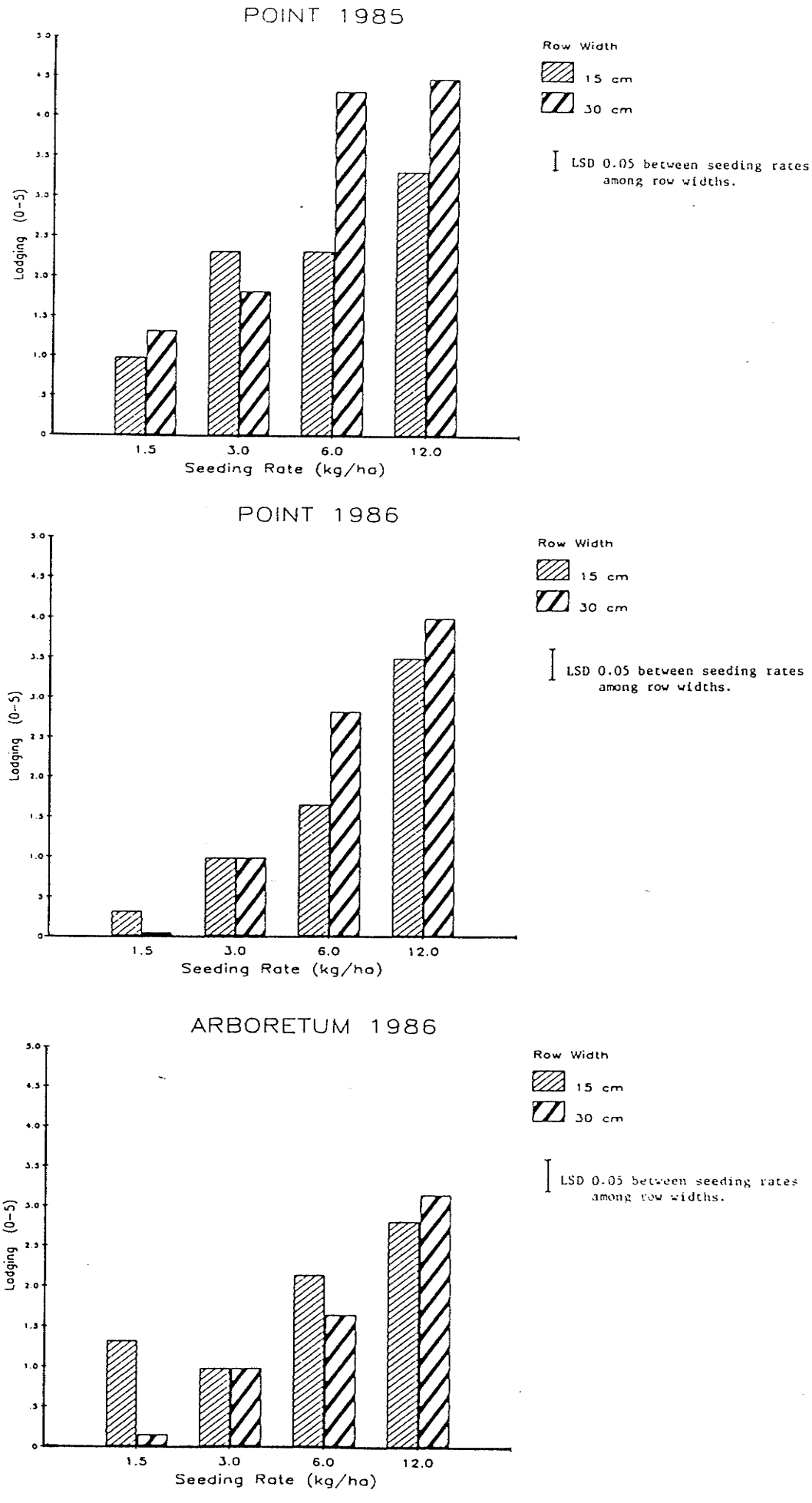


Figure 4.3 Effect of row width (cm) and seeding rate (kg ha^{-1}) on lodging (0 to 5).

detailed analysis of the relationship between lodging, disease and yield loss in rapeseed is needed.

4.3.6 Interrelationship of some agronomic characteristics and yield.

Correlation coefficients were determined among plant m^{-2} at harvest, terminal plant height, harvest index, lodging and yield. The 15 and 30 cm row widths were analysed separately. A test of homogeneity indicated that correlation coefficients from the three locations were homogeneous, therefore they could be pooled (Gomez and Gomez 1984, Table 4.11).

Plants m^{-2} at harvest was negatively correlated with yield for both the 15 and 30 cm row widths (Table 4.11). As plants m^{-2} increased, competition for essential factors increased and as a consequence yield decreased. In contrast Clarke and Simpson (1978b) reported that under Saskatchewan conditions, plant density was positively correlated with seed yield. The difference between the two studies arises from the fact that the low available soil moisture conditions in Saskatchewan limited the extent to which rapeseed, seeded at low seeding rates, could compensate for the additional space. However, when environmental conditions favor plant compensation, as in the case of the current research, plants seeded at lower rates can produce equal or higher yields than those seeded at high rates.

Terminal plant height was negatively correlated with plant m^{-2} for the 15 cm wide rows but not for the 30 cm wide rows. While plant height differences between seeding rates were inconsistent among the three locations the lower rates resulted in slightly taller plants. It is

TABLE 4.11 Correlation coefficients for agronomic parameters and yield (top line 15 cm and bottom line 30 cm row widths).

	Height	HI	Lodging	Yield
Plants m^{-2}	-0.66 *	-0.19	0.94 **	-0.74 **
	-0.54	-0.29	0.94 **	-0.61 *
Plant height		-0.22	-0.55	0.40
		0.53	-0.47	0.59 *
Harvest index (HI)			-0.32	0.49
			-0.32	0.73 **
Lodging				-0.76 **
				-0.53

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

conceivable that plants seeded at lower rates did not expend as much energy in competition at bolting and were able to utilize the additional assimilate to produce a taller plant at maturity. Terminal plant height was not correlated with harvest index or lodging. As plant height in the 30 cm wide rows plots increased yield increased. Plant height and yield decreased as seeding rate increased.

Apparent harvest index was significantly correlated with yield at the 30 but not at the 15 cm row width (Table 4.11). There are no reports in the literature correlating harvest index from different seeding treatment with yield. Due to plant compensation for the spatial environment, harvest index is not an appropriate agronomic index to use to account for yield differences among different plant densities.

As plant density increased, lodging increased and yield decreased (Table 4.11). Under high densities rapeseed had thin stems, and was more susceptible to lodging and may have been more susceptible to stem diseases such as sclerotinia or blackleg (Leptosphaeria maculans). Thompson and Hughes (1984) determined that in a lodged crop there was a greater incidence of disease and concluded that higher yield came from a crop that was not lodged. It is possible that lodging and the conditions resulting from lodging were responsible for the yield differences found between the seeding rates in this experiment. Lodging was not significantly correlated with seed yield for the 30 cm row width treatment. This was probably due to the fact that there was little difference in yield between seeding rates at the 30 cm wide rows.

4.3.7 Quality characteristics

4.3.7.1 Oil and protein concentration.

Significant differences in oil concentration due to row widths and seeding rates occurred only at the Point in 1986 (Appendix II, Table 12). The seed from the 15 cm row width was higher in oil concentration than the seed from the 30 cm row width (Table 4.12). As seeding rate increased, oil concentration tended to decrease. Combined analysis indicated that average oil concentration was significantly different at each environment (Appendix II, Table 13). The Point in 1985 produced the lowest average oil concentration followed by the Arboretum and the Point in 1986. Greater differences in oil concentration existed between environments than among seeding rates or row widths within an environment.

The 30 cm row wide rows resulted in a significantly higher protein concentration at the Point in 1986 (Appendix II, Table 12; Table 4.12). At the Point and Arboretum in 1986, the 1.5 kg ha^{-1} seeding rate produced a significantly lower protein concentration than the 12 kg ha^{-1} rate. Combined analysis indicated that significant differences for protein concentration occurred between all locations (Appendix II, Table 13). The Point in 1986 produced the lowest protein followed by the Arboretum in 1986 and the Point in 1985. Again, greater differences in protein concentration occurred between environments than between seeding rate or row widths within an environment.

Kondra (1975, 1977) and Scarisbrick et al. (1982) reported no significant differences in oil and protein concentration in rapeseed

TABLE 4.12 Effect of row width (cm) and seeding rate (kg ha^{-1}) on oil and protein (percent).

Location	Point 1985		Point 1986		Arboretum 1986	
	Oil	Protein	Oil	Protein	Oil	Protein
Row width						
15	45.1 a	24.9 a	46.9 a	22.3 b	45.8 a	24.4 a
30	44.7 a	25.3 a	46.2 b	23.5 a	45.7 a	24.4 a
Seeding rate						
1.5	45.1 a	24.5 a	46.9 a	22.5 b	45.9 a	24.1 b
3.0	45.3 a	24.8 a	46.8 a	22.8 ab	45.7 a	24.2 ab
6.0	44.8 a	25.4 a	46.4 b	23.2 a	45.8 a	24.3 ab
12.0	44.5 a	25.6 a	45.9 b	23.2 a	45.5 a	25.0 a

a,b means within row widths, seeding rates and locations for oil and protein percent followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

seeded at different row widths and seeding rates. Clarke (1977) observed that rapeseed seeded at 20 kg ha^{-1} in 30 cm wide rows produced seed with a significantly lower oil concentration than at 2.5 kg ha^{-1}. It is interesting to note that in all of these studies oil and protein concentration varied more among environments than within seeding rates. Olsson (1960) attributed the large differences in oil concentration that occurred between environments mainly to soil moisture and temperature differences during ripening.

Diepenbrock and Geisler (1979) observed, that during the final stages of seed ripening, the oil concentration decreased slightly, while the protein concentration increased slightly. They also showed that in low density plants, branch raceme pods contributed more to yield than main raceme pods. This suggests that the small differences in oil concentration between the high and low seeding rates found in this and other studies may be due to differing levels of seed maturity caused by plant density. Plants from low densities would have a large proportion of the seeds produced from less mature branch pods with higher oil and lower protein concentration than mature seeds from the main raceme.

In the current research there was a negative relationship between oil and protein concentration similar to the that determined by Bhatty (1964). Rapeseed with high oil had a lower protein concentration and vice versa.

The results from this experiment indicate that altering seeding rate and row width has very little effect on the protein and oil concentration of rapeseed. Protein and oil concentration varied more between environments than among plant densities within an environment.

4.3.7.2 Chlorophyll concentration.

Seed chlorophyll determinations were performed on the seed from the yield component study. Seeds from the branch and main racemes were analysed separately and total seed chlorophyll calculated using a weighted mean. There were no significant differences in branch and main raceme seed chlorophyll concentration due to row width or seeding rate at the Point 1985 and Arboretum 1986 (Appendix II, Table 14). Significant seeding rate effects occurred for branch seed chlorophyll concentration at the Point in 1986. Significant seeding rate effects occurred for total seed chlorophyll concentration at both Point locations but not at the Arboretum. A significant row width by seeding rate interaction occurred for branch seed chlorophyll and total seed chlorophyll concentration at the Point 1986 location.

The 1.5 kg ha^{-1} seeding rate resulted in the highest branch seed chlorophyll at the Point in 1985 and Arboretum in 1986 (Table 4.13). At the Point in 1986, the 12 kg ha^{-1} seeding rate produced the highest branch seed chlorophyll concentration followed by the 1.5 kg ha^{-1} rate. There were no significant differences in main seed chlorophyll concentration at any location. At the Point in 1985 the 1.5 kg ha^{-1} seeding rate produced seed with significantly higher total chlorophyll concentration than the 3, 6 and 12 kg ha^{-1} rates. At the Point 1986 the 1.5 kg ha^{-1} seeding rate produced significantly higher total seed chlorophyll levels than the 3 and 6 but not the 12 kg ha^{-1} rates. While there were no significant differences in total seed chlorophyll

TABLE 4.13 Effect of row width (cm) and seeding rate (kg ha^{-1}) on seed chlorophyll (ppm)

	Branch chlorophyll	Main chlorophyll	Total chlorophyll
		Point 1985	
Row width			
15	26.1 a	14.7 a	22.0 a
30	22.3 a	12.2 a	18.0 a
Seeding rate			
1.5	27.8 a	13.9 a	24.2 a
3.0	21.5 a	12.5 a	18.5 b
6.0	23.0 a	13.3 a	19.5 b
12.0	24.5 a	14.2 a	17.7 b
		Point 1986	
Row width			
15	18.1 a	9.7 a	13.6 a
30	21.1 a	10.1 a	14.0 a
Seeding rate			
1.5	21.9 b	10.1 a	17.5 a
3.0	13.1 c	9.8 a	11.5 b
6.0	14.8 c	8.7 a	11.1 b
12.0	28.5 a	10.8 a	15.7 a
		Arboretum 1986	
Row width			
15	20.8 a	15.3 a	18.9 a
30	21.9 a	13.6 a	18.8 a
Seeding rate			
1.5	23.6 a	14.9 a	21.6 a
3.0	23.7 a	14.8 a	17.7 a
6.0	19.5 a	13.1 a	16.9 a
12.0	18.4 a	15.0 a	19.3 a

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

concentration at the Arboretum 1986 location, the 1.5 kg ha^{-1} rate did result in the highest chlorophyll concentration.

The total seed chlorophyll concentration was derived from the branch and main seed chlorophyll concentrations and the proportional contribution each made to the total seed yield in each sample. At low seeding rates, the majority of the seeds were produced on the branches and at high seeding rates, the reverse was true. Therefore it was expected that chlorophyll concentration would be highest at the 1.5 kg ha^{-1} rate and lowest at the 12 kg ha^{-1} rate. While this trend is evident at the Point in 1985, at the Point and Arboretum in 1986 the 12 kg ha^{-1} rate resulted in total seed chlorophyll greater than the 3 and 6 kg ha^{-1} rates (Table 4.13, Figure 4.4). In 1986 rapeseed was infected with sclerotinia to a high degree (Table 4.10). Seeds from plants seeded at 12 kg ha-1, especially in the 30 cm wide rows, may have been less mature than those at lower densities since these plants were injured by disease before the seeds could mature. Loof (1972) found that in uneven stands or those damaged by drought, flooding, insects and disease, the chlorophyll concentration of the seeds was high even when threshing was postponed.

Canadian Trading Rules for canola oil have established 25 ppm chlorophyll as a maximum allowable level for top grade crude oil. Daun (1987) found that oil chlorophyll levels of 25 ppm corresponded to seed chlorophyll levels of 22 ppm. Total seed chlorophyll concentration exceeded 22 ppm at the 1.5 kg ha^{-1} seeding rate seeded in 15 cm rows at the Point in 1985 (Figure 4.4). Seed chlorophyll concentrations were

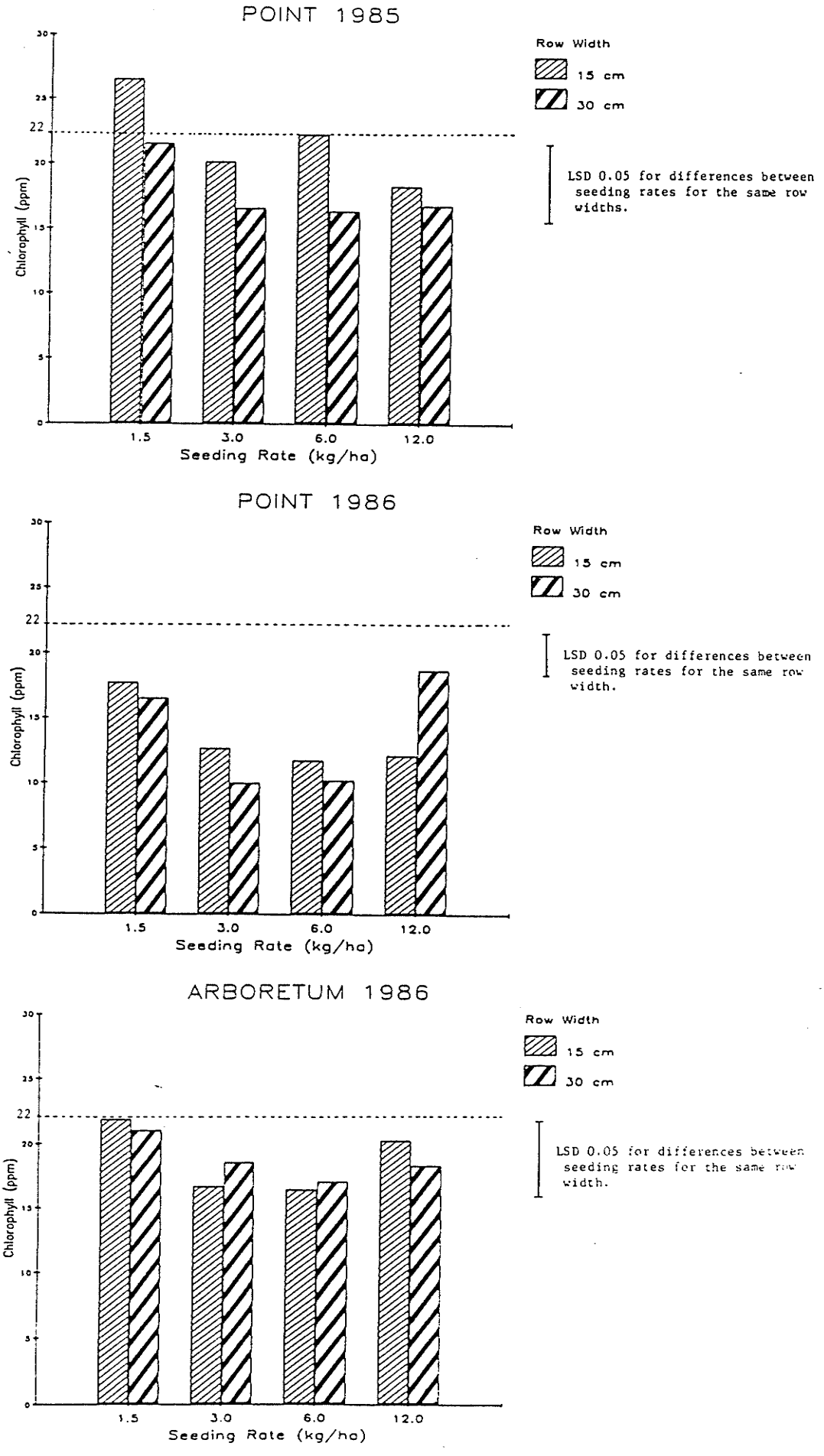


Figure 4.4 Effect of row width (cm) and seeding rate (kg ha^{-1}) on seed chlorophyll concentration (ppm).

close to 22 ppm when rapeseed was seeded at the 6 and 1.5 kg ha^{-1} rates at the Point 1985 and Arboretum 1986, respectively.

In Canada, the yearly average seed chlorophyll concentration has varied from a high of 28 ppm to a low of 11 ppm with a mean of 19.6 ppm (Daun 1987). Total seed chlorophyll concentrations from this experiment fell within this range. While only one seeding rate at one locations exceeded 22 ppm it is evident that when lower seeding rates are used the risk due to uneven maturity and high chlorophyll concentration are increased. The problem of high seed chlorophyll concentration can not be solved by agronomic practices alone. Disease, lodging and the vagaries of the weather at harvest combine to create a complex problem. If possible, plant breeders should select genotypes which lose seed chlorophyll concentration at a faster rate during seed maturation. Researchers may determine that a reduction in seed chlorophyll will lead to a reduction in seed weight, fatty acid concentration and potentially a reduction in early spring vigor. The relationship between seed chlorophyll and these parameters must be investigated before plant breeding begins. If increased shattering resistance was introduced into B. napus the seed chlorophyll problem may be reduced in southern regions, since producers could leave rapeseed standing in the field for a longer period before swathing to allow greater seed maturity on the branch racemes. Selection for lower seed chlorophyll must be conducted under uniform plant densities to eliminate the effects due to increased or decreased branching in response to the spatial environment.

4.4. Summary and Conclusion.

The effect of varying row width and seeding rate on the yield and agronomic characteristics of Westar rapeseed was studied over two years at two locations. The four seeding rates resulted in four plant densities at each location. As the seeding rate increased, more plants were lost at emergence. The 15 cm row width had a higher percentage plant establishment and density than the 30 cm row width. As the seeding rate increased the mortality rate increased especially in the 30 cm rows.

As seeding rate increased, the number of growing degree days to first flower and physiological maturity decreased slightly. However, the differences in rate of development were not of the magnitude that would justify changing the recommended seeding rates. Seeding rates alone can not be used to promote early maturity in rapeseed.

As plants m^{-2} increased, they were subject to an increasing degree of intrarow competition for available resources. Plants grown at the highest density were more etiolated at bolting than those grown at a lower density. However, height differences at maturity between the different densities were small.

The 15 cm wide rows yielded significantly more than the 30 cm wide rows for most seeding rates at all locations. Narrow rows resulted in a more even distribution of plants with a lower intraplant competition. It is likely that even higher yields could be achieved if row widths are reduced further. This has yet to be tested on a field scale. Donald (1963) proposed that seed yield in many crop species was similar over a wide range of densities due to plant plasticity and yield component

compensation. Yield differed only between the extremes of plant density. There were a wide range of seeding rates which resulted in the same yields. Under optimum conditions for rapeseed cultivation in southern Manitoba, yields may be increased using seeding rates of 1.5 or 3.0 kg ha^{-1} (30 to 100 plants m^{-2}) which are lower than the recommended rates of 6 to 8 kg ha^{-1}.

One of the reasons why current agronomic practices recommend seeding at a high rate (6 to 8 kg ha^{-1}, 200 to 300 plants m^{-2}) is to insure competition with weeds at early growth stages. However, the advantage of high interspecies competition is reduced by the increase in intracrop competition resulting in lower yields. Attention must be paid to weed control if low seeding rates are used. Currently the price of seed is not a large portion of the cost of rapeseed production and high plant densities provide a buffer in case of poor emergence or high plant mortality. If in the future hybrid rapeseed is grown, seed costs may become an important factor. Plant density studies must be repeated with these hybrids.

The primary yield component affected by row width and seeding rate was the number of pods $plant^{-1}$. As seeding rate decreased the number of branch pods $plant^{-1}$ and branch seeds pod^{-1} increased significantly. The number of branches and branch pods produced served to buffer the effect of a reduced plant density. The expected yield $plant^{-1}$ was on average 1.6 times greater than the observed yield plant, however, the response to the plant density treatments was the same in the expected and observed yield $plant^{-1}$. This suggests that either the yield component sampling procedure was biased or that yield was lost during harvesting.

As seeding rate increased from 1.5 to 12 kg ha^{-1} lodging increased. Lodging was positively correlated with plant density and negatively correlated with yield. Plants produced at high densities were thin stemmed and lodged easily. It is possible that the high degree of lodging and disease associated with the high density populations resulted in the yield differences noted in this study.

While protein and oil concentrations were not altered by plant density, seed chlorophyll concentration was. As seeding rate decreased, seed chlorophyll concentration increased. Branch raceme seeds had a higher chlorophyll concentration than main raceme seeds. Plants seeded at low seeding rates had a greater proportion of their yield produced on the branch racemes. Therefore, total seed chlorophyll concentration was higher at the lower seeding rates. Seed chlorophyll was greater or equal to 22 ppm, (the maximum allowable for Number 1 Grade rapeseed) at the 1.5 kg ha^{-1} rate at two locations. High seed chlorophyll concentration will reduce the grade of rapeseed, thereby nullifying yield gains resulting from the use of low seeding rates. This may be a particular problem in more northern rapeseed growing regions when rapeseed is damaged by an early frost. However, surveys have indicated that the highest seed chlorophyll concentration comes from areas of southern Manitoba. Results from the current experiment suggest that seed chlorophyll concentrations are higher in this region due to the increased branching and yields that are a direct result of increased available soil moisture, warmer average temperatures and a longer growing season. Agronomic management practices and plant breeding must be used together to address this problem.

5.0 THE EFFECT OF PLANT DENSITY ON GROWTH ANALYSIS CHARACTERS.

5.1 Introduction.

Growth analysis can be used for examining the effects of agronomic treatments on the net photosynthetic production, development and morphology of crops. Radford (1967) outlined procedures for calculating growth characters from the fitted curves of plant dry weight (W) and leaf area index (LAI) over time. This method has been referred to as the functional approach to growth analysis and is useful in identifying the general trends of growth characters. Leaf area duration (LAD) expresses the magnitude and duration of the leaf area of a crop (Kvet et al. 1971). Crop growth rate (CGR) represents the increase over time in crop dry weight per unit area and indicates the dry weight production efficiency of the crop. Net assimilation rate (NAR) represents the net efficiency of dry weight production per unit leaf area. LAD, CGR and NAR can be calculated from equations derived form the appropriate regression equation of W and LAI over time.

Accumulated thermal indices are more accurate at predicting growth and development than days (Gilmore and Rogers 1958; Major et al. 1983 and Daughtry et al. 1984). Despite their general acceptance, accumulated thermal indices have rarely been used in growth analysis (Russell et al. 1983). Their use should make comparisons among and within growth analyses more universal.

Growth analysis has been used to characterize the growth of rapeseed under different environments (Allen et al. 1971; Thurling 1974a; Allen and Morgan 1975 and Richards and Thurling 1978). Major (1977) used growth analysis to study the role of leaves in seed

development. Clarke and Simpson (1978a) observed the effects of seeding rates of 2.5, 5, 10, and 20 kg ha^{-1} on several growth characters. Kasa and Kondra (1986) examined eight cultivars to test the feasibility of using growth characters as selection parameters in a breeding program.

The environment can affect most growth characters (Donald 1963). Rapeseed growth analyses has not been done under southern Manitoba conditions. Accordingly, the objectives of this research were to examine the effects of varying row width and seeding rates on several growth characters of rapeseed cv. Westar, and to use growing degree days where appropriate as a measurement of time in the analysis.

5.2. Materials and Methods.

5.2.1 Field design

Westar rapeseed was seeded in a split-plot design by an eight row belt-cone seeder equipped with packing wheels. Rapeseed was seeded to a depth of 2 cm. Row widths of 15 and 30 cm were used as main plot treatments while seeding rates of 1.5, 3.0, 6.0 and 12.0 kg ha^{-1} were subplot treatments. Individual plots consisting of 16 rows 5.5 m long were replicated six times. The two exterior rows from each plot were used as guard rows. The two center rows were harvested for yield and were bordered by guard rows. The ten remaining rows were used for growth analysis sampling. Sampling areas consisted of 0.5 m from two adjacent rows. Each sampling area was bordered on either side by an intact row and on either end by at least 0.5 m of a row. Ten relatively uniform sampling areas were found at an early growth stage and marked with a 1 m stake for ease of future use. A sampling area from each plot was chosen at random on the day of sampling.

The experiment was seeded at the Point and Arboretum field sites at the University of Manitoba. The Point soil is a Riverdale silty loam, while the Arboretum soil is a Red River clay. The experiment was seeded at the Point on May 15 in 1985 and on May 13 and 21 at the Point and Arboretum, respectively, 1986. Land at both sites was fall prepared. The Point sites were treated with granular trifluralin while the Arboretum was left untreated. At the Point, 110 kg ha^{-1} of 34-0-0 and 15 kg ha^{-1} of S was fall broadcast and incorporated. The Arboretum was not fertilized. Plots were hand weeded throughout the growing season.

Granular Furadan (carbofuran) was applied with the seed at 5 kg ha^{-1} to prevent damage from flea beetles.

Growing degree days (GDD) from seeding to each growth stage sampled were calculated using Equation 5.1, a 5°C baseline temperature (b_o) and locally collected daily mean temperatures (Tm). GDD were used instead of days as a measurement of time where appropriate.

$$GDD = \sum_{S1}^{S2} (Tm - b_o) \qquad (5.1)$$

where S1 and S2 are growth stages.

5.2.2 Sampling procedure and growth analysis techniques.

Phenological stages were observed every two days and sampling performed at growth stages HB(2.1, 3.1, 4.1, 4.3, 5.1, and 5.3) (Harper and Berkenkamp 1975). The plants from a sampling area were pulled from the ground and the roots removed at the root/shoot interface. A representative subsample of five plants were removed for leaf area determination and dry matter partitioning. The remaining plants from the sample were dried for 48 hours at 80°C in a drying oven before being weighed.

The subsamples were kept in cold storage (4°C) until they were processed. In the laboratory, plants were dissected into leaves, stems and pods. Leaf areas were determined using a Li Cor Portable area meter model Li 3000 (LAMBDA Instruments corp.) Only leaves that were at least 50 % green were analyzed. Components were dried for 48 hours at 80°C before being weighed. Partitioned dry weight and leaf area from the 5 plant sample were used to determine these characters from the bulk sample. Results were converted to square meter area basis for reporting purposes

5.2.3 Growth character calculations.

Analyses of variance of dry weight m^{-2} and leaf area index were conducted for each sample at each location. A test of homogeneity of error variances was done for each sample to determine if locations could be combined. A test of homoscedasticity of sample error variance within locations was done to determine if a transformation of the W and LAI data was necessary.

Leaf area index/GDD and dry weight/GDD relationships were fitted in the natural logarithmic ($\log_e$) form using the least squares regression technique. An appropriate polynomial equation was selected based on the regression coefficient, standard error and shape of the data. These equations were determined for each plot within each location.

Curves of untransformed LAI versus GDD were determined for each plot at each location using least squares regression techniques. Leaf area duration was the integral of the LAI versus time (days) curve. LAD was determined for the vegetative period (HB2.1 to HB4.1), reproductive period (HB4.1 to HB5.3) and the total growth duration (HB2.1 to HB5.3). Days from seeding for the appropriate durations were substituted into the integrated equations to determine the LAD. An analysis of variance was conducted for each duration at each location.

Crop growth rate and net assimilation rate were determined for each plot for key growth stages by using the equations determined for W and LAI versus GDD. CGR and NAR were determined by substituting appropriate GDD to the growth stage and solving the equations.

$$CGR = \frac{1}{P} \times \frac{dw}{dt} = f'W(GDD) \times \exp[fW(GDD)] \quad (5.2)$$

$$NAR = \frac{1}{LA} \times \frac{dw}{dt} = f'W(GDD) \times \exp[fW(GDD)-fLA(GDD)] \quad (5.3).$$

where: P= land area m^{-2}
w= dry weight g
t= time
LA = Leaf area m^{-2}
GDD = growing degree days
fW(GDD) and fA(GDD) = functions of appropriate regression equations.
(derived from Hunt 1982)

An analysis of variance was conducted on the CGR and NAR values at each growth stage. Treatment mean values of the $\log_e$ of W and LAI versus GDD were used to plot curves representing mean values of CGR and NAR.

Correlation coefficients of among yield (kg ha^{-1}) plants m^{-2} and growth characters were calculated for at each location. Row widths were examined separately. A test of homogeneity indicated whether the correlation coefficients from the three locations could be combined.

5.3 Results and Discussion

5.3.1 Dry weight.

Significant differences in dry weight per square meter (W) occurred between the 15 and 30 cm row widths at all locations for all growth stages sampled except the early vegetative stage (HB2.1) (Appendix III, Table 1). When competition was not a factor, plants seeded in 15 cm wide rows produced more W than those seeded in 30 cm wide rows (Table 5.1).

There were significant differences in W among seeding rates at early vegetative development (Appendix III, Table 1). W increased as seeding rate increased from 1.5 to 12.0 kg ha^{-1} (Table 5.1). After the early vegetative period there were no significant differences in W among the seeding rates. While not significant, as seeding rate increased, W decreased at physiological maturity (HB5.3), at the Point in 1985 and 1986. At the Arboretum the 1.5 and 3.0 kg ha^{-1} seeding rates produced significantly more dry weight than the 6.0 and 12.0 kg ha^{-1} rates at growth stage HB5.3.

Dry weight m^{-2} data fitted quadratic polynomials of the form $\log_e W = a + b(GDD) + c(GDD)^2$, where a, b and c are constants and GDD are determined from seeding. Buttery and Buzzell (1969) and Clarke and Simpson (1979) determined that cubic polynomials were most appropriate for fitting curves of the $\log_e$ of soybean and rapeseed dry weight production, respectively, over time. In the current study the R^2 values ranged from 0.90 to 0.96 (Appendix III, Table 2). The use of the cubic polynomial did little to decrease the standard error or increase the R^2. Cubic polynomials were found to result in too high a peak in W

TABLE 5.1 Effect of row width (cm) and seeding rate (kg ha^{-1}) on dry weight (g m^{-2}).

			Point 1985			
Growth stage	2.1	3.1	4.1	4.3	5.1	5.3
GDD	264	430	586	721	859	1141
Row width						
15	29.4 a	282.3 a	602.7 a	914.7 a	1408.0 a	2142.3 a
30	26.6 a	217.9 b	441.6 b	648.1 b	915.1 b	1202.1 b
Seeding rate						
1.5	11.9 d	205.3 b	535.2 a	763.0 a	1191.8 a	1839.5 a
3.0	19.5 c	216.0 b	504.8 a	787.1 a	1240.1 a	1845.2 a
6.0	32.2 b	291.7 a	530.5 a	818.8 a	1129.9 a	1563.6 a
12.0	48.3 a	287.7 a	518.1 a	756.8 a	1084.2 a	1440.4 a
			Point 1986			
Growth stage	2.1	3.1	4.1		5.1	5.3
GDD	233	463	526		821	1152
Row width						
15	35.2 a	380.8 a	564.4 a	--	923.8 a	1291.0 a
30	28.5 a	251.6 b	346.1 b	--	698.1 a	867.8 b
Seeding rate						
1.5	14.2 d	293.6 a	428.5 a	--	920.4 a	1171.1 a
3.0	22.8 c	299.7 a	418.7 a	--	812.4 a	1136.1 a
6.0	41.3 b	319.2 a	470.0 a	--	757.5 a	1080.2 a
12.0	49.2 a	352.2 a	474.0 a	--	753.4 a	930.2 a
			Arboretum 1986			
Growth stage	2.2	3.3		4.3	5.1	5.3
GDD	332	598		747	888	1164
Row width						
15	27.3 a	239.0 a	--	388.4 a	642.5 a	748.8 a
30	24.3 a	170.0 b	--	270.1 b	424.6 b	504.8 b
Seeding rate						
1.5	13.3 c	181.1 a	--	308.0 a	625.7 a	683.6 ab
3.0	21.3 b	219.3 a	--	347.1 a	532.9 a	784.5 a
6.0	26.9 b	208.3 a	--	319.9 a	489.3 a	554.1 b
12.0	41.5 a	209.3 a	--	342.2 a	486.5 a	484.9 b

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

-- data not collected at this growth stage.

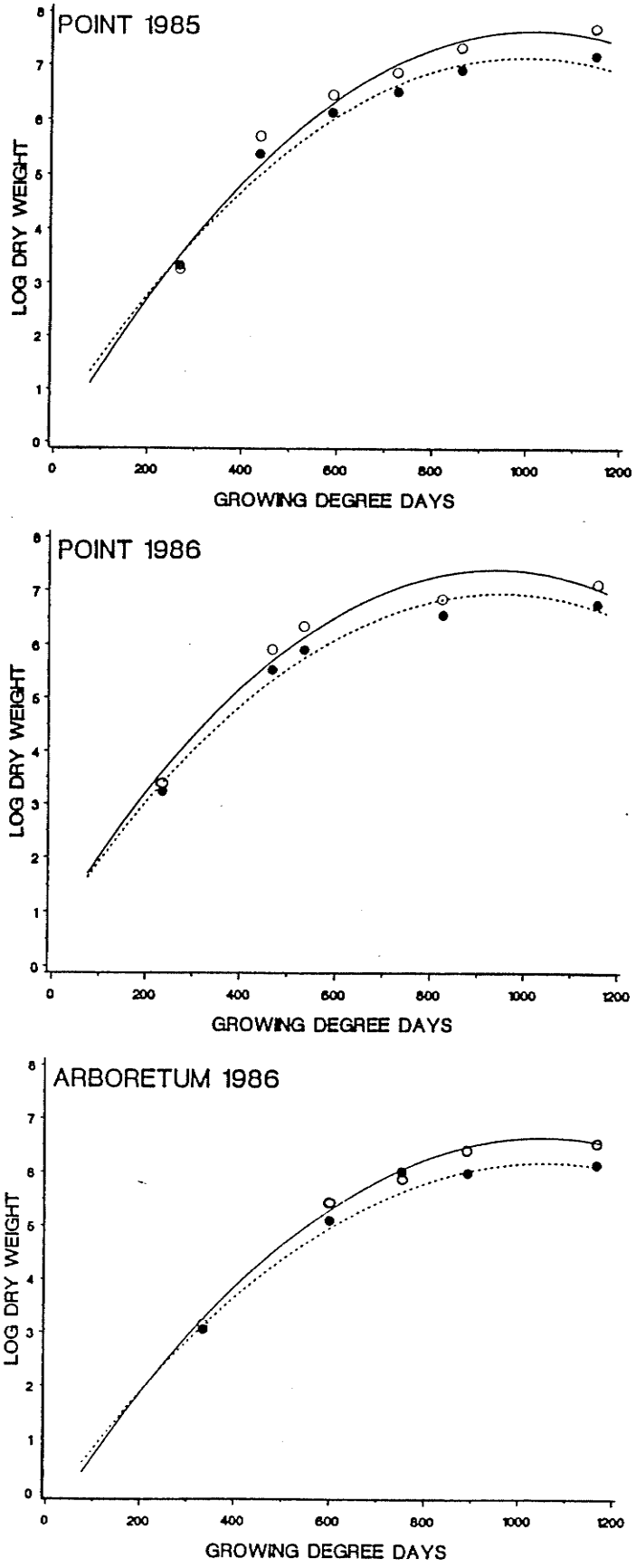


Figure 5.1 Effect of row width (cm) on the relationship between the natural LOG_e of dry weight (g) and growing degree days, ——○15 and ------●30 cm row widths.

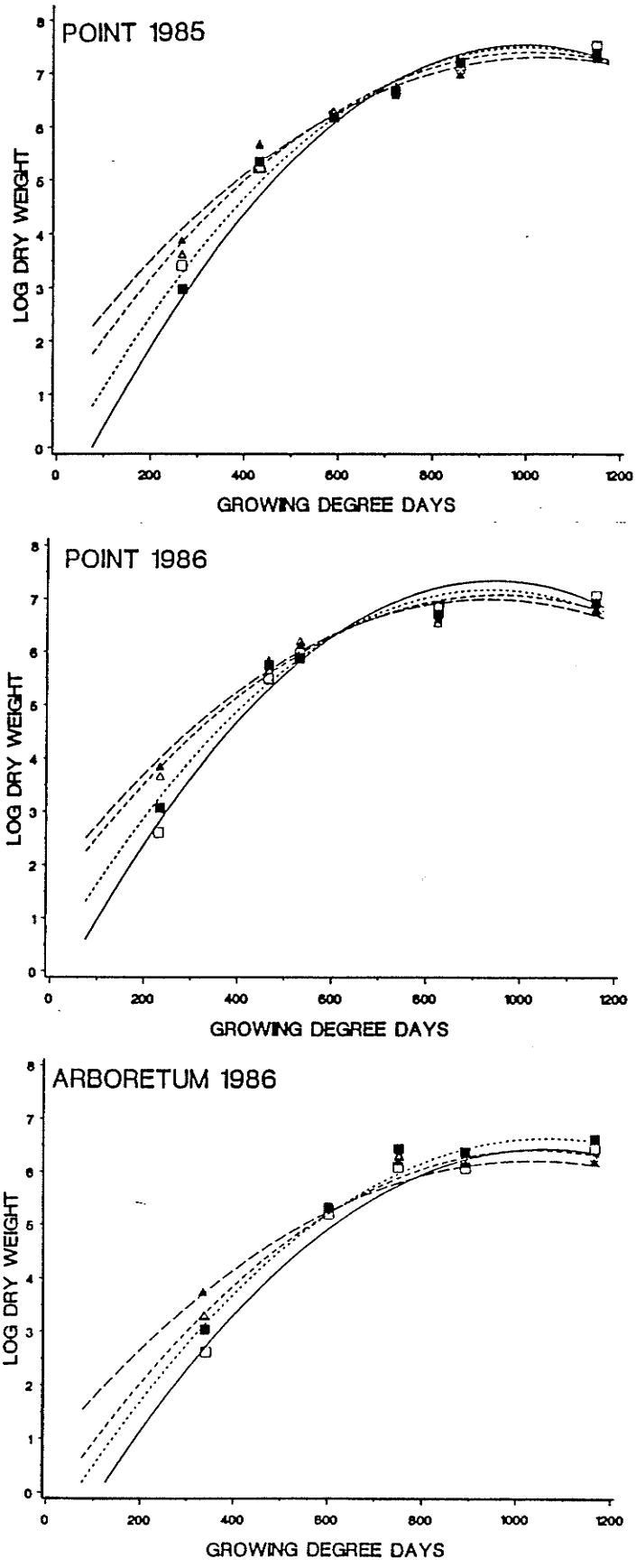


Figure 5.2 Effect of seeding rate on the relationship between the natural LOG_e of dry weight (g) and growing degree days, ——□1.5, ... ■ 3.0, ------ △6.0 and – – –▲12 kg ha-1.

production and exaggerated the decrease in W at physiological maturity. The W curves in Figure 5.1 and 5.2 support the conclusions determined from the analysis of variance. The 15 cm row width produced more W at all locations than the 30 cm wide rows. The seeding rate curves show that while differences in W occur early in the growing season, these differences quickly become negligible. There is a point on the graphs, shortly after flowering, where the seeding rate curves intersect (Figure 5.2). Before the intersection, W increased as seeding rate increased, then the situation was reversed.

Competition and compensation effects were evident in W production. At the narrow row width there was less intrarow competition at similar seeding rates and the plants were able to utilize the available space and produce more dry weight. At the early vegetative stages the higher seeding rates resulted in more W than the lower rates because there were more plants m^{-2}. As growth progressed, the individual plants at the lower seeding rates compensated for the lower densities by producing more W than the individual plants at the higher rates. These results confirm the that the theories of Donald (1963) also apply to rapeseed.

The pattern of dry weight accumulation in this experiment was similar to that reported by other researchers (Allen and Morgan 1975; Major 1977; Clarke and Simpson 1978a and McGregor 1987). However, the W at maturity at the Point in both 1985 and 1986 was greater than previously reported.

Clarke and Simpson (1978a) observed that rapeseed seeded at 20 kg ha^{-1} produced more W at maturity than when seeded at 5 or 2.5 kg ha^{-1}. Their experiment was conducted in Saskatchewan under lower available moisture conditions than that which occurred in 1985 and 1986 in

Manitoba. The disagreement between their observations and the current research underscores the fact that environmental conditions must be favorable for compensation to occur.

5.3.2 Leaf area index.

Plants seeded in 15 cm wide rows produced a greater LAI than those seeded in 30 cm wide rows at all growth stages at all locations. Differences between the 15 and 30 cm row widths were significant during flowering (HB4.1 to HB5.1) (Table 5.2; Appendix III, Table 3). While the 15 cm wide rows resulted in a greater LAI at physiological maturity (HB5.3) at all locations, the results were significantly different only at the Point 1985 location.

Significant LAI differences between seeding rates occurred at the early growth stages (HB2.1 and HB3.1) (Table 5.2; Appendix III, Table 3). The LAI response to seeding rate was largely linear in nature. At the early growth stages, as seeding rate increased from 1.5 to 12 kg ha^{-1}, the LAI increased. At flowering (HB4.1) significant differences in LAI between seeding rates occurred at the Point in 1986. There were no significant differences in LAI between seeding rates from flowering to maturity.

Polynomial regression equations of the form $\log_e LAI = a + b(GDD) + c(GDD)^2$ resulted in curves that fit the data well with R^2 ranging from 0.67 to 0.92 (Appendix III, Table 4). In some cases maximum and minimum LAI were either over- or under-estimated but in general the curves represented the data (Figures 5.3 and 5.4). This form of the equation was used by Buttery (1969) and Buttery and Buzzell (1974) in soybean and by Clarke and Simpson (1979) in rapeseed.

TABLE 5.2 Effect of row width (cm) and seeding rate (kg ha^{-1}) on leaf area index (LAI) (m^2 leaf area x m^{-2} land area).

			Point 1985			
Growth stage	2.1	3.1	4.1	4.3	5.1	5.3
GDD	264	430	586	721	859	1141
Row width						
15	0.52 a	4.23 a	7.14 a	5.84 a	4.76 a	1.18 a
30	0.43 a	3.73 a	5.68 b	4.45 b	3.56 a	0.63 b
Seeding rate						
1.5	0.16 d	3.12 b	6.73 a	4.99 a	4.44 a	1.00 a
3.0	0.32 c	3.41 b	5.50 a	4.99 a	4.04 ab	0.98 a
6.0	0.55 b	4.41 a	6.33 a	5.29 a	3.32 b	0.73 a
12.0	0.87 a	4.96 a	7.07 a	5.36 a	4.90 a	0.90 a
			Point 1986			
Growth stage	2.1	3.1	4.1		5.1	5.3
GDD	233	463	526		821	1152
Row width						
15	0.63 a	5.70 a	6.79 a	--	2.69 a	0.25 a
30	0.56 a	4.23 b	4.69 b	--	2.08 a	0.21 a
Seeding rate						
1.5	0.28 b	3.68 b	5.04 b	--	2.56 a	0.17 a
3.0	0.43 b	4.77 ab	5.01 b	--	2.21 a	0.20 a
6.0	0.78 a	5.60 a	6.93 a	--	2.49 a	0.26 a
12.0	0.89 a	5.88 a	5.99 a	--	2.28 a	0.29 a
			Arboretum 1986			
Growth stage	2.2	3.3		4.3	5.1	5.3
GDD	332	598		747	888	1164
Row width						
15	0.39 a	3.22 a	--	3.20 a	2.26 a	0.14 a
30	0.38 a	2.38 b	--	2.24 b	1.12 b	0.05 a
Seeding rate						
1.5	0.20 c	2.46 a	--	2.61 a	1.77 a	0.18 a
3.0	0.34 bc	2.90 a	--	2.76 a	2.38 a	0.13 a
6.0	0.41 b	2.83 a	--	2.57 a	1.43 a	0.04 a
12.0	0.59 a	3.01 a	--	2.96 a	1.18 a	0.04 a

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

-- data not collected at this growth stage.

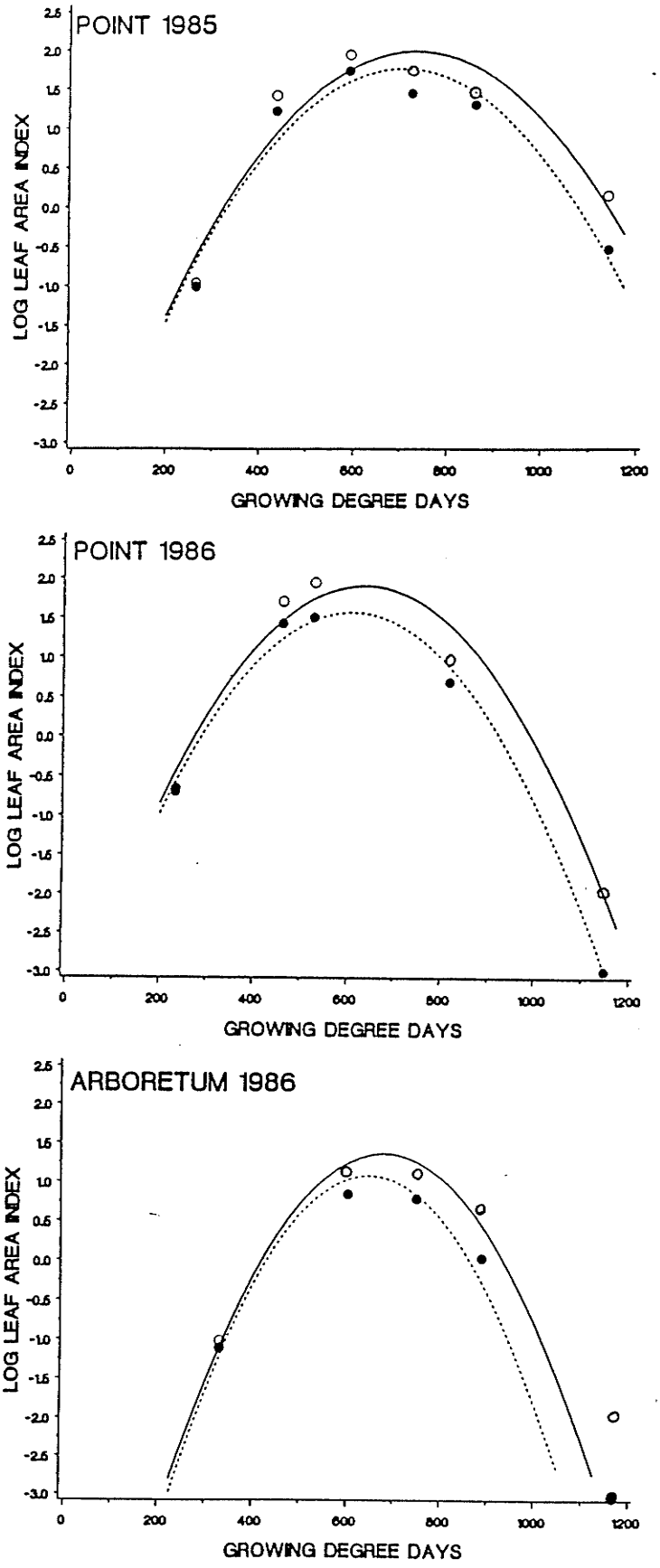


Figure 5.3 Effect of row width on the relationship between the natural LOG_e of leaf area index and growing degree days, ——○15 and - - - -●30 cm row widths.

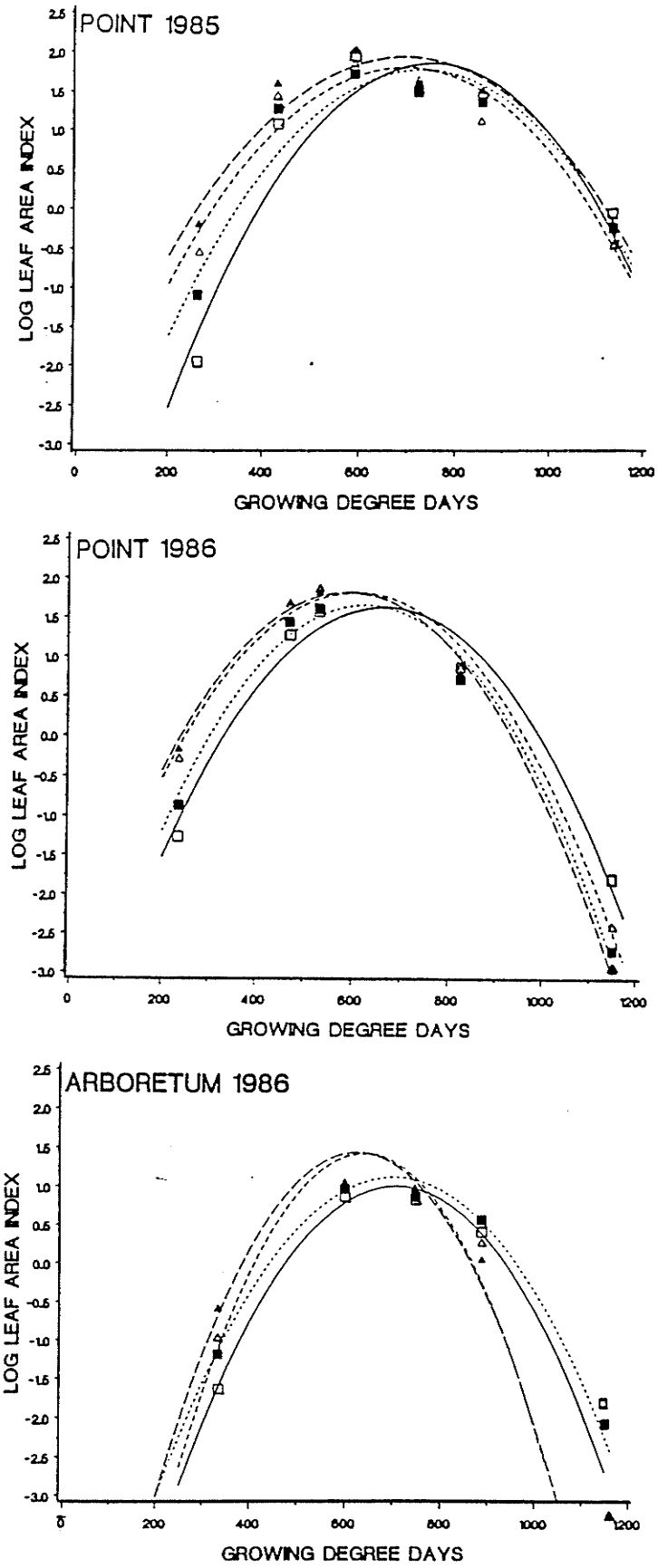


Figure 5.4 Effect of seeding rate on the relationship between the natural LOG of leaf area index and growing degree days, —— □1.5, ... ■3.0, ---- △6.0 and ——— ▲12 kg ha-1.

The LAI curves showed that the 15 cm wide rows produce a greater LAI than the 30 cm wide rows (Figure 5.3). Figure 5.4 shows that while differences in LAI may have occurred between seeding rates at early growth stages, these differences were reduced as the plants grew. As noted with dry weight, the seeding rate curves intersect at a point which occurs near the end of flowering. LAI increased as seeding rate increased to this point and then the reverse tended to occur. A greater LAI after flowering may be important to yield as several researchers have reported (Major and Charnetski 1976; Clarke and Simpson 1978a and Rood and Major 1984).

The concepts of crop competition and compensation can be used to explain many of the differences and similarities in LAI that occurred between treatments. Plants seeded in 15 cm row widths utilized the available space to produce a greater LAI than those seeded in 30 cm wide rows. Donald's (1963) plant density-equilibrium theory can be applied to LAI. Significant differences in LAI between seeding rates at early growth stages were the result of a greater number of plants m^{-2}. As they grew, plants at the lower densities compensated for available space and produced more leaf area than those at higher densities. This resulted in similar LAI between seeding rates at flowering (HB4.1) the period of maximum LAI (Thurling 1974a; Allen and Morgan 1975; Major 1977 and Clarke and Simpson 1978a). Clarke (1977) also observed that seeding rate differences for LAI were only significant at early growth and that at flowering there were no LAI differences between seeding rates ranging from 2.5 to 20.0 kg ha^{-1}.

LAI only provides an indication of potential photosynthetic productive efficiency of a crop canopy and provides no indication of the

degree to which shading occurs within the canopy. Since the highest seeding rate produced the lowest yield, while at the same time producing the same LAI, it must be concluded that a higher degree of shading occurred at the higher rates thereby reducing the plants photosynthetic efficiency.

5.3.3 Leaf area duration.

Leaf area duration takes into account both the magnitude of the leaf area and its persistence in time. LAD was determined from the integral of the polynomial regression equation describing the development of the untransformed LAI over time (days). Cubic polynomial equations were found to provide the most appropriate fit to the data. Quadratic curves generally underestimated the peak LAI which occurred during flowering. LAD values for each plot were interpolated by substituting days after seeding for the appropriate growth stages into the equations. Vegetative, reproductive and total growth durations were examined. An analysis of variance was conducted on the interpolated values (Appendix III, Table 5).

For all the durations measured, plants grown in 15 cm wide rows had a greater LAD than those grown in 30 cm rows at all locations (Table 5.3). Significant differences between row widths occurred at the Point locations but not the Arboretum.

During the vegetative duration, as seeding rate increased LAD significantly increased at the Point. While this trend was evident at the Arboretum, there were no significant differences between seeding rates. The higher seeding rates had a greater LAD during the vegetative duration due the greater plant population.

TABLE 5.3 Effect of row width (cm) and seeding rate (kg ha^{-1}) on leaf area duration (LAD) (Days).

	Vegetative duration (HB2.1 to HB4.1)	Reproductive duration (HB4.1 to HB5.3)	Total growth duration (HB2.1 to HB5.3)
		Point 1985	
Row width			
15	106.0 a	167.5 a	273.6 a
30	89.3 b	132.7 b	222.0 b
Seeding rate			
1.5	84.8 bc	160.4 a	244.8 b
3.0	81.8 c	144.5 ab	232.2 b
6.0	104.6 ab	127.6 b	226.2 b
12.0	119.8 a	168.1 a	287.9 a
		Point 1986	
Row width			
15	119.2 a	128.4 a	247.6 a
30	81.9 b	91.7 b	173.6 b
Seeding rate			
1.5	76.8 b	108.8 a	185.6 b
3.0	89.0 b	95.2 a	184.2 b
6.0	118.3 a	124.7 a	240.0 a
12.0	118.1 a	114.4 a	232.5 a
		Arboretum 1986	
Row width			
15	52.0 a	97.3 a	149.3 a
30	42.6 a	63.5 a	106.1 a
Seeding rate			
1.5	42.0 a	94.1 a	136.1 a
3.0	46.4 a	102.8 a	149.2 a
6.0	47.2 a	65.6 a	112.9 a
12.0	53.4 a	59.2 a	112.6 a

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

No clear trends were evident for seeding rate differences in LAD for the reproductive duration. There were no significant differences between the 1.5 and 12.0 kg ha^{-1} seeding rates at any locations. Similar results were obtained by Clarke (1977) in rapeseed seeded at rates varying from 2.5 to 20 kg ha^{-1}.

The total growth duration represented the total of the vegetative and reproductive durations. The highest seeding rates resulted in significantly higher LADs at the Point locations. Since there were no significant differences between the seeding rates during the reproductive durations the differences observed were the result of growth during the vegetative duration.

Seeding rate affects the time of occurrence and magnitude of maximum LAI. Situations may occur when a large LAI occurring for a short period of time can result in a similar LAD in a crop as one produced from a lower LAI occurring over a longer duration. Plants seeded in 15 cm row widths had a greater LAD than those seeded in 30 cm wide rows for all intervals examined. The more even distribution of plants resulting from the narrower row widths resulted in the greater LAD. However, seeding rates differing by a magnitude of eight produced similar LAD. Therefore, different densities within the same row width resulted in crops with similar opportunities for photosynthesis.

5.3.4 Crop growth rate.

Crop growth rate is a measure of the rate of dry weight production per unit area of land and represents the net result of photosynthesis, respiration and canopy area interaction (Hunt 1982). CGR equations were determined for each plot at each location from the quadratic regression

equation of the $\log_e$ of weight versus GDD (Equation 5.2). CGR at key growth stages were interpolated by substituting GDD corresponding to that stage into the equations. An analysis of variance was done on the interpolated values (Appendix III, Table 6). Treatment means were used in regression equations to plot the CGR curves.

Plants grown in 15 cm row widths had greater CGR than those grown in 30 cm wide rows (Table 5.4; Figure 5.5). Significant differences in CGR occurred between the seeding rates at different growth stages at the three location (Appendix III, Table 6). Generally, the CGR increased as seeding rate increased at the early growth stages (HB2.1 to HB3.1). Maximum CGR occurred during flowering (HB4.1 to HB4.4) at all locations (Table 5.4). At its maximum point, the CGR decreased as seeding rate increased (Figure 5.6). The CGR was greater at the Point in 1985 and 1986 then at the Arboretum 1986.

The shape of the CGR curves from the present study correspond with those determined by Major (1977) and Clarke and Simpson (1978a). In all studies, CGR was low at the beginning of the season, increased to a maximum at flowering and then decreased as LAI decreased after flowering.

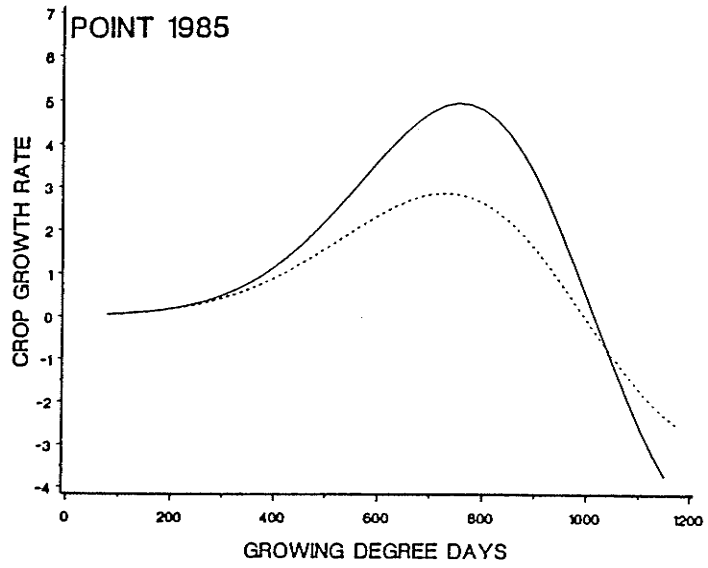
The CGR response to seeding rate from the current study is opposite to that determined by Clarke (1977). Lower available soil moisture in Saskatchewan limited the extent of crop compensation at the lower seeding rates.

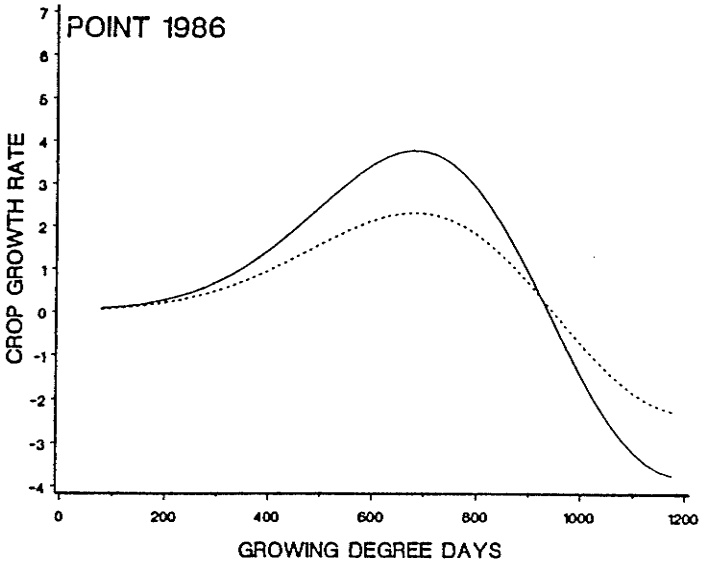
The Arboretum maximum CGR were similar to those determined by Major (1977) and Clarke (1977), while CGR at the Point in 1985 and 1986 were 2.5 times greater.

TABLE 5.4 Effect of row width (cm) and seeding rate (kg ha^{-1}) on crop growth rate (CGR) (g m^{-2} GDD^{-1}).

Growth stage	2.1	3.1	4.1	4.3	5.1	5.3
			Point 1985			
GDD	264	430	586	722	859	1141
Row width						
15	0.38 a	1.43 a	3.41 a	4.93 a	4.18 a	-3.25 a
30	0.33 b	1.07 b	2.21 b	2.83 b	2.11 b	-2.06 a
Seeding rate						
1.5	0.21 b	1.11 c	3.26 a	5.14 a	4.33 a	-4.07 b
3.0	0.27 b	1.17 cb	2.85 ab	3.99 b	3.19 b	-2.77 ab
6.0	0.44 a	1.38 a	2.76 bc	3.52 bc	2.76 b	-2.23 a
12.0	0.49 a	1.33 ab	2.38 c	2.87 c	2.28 b	-1.55 a
			Point 1986			
GDD	233	412	528	671	821	1152
Row width						
15	0.41 a	1.52 a	2.73 a	3.75 a	2.58 a	-3.70 b
30	0.30 b	1.03 b	1.75 b	2.33 b	1.64 b	-2.19 a
Seeding rate						
1.5	0.21 c	1.18 a	2.48 a	3.92 a	2.92 a	-3.88 b
3.0	0.30 b	1.30 a	2.46 a	3.53 a	2.43 a	-3.38 b
6.0	0.42 a	1.29 a	2.04 b	2.41 b	1.72 b	-2.35 a
12.0	0.47 a	1.33 a	1.98 b	2.30 b	1.38 b	-2.17 a
			Arboretum 1986			
GDD	284	505	631	747	888	1164
Row width						
15	0.17 a	0.79 a	1.39 a	1.80 a	1.58 a	-0.46 a
30	0.14 a	0.54 b	0.86 b	1.04 b	0.85 b	-0.83 a
Seeding rate						
1.5	0.10 c	0.60 a	1.18 a	1.66 a	1.65 a	-0.32 a
3.0	0.14 b	0.71 a	1.28 a	1.70 a	1.56 a	-0.82 a
6.0	0.17 b	0.68 a	1.09 a	1.28 b	0.96 b	-0.83 a
12.0	0.22 a	0.68 a	0.96 a	1.03 b	0.71 b	-0.61 a

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.





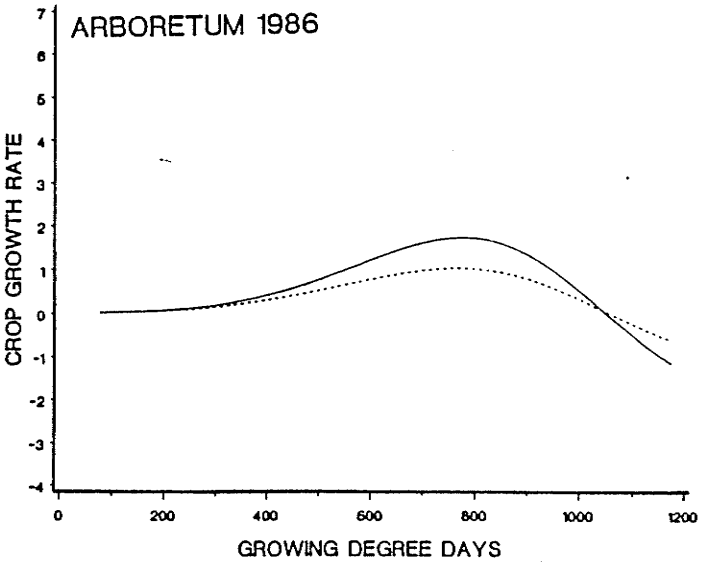


Figure 5.5 Effect of row width on crop growth rate ($g\ m^{-2}\ GDD^{-1}$), ——— 15 and ------ 30 cm row widths.

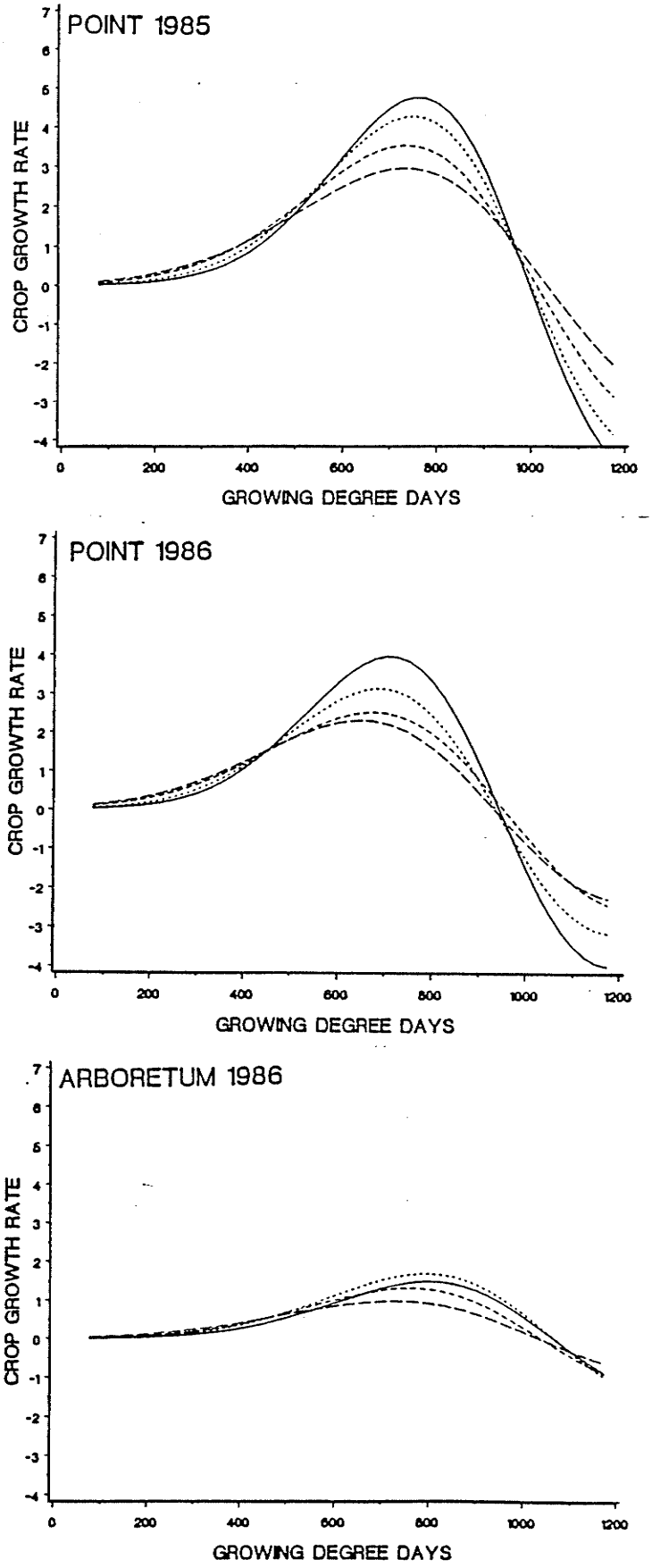


Figure 5.6 Effect of seeding rate on crop growth rate (g m^{-2} GDD^{-1}), ——— 1.5, ------ 3.0, ----- 6.0 and – – – – 12 kg ha^{-1}.

The lower intrarow competition in the 15 cm wide rows resulted in more W production and a greater CGR than the 30 cm wide rows. Rapid growth from bolting to the end of flowering of individual plants at lower seeding rates resulted in a higher CGR.

5.3.5 Net assimilation rate.

Net assimilation rate is a measure of the amount of carbon fixed per unit of leaf area over time and provides an estimate of the average productive efficiency of the crop canopy. NAR equations were determined from quadratic regression equations of the $\log_e$ W and $\log_e$ LAI over GDD (Equation 5.3). Values for NAR at several key growth stages were interpolated for each plot by substituting GDD corresponding to that stage into the equations. An analysis of variance was done on the interpolated values (Appendix III, Table 7.). Treatment means were used to plot the NAR curves.

NAR were greater in plants seeded in 15 cm row widths than in plants seeded in 30 cm wide rows. However, significant differences in NAR due to row width occurred only at the Point 1985 (Table 5.5). As seeding rate increased the NAR decreased. Significant differences in NAR between seeding rates at the Point were more prominent at the early growth stages. Generally the 1.5 and 3.0 kg ha^{-1} treatments had higher NAR than the 6 and 12.0 kg ha^{-1} treatments. There were no significant differences in NAR at the Arboretum 1986.

The shape of the NAR curves for row width and seeding rate are similar at the Point locations (Figures 5.7 and 5.8). NAR were initially high, decreased as the season progressed, increased slightly towards the end of development and then decreased rapidly. The NAR

TABLE 5.5 Effect of row width (cm) and seeding rate (kg ha^{-1}) on net assimilation rate (NAR) (g m^{-2} GDD^{-1}).

Growth stage	2.1	3.1	4.1	4.3	5.1
			Point 1985		
GDD	264	430	586	722	859
Row width					
15	0.671 a	0.580 a	0.594 a	0.650 a	0.658 a
30	0.666 a	0.488 b	0.458 b	0.484 b	0.471 b
Seeding rate					
1.5	0.936 a	0.665 a	0.603 a	0.615 a	0.579 a
3.0	0.675 a	0.596 a	0.614 a	0.666 a	0.641 a
6.0	0.589 b	0.493 b	0.515 a	0.580 a	0.608 a
12.0	0.476 c	0.381 c	0.374 b	0.408 b	0.428 a
			Point 1986		
GDD	233	412	528	671	821
Row width					
15	0.608 a	0.479 a	0.493 a	0.576 a	0.629 a
30	0.535 a	0.394 a	0.423 a	0.535 a	0.708 a
Seeding rate					
1.5	0.646 ab	0.568 a	0.611 a	0.741 a	0.823 a
3.0	0.666 a	0.499 a	0.536 a	0.666 a	0.806 a
6.0	0.475 b	0.343 b	0.349 b	0.415 b	0.514 b
12.0	0.499 ab	0.336 b	0.334 b	0.399 b	0.525 b
			Arboretum 1986		
GDD	284	505	631	747	888
Row width					
15	0.879 a	0.431 a	0.438 a	0.542 a	0.854 a
30	0.734 a	0.379 a	0.388 a	0.491 a	0.831 a
Seeding rate					
1.5	0.891 a	0.475 a	0.470 a	0.555 a	0.786 a
3.0	0.854 a	0.444 a	0.459 a	0.575 a	0.944 a
6.0	0.839 a	0.419 a	0.450 a	0.613 a	1.100 a
12.0	0.643 a	0.283 a	0.271 a	0.321 a	0.542 a

a-c means within row widths, seeding rates and locations followed by the same letter are not significantly different at the LSD = 0.05 level of probability.

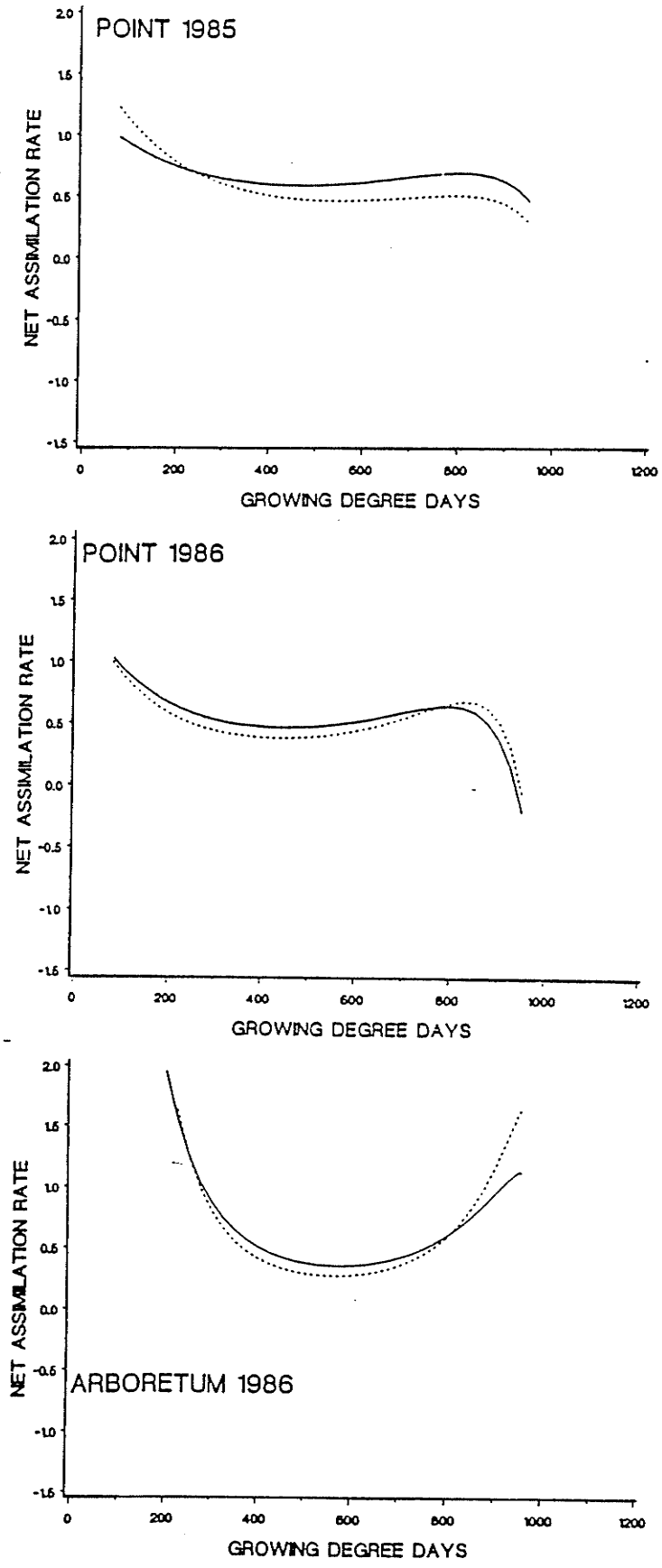


Figure 5.7 Effect of row width on net assimilation rate (g m^{-2} GDD^{-1}), ——— 15 and ----- 30 cm row widths.

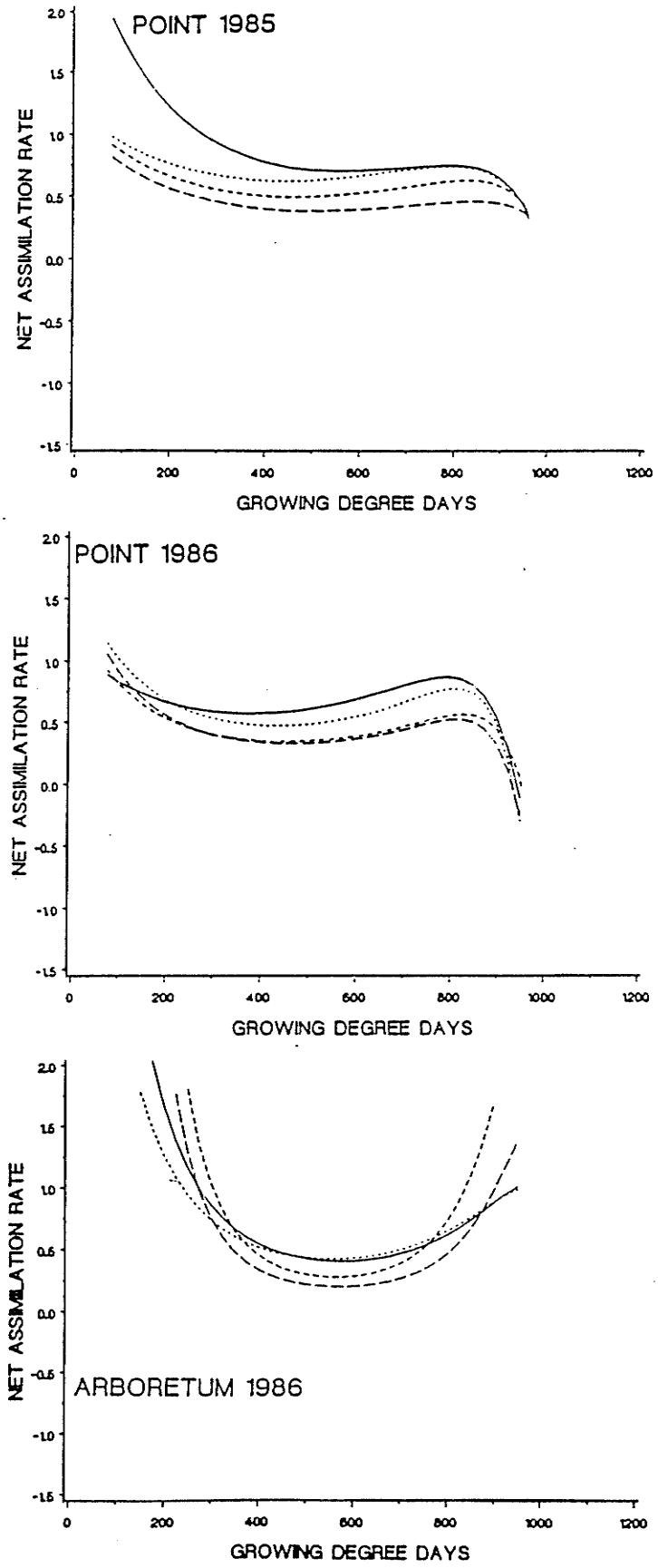


Figure 5.8 Effect of seeding rate on net assimilation rate (g m^{-2} GDD^{-1}), ——— 1.5, ----- 3.0 ----- 6.0 and — — — 12 kg ha^{-1}.

curves from the Arboretum appear to be exaggerated at the beginning and end of development, while quite similar to the Point curves for the majority of the growing season. The bias in the Arboretum NAR curves may have been due to a poorer fit at the beginning and end of development of the quadratic regression equation describing $\log_e$ LAI versus GDD. Buttery and Buzzell (1974) warned that bias can easily be introduced into derived growth characters if the regression equations do not truly represent the growth of the plants.

The shape of the NAR curves over the growing season in the present study were similar to those determined by Allen and Morgan (1972, 1975) and Clarke and Simpson (1978a) for rapeseed, and Buttery (1969) and Koller et al. (1970) for soybeans. NAR values at flowering were similar to those determined in other rapeseed growth analyses (Thurling 1974a, Allen and Morgan 1975, and Clarke and Simpson 1978a).

NAR were the highest at the lowest seeding rate and decreased as seeding rate increased (Figure 5.8). This was also observed by Clarke and Simpson (1978a) for rapeseed and for soybeans by Buttery (1969). This indicates that canopies formed by plants seeded at low seeding rates were more efficient at producing dry weight than those seeded at higher rates.

After the initial decrease there was an upswing and peak in the NAR (Figures 5.7, 5.8). The upswing began at mid flowering and peaked shortly after the beginning of the seed ripening period. During this period the leaves were rapidly senescing. This upswing was noted in soybean by Buttery (1969) and Koller et al. (1970) and in rapeseed by Allen and Morgan (1975) and Clarke and Simpson (1978a). Since this upswing in NAR occurred when the leaves were senescing there must have

been an alternative source of photosynthates to supply the developing seeds. Assimilates for the developing seeds may have come from the developing pods (Allen et al 1972) and/or have been translocated from the senescing leaves and stems (Major et al. 1978). Alternatively, Clarke and Simpson (1978a) proposed that the maturing rapeseed seeds triggered an increase in the photosynthetic activity of the remaining active tissue. This theory was proposed by Koller et al. (1970) for soybeans and Thorne and Koller (1974) and Laurer and Shibbes (1987) observed that developing soybean seeds influenced leaf photosynthetic rates. Similar research has not been done in rapeseed.

It is possible that the rapeseed plant uses some aspects or all of the above mechanism to ensure seed filling. An improved understanding of this process in rapeseed and selection for a higher NAR during flowering could lead to higher yielding cultivars. The results from this study clearly show that NAR is influenced by the population density. NAR was higher at 15 cm row widths and at low seeding rates than at 30 cm wide rows and higher seeding rates. Uniform plant density must be maintained when selecting for improved NAR.

5.3.6 Interrelationship of growth characters with plants m^{-2} and yield

Treatment means of several growth characters were correlated with plants m^{-2} and yield at each location. Row widths were analyzed separately. A test of homogeneity of correlation coefficients indicated that the coefficients were homogeneous and could be pooled.

As plant density increased in the 30 cm row width plots the LAI increased at flowering (HB4.1) and at the beginning of seed maturity (HB5.1) (Table 5.6). LAD during the vegetative phase was positively

TABLE 5.6 Correlation coefficients for growth characters with plants m^{-2} and yield, (kg ha^{-1}) (top line 15 cm, bottom line 30 cm row width).

	Plants m^{-2}	Yield
LAI HB4.1	0.47	0.23
	0.90 **	-0.41
LAI HB5.1	-0.42	0.59 *
	0.67 *	-0.35
LAD vegetative	0.87 **	-0.40
	0.87 **	-0.67 *
LAD reproductive	-0.14	0.38
	-0.40	-0.64
LAD total	0.27	-0.07
	0.49	-0.68 *
Dry weight HB4.1	0.24	0.12
	0.03	-0.15
Dry weight HB5.1	-0.67 *	0.71 **
	-0.35	0.30
NAR HB4.1	-0.86 **	0.68 *
	-0.88 **	0.61 *
NAR HB5.1	-0.63 *	0.58 *
	-0.81 **	0.64 *
CGR HB4.1	-0.60 *	0.54
	-0.57	0.33
CGR HB5.1	-0.96 **	0.71 **
	-0.80 **	0.01

*, ** significant at the 0.05 and 0.01 levels of probability.

correlated with plants m^{-2} for both row widths. Dry weight m^{-2} at the HB5.1 stage was positively correlated with yield for the 15 cm rows but not the 30 cm rows. As plant density increased NAR decreased at the HB4.1 and HB5.1 stages for both row width treatments. CGR increased as plant density decreased at the HB4.1 stage and at the HB5.1 stage for the 15 cm row width and for both row widths, respectively.

Yield was positively correlated with LAI at the HB5.1 stage for the 15 cm wide rows but not the 30 cm wide rows (Table 5.6). However, LAD was negatively correlated with yield at the vegetative and reproductive duration for plants seeded in 30 cm wide rows. Plants grown in 15 cm wide rows that produced the greatest W at the HB5.1 stage, also produced the highest yield. Yield was positively correlated with NAR at both the HB4.1 and HB5.1 stages for both row widths. Yield was positively correlated with CGR for the 15 cm wide row treatment at the HB5.1 stage.

Contrary to the observations of Clarke and Simpson (1978b), seeding rates that resulted in a high LAD during the reproductive phase did not produce the highest yields. This indicates that under a competitive situation, a higher degree of intracrop shading occurs. This can result in crop canopy that is a photosynthetic burden, leading to reduced yields. The disagreement between the results of Clarke and Simpson (1978b) and the current research emphasize that the optimum LAI and LAD, resulting from different population densities, will depend largely on the environment. It is the environment that controls the extent that an individual plant can compensate for available space.

Perhaps the selection, under uniform plant density, for higher NAR and CGR during the flowering and seed filling periods may lead to higher

yields. However, Kasa and Kondra (1986) determined no direct relationship between the genotypic differences for NAR and yield.

From the current research it can be concluded that under environmental conditions that favor compensation, low seeding rates resulted in a crop with a higher NAR during flowering and seed filling (the most critical phases of crop growth). Yields were greatest at low seeding rates largely due to the improved photosynthetic efficiency of the crop canopy.

5.4 Summary and Conclusions

The effect of varying row widths and seeding rates on growth analysis characters of Westar rapeseed were examined. Patterns of dry weight and leaf area index accumulation were similar at the three locations. Plants seeded in 15 cm row widths had significantly greater W and LAI than plants seeded in 30 cm wide rows at most growth stages. Due to planting geometry, there was less intrarow competition in the 15 cm wide rows than in the 30 cm rows. Lower intrarow competition resulted in the production of a greater leaf area and more W per area.

At early growth stages W and LAI increased as seeding rate increased due to the presence of more plants m^{-2}. As the plants grew the differences between seeding rates decreased and became negligible. In this study the capacity to compensate for available space resulted in no significant differences in W and LAI between seeding rates at flowering. The growth of individual plants was suppressed by high seeding rates and promoted by low seeding rates.

There were no seeding rate differences in LAD during the intervals examined. While the lower seeding rates had lower LAI, they maintained the leaf area for a greater length of time resulting in similar total photosynthetic production among the seeding rates. Plants seeded in 15 cm wide rows had a larger LAI than those in 30 cm rows, therefore had greater LAD.

Lower intrarow competition resulted in greater CGR and NAR for the plants seeded in 15 cm rows than those seeded in 30 cm rows. At early growth stages CGR increased as seeding rate increased. As the plants grew CGR increased at faster rates for the lower seeding rates than for the higher rates until a point was reached when CGR decreased with

increased seeding rate. Plants seeded at lower seeding rates had higher NAR than those seeded at the higher rates. This indicates that at lower seeding rates there was less inter and intraplant shading resulting in more carbon fixed per unit leaf area.

Of the growth characters examined, NAR provided the most appropriate explaination for the yield differences observed between the seeding rates and row widths. Plants seeded in 15 cm rows at 1.5 and 3 kg ha^{-1} seeding rates had the highest NAR values during the period of maximum crop growth and produced the highest yields.

Comparison of the results from this study with those done in Saskatchewan revealed that environmental conditions will affect the degree to which plants can compensate for available space. More research needs to be done on the effect of environmental factors, such as available soil moisture and fertility, on the growth characters of rapeseed. The use of GDD as a measurement of biological time facilitated the comparison of growth characteristics among locations. The use of GDD in future rapeseed growth analyses may lead to increased understanding of the physiological responses to various treatments previously masked by the normal response to changing temperature.

6.0 GENERAL SUMMARY AND CONCLUSIONS

Westar rapeseed was grown under different temperatures regimes in controlled environment chambers. A $5^{o}C$ baseline temperature was calculated from the relationship between percent development per day (%DPM day^{-1}) and the LOG_{10} of temperature, and was verified with field grown rapeseed. The growing degree day equation using $5^{o}C$ as a baseline temperature and the equation describing the relationship of temperature and %DPM were superior to calendar days in predicting phenological development. An equation was developed relating %DPM to GDD and the growth stage key (%DPM = 0.083(GDD) + 5.205).

Since GDD were determined to be more accurate than days at predicting phenological development, they were used as a measure of time in the growth analysis of rapeseed. If future growth analyses for the rate parameters used GDD as a measure of time, studies from different environments could readily be compared. In addition, the use of GDD in the growth analysis equations makes it easier to adapt these equations to more advanced crop models.

The study examined the effects of 15 and 30 cm row widths and seeding rates of 1.5, 3.0, 6.0 and 12.0 kg ha^{-1} on agronomic characteristics of rapeseed. More plants emerged and survived to maturity at the 15 cm than at 30 cm wide rows. Plants seeded in 15 cm wide rows out yielded those in 30 cm wide rows. The higher yields were the result of more pods $plant^{-1}$ and a greater number of seeds pod^{-1}. There were no significant differences due to row widths in harvest index, lodging, and protein, oil and chlorophyll concentration.

As seeding rate increased from 1.5 to 12 kg ha^{-1}, plant mortality increased. Higher seeding rates were less efficient in terms of plants produced per seeds sown. As seeding rate increased, yield decreased. The highest yields were achieved at 1.5 kg ha^{-1} seeded in 15 cm wide rows at the Point in 1985 and 1986. At the Arboretum in 1986 the highest yields were achieved at the 3.0 kg ha^{-1} seeding rate. Rapeseed plants compensate for lower densities with the production of more branches and branch pods. Plants seeded at 1.5 kg ha^{-1} produced significantly more pods $plant^{-1}$ and seeds pod^{-1} than those seeded at 12 kg ha^{-1}. The effects of lodging may have been responsible for the yield differences between seeding rates as lodging was positively correlated with plant density and negatively correlated with yield. There were no significant differences due to seeding rate for harvest index and protein and oil concentration.

Plants seeded at the 1.5 kg ha^{-1} seeding rate produced seed significantly higher in chlorophyll concentration than those seeded at the 3 and 6 kg ha^{-1} rates. Chlorophyll concentration was greater or equal to the maximum allowable seed concentration when plants were seeded at 1.5 kg ha^{-1} in 15 cm row widths. However, seed chlorophyll concentration was also high at the 12 kg ha^{-1} rate. This indicates that high chlorophyll levels are not strictly related to plant density. However, breeders should be aware that chlorophyll concentration is strongly affected by agronomic practices when they select lines with lower concentrations.

Growth analysis was used to examine the effects of altering row width and seeding rate on plant morphology and development. Plants

seeded in 15 cm wide rows produced a greater final dry weight, LAI, LAD, CGR and NAR than those grown in 30 cm rows. In general, plants seeded at high rates had higher W and LAI production and higher CGR at earlier growth stages than those seeded at low seeding rates. However, the W and LAI differences between seeding rates decreased as the plants grew until they were negligible at flowering. Maximum CGR occurred during flowering. At flowering, CGR at the 1.5 and 3.0 kg ha^{-1} were significantly greater than those at the 6.0 and 12.0 kg ha^{-1} rates. CGR during flowering was significantly correlated with yield. Low seeding rates resulted in plants with higher NAR values than those seeded at high rates. The canopies formed at the low seeding rates were more photosynthetically efficient in terms of carbon fixed per unit leaf area than those established under higher seeding rates.

The principles of plant competition for available resources and plant compensation can be applied to the results from these experiments. There was less intrarow plant competition for plants seeded in the 15 cm wide rows than those seeded in 30 cm rows. As a consequence of reduced competition, these plants were superior to those seeded in the wider rows for almost every characteristic studied. The results from these experiments draw attention to the risks inherent in the assessment of any genotype at noncommercial row widths or seeding rates. It can not be assumed that the yield at 30 cm will be reproduced at 15 cm. Producers should be encouraged to seed rapeseed in narrow rows.

The effects of competition and compensation makes seeding rate recommendations difficult. Currently recommended seeding rates for Manitoba are in the 6 to 8 kg ha^{-1} range. These rates allow for a 30 to

50 % mortality rate and rely on the concept of self thinning to produce a viable population. The results from this experiment show that self thinning does not lead to maximum yields. In a high density situation, plants enter into competition with their neighbors early in growth and show a reduction in growth rate which becomes progressively more marked as competition intensifies. The recommended rates provide a large population to compete with weeds at early growth stages. However, higher interspecific competition also results in higher intraspecific competition negating the yield benefits achieved through better weed control. In southern Manitoba under good growing conditions, higher yields can be achieved with seeding rates as low as 1.5 to 3.0 kg ha^{-1}. With lower rates, greater attention must be paid to weed and pest control at the early stages of growth. Optimum seeding rates will vary with the growing region. Producers should be encouraged to try different seeding rates under their own growing conditions.

An understanding of competition among plants requires a greater knowledge of the response of plants to their environment and the environmental stresses imposed on them by the planting arrangement. Further research should be conducted on the effects of high temperature on reproductive development. Potential improvements in the GDD model can be made by incorporating the effects of light duration and intensity. More advanced crop growth models must be made using the results from growth analysis experiments and temperature-development rate equations. Experiments need to be done investigating the seedbed conditions that lead to maximum emergence and survival of plants seeded at lower rates. The interaction of other environmental variables such

as soil moisture and fertility with seeding density must be examined. It is possible that seeding rate recommendations can be based on the amount of available soil moisture at seeding. Perhaps seeding rate recommendations should be based on plant density instead of a kg ha^{-1} basis. Studies must be done on the effects of seeding rate on weed and pest infestation. It is necessary to determine the LAI at which maximum interspecific competition occurs and its effect on intraspecific competition. Breeders may be able to select genotypes which maximize the transfer of assimilates from the source to the developing seeds. The influence of plant morphology on lodging and the interaction of plant density and diseases warrants further study. There is some indication in the literature that row widths narrower than 15 cm will result in even higher yields. This must be examined with conventional seeding equipment. Seeding rate studies using commercial farming practices should be done to determine the interaction of management practices and seeding rates.

Donald (1963) observed that there was a need for a greater understanding of the effects of planting density on crop species. It is hoped that this research has led to a clearer understanding of the morphological and agronomic response of rapeseed to changes in row widths and seeding rates as well as suggesting new areas of research which will lead to improved yields.

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APPENDIX I.

TABLE 1. Modified Hoaglands solution as used in the Earhart-Campbell phytotron.

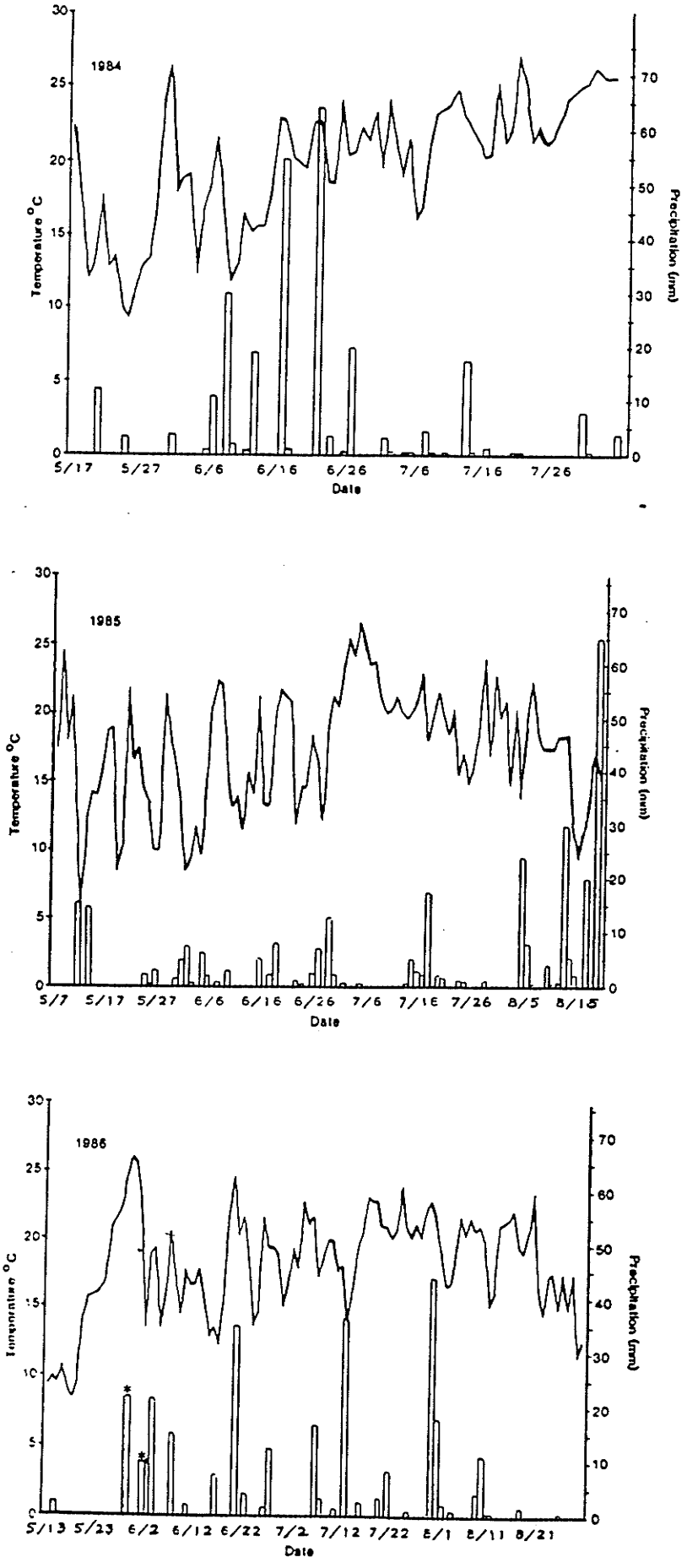
Solution	Name	Formula	g l^{-1}
A	Calcium nitrate	$Ca(NO_3)^2 .4H_2O$	295.00
B	Potassium phosphate	KH_2PO_4	34.25
B	Potassium nitrate	KNO_3	126.65
B	Magnesium sulfate	$MgSO_4 .7H_2O$	126.65
B	Zinc sulfate	$ZnSO_4 .7H_2O$	0.0555
B	Manganous sulfate	$MnSO_4 .H_2O$	0.3905
B	Copper sulfate	$CuSO_4 .5H_2O$	0.0206
B	Boric acid	H_3BO_3	0.725
B	Molybdic acid	$MoO_3 .2H_2O$	0.0046
C	Sequestrene iron	$FeSO_4 .7H_2O$	24.90
	EDTA		26.10

2 ml of solution A, B and C in 100 ml of water

APPENDIX I.

TABLE 2. Mean calendar days, growing degree days and observed and predicted percent development to physiological maturity (%DPM).

Growth stage		Calendar days		Growing degree days		Observed %DPM		Predicted %DPM	
	n	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.0	8	8.7	1.7	98	31.5	10.5	2.3	9.3	2.1
1.1	7	14.0	1.1	158	33.6	16.1	1.0	14.8	1.9
1.2	6	16.8	1.6	180	10.2	19.1	1.7	17.0	1.2
2.1	9	21.6	3.3	246	27.7	24.9	3.3	22.7	2.5
2.2	10	26.0	3.8	294	33.1	30.0	3.9	27.2	3.1
2.3	8	29.3	4.2	333	37.9	33.5	4.4	30.8	3.5
2.4	9	32.9	3.9	374	38.9	37.8	4.4	34.5	3.6
2.5	8	34.5	3.9	398	37.2	39.5	3.9	36.2	2.8
3.1	9	38.7	3.0	449	44.5	44.5	3.1	40.6	2.6
3.2	9	41.6	4.1	501	44.4	48.5	4.1	44.9	3.3
3.3	7	44.4	3.1	531	47.4	50.6	3.8	47.9	3.1
4.1	9	46.9	4.1	576	38.5	53.6	3.6	51.4	2.9
4.2	7	49.0	4.5	617	43.7	56.7	3.7	54.5	3.4
4.3	10	54.0	3.8	687	52.3	62.4	4.3	60.6	3.9
4.4	9	61.4	2.7	796	59.1	70.4	4.1	69.6	4.1
5.1	9	65.9	3.2	860	45.1	75.7	.8	74.8	3.2
5.2	10	75.2	4.2	1004	69.2	86.9	3.2	86.8	5.4
5.3	10	86.6	4.5	1157	25.2	100.0	0.0	100.0	2.3



APPENDIX I.
Figure 1. Daily mean temperature and precipitation for May to August, 1984 to 1986.

= precipitation
* = irrigation.

APPENDIX II.

TABLE 1. Mean squares and degrees of freedom for plants m^{-2} and percent seeded stand.

		Point 1985		Point 1986		Arboretum 1986	
	df	HB2.1	HB5.3	HB2.1	HB5.3	HB2.1	HB5.3
Source				Plants m^{-2}			
Replication	4	140.4	353.9	1673.7	382.5	324.9	214.1
Row width	1	1074.3	2639.0*	5905.1	3832.5	245.3	1456.7**
Error a	4	142.3	284.4	655.6	5609.6	51.6	12.7
Rate	3	39922.3**	27949.3**	158640.2**	68699.1**	9383.9**	5637.1**
Row x Rate	3	258.5	337.0	819.3	2440.7	220.4	971.9**
Error b	24	150.1	209.8	1515.5	3420.7	420.3	139.0
				Percent seeded stand			
Replication	4	49.9	166.2	233.2	40.8	16.5	121.3
Row width	1	344.0	3956.1**	812.1*	271.5	107.0	27.1**
Error a	4	66.8	107.0	53.3	266.3	50.2	73.6
Rate	3	2017.2**	1168.0*	92.9	1084.5 *	1000.5**	471.4**
Row x Rate	3	69.2	511.8	27.4	258.9	152.0	79.3
Error b	24	55.7	173.1	212.9	317.1	113.8	75.5

*, ** significant at the 0.05 and 0.01 levels of probability, respectively.

APPENDIX II.

TABLE 2. Mean squares and degrees of freedom for plants m^{-2} (P m^{-2}) and percent seeded stand (%SS), data combined over growth stages.

		Point 1985		Point 1986		Arboretum 1986	
Source	df	Pm^{-2}	%SS	Pm^{-2}	%SS	Pm^{-2}	%SS
Replication	4	362.3	117.9	366.5	339.4	212.7	92.1
Row width	1	3540.5	4707.9**	111.6	15.4	1448.8*	121.0
Error a	4	143.0	105.4	3251.3	1039.1	9.3	61.8
Rate	3	67325.3**	4162.6**	21624.8**	2590.8**	14753.6**	1375.1**
Row x Rate	3	155.2	340.7	504.3	134.6	1020.1	204.5
Error b	24	156.0	160.1	2184.8	446.2	285.3	113.7
Stage	1	4672.6 **	3557.8 **	25031.2**	2657.4*	2264.6**	526.7*
GSxRow	1	172.9	1653.5 **	9626.1	3819.2**	253.2	13.1
GSxRate	3	546.3	51.6	11095.5*	1437.5*	267.3	96.8
GSxRowxRate	3	440.3	646.4	1128.6	61.7	172.2	26.6
Error c	32	204.9	190.5	2651.5	464.6	239.7	70.2

APPENDIX II.

TABLE 3. Mean squares and degrees of freedom for growing degree days to specific growth stages.

Source	df	Growth Stage 1.0	2.1	3.1	4.1	5.1	5.3
Point 1985							
Replication	5	0.0	0.0	15.4	204.1	416.8	95.1
Row width	1	0.0	0.0	1.9	9.7	.6	33.1
Error a	5	0.0	0.0	6.4	173.0	128.1	181.9
Seeding rate	3	0.0	0.0	16.9	61.6	1986.7 **	480.6
linear	1	0.0	0.0	36.1 *	171.2	4957.7 **	86.6
quadratic	1	0.0	0.0	14.3	1.0	947.7 **	148.6
cubic	1	0.0	0.0	.4	12.6	54.7	1206.6 **
Row x Rate	3	0.0	0.0	1.9	113.4	229.4	75.4
Error b	30	0.0	0.0	7.9	79.7	101.5	168.8
Point 1986							
Replication	5	0.0	0.0	120.6	100.2	1452.6	430.1
Row width	1	0.0	0.0	143.5	276.5 **	2120.0	414.2
Error a	5	0.0	0.0	102.2	27.6	1634.7	113.4
Seeding rate	3	0.0	0.0	97.6	5.9	549.3	243.0
linear	1	0.0	0.0	210.9	1.4	616.9	409.7
quadratic	1	0.0	0.0	74.5	13.2	37.0	258.2
cubic	1	0.0	0.0	7.4	3.1	994.0	61.1
Row x Rate	3	0.0	0.0	36.4	80.6	2098.8	77.2
Error b	30	0.0	0.0	53.2	43.2	2300.5	253.6
Arboretum 1986							
Replication	5	504.6	0.0	0.0	311.7	--	126.4
Row width	1	37.1	0.0	0.0	1146.6 *	--	843.0 *
Error a	5	14.8	0.0	0.0	24.1	--	99.4
Seeding rate	3	37.1	0.0	0.0	3993.1 **	--	975.2 **
linear	1	93.2	0.0	0.0	9181.7 **	--	2644.6 **
quadratic	1	17.6	0.0	0.0	2043.2 **	--	272.1
cubic	1	17.9	0.0	0.0	754.4	--	8.9
Row x Rate	3	37.1	0.0	0.0	227.8	--	92.2
Error b	30	51.9	0.0	0.0	107.3	--	119.4

-- data was not collected at the growth stage.

APPENDIX II.

TABLE 4. Mean squares and degrees of freedom for plant height at separate growth stages.

Source	df	Growth Stage 1.0	2.1	2.3	2.5	3.1	3.3	4.1	4.4
Point 1985									
Replication	5	0.0	0.0	0.0	24.9	15.2	79.9	28.7	45.6
Row width	1	0.0	0.0	0.0	17.5	12.0	111.1	157.7	.1
Error a	5	0.0	0.0	0.0	15.4	9.1	105.8	81.4	12.3
Seeding rate	3	0.0	0.0	0.0	313.6 **	429.3 **	194.2 **	116.0 *	38.5
linear	1	0.0	0.0	0.0	838.2 **	1161.4 **	463.2 **	241.6 **	54.0
quadratic	1	0.0	0.0	0.0	100.9 **	120.8 **	97.4	105.1	61.3
cubic	1	0.0	0.0	0.0	1.7	5.7	22.0	1.3	.2
Row x Rate	3	0.0	0.0	0.0	11.2	9.5	34.6	66.4	13.1
Error b	30	0.0	0.0	0.0	7.4	3.6	36.5	28.1	30.0
Point 1986									
Replication	5	0.0	0.0	.9	47.3	77.5	56.2	109.3	105.5
Row width	1	0.0	0.0	6.1 *	3.0	40.3	38.5	30.1	2.1
Error a	5	0.0	0.0	.5	1.9	14.4	6.2	14.6	17.1
Seeding rate	3	0.0	0.0	5.4 **	116.9 **	257.5 **	43.7	13.1	246.3 **
linear	1	0.0	0.0	14.5 **	320.5 **	703.1 **	15.8	19.0	714.5 **
quadratic	1	0.0	0.0	.7	29.6	56.9 *	114.9 *	14.3	.5
cubic	1	0.0	0.0	.9	.6	12.5	.4	6.0	23.9
Row x Rate	3	0.0	0.0	2.1 *	1.8	10.6	12.7	5.1	24.3
Error b	30	0.0	0.0	.6	8.0	11.6	22.6	11.5	12.4
Arboretum 1986									
Replication	5	0.0	--	.9	17.2	17.2	47.7	--	131.6
Row width	1	0.0	--	0.0	35.0	35.0 *	426.1 *	--	229.7 **
Error a	5	0.0	--	.1	6.6	7.9	37.7	--	45.9
Seeding rate	3	0.0	--	.8	52.6 **	149.7 **	864.4 **	--	154.6
linear	1	0.0	--	1.4	142.8 **	199.4 **	1369.0 **	--	148.3
quadratic	1	0.0	--	.1	7.6	248.5 **	1003.1 **	--	290.3 **
cubic	1	0.0	--	.9	7.4	1.2	221.1 *	--	25.2
Row x Rate	3	0.0	--	.3	8.1	2.2	32.0	--	30.7
Error b	30	0.0	--	.4	10.3	18.6	32.6	--	54.6

-- data was not collected at this growth stage.

APPENDIX II.
TABLE 5. Mean squares and degrees of freedom for yield (Kg ha-1).

Source	df	Point 1985	Point 1986	Arboretum 1986
Replication	5	501752.9	718079.7	412431.1
Row width	1	4247229.1 *	3590398.6 *	2864906.1 **
Error a	5	271772.3	267565.6	45308.8
Seeding rate	3	686372.4 **	10427089.0 **	708352.5 *
linear	1	1400387.2 **	2987412.1 *	527742.5
quadratic	1	637682.2 **	60940.8	628363.1
cubic	1	21047.8	348718.2	968952.0 *
Row x Rate	3	476178.6 **	79773.9	62789.9
Error b	30	84100.1	175596.0	171135.5

APPENDIX II.
TABLE 6. Mean square and degrees of freedom for yield (Kg ha-1), all locations combined.

Source	df	All locations
Locations	2	14444215.1 *
Error a	15	403660.5
Row width	1	10634501.5
Location x Row	2	34016.2
Error b	15	14882.2
Seeding rate	3	1511669.0 **
Location x Rate	6	462882.3 **
Row x Rate	3	369687.5
Loc x Row x Rate	6	258999.6
Error c	90	143610.6

APPENDIX II.

TABLE 7. Mean squares and degrees of freedom for yield components plant^{-1} and expected (Ex) and observed (Obs) yield plant^{-1}.

Source	df	Pods plant^{-1}	Seeds pod^{-1}	1000 Seed weight (g)	Ex yield plant^{-1}	Obs yield plant^{-1}
			Point 1985			
Replication	5	989.4	6.4	0.20	14.4	1.7
Row width	1	728.5	5.1	0.01	8.1	13.6
Error a	5	117.8	11.8	0.24	5.1	3.6
Seeding rate	3	57902.0 **	18.4 *	0.06	531.6 **	279.8 **
Row x Rate	3	925.4	3.2	0.01	12.3	3.9
Error b	30	875.8	4.8	0.08	2.7	3.4
			Point 1986			
Replication	5	624.6	3.0	0.08	5.4	0.5
Row width	1	2926.6 *	12.6 *	0.05	21.7 **	2.6
Error a	5	209.0	1.3	0.05	0.7	0.4
Seeding rate	3	18157.7 **	5.1	0.18	102.7 **	53.3 **
Row x Rate	3	446.3	0.4	0.08	2.7	3.6 **
Error b	30	388.0	5.6	0.06	2.5	0.3
			Arboretum 1986			
Replication	4	5241.1	6.9	0.05	31.8	19.2
Row width	1	976.1	3.1	0.04	1.9	6.6
Error a	4	2191.9	2.0	0.05	6.9	7.8
Seeding rate	3	26219.6 **	25.4 **	0.10	125.9 **	112.4 **
Row x Rate	3	1012.3	0.9	0.10	6.0	6.1
Error b	24	1380.3	3.3	0.07	5.1	4.8

APPENDIX II.

TABLE 8. Mean squares and degrees of freedom for branch/main ratios for yield components and yield.

Source	df	BP/MP +	BSP/MSP	BWT/MWT	PBY/PMY
		Point 1985			
Replication	5	.224	.008	.006	.192
Row Width	1	.115	.014	.006	.043
Error a	5	.352	.004	.004	.215
Seeding Rate	3	19.610 **	.019	.013 *	12.863 **
linear	1	49.450 **	.004	.035 **	32.595 **
quadratic	1	8.920 **	.033	.004	5.922 **
cubic	1	.450	.021	.002	.073
Row x Rate	3	.270	.009	.004	.098
Error b	30	.360	.016	.003	.245
		Point 1986			
Replication	5	.220	.027	.002	.128
Row Width	1	.929 *	.003	.000	.537
Error a	5	.089	.061	.005	.124
Seeding Rate	3	5.240 **	.055	.002	2.811 **
linear	1	11.730 **	.081	.003	7.092 **
quadratic	1	3.709	.079	.002	1.261 **
cubic	1	.282	.005	.001	.080
Row x Rate	3	.123	.004	.006	.069
Error b	30	.135	.024	.004	.075
		Arboretum 1986			
Replication	4	3.173	.034	.010	2.153
Row Width	1	1.134	.009	.016	.950
Error a	4	1.323	.004	.003	.433
Seeding Rate	3	13.507 **	.135 **	.004	9.100 **
linear	1	32.045 **	.168 **	.000	22.568 **
quadratic	1	5.542 *	.047	.012	4.732 *
cubic	1	2.935	.189 **	.000	.001
Row x Rate	3	.472	.020	.009	.374
Error b	24	1.290	.021	.008	.752

+ = ratios BP/MP =branch/main raceme pods, BSP/MSP = branch/main raceme seeds/pod, BWT/MWT = branch/main raceme seed weight, PBY/PMY = branch/main raceme percent yield.

APPENDIX II.

TABLE 9. Mean squares and degrees of freedom for yield components from branch and main racemes.

Source	df	BNPD	MNPD	BSEP	MSEP	BSWT	MSWT	%BSW	%MSW
				Point 1985					
Replication	5	691.1	54.4	7.6	9.0	.23	.02	56.6	65.2
Row Width	1	595.0	6.0	.5	13.0	.01	.06	.3	4.6
Error a	5	232.8	30.3	12.8	9.0	.30	.20	99.9	88.8
Seeding Rate	3	46679.5 **	658.0 **	43.5 **	31.0 *	.18	.04	3335.2 **	3734.7 **
linear	1	114788.9 **	1837.7 **	85.5 **	90.5 **	.39	.01	9604.9 **	10722.8 **
quadratic	1	24726.8 **	96.5 *	28.2	2.2	.00	.05	329.2 *	441.7 *
cubic	1	523.9	39.8	16.7	.3	.17	.07	41.5	39.7
Row x Rate	3	751.2	8.7	5.0	8.2	.03	.01	13.9	10.6
Error b	30	776.9	16.2	7.1	10.2	.10	.08	66.3	68.5
				Point 1986					
Replication	5	449.5	30.5	13.2	4.0	.12	.10	337.0	307.5
Row Width	1	1832.7 *	127.4 *	12.6	31.7	.07	.03	67.7	195.9
Error a	5	167.8	7.2	12.0	14.5	.15	.03	244.4	312.2
Seeding Rate	3	12296.3 **	601.8 **	27.8	35.1	.16	.12	1757.2 **	2015.9 **
linear	1	27660.4 **	1671.8 **	78.2 **	19.2	.39 *	.17	5073.9 **	5843.2 **
quadratic	1	8477.2 **	132.5 **	4.0	79.3 *	.05	.15	78.3	106.2
cubic	1	751.3	1.1	1.3	6.9	.03	.02	119.5	98.3
Row x Rate	3	268.7	49.4 *	1.4	6.1	.19 *	.06	24.9	28.3
Error b	30	275.8	15.7	7.6	12.7	.06	.08	141.8	133.8
				Arboretum 1986					
Replication	5	4314.8	85.1	16.9	1.4	.10	.12	235.2	242.4
Row Width	1	900.6	1.5	.1	5.4	.11	.01	127.7	131.2
Error a	5	1907.6	28.8	13.3	4.5	.16	.01	56.3	61.4
Seeding Rate	3	23030.5 **	131.1	68.6 **	7.2 *	.08	.06	1183.1 **	1197.2 **
linear	1	56298.2 **	387.7 *	136.8 **	15.4 *	.01	.00	3380.8 **	3368.2 **
quadratic	1	11979.7 **	.0	18.2	.3	.11	.00	213.2	222.9
cubic	1	813.7	5.5	50.6 *	5.9	.10	.18	.3	.6
Row x Rate	3	701.7	59.5	11.3	.9	.15	.04	34.6	36.1
Error b	30	1245.2	46.7	11.1	2.3	.12	.06	83.9	80.9

B = branch raceme, M = main raceme.
NPD = number of pods plant -1, SEP = number of seeds pod-1.
SWT = 1000 seed weight, %SW = percent of the total yield.

APPENDIX II.
TABLE 10 Mean squares and degrees of freedom for harvest index.

Source	df	Point 1985	df	Point 1986	df	Arboretum 1986
Replication	5	25.2	5	8.9	4	2.5
Row width	1	55.9	1	1.8	1	31.8
Error a	5	12.0	5	48.0	4	18.7
Seeding rate	3	37.8	3	12.3	3	18.2
linear	1	78.6	1	33.8	1	2.7
quadratic	1	.1	1	.8	1	22.1
cubic	1	34.7	1	2.3	1	22.8
Row x Rate	3	56.4	3	73.1 **	3	.2
Error b	30	20.0	30	10.0	24	27.3

APPENDIX II.
TABLE 11 Mean squares and degrees of freedom for lodging (0 to 5 scale).

Source	df	Point 1985	Point 1986	Arboretum 1986
Replication	5	1.6	1.9	.9
Row width	1	6.8	1.3	1.3
Error a	5	1.6	.7	1.8
Seeding rate	3	18.9 **	29.5 **	12.5 **
linear	1	47.1 **	85.2 **	37.0 **
quadratic	1	8.0 **	2.5 *	.3
cubic	1	1.6	.8	.2
Row x Rate	3	3.5 *	1.3	1.3
Error b	30	1.0	.4	.9

APPENDIX II.
TABLE 12. Mean squares and degrees of freedom for percent oil and protein.

Source	df	Point 1985	Point 1986	Arboretum 1986
		Oil %		
Replication	5	3.45	2.26	2.01
Row width	1	2.17	5.95 *	.20
Error a	5	.43	.13	.32
Seeding rate	3	1.50	2.55 **	.43
linear	1	3.90 *	7.37 *	1.12
quadratic	1	.01	.11	0.00
cubic	1	.60	.16	.27
Row x Rate	3	.16	.11	.17
Error b	30	.90	.35	.46
		Protein %		
Replication	5	5.29	2.58	1.25
Row width	1	2.00	16.33 **	.03
Error a	5	.45	.74	.05
Seeding rate	3	2.71	1.39	1.84
linear	1	6.97	1.98	5.36
quadratic	1	1.10	2.20	.12
cubic	1	.06	0.00	.04
Row x Rate	3	1.38	.54	.66
Error b	30	1.00	.80	.82

APPENDIX II.
TABLE 13. Mean square and degrees of freedom for oil and protein percent combined over locations.

Source	df	Oil	Protein
Location	2	30.64 **	59.04 **
Error a	15	2.54	3.04
Row width	1	6.33 **	9.30 **
Location x row	2	.99	4.53
Error b	15	.29	.37
Seeding rate	3	3.74 **	5.03 **
Location x rate	6	.37	.46
Row x Rate	3	.10	1.57
Site x Row x Rate	6	.16	.50
Error c	90	.57	.87

APPENDIX II.

TABLE 14. Mean squares and degrees of freedom for branch, main and total seed chlorophyll (ppm).

Source	df	Branch Chlor	Main Chlor	Total Chlor
		Point 1985		
Replication	5	15.11	12.40	6.66
Row width	1	173.77	75.80	188.65
Error a	5	114.74	16.07	86.35
Seeding rate	3	88.22	6.99	101.95 *
linear	1	7.03	5.15	149.97 *
quadratic	1	128.47	5.75	48.06
cubic	1	129.17	10.06	107.82
Row x Rate	3	5.47	7.09	11.05
Error b	30	31.14	11.27	24.98
		Point 1986		
Replication	5	67.70	28.60	45.58
Row width	1	108.42	2.27	1.55
Error a	5	17.52	9.40	5.39
Seeding rate	3	597.02 **	9.50	107.36 **
linear	1	715.41 **	4.16	1.27
quadratic	1	904.96 **	22.61	262.49 **
cubic	1	170.68 *	1.73	58.30 **
Row x Rate	3	219.22 **	18.64	52.55 **
Error b	30	27.69	10.53	7.70
		Arboretum 1986		
Replication	4	71.43	23.52	52.76
Row width	1	12.18	25.97	.07
Error a	4	15.47	4.93	3.35
Seeding rate	3	75.65	8.27	43.56
linear	1	13.46	4.30	5.10
quadratic	1	199.30	1.08	108.21
cubic	1	14.20	19.43	17.38
Row x Rate	3	10.41	18.80	7.02
Error b	24	34.41	12.65	23.57

Chlor = chlorophyll ppm.

APPENDIX III.

TABLE 1 Mean squares and degrees of freedom for dry weight (W) (g m-2).

Source	df	2.1	df	3.1	df	4.1	df	4.3	df	5.1	df	5.3
						Growth Stage						
						Point 1985						
Replication	4	233.7	4	2652.2	4	4931.7	3	37622.6	4	55019.2	4	165589.1
Row width	1	83.5	1	41287.7 **	1	25959.5 **	1	568497.8 **	1	2429306.9 **	1	8840512.6 **
Error a	4	29.3	4	1733.5	4	6860.2	3	18269.5	4	18807.8	4	43030.4
Seeding rate	3	2532.5 **	3	20934.2 **	3	1391.8	3	6345.7	3	6345.7	3	411371.5
linear	1	7449.6 **	1	42826.6 **	1	146.6	1	826.3	1	826.3	1	1095690.5
quadratic	1	147.8	1	15476.8 **	1	9.5	1	18119.2	1	18119.2	1	54585.4
cubic	1	0.0	1	4499.2	1	5410.9	1	909.6	1	909.6	1	83838.5
Row x Rate	3	352.0 **	3	1967.2	3	5212.5	3	1853.8	3	1853.8	3	298265.1
Error b	24	66.5	24	1371.9	24	14275.4	18	26697.4	24	26697.4	24	285295.7
						Point 1986						
Replication	3	370.2	4	6860.3	4	1724.7		--	3	21691.2	4	28067.7
Row width	1	366.5	1	166861.8 **	1	476570.7 **		--	1	407343.4 **	1	1790432.3 **
Error a	3	72.4	4	4894.1	4	3475.0		--	3	1531.6	4	17473.0
Seeding rate	3	2091.8 **	3	6956.8	3	14690.1		--	3	48404.8	3	112970.3
linear	1	5490.2 **	1	14695.0	1	18139.7		--	1	87748.3	1	337728.3 *
quadratic	1	756.0	1	1643.9	1	14600.8		--	1	499969.2	1	892.4
cubic	1	29.2	1	4531.7	1	11329.8		--	1	7497.0	1	290.1
Row x Rate	3	124.7	3	5338.2	3	4436.6		--	3	29586.1	3	85071.5
Error b	18	45.5	24	7476.8	24	74446.4		--	18	20943.4	24	50831.2

Source	df	2.2	3.3	4.3	5.1	5.3
			Arboretum 1986			
Replication	3	27.9	7203.2	--	21848.8	15227.4	5259.2
Row width	1	70.6	38115.6 *	--	111961.5 *	379736.5 **	476434.4 *
Error a	3	15.7	3587.8	--	5814.9	10358.3	34220.8
Seeding rate	3	1131.8 **	2143.6	--	2732.9	33772.5	142718.0 *
linear	1	3323.3 **	983.9	--	1780.6	28796.4	308827.6 *
quadratic	1	19.9	1863.8	--	17.9	13474.3	3320.2
cubic	1	52.2	3583.0	--	6400.2	19565.1	142718.0 *
Row x Rate	3	24.2	1396.6	--	8972.6	68278.1	29686.1
Error b	18	35.1	1396.8	--	5280.6	19152.0	44475.4

*, ** significant at the .05 and .01 level of probability.

-- data not collected at this growth stage.

APPENDIX III.
TABLE 2. Equations, R^2 and standard errors for dry weight (W) gain ($g\ m^{-2}$) over time (GDD).

Treatment	Equation	n	R^2	SEE
	Point 1985			
15 cm row	$Log_e W = 0.003 + GDD \times (.015 - 7.45\ E^{-6} \times GDD)$	96	.91	.48
30 cm row	$Log_e W = 0.327 + GDD \times (.014 - 6.89\ E^{-6} \times GDD)$	96	.94	.33
1.5 rate	$Log_e W = -1.278 + GDD \times (.018 - 8.89\ E^{-6} \times GDD)$	48	.93	.46
3.0 rate	$Log_e W = -0.354 + GDD \times (.016 - 7.86\ E^{-6} \times GDD)$	48	.94	.37
6.0 rate	$Log_e W = 0.828 + GDD \times (.013 - 6.44\ E^{-6} \times GDD)$	48	.93	.36
12.0 rate	$Log_e W = 1.466 + GDD \times (.011 - 5.48\ E^{-6} \times GDD)$	48	.92	.33
	Point 1986			
15 cm row	$Log_e W = 0.671 + GDD \times (.014 - 7.63\ E^{-6} \times GDD)$	80	.90	.45
30 cm row	$Log_e W = 0.675 + GDD \times (.013 - 6.97\ E^{-6} \times GDD)$	80	.94	.33
1.5 rate	$Log_e W = -0.628 + GDD \times (.017 - 8.95\ E^{-6} \times GDD)$	40	.95	.36
3.0 rate	$Log_e W = 0.247 + GDD \times (.015 - 7.90\ E^{-6} \times GDD)$	40	.91	.44
6.0 rate	$Log_e W = 1.396 + GDD \times (.012 - 6.23\ E^{-6} \times GDD)$	40	.92	.35
12.0 rate	$Log_e W = 1.677 + GDD \times (.011 - 6.11\ E^{-6} \times GDD)$	40	.92	.31
	Arboretum 1986			
15 cm row	$Log_e W = -0.633 + GDD \times (.014 - 6.63\ E^{-6} \times GDD)$	80	.93	.34
30 cm row	$Log_e W = -0.346 + GDD \times (.013 - 5.88\ E^{-6} \times GDD)$	80	.92	.33
1.5 rate	$Log_e W = -1.607 + GDD \times (.015 - 7.18\ E^{-6} \times GDD)$	40	.94	.37
3.0 rate	$Log_e W = -0.835 + GDD \times (.015 - 7.18\ E^{-6} \times GDD)$	40	.92	.39
6.0 rate	$Log_e W = -0.292 + GDD \times (.013 - 6.22\ E^{-6} \times GDD)$	40	.96	.25
12.0 rate	$Log_e W = 0.776 + GDD \times (.011 - 5.07\ E^{-6} \times GDD)$	40	.93	.28

GDD = growing degree days, row = row width and rate = seeding rate.

APPENDIX III.

TABLE 3 Mean squares and degrees of freedom for leaf area index (LAI).

Source	Growth Stage 2.1 df	2.1	3.1 df	3.1	4.1 df	4.1	4.3 df	4.3	5.1 df	5.1	5.3 df	5.3
Point 1985												
Replication	4	.001	4	.79	4	3.43	3	1.14	4	.60	4	.27
Row width	1	.068	1	2.51	1	21.22 **	1	15.34 **	1	13.48	1	3.04 **
Error a	4	.014	4	1.25	4	1.47	3	1.03	4	1.97	4	.02
Seeding rate	3	.956 **	3	7.40 **	3	4.54	3	.39	3	4.53 **	3	.14
linear	1	2.810 **	1	20.34 **	1	4.21	1	.81	1	1.98	1	.07
quadratic	1	.055 *	1	1.53	1	3.06	1	.08	1	11.37 **	1	.29
cubic	1	.003	1	.32	1	6.35	1	.21	1	.24	1	.07
Row x Rate	3	.100 **	3	.75	3	3.27	3	.26	3	4.63	3	.09
Error b	24	.012	24	.84	24	3.18	18	1.71	24	.88	24	.13
Point 1986												
Replication	3	.364	4	1.53	4	1.65		--	3	.01	4	.06
Row width	1	.031	1	21.59	1	44.07 **		--	1	2.99	1	.02
Error a	3	.025	4	1.49	4	1.73		--	3	.60	4	.04
Seeding rate	3	.650 **	3	10.19 **	3	8.32 *		--	3	.22	3	.03
linear	1	1.655 *	1	22.57 **	1	7.21		--	1	.10	1	.05
quadratic	1	.277	1	7.38 *	1	12.61 *		--	1	.00	1	.04
cubic	1	.017	1	.63	1	5.14		--	1	.55	1	.00
Row x Rate	3	.032	3	1.79	3	4.37		--	3	.75	3	.10
Error b	18	.021	24	1.71	24	2.76		--	18	.27	24	.09

Source	df	2.2	3.3	4.3	5.1	5.3
Arboretum 1986						
Replication	3	.024	2.07	--	2.86	2.86	.01
Row width	1	.002	5.57 *	--	7.37 **	10.26 *	.06
Error a	3	.006	.79	--	.96	.93	.02
Seeding rate	3	.209 **	.45	--	.25	2.13	.04
linear	1	.597 **	.75	--	.41	2.21	.08
quadratic	1	.010	.16	--	.15	3.68	.03
cubic	1	.020	.44	--	.20	.00	.00
Row x Rate	3	.007	.03	--	2.13 **	2.72	.01
Error b	18	.019	.43	--	.38	1.22	.01

*, ** significant at the .05 and .01 level of probability.

-- data not collected at this growth stage.

APPENDIX III.

TABLE 4. Equations, R^2 and standard errors for leaf area index (LAI) over time (GDD).

Treatment	Equation	n	R^2	SEE
	Point 1985			
15 cm row	Log_e LAI= -4.41 + GDD x (.018 - 1.20 E^{-5} x GDD)	96	.77	.55
30 cm row	Log_e LAI= -4.53 + GDD x (.018 - 1.27 E^{-5} x GDD)	96	.84	.45
1.5 rate	Log_e LAI= -6.35 + GDD x (.022 - 1.47 E^{-5} x GDD)	48	.87	.51
3.0 rate	Log_e LAI= -4.71 + GDD x (.018 - 1.23 E^{-5} x GDD)	48	.86	.42
6.0 rate	Log_e LAI= -3.70 + GDD x (.016 - 1.16 E^{-5} x GDD)	48	.83	.44
12.0 rate	Log_e LAI= -3.11 + GDD x (.017 - 1.20 E^{-5} x GDD)	48	.77	.55
	Point 1986			
15 cm row	Log_e LAI= -3.98 + GDD x (.019 - 1.47 E^{-5} x GDD)	80	.81	.73
30 cm row	Log_e LAI= -4.10 + GDD x (.019 - 1.54 E^{-5} x GDD)	80	.76	.98
1.5 rate	Log_e LAI= -4.85 + GDD x (.020 - 1.48 E^{-5} x GDD)	40	.92	.41
3.0 rate	Log_e LAI= -4.53 + GDD x (.020 - 1.60 E^{-5} x GDD)	40	.76	.97
6.0 rate	Log_e LAI= -3.41 + GDD x (.017 - 1.14 E^{-5} x GDD)	40	.79	.85
12.0 rate	Log_e LAI= -3.36 + GDD x (.018 - 1.51 E^{-5} x GDD)	40	.75	1.06
	Arboretum 1986			
15 cm row	Log_e LAI= -7.98 + GDD x (.028 - 2.94 E^{-5} x GDD)	80	.70	1.21
30 cm row	Log_e LAI= -8.47 + GDD x (.030 - 2.93 E^{-5} x GDD)	80	.77	1.26
1.5 rate	Log_e LAI= -8.28 + GDD x (.026 - 1.86 E^{-5} x GDD)	40	.67	1.14
3.0 rate	Log_e LAI= -6.97 + GDD x (.023 - 1.65 E^{-5} x GDD)	40	.81	.70
6.0 rate	Log_e LAI= -9.50 + GDD x (.034 - 2.68 E^{-5} x GDD)	40	.85	1.19
12.0 rate	Log_e LAI= -8.17 + GDD x (.031 - 2.47 E^{-5} x GDD)	40	.85	1.15

GDD = growing degree days, row = row width and rate = seeding rate.

APPENDIX III.

TABLE 5 Mean squares and degrees of freedom for leaf area duration (LAD).

Source	df	Vegetation duration (2.1 to 4.1)	Reproductive duration (4.1 to 5.3)	Total duration (2.1 to 5.3)
			Point 1985	
Replication	3	53.9	571.0	967.1
Row	1	2249.5 *	9684.8 *	21269.5 *
Error a	3	160.3	650.9	840.1
Rate	3	2574.6 **	2589.2 *	6197.3 **
Row x Rate	3	241.0	1883.3 *	2166.5
Error b	18	427.2	575.4	1166.2
			Point 1985	
Replication	3	141.3	68.7	202.9
Row	1	11134.1 **	10756.8 **	43778.4 **
Error a	3	211.9	57.5	300.1
Rate	3	3521.0 **	1001.1 *	7098.9 *
Row x Rate	3	301.6	603.5 *	305.5
Error b	18	414.7	512.2	1418.1
			Arboretum 1986	
Replication	3	206.5	3475.4	440.4
Row	1	709.7	9139.5	14642.9
Error a	3	173.8	960.0	1879.5
Rate	3	178.2	3613.3	2607.9
Row x Rate	3	70.5	6122.3	7148.6
Error b	18	212.8	3336.2	4402.3

*,** significant at the 0.05 and 0.01 level of probability.

APPENDIX III.

TABLE 6 Mean squares and degrees of freedom for crop growth rate (CGR).

Source	df	Growth Stage 2.1	3.1	4.1	4.3	5.1	5.3
				Point 1985			
Replication	3	.0093	.0433	.1913	.1730	.4280	2.0170
Row width	1	.0265 **	1.0220 **	11.5080 **	35.3400 **	34.2790 **	11.1980
Error a	3	.0003	.0281	.3000	.6412	.2770	2.1580
Seeding rate	3	.1428 **	.1292 *	1.0430 **	7.3100 **	6.1440 **	9.0850 **
linear	1	.3656 **	.2106 *	2.7520 **	17.8830 **	14.1140 **	27.2251 **
quadratic	1	.0580 **	.1574 *	.1210	2.7790 *	3.0440	13.8353
cubic	1	.0047	.0197	.2566	1.2560	1.2760	1.6120
Row x Rate	3	.0191 *	.0133	.3285	2.0080	1.4830	4.6120
Error b	18	.0039	.0334	.1921	.3790	.8310	1.6470
				Point 1986			
Replication	3	.0206	.0079	.0569	.6600	.3840	1.0710
Row width	1	.0882 **	1.8964 **	7.6734 **	16.0030 **	7.0690 *	18.2710 **
Error a	3	.0023	.0167	.0740	.1640	.0144	.4050
Seeding rate	3	.1094 **	.0340	.5590 *	5.2220 **	3.8230 **	5.3782 **
linear	1	.2789 **	.0538	1.3210 **	12.0510 **	9.8800 **	12.7420 **
quadratic	1	.0490 **	.0167	.2300	3.3080	1.5880 *	3.2870 *
cubic	1	.0002	.0312	.1266	.3080	.0000	.1050
Row x Rate	3	.0067	.0160	.2760	1.3766 *	.6111	.4310
Error b	18	.0029	.0245	.1185	.2941	.2278	.7376
				Arboretum 198			
Replication	3	.0005	.0219	.0428	.0175	.1619	1.5498
Row width	1	.0085	.5100 **	2.2470 **	4.6890 **	4.3220 **	1.1363
Error a	3	.0009	.0106	.0195	.0249	.1237	.4710
Seeding rate	3	.0223 **	.0159	.1512	.8310	1.6752 **	.4520
linear	1	.0652 **	.0077	.3593 *	2.2690	4.4745 **	.6060
quadratic	1	.0015	.0134	.0021	.0340	.3726	.9500
cubic	1	.0010	.0265	.0921	.1890	.1785	.3460
Row x Rate	3	.0010	.0149	.1227	.9380	.5890	.9380
Error b	18	.0009	.0130	.0518	.1206	.2362	.5440

*, ** significant at the 0.05 and 0.01 level of probability.

APPENDIX III.

TABLE 7 Mean squares and degrees of freedom for net assimilation rate

Source	df	Growth Stage 2.1	3.1	4.1	4.3	5.1
				Point 1985		
Replication	3	.0280	.0050	.0040	.0030	.0130
Row width	1	.0002	.0690 **	.1485 *	.2200 *	.2790 *
Error a	3	.0080	.0010	.0070	.0160	.0240
Seeding rate	3	.3080 **	.1230 **	.0983 **	.1010 **	.0715
linear	1	.6990 **	.3545 *	.2860 **	.2670 **	.1540 *
quadratic	1	.1530 **	.0142	.0010	.0200	.0530
cubic	1	.0710	.0000	.0070	.0150	.0080
Row x Rate	3	.0420 *	.0080	.0107	.0190	.0330
Error b	18	.0090	.0080	.0117	.0140	.0300
				Point 1986		
Replication	3	.0230	.0030	.0093	.0230	.0219
Row width	1	.0428	.0578	.0392	.0132	.0545
Error a	3	.0267	.0122	.0212	.0167	.0410
Seeding rate	3	.0778	.1065 **	.1520 **	.2430 **	.2326 **
linear	1	.0138 *	.2350 **	.3452 **	.5500 **	.4798 **
quadratic	1	.0494	.0807 **	.1070 **	.1580 **	.1489
cubic	1	.0459	.0037	.0067	.0207	.0691
Row x Rate	3	.0469	.0136	.0196	.0313	.0191
Error b	18	.0272	.0070	.0105	.0132	.0395
				Arboretum 1986		
Replication	3	.2690	.0125	.0360	.1150	.6580
Row width	1	.1670	.0220	.0200	.0210	.0040
Error a	3	.0470	.0050	.0140	.0610	.7450
Seeding rate	3	.1000	.0580	.0710	.1390	.4401
linear	1	.2810 *	.1680 *	.1920 *	.2860	.4130
quadratic	1	.0140	.0030	.0220	.1290	.9051
cubic	1	.0040	.0020	.0000	.0030	.0010
Row x Rate	3	.1020	.0053	.0200	.0620	.4450
Error b	18	.0364	.0240	.0390	.0740	.3230

*, ** significant at the 0.05 and 0.01 level of probability.