The Effects of Moisture Stress on Rapeseed (*Brassica napus* L.).

by

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A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Plant Science

Winnipeg, Manitoba

ISBN 0-315-48049-1

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(BRASSICA NAPUS L.)

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HEATHER MCPHERSON

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

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ABSTRACT

The effect of soil moisture stress on six rapeseed Brassica napus L.) cultivars was investigated in a field study conducted at the University of Manitoba in 1985 and 1986. Irrigated, nonirrigated, and late sowings were established at the University of Manitoba Point field station. A second location was situated at the University of Manitoba Portage la Prairie field station to determine the effects of a different soil type on moisture stress in rapeseed. Effects of moisture stress were measured by monitoring growth stages, stomatal resistance, yield and yield components, and quality components.

Increased soil moisture through irrigation had little effect on yield or quality in comparison to the nonirrigated treatment. Stomatal resistance measurements did not differ between the irrigated and nonirrigated treatments, or between cultivars. The use of measurements such as stomatal resistance are limited to years in which the evaporative demand is high, and when water stress can be imposed.

Delayed seedings reduced the time required to reach maturity in 1985 and 1986, and resulted in decreased oil content. Delayed seedings had no effect on yield while yield components of each cultivar differed in their response. Later flowering cultivars had a lower rate of pod abortion and a higher number of seeds per plant. Number of seed per pod and 1000 seed weight were lower in these cultivars. Cultivars of early maturity were high yielding over all treatments.

ACKNOWLEDGEMENTS

I would like to thank a number of people involved with the completion of this thesis.

I am indepted to my advisor, Dr. Rachael Scarth, without whom this thesis would not have been possible. Her time and understanding meant that this research project was always enjoyable and this was deeply appreciated.

I would also like to express my gratitude to Dr. C.F. Shaykewich for his help on the soil physics portion of this thesis, and to Dr. R. Rimmer for his help with statistical analyses. Their comments and suggestions were of great value.

Many thanks to Ms. Judith Nugent-Rigby and Mr. John Watson for their technical assistance.

The typing skills of Mr. Russell McPherson and Ms. Linda Williamson and the artistic ability of Mr. John Gustavson were greatly appreciated.

I would like to thank my family for their support and understanding, A special thanks to Keith, who was always there.

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Chapter I

INTRODUCTION

Oilseed rape is an important crop in Canada, Europe, the USSR, China, Japan, India, South America, and South Africa. The exact origin of rapeseed is not known, but it is thought to have originated in the Eurasia region. The earliest references to rape cultivation are from India, China, and Japan dating back to 2000 BC (Weiss, 1983).

The production of oilseed rape (*Brassica napus* and *B. campestris*) is of major economic importance in Canada. Canada is both a leader in production of canola oil and the world's largest exporter of seed. If Canada is to maintain her position on the international canola market, production must be maintained or increased. To accomplish this, environmental factors which limit production must be overcome. One such factor is available soil moisture.

The effect of drought on determining yield has important implications for stability of returns on the Canadian Prairies. Maximum yield cannot be achieved unless the soil moisture is maintained in the upper half of the available range until pod ripening. Drought during the latter portion of the growing season is a common occurrence on the Canadian Prairies. Rapeseed cultivars are most sensitive to drought stress at flowering. Yield, and the yield components of pods per plant, pods per main branch and seeds per pod have been shown to be significantly reduced by drought (Richards and Thurling, 1978b). The interaction between water stress and yield of rape must be minimized by establishing cultivars able to avoid drought through early maturity, or by establishing drought tolerant cultivars. Early flowering cultivars could potentially avoid some degree of drought stress by flowering prior to the drier portion of the summer. The length of the flowering period is also affected by moisture conditions. Alleviating water stress through irrigation extends the flowering period, allowing the production of more flowers, pods, and seeds (Krogman and Hobbs, 1975).

Delayed seedings will reduce the time required to reach maturity. A shorter maturation period will decrease the plant's nutritional status, which in turn will lead to reductions in yield. Delays in seeding also have the potential to expose the crop to drought during or prior to flowering. Available soil moisture will also be depleted since late sowings cannot take maximum advantage of the high soil moisture following spring thaw. Soil moisture reserves are therefore less than optimal. Drought stress combined with limited moisture reserves and a decrease in the plant's nutritional status will drastically reduce yields.

The objective of this study was to determine the effects of soil moisture availability on stomatal resistance, days to maturity, yield and yield components, and oil and protein content of six canola cultivars with distinct genetic backgrounds.

Chapter II

LITERATURE REVIEW

2.1 MOISTURE STRESS

Stress can be defined as an environmental condition or combination of conditions that restrict a plant from realizing its genetically determined potential for growth, development, and reproduction (Jones and Qualset, 1984). Plant growth and development is limited by either too little or too much water. Insufficient or excess quantities of water at any particular growth stage will reduce plant photosynthesis, resulting in decreased yield potential (Kozlowski, 1968). Overirrigation will cause water logging of the soil, resulting in reduced plant growth brought about by reductions in oxygen levels (Jones and Qualset, 1984). Water stress is one of the major causes of reduction in leaf area. This reduction can be due to inhibition of cell division, of cell enlargement, or both (McCree and Davis, 1974). Limited water availability is one of the most widespread environmental restrictions that a plant must overcome in order to realize its yield potential (Ceccarelli, 1984).

Drought stress arises in situations where less than ideal soil moisture conditions prevail, or where there is insufficient water for crop production. On the Canadian Prairies lack of adequate moisture is a common occurrence. Deviations from ideal conditions occur annually for short periods of time. During summers of prolonged soil moisture deficit, the stress imposed on the plants will result in significant yield reductions (Phillips and Poyser, 1981).

In plants, the internal water deficit is controlled by the rate of water uptake through root absorption, and the rate of water loss by transpiration. A diurnal cycle exists in the plant. During the day transpiration exceeds absorption, leading to internal water deficits. These deficits are reduced or eliminated during the night when absorption and transpiration are both low, but the rate of absorption exceeds the rate of transpiration (Kozlowski, 1968).

Water moves from sites of high to those of low potential. A plant must extract water from the soil against gravity and the resistance to liquid flow through the vascular system. In order for the uptake of soil water by plant roots, the water in contact with the root must be at a higher potential than that in the root. The water potential of the soil decreases as the water content decreases. The water potential in the plant required to remove water from the soil must therefore decrease as the water content of the soil decreases. If the soil water uptake continues, the soil water potential will decrease until the water potential is equal to the root water potential. At this point, uptake will cease unless water from the surrounding soil moves towards the root in response to the reduction in water potential of the soil adjacent to the root (Gardner, 1960). Reduction of the water potential of the root medium has been shown to immediately decrease the growth rate of maize (Acevedo, Hsiao, and Henderson, 1971) and barley leaves (Matsuda and Riazi, 1981).

The potential energy of the water in the plant must also be lower than that of the soil. The water potential gradient increases as the evaporation demand of the plant increases. Water deficits will occur in the tissues of all transpiring plants as a result of the water flow along this pathway. As the stomata open, the lower water potential of the environment forces the movement of water out of adjacent tissue such as the cortex and the phloem. This provides the driving force for the movement of water from the soil, through the plant, to the environment. As a result of this water loss, water deficits develop in the leaf, stem, and root tissue (Turner and Begg, 1981).

2.1.1 Stomatal Resistance

Drought resistance of crop plants can be measured using physiological characters. One method used is the regulation of water loss by stomata. Diffusion porometers have been developed which measure the conductance of water vapor by both the cuticle and stomata. The conductance of the cuticle is very low compared with the conductance of the stomata, and is unaffected by the environmental variables. The diffusion porometer is therefore considered to measure only stomatal conductance (Ceccarelli, 1984). The inverse of stomatal conductance is stomatal resistance.

A high stomatal resistance can increase the plant's ability to withstand drought conditions. An increase of stomatal resistance slows the use of limited water supplies resulting in a greater availability of water for later growth stages, prevents water stresses during the diurnal cycle, and maximizes total photosynthate assimilation with a given amount of available water (Ceccarelli, 1984). In most drought resistant plants, stomata close more rapidly than in less resistant plants. Stomatal closure maintains a favourable water balance in the plant and retards transpiration (Parker, 1968).

One of the many methods used to measure the stomatal behaviour of an actively photosynthesizing and respiring leaf is to enclose the leaf in a leaf chamber. The humidity of the air in the chamber will increase, and the carbon dioxide levels will decrease. The rate of humidity and carbon dioxide exchange depends directly upon the stomatal conductance. Field measurements on wheat and barley have indicated that the optimum temperature for carbon dioxide uptake was 24°C. Above this temperature, carbon dioxide uptake decreased due to increases in stomatal resistance (Leach, 1979). With broad bean (*Vicia faba*) stomatal opening increases from 5°C with an optimal opening in the 35-40°C range. Cooler soybean canopies result from increased transpirational cooling, with greater rates of stomatal opening at higher air temperatures (Harris, Schapaugh and Kanemasu, 1984). These authors found lower canopy temperatures under irrigated conditions as opposed to dryland conditions. Leaf temperatures under water stress before an irrigation are 2°C above air temperature due primarily to partial stomatal closure, resulting in a lower amount of evaporative cooling caused by a soil water deficit (Ehrler et al, 1978).

Harris, Schapaugh and Kanemasu (1984) also found differences in canopy temperatures between cultivars. They suggested that this reflected differences in transpiration rate. The cultivars with cooler canopies transpired at a higher rate and were therefore able to maintain high photosynthetic rates. The cultivars with warm canopies had some or all stomates closed, reducing carbon dioxide exchange, and therefore photosynthesis, ultimately limiting seed yield.

Ehrler and van Bavel (1967) found leaf temperatures of sorghum to be strongly related to soil water availability. Leaf temperatures of plants grown in dry soil were greater than the air temperature. These high leaf temperatures were attributed to a reduction in transpiration due to stomatal closure.

Evidence indicates that photosynthesis is inhibited by water deficits occurring under natural conditions. Water deficits result in stomatal closure and losses of chloroplast activity. Water deficits also lead to a decreased development of leaf area, and early leaf senescence. The loss of leaf area substantially reduces photosynthetic activity. Grain production is limited more by loss of photosynthate than by translocation losses. Water deficiencies therefore decrease grain yield by decreasing the photosynthate accumulated over the growing season (Boyer, 1976). However, Cihu and Brun (1975) stated that a change in stomatal resistance has a greater effect on transpiration than on photosynthesis because it constitutes a larger proportion of the total resistance of water vapor diffusion than it does for carbon dioxide diffusion.

2.2 SOIL AND PLANT WATER RELATIONS

The ability of the plant to take up water is dependent on the ability of the roots to absorb water from the soil, and on the ability of the soil to move water towards the root in sufficient quantities to fulfill the transpiration requirements. These requirements in turn depend on the properties of the soil, the properties of the plant, as well as the meteorological conditions (Hillel, 1980).

The processes of transpiration and absorption are controlled by a number of factors. Transpiration, the movement of moisture from the plant to the atmosphere, is controlled by solar radiation, temperature, humidity, wind (the aerial environment), and leaf structure and stomatal opening. Absorption, or the rate of water absorption from the soil by the plant roots, is controlled in part by transpiration, as well as soil factors including soil temperature, moisture tension, aeration, and concentration of the soil solution. The size and distribution of the root system is also important (Kozlowski, 1968).

2.2.1 Physical Soil Properties

Van Bavel (1953) states that the primary factor in soil-plant water relations are the forces with which water is held by the soil. Early work relating soil water to plant response introduced the concepts of field capacity and wilting coefficient. Field capacity is the amount of water held in the soil after excess water has drained away and the rate of downward movement has decreased. The rate of downward movement decreases two to three days following rain or irrigation (Veihmeyer and

Hendrickson, 1949). However, field capacity is not an equilibrium condition. Slow drainage occurs for weeks following a period of wetting (Salter and Williams, 1965). To account for this, Wilcox (1962) expanded the definition of field capacity as the upper limit of soil moisture that is available for plant use. This includes water use from the moment of water additions but excludes all loss of water through drainage below root level. In general, only half of the total water that a soil can hold at field capacity is available soil moisture (Thomas, 1984).

The highest yields of rapeseed are obtained when soil moisture is maintained above 50% of the available soil moisture. Yields will be reduced when available soil moisture falls below 75% but they are generally not significantly lower than yields obtained at 50% available moisture (Thomas, 1984).

Permanent wilting percentage is the critical soil moisture content denoting the lower limit of readily available moisture to plants for growth (Hendrickson and Veihmeyer, 1945). At the permanent wilting point the soil is no longer able to supply water at a sufficient rate to maintain turgor. Leaves will not recover turgor in a water saturated environment without addition of water to the soil (Veihmeyer and Hendrickson, 1949).

Veihmeyer and Hendrickson (1927) found that the soil moisture supply of a loam soil fluctuated between wide limits. The range of fluctuations in the soil moisture was determined to be the maximum field capacity and the wilting coefficient. The difference between the field capacity and permanent wilting percentage is the amount of water available to plants in the soil. Available water is the total amount of extractable water from the soil profile to be used by the plant in the growth and maturing processes (Jamison, 1956).

A soil factor affecting availability of water is soil texture. Coarse textured soils are very low in available moisture, while there is little difference in amount of available moisture between medium and fine textured soils. This relationship arises from the interaction of field capacity and permanent wilting point. As soils become finer in texture, there is an initial increase in field capacity. This increase is much slower in coarser soils. As soil texture becomes finer, field capacity increases at a decreasing rate, and the wilting coefficient increases at an increasing rate. As the soil gets heavier, the wilting coefficient increases as rapidly as the field capacity. There is therefore little difference in available water between soils of medium to fine texture (Wilcox and Spilsbury, 1941).

Silt content is the most important factor determining available water. As silt content increases, so does available water. Medium textured soils allow a good degree of moisture infiltration. These soils provide good drainage, and have a high water holding capacity. Silty soils generally have better granular structure than other soils enabling firm packing for a seed bed without baking or crusting. This promotes rapid germination and uniform stands. For these reasons medium textured soils are most suitable for rapeseed production (Thomas, 1984).

Another soil factor affecting plant development is soil aeration. When the amount of water in the soil exceeds the soil's water holding capacity, water logging or flooding may occur. A water logged soil slows down or stops gas exchange between the soil and atmosphere. The resulting oxygen deficiency will reduce root respiration and growth (Thomas, 1984). Rapeseed, like other crops, can withstand only brief periods of oxygen deficiency.

2.2.2 Plant Factors

Plant factors that affect the available moisture supply are the growth stage, and degree of turgor of the plant, the plant's rooting habit, and the plant's ability to resist drought (Jamison, 1956). The soil zone penetrated by roots will have less available water than soil at deeper depth where roots do not penetrate. Plants extract water from soil depths where the root density is greatest (Miller, 1967). Injury to plant roots by flooding may reduce the absorption of water through plugging of conductive tissue or the reduction of absorptive surfaces (Jamison, 1956). The root zone of the seedling rapeseed is 5-6 cm which extends to approximately 1-2 metres by the flowering and ripening stage (Thomas, 1984). Root penetration also depends upon soil texture. Maximum root penetration occurs sooner after planting in heavier clay soils than sandy soils. Root penetration was also six times greater in sandy and sandy loam soils compared to clay soils (Tennant, 1976).

2.2.3 Climatic Factors

Meteorological conditions have a great influence on the transpiration rate provided water availability is high (Hillel, 1980). Transpiration rates increase with increases of air temperature and decreases of relative humidity. Wagoner (1969 as cited in Hagen and Skidmore, 1974) found that increasing windspeed from 1.225 cm/sec to 22 cm/sec decreased photosynthesis by 2% but increased transpiration by 15%. Soil evaporation losses may be increased by soil-air diurnal temperature differences. During cool nights, soil moisture moves from subsoil layers to condense on the surface. This moisture is then lost through evaporation during the high day temperatures (Jamison, 1956). High temperatures bring about vaporization of water and its transfer from soil and plant surfaces to the surrounding air (Naniken, Weigand and Willis, 1974).

2.3 RAPESEED

The genus *Brassica* belongs to the Cruciferae family, containing 160 interrelated species many of which are of agricultural importance. The two most important as commercial oilseed producers are *Brassica napus* L. known as Argentine or swede rape, and *Brassica campestris* L., commonly called Polish or turnip rape. Other closely related *Brassica* species include *Brassica juncea* also called Indian or Brown mustard, *Brassica carinata*, or Abyssian mustard, *Brassica nigra*, or black mustard, and *Brassica oleracea* which includes kale, cabbage, and brocolli crops. The botanical relationships among these *Brassica* species was confirmed by the Japanese scientist U by interspecific hybridization (Fig. 1, Hougen and Stefansson, 1982). The triangle of U was designed to illustrate the relationship between the three diploid species, B. nigra (n=8), B. oleracea (n=9) and B. campestris (n=10), and the amphidiploid or allotetraploid species B. carinata (n=17), B. juncea (n=18) and B. napus (n=19). The allotetraploid species originated from crosses between the diploid species with subsequent chromosome doubling.

The major components of rapeseed are oil, protein, and carbohydrates. The quality of rapeseed depends on both the quality of the oil and the quality of the protein. Rapeseed was initially grown in Canada for production of oil for industry and domestic lighting during war time shortages. Erucic acid, a long chain fatty acid, constituted 24-50% of the total fatty acids in the rapeseed oil (Hougen and Stefansson, 1982). Since the Second World War, the primary use of rapeseed has been as an edible oil. However, nutritional studies indicated that there were possible detrimental effects from ingestion of large amounts of rapeseed oil with high levels of erucic acid. Diets containing high proportions of erucic acid caused abnormalities of fat utilisation in the heart and skeletal muscles of many animal species (Hougen and Stefansson, 1982). Plant breeders in Canada identified a source of low erucic acid gene in the European cultivar Liho. By 1970 a changeover was made in Canada to low erucic cultivars. By 1980 the average erucic acid level was less than 2%. The gene sources for the absence of erucic acid have since been widely used to develop cultivars with seed oil low in erucic acid.

The residue after oil extraction from the seed is the rapeseed meal. The meal contains protein, crude fibre, ash, carbohydrates, and small

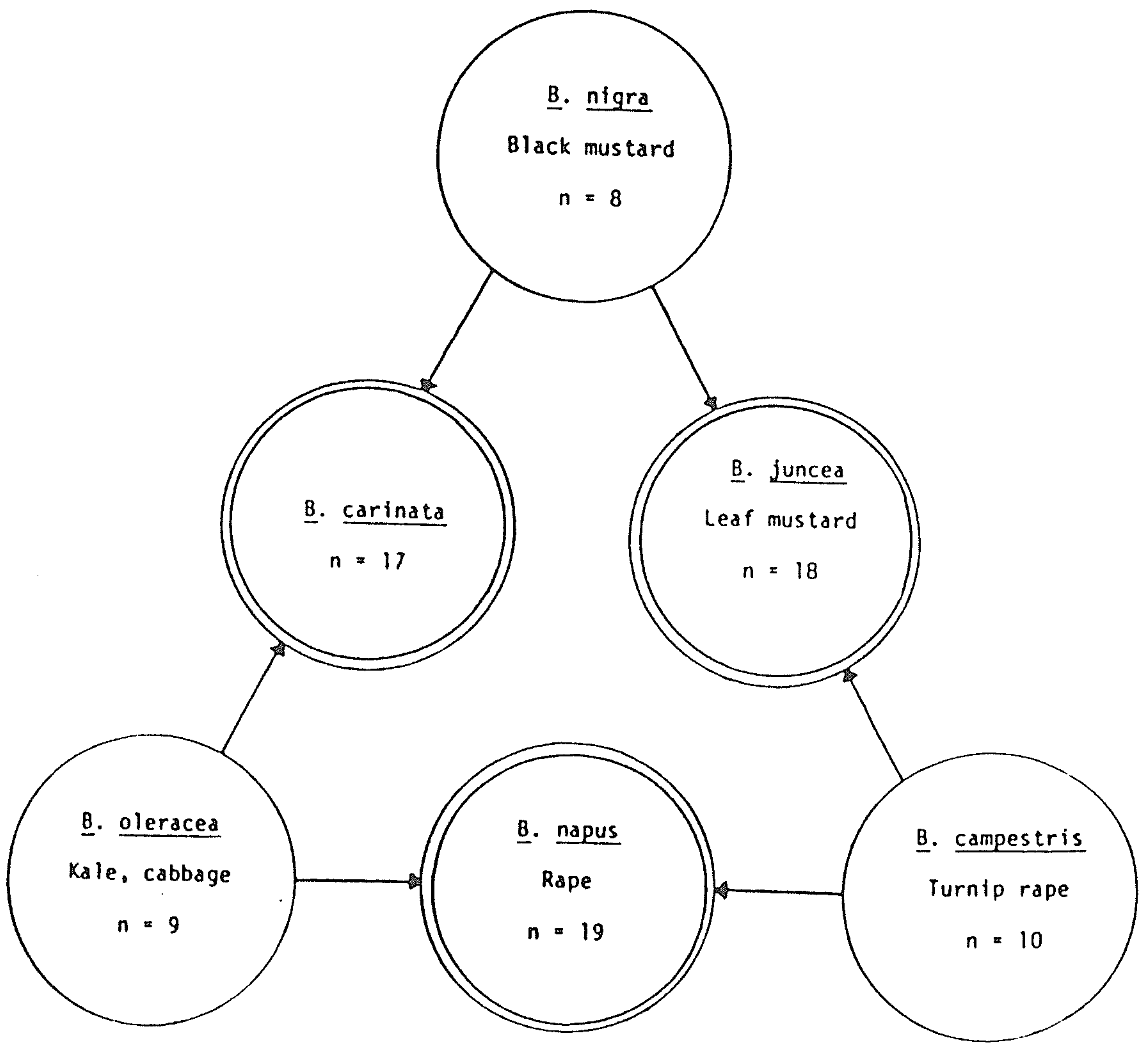


Figure 1. Triangle of U. Diploid species form the corners with the allotetraploid species on the sides of the triangle (Hougen and Stefansson, 1982).

amounts of less desirable components. Rapeseed meal is somewhat lower in protein than soybean meal, the standard for the feed market, and higher in crude fibre. The meal is used extensively as a protein supplement in animal rations since the protein content is relatively high and the amino acid composition is relatively well balanced. However, physiological problems occurred when rapeseed meal was fed extensively to livestock. The problem arose from the presence of glucusinolates in the meal. Glucosinolates are nontoxic, but some of the products of hydrolysis have goitrogenic and other antinutritional properties. Their breakdown products also produce a pungent taste that decreases the palatability of the meal (Hougen and Stefansson, 1982). Plant breeders found reduced levels of glucosinolates in the rape cultivar Bronowski. This characteristic was then incorporated into commercial cultivars (Stefansson, 1983).

In 1974 the rapeseed cultivar Tower was released. This cultivar produced oil very low in erucic acid content as well as seed that was low in glucosinate content. The term canola was developed to distinguish between the new improved commodities from the old less desirable product, applied to the seed and derived products of B. napus and B. campestris that have less than 2% erucic acid in the oil, and less than 30 micromoles glucosinolate per gram in the oil free meal.

2.4 RAPESEED AGRONOMY

The winter form of B. napus has become the dominant form of rapeseed grown in Europe, surviving the mild winters and producing high seed yields (Hougen and Stefansson, 1982). The average yield in the European rapeseed growing countries is 2 tonnes per hectare. Winter rapeseed is sown in September and harvested in July, requiring a 320 day growth period. Winter forms of rapeseed and turnip rape have not sufficient hardiness to withstand the severe Prairie winters. The early maturing spring forms of the two rapeseed species therefore predominate in Western Canada. Spring rapeseed is relatively well adapted to cool climates, requiring a growing season of 110 days. In Western Canada a growth period of 110 days is required for B. napus. Average yield of B. napus is 1.2 tonnes/ha (Thomas, 1984).

2.4.1 Components of Yield

The components of seed yield in oilseed rape include seed weight, number of seeds per pod, the number of pods per plant and 1000 seed weight. These components are affected by plant density (Degenhardt and Kondra, 1981), by irrigation (Krogman and Hobbs, 1975, Clarke and Simpson, 1978b), by seeding date (Mendham and Scott, 1975, Degenhardt and Kondra, 1981), and by fertilizer treatments (Krogman and Hobbs, 1975, Singh and Yusef, 1979).

The number of pods is an important limitation on seed yield. This is attributable to the indeterminant flowering habit of rapeseed, and the fact that the number of flower initials is usually limited. Under normal environmental conditions only 1/10th to 1/50th of the flower initials develop into flowers (Olsson, 1960) and thus into pods. Although the plant is capable of developing a much larger number of flowers and pods, environmental restrictions prevent the realization of the plant's genetic potential. This results in a high frequency of pod abortion, which can be defined as the failure of pods to elongate, increase in girth and become seed bearing (McGregor, 1981).

Complex interrelationships exist between yield components of rapeseed. Thurling (1974b) found that decreases in the number of pods per plant with later sowing dates were compensated by increases in the number of seeds per pod in B. napus, and seed weight and number of seeds per pod in B. campestris. Olsson (1960) found a negative correlation between seed size and number of seeds per pod. Clarke and Simpson (1978b) found high compensation in 1000 seed weight relationships to pod and seed number in rapeseed.

Negative correlations among morphological components of yield is a widespread phenomenon that occurs in many plant species (Adams, 1967). This compensation is inevitable when sequentially developing yield components share common minerals and metabolic materials that have limited availability.

Seed yield and maximum leaf area index were shown to be positively correlated (Clarke and Simpson, 1978a). Leaves are the most important source of phosphates for seeds (Major, 1977). However, B. napus does not increase leaf area beyond the commencement of flowering. Leaves senesce at the beginning of pod growth (Clarke and Simpson, 1978a).

Total dry weight after flowering continues to increase in spite of the declining leaf area. The two to three week period after flowering is critical in determining the plant's yielding capacity (Tayo and Morgan, 1975). Allen, Morgan and Ridgman (1971) suggest that, in Britain, seed yield is not only influenced by leaf area index but actively photosynthesizing pod tissue is also responsible to a large degree for the plant's increased dry weight. Brar and Thies (1977) also found that pods were a source of photosynthate for seed development. Canadian studies indicated that photosynthates were translocated from the leaves to the infloroscence and the seed. These photosynthates move selectively to the pods in which seeds were filling, avoiding barren pods (Freyman, Charnetski, and Crookston, 1973).

2.4.2 Effect of Seeding Date on Yield

Date of planting affects the agronomic characteristics of rape. In Western Canada, early seeding of *B. napus* will usually produce a higher seed yield, and will reduce the risk of autumn frost. Optimum planting date for rapeseed in Western Canada was indicated to be the 8th of May (Gross, 1964). In Western Canada (Gross, 1964) and in Western Australia (Thurling, 1974b), seed yields have been shown to decrease significantly with delays of seeding in spring cultivars of both *B. napus* and *B campestris*. Delayed sowing also significantly affects all yield components. Delayed seeding potentially exposes the plants to moisture stress at a more vulnerable growth phase. The result is declining seed yields due to a reduction in the number of pods per plant which is under strong environmental control. The immature pods towards the canopy top are the likely organs to be adversely affected by periods of drought (Daniels, Scarisbrick, and Smith, 1984). Delays in seeding result in a shorter time to maturity, brought about by a reduction in the time required for vegetative and reproductive growth phases (Gross and Stefansson, 1966). Days to first flower was shown to be 12 days less for plants seeded three weeks later than an early seeding (McGregor, 1981). Kondra (1976) studied effects of four planting dates on yield. The last planting date froze prior to maturation, while the first seeding date had highest yields, and highest oil and protein content. The yields of intermediate plantings were slightly depressed.

Sowing delays with rapeseed also reduce the contribution of the lowermost primary branches, thereby increasing the importance of the main stem. The number of pods and the number seeds per pod on the main stem however, increases with delays in sowing, although overall yield is reduced (Scarisbrick, Daniels, and Alcock, 1981). To obtain higher yields on a late sowing, vegetative growth needs to be followed by the production of fewer pods than an early seeding. Each pod would then be able to maintain the potential number of seeds to give a high yield.

Mendham, Shipway and Scott (1981) found that leaf area index was reduced by late sowing of rapeseed. Delayed sowings of winter rapeseed limits plant size prior to inflorescence initiation. This in turn limits productivity in spring since there appears to be a critical size for plants to have reached by initiation. Below this size, yield is diminished (Mendham and Scott, 1975). Declines in seed yield were shown to be associated with a reduction of the total dry weight of the plant. This was closely correlated with the duration of the vegetative growth stages. Total dry weight of the plant at the end of the vegetative phase is determined by the duration of this phase (Thurling, 1974a). The decrease in yield due to later sowing date was associated with a reduction of the total dry weight of the plant at maturity (Degenhardt and Kondra, 1981).

2.4.3 Effects of Moisture Stress on Yield

In *B. napus* the yield components of pods per plant, pods per main branch, branches per plant and seeds per pod have been shown to be significantly reduced by drought (Richards and Thurling, 1978a). Irrigation can slow the senescence of leaves which effectively increases the total leaf area of the plant, resulting in a higher yield. Yield increases from a continued high volume of available moisture was due to the greater combined amounts of photosynthetic leaf and pod tissue (Krogman and Hobbs, 1975).

Anderson's (1980) comparison of water use responses of barley, lupin, and rapeseed suggested that rapeseed failed to allocate significant portions of its dry matter to seed production under conditions of soil water stress. Barley had a greater drought tolerance, and higher water use efficiency of grain production. In sunflower (Anderson, 1979) highest water use efficiencies were associated with higher yields. Water stress on corn yield significantly reduces kernel number, kernel weights, and percentage developed kernels (Claassen and Shaw, 1970).

Increases in seed dry weight under irrigation could be due to the retranslocation of carbohydrates to the seed from plant parts such as leaves, stems, and roots (Major, 1977). If the moisture supply is adequate, the continued expansion of green tissue in the form of pods will supply nutrients for the developing seed. The number of seeds per pod is determined late in the ripening phase, which is in turn determined by the ability of the individual pod to supply assimilates. Water stress then decreases seed number through the effects of limited assimilates from a reduced pod surface area.

The number of branches per plant increases with irrigation. This increase is due to a lengthening of the flowering period (Clarke and Simpson, 1978b). Secondary branches also influence seed yield. The number of secondary branches, as well as the number of pods, and number of seeds are strongly linked with moisture supplies (Campbell and Kondra, 1978). Oil content has also been shown to increase with irrigation (Krogman and Hobbs, 1975, Singh and Yusef, 1979).

Clarke and Simpson (1978a) found that under rain fed conditions there was a rapid production of dry matter during the bolting, flowering and early ripening stages. Irrigation during the flowering period was particularly important in order to realize the full yield potential of rapeseed (Clarke and Simpson, 1978b). Under irrigation dry matter production continued at a higher rate into the ripening phase and leaf area was maintained at a higher level after flowering. When moisture is nonlimiting, dry matter production continued at a high rate until maturity.

2.5 GROWTH ANALYSIS

Growth analysis has been widely used to study crop and cultivar response to environmental conditions. Growth studies are useful for the identification of developmental phases and their interaction with the environment which together influence yield (Clarke et al, 1984). Studies involving *B. napus* have indicated that earliness of initial growth stages contributes to earliness of subsequent growth stages (Campbell and Kondra, 1978). Time to first flower can therefore be used to determine time to maturity since time to first flower is a major factor in determining the time of later growth stages.

2.5.1 Interaction of Growth Stages and Drought Stress

Growth analysis has been used directly to study the adaptation of 23 wheat genotypes to drought conditions over a five year period (Clarke et al, 1984). Differences in preanthesis growth rate occurred in only one of the five years, and this difference was not related to drought resistance or yield. The conclusion from this study was that growth analysis is a labor intensive procedure that is unlikely to identify traits that are strongly related to drought resistance.

Robins and Domingo (1953) found that soil moisture depletion to the permanent wilting percent in corn at certain growth stages decreased grain yields. Water deficits for a period of one or two days at silking decreased yield by 22% and moisture deficits of six to eight weeks resulted in a 50% yield reduction. They show that water stress after maturity had no effect on yield. A grain yield reduction of 12-15% has been observed in corn when stress occurred at the vegetative period, and a 30% reduction when stress occurred in the three week period after silking (Claassen and Shaw, 1970). Peak water demand by sunflowers occurs immediately after anthesis (Anderson, 1979).

A growth stage key was developed for rapeseed by Harper and Berkenkamp (1975). This key divides the lifecycle of rapeseed into six growth stages based on the development of the primary stem and inflorescence. Each of the six stages are divided into a number of substages. This key, and others like it define the growth of the crop, enabling an accurate study of rapeseed as it matures.

Studies involved with _B. napus_ have indicated that soil moisture stress after flowering is the major environmental factor affecting development and yield (Richards and Thurling, 1978b). Yields are also significantly reduced when drought is applied prior to flowering (Richards and Thurling, 1978a). On the Canadian Prairies, drought during the latter portion of the growing season is a common occurrence. It is conceivable that early flowering cultivars could potentially avoid some degree of drought stress by flowering prior to the drier portion of the summer. To obtain higher yields in environments where a late drought is a common feature, those characteristics determined after flowering will have a greater influence on yield than those measured before flowering (Richards and Thurling, 1978b).

Moisture stress occurring between flowering and maturity is another environmental factor that affects growth, development and yield. Declines in yield are associated with a reduction of pre-anthesis growth and a reduction of the dry matter accumulated prior to anthesis (Richards and Thurling, 1978b).

McCree and Davis (1974) suggest that water stress in early growth stages of sorghum could be advantageous if it results in a lower leaf area with stomates staying open under stress later in the season when the grain is being filled.

Alleviating water stress through irrigation increases leaf area index, which is correlated with seed yield. Pod surface area and 1000 seed weight are also increased (Clarke and Simpson, 1978a and b). Irrigation lengthens the flowering period, enabling the production of more flowers, and ultimately more pods and more seeds.

2.6 BREEDING FOR DROUGHT RESISTANCE

Drought resistance can be divided into three categories: drought escape, drought avoidance, and drought tolerance. Drought escape is the ability of plants to complete their life cycle before soil and plant water deficits develop (Ceccarelli, 1984). Selection for early flowering and early maturity is a breeding strategy that has been used to avoid moisture stress in rapeseed. Campbell and Kondra (1977) bred for early maturity as a method to improve yield and facilitate the growing of rapeseed to increase the production area of rapeseed in western Canada. In Western Australia rapeseed cultivation is dependent on rainfall characteristics. A suggested breeding strategy designed to utilize dry weight accumulation patterns is to modify the developmental pattern by lengthening the bolting stage relative to the vegetative stages (Thurling, 1978). This would decrease the amount of time required to reach maturity, thereby avoiding a late drought. Thurling and Das (1979a & b) identified one major gene in the Japanese cultivar Isuzu that was responsible for differences in flowering time. New genotypes derived from crosses involving the cultivar Isuzu flowered earlier than cultivars presently grown in Western Australia. These cultivars could be useful in developing B. napus cultivars adapted to drier areas than those that are now considered suitable for rapeseed production.

Heritabilities for the characteristic of days to first flower were found that ranged from 21% to 61%. Maturity heritabilities were found that ranged from 16% to 36% in a Canadian study (Campbell, Degenhardt, and Kondra, 1978). These statistics indicate that selection for first flower could result in genetic gains. In the same study, yield was shown to be negatively correlated with maturity in the earliest maturing line, indicating earliness is associated with higher yield, and that it is possible to alter growth characteristics to produce a yield increase. Clarke et al (1984) suggest that drought escape through a rapid early growth rate and early flowering is a breeding strategy that could prove successful in wheat breeding in Saskatchewan. Dedio (1975) found associations between high water retention ability and late heading in wheat. He suggests that the genes controlling these characters are linked, or that there is a pleiotrophic effect. Screening and selection for drought escape by altering maturity or developmental patterns is a simple method of achieving drought resistance (Clarke and Townley-Smith, 1984). However, the effectiveness of selecting for these characters may decline after a few generations since days to first flower in rapeseed is highly heritable (Richards and Thurling, 1979a). As well, selecting for earliness may be advantageous in years of severe drought, but the response of the crop could be limited during seasons of better than average climatic conditions (Richards and Thurling, 1979a).

Drought avoidance is the ability of the plant to keep tissue water potential above a critical value that would cause 50% killing of the cells. Avoidance mechanisms will keep a high water potential by the root's absorption of water, the conduction of this water to the shoot, or by the ability to reduce water losses (Ceccarelli, 1984).

An extensive root system has been shown to be associated with drought resistance in wheat, while selection for high yield under moisture stress conditions will select for larger root systems (Hurd, 1974). In rapeseed, however, this relationship was not found. Increased root weight has been associated with increased yield, but, in rapeseed, this has been shown to be primarily due to a common association with plant size (Richards and Thurling, 1978a). This work does suggest that the association between a smaller root weight and seed yield could be the result of a greater mobilization of reserves from the root to the above ground portion of the plants during the period of moisture stress. High yielding genotypes under drought conditions had a large plant weight and/or a large number of seeds per pod. Richards and Thurling (1978a) suggest that because of these attributes, the plants were able to maintain photosynthesis under stressed conditions.

Other avoidance mechanisms that breeders are attempting to take advantage of include stomatal control of transpiration, the shape, morphology and orientation of leaves in relation to water loss (Clarke and Townley-Smith, 1984), the ability to maintain a high leaf water potential when soil water potential is low, and a low resistance to water flow between root and leaves. Another method of reducing water loss is by leaf movement, increased leaf waxiness and increased leaf pubescence (Ceccarelli, 1984) Dense pubescence has been shown to increase water use efficiency in some soybean cultivars (Clawson et al, 1986).

Position of leaves, and degree of leaf rolling has been shown to affect water retention in wheat (Dedio, 1975). Other drought resistant wheat cultivars avoid water stress by maintaining high osmotic potential (Keim and Kronstadt, 1981). Sorghum genotypes avoid water stress by maintaining low leaf diffusion resistance, by developing a high soil to leaf water potential gradient, allowing utilisation of stored moisture, and through low initial water use relative to the total used at maturity (Blum, 1974).

Barley genotypes with low stomatal frequency were found to have lower transpiration, and higher stomatal resistance. However, there was no effect on photosynthesis (Miskin, Rasmusson, and Moss, 1972). In soybeans, water stressed plants also had a greater stomatal frequency and a smaller leaf area than non-water stressed plants (Cihu and Brun, 1975).

Drought tolerance involves the plant's ability to maintain growth, production, and development at low water potentials, and for the protoplasm to survive and recover from severe water deficits. The maintenance of positive or constant turgor as water potential decreases is an important adaptation to water deficits (Ceccarelli, 1984). Winter wheat cultivars have been identified that produce a high number of spikes per square meter, while under a high degree of internal water stress (Keim and Kronstadt, 1981).

One approach used to increase yield under drought conditions has been the selection of high yields under conditions of adequate water supply. A high increase in yield potential has in the past led to increased yield under drought (Turner and Begg, 1981). However, most research is directed to the alternative of selecting for high and stable yields under conditions of water stress. Rapeseed breeders have reported that yield advances in a droughted environment were greater if selection occurred in a droughted environment rather than an environment where water was nonlimiting (Richards and Thurling, 1978a, 1979a). Since non-drought and drought yields are not directly correlated, the alternative breeding approaches are to either select under stress environments only, or to consider yield and stability by testing for yield under a range of environments.

The physiological responses and genetic character interactions involved in confiring drought resistance are complex. Drought resistance is the result of morphological and physiological characters that are many and often act independently. There are generally many genes involved in drought resistance, and there is likely a genotype/environment interaction (Richards, 1978). Physiological and biochemical characters that have been identified that could influence the performance of B. napus and B. campestris include leaf prolene accumulation, leaf chlorophyll stability, and germination percentage (Richards and Thurling, 1979b). Each of these characters has a significant genetic component, although correlations with yield are low.

2.6.1 Summary

Selection strategies that have been employed to increase yield under drought conditions in rapeseed include simultaneous selection for earliness and high yield (Richards and Thurling, 1979a) and by modifying developmental patterns to increase the proportion of dry matter accumulated prior to anthesis (Richards and Thurling, 1978a). Selecting for a high harvest index has proven useful in rapeseed (Thurling, 1974a, Degenhardt and Kondra, 1981) and other crops such as wheat (Nass 1980). Clarke and Simpson (1978b) suggest that a possible avenue for yield improvement under drought would be to improve the supply of metabolic inputs during the development of each of the yield components by increasing leaf area and leaf duration. Selection for limited branching and increased pod numbers on the main raceme (Clarke and Simpson, 1978b), or for large plant weight and/or a large number of seeds per pod with increased branches (Richards and Thurling, 1978a) have also been suggested. Another approach to increase yield is to increase the photosynthetic capacity or to reduce pod number with a concomitant increase in the mean number of seeds per pod (Daniels, Scarisbrick, and Smith, 1984).

Seed yield is influenced by a number of morphological and physiological characters that interact in complicated ways. The actions and interactions of these characters result in varying numbers of pods per plant, seeds per pod, and seed size. Selecting for high number of pods as suggested by Richards and Thurling (1978a) to achieve advances in yield could be limiting since this character has been shown to be under environmental control. Olsson (1960) found no correlation between seed yield of the mother plant and of the progeny.

Plant breeders, in their attempts to improve yield under conditions of moisture stress must also include desirable quality characteristics and hybrid vigor. Breeders need to exploit drought avoidance and tolerance mechanisms in order to achieve drought resistance.

Chapter III

MATERIALS AND METHODS

An experiment with six cultivars of Brassica napus was conducted over the summers of 1985 and 1986 to determine the effects of drought on yield, yield components, and quality. Growth analysis and stomatal resistance were also recorded. The six cultivars used included the three Canadian cultivars Westar, Regent, and Pivot, as well as the three Swedish cultivars Karat, Global, and Topas. These cultivars were chosen to give a wide range of maturities. Westar was considered to be an early maturing cultivar, Regent, Pivot, and Topas were of intermediate maturity, while Global and Karat were relatively late maturing cultivars under Canadian conditions.

3.1 EXPERIMENTAL DESIGN AND PROCEDURE

A randomized complete block design experiment consisting of six replicates of the six cultivars was used. Treatment plots consisted of four rows six m long. The replicates were separated by a 1.5 m pathway. Seeding was accomplished using a double disc belt cone seeder. The granular insectide Furidan was applied with the seed, and fertilizer (16-20-0) was incorporated at a rate of 112.3 kg/ha at the time of seeding. In 1986 seed was also treated with the fungicide Rovral.

Following emergence, stand counts were made to determine correlations between stand and yield.

Two experimental locations were used for this study. The first location was situated on a Riverdale floodplain clay at the University of Manitoba. At this location there were three treatment sites. Two of these treatment sites were sown on May 7 in 1985, and on May 13 in 1986. Irrigation was available at one treatment, which shall be referred to as the irrigated treatment. The treatment without irrigation shall be referred to as the nonirrigated or the early treatment. A third treatment, referred to as the late site was seeded on May 21 in 1985, and on June 4 in 1986. The later sowing in 1986 was necessary because of dry seed bed conditions in the three weeks after the early sowing. The late sowing was made after a rainfall had made soil moisture suitable for planting. The second experimental location was situated at the Portage la Prairie research station on a Newhorst soil. The Portage treatment was seeded on May 16 in 1985, and on May 27 in 1986.

In 1985 the irrigated treatment received 56 mm of irrigated precipitation 63 days after sowing. when the soil moisture was approximately 70% of field capacity, which was assigned to be the level at which moisture stress began. In 1986 the irrigated site received 33 mm water 15 days after sowing. At this time the plants were visibly wilting due to high temperatures and the lack of rainfall since seeding.

3.2 SOIL MEASURMENTS

The soil moisture profiles were monitored weekly for each treatment. The measurements for the first week were taken by measuring gravimetric water content, which was converted to volumetric water content. All measurements following the first sampling were taken using the Troxler neutron probe which measures volumetric water content directly. Precipitation and water applied by irrigation were measured throughout the summer. Bulk density, permanent wilting point, and field capacity were also determined. Using these measurements, the weekly moisture available to the plants over the season was calculated. The total amount of water used by the plants was also calculated.

3.2.1 Soil Moisture

Soil samples were taken at six locations within each of the four treatments. One measurement was taken in each replicate. On the day of seeding, soil samples were taken using an auger with a 11 cm diameter at depths of 0-15 cm, 15-30 cm, 30-45 cm, 60-90 cm, and 90-120 cm. Soil moisture content was measured on these samples using gravimetric water content. Gravimetric water content was measured by weighing a sample of field soil, oven drying the soil for 48 hr at 100°C, and reweighing the soil sample. The difference between the soil weights provided a measure of the weight of water in the soil sample. Dividing the weight of water by the weight of oven dry soil gave a measure of the gravimetric water content. To convert gravimetric water content to volumetric water content, the gravimetric water content was multiplied by bulk density. Weekly soil moisture measurements were taken at these sites and at these depths until harvest. The 0-15 cm soil moisture content was sampled by taking the gravimetric water content.

The 15-30 cm, 30-45 cm, 45-60 cm, 60-90 cm, and the 90-120 cm depths were sampled using the Troxler Neutron probe. This probe measures volumetric water content directly. The probe emits fast neutrons from a

Am-Be source. These neutrons collide with the H atoms in the water molecules, causing the neutrons to slow down. The 'thermal' neutrons are then detected and measured by a sensor. The proportion of fast neutrons that are slowed down depends upon the concentration of the H atoms (or water molecules) in the soil medium into which the fast neutrons are released. The Troxler probe then records the number of slow neutrons detected per minute, and calculates volumetric water content.

3.2.2 Bulk Density

Bulk density was measured in the field by collecting a soil sample with an 11 cm auger. The depth and diameter of the soil core taken was measured to provide a measure of the soil volume. The soil was then oven dried for 48 h. Bulk density was calculated by dividing the weight of oven dry soil by the volume of soil taken in the field.

3.2.3 Field Capacity

Field capacity was measured by thoroughly saturating 3 sq m of soil for each soil type. The square was covered with plastic and the water was allowed to filter through the soil profile for 48 h. Following this period, volumetric water content was measured using the Troxler Neutron probe.

3.2.4 Permanent Wilting Point

A surface soil sample was analysed in the lab to determine permanent wilting point, to analyze particle size, and to determine particle density. Permanent wilting point was determined by growing three tomato plants in a small sealed container of field soil. When the plants were 30 cm in height the plants were watered to field capacity. The plants were then deprived of further inputs of water. Daily measurements of the length and maximum width of leaves on the top three branches were made on each plant. When dimensions of the leaves of all branches were the same as the previous day, the plants were removed from the soil. The soil in the container was then removed, weighed, oven dried at 110°C for 48 h, cooled in a dessicator, and reweighed to provide a measurement of the water content as a percentage by weight of the dry soil. This method assumes that loss of turgor in lower leaves occurs at the same soil water content as the cessation of growth. Permanent wilting point is defined as the lower limit of soil water available for plant growth.

3.2.5 Particle Size Analysis

The particle size analysis was performed using the pipette method. Two 10 g soil samples were reacted with H202 until no further reaction occurred. Peroxide was used to digest organic matter. Excess peroxide was removed by evaporation, and 200 ml of water was added. This mixture was stirred for 15 min. Sand was removed from the sample by pouring the suspension through a 300 mesh seive. A number of washes were made to ensure that all silt and clay passed through the seive. The sand was then dried and weighed. The remaining suspension was brought up to a volume of 1000 ml. After the suspension was completely stirred, a 25 ml aliqout of silt and clay at a 10 cm depth was removed. This sample was then dried and weighed. After 6 h 20 min, the settling time required for 2 micron particles to fall 10 cm, a 10 ml aliquot of the suspension from a 10 cm depth was removed. This sample was then dried and weighed. This constituted the clay fraction. The percent sand, silt, and clay was then calculated on the basis of the total mineral weight of the soil.

3.2.6 Particle Density

Particle density, or mass of solids per unit volume was measured by determining the difference between the weight of oven dry soil, and the volume of water displaced by the same mass of soil. Particle density was used to calculate soil moisture when water stood in the access tubes because of soil flooding. Under these conditions it was not possible to use the neutron probe. The pore space of the soil was calculated as 1 - (bulk density/particle density).

3.2.7 Available Moisture

Available moisture to the plants was calculated as the summation of

(volumetric water content - (permanent wilting point x bulk density) x depth.

for each depth measured. Depth in the calculation refers to the depth of the soil layer sampled. Total water used by the plants was calculated as the summation of weekly water used:

available water (planting) - available water (harvest) + precipitation.

3.3 PLANT MEASUREMENTS

Growth stages were monitored for each cultivar on each plot from seeding to harvest. The revised growth stage key of Harper and Berkenkamp (1975) was used. Stand counts were determined when the plants were established. Stomatal resistance was measured on the nonirrigated and irrigated treatments for an early (Westar), intermediate (Pivot) and late maturing (Global) cultivar. Flower and pod development were measured on five randomly selected plants per plot per cultivar in three of the six replicates per site. From this analysis, a measure of % pod abortion, the number of pods per plant, and the number of seeds per pod was obtained. Seed yield was determined by harvesting 4.5 m of the inner two rows of a four row plot. Quality analysis was also performed for % oil and protein content.

3.3.1 Growth Analysis

Growth analysis was used to monitor the plant's response to drought stress. The revised growth stage key for *B. napus* and *B. campestris* by Harper and Berkenkamp (1975) was used for the analysis. The key divides the lifecycle of rapeseed into six growth stages, based on the development of the primary stem and inflorescence. Each of the stages are divided into a number of substages (Fig. 2).

Stages 0-2 correspond to the vegetative stages of growth, and stages 3-5 correspond to the reproductive stages of growth. Stage 0 indicates preemergence. Stage 1 follows the plant's growth from the emergence of the cotyledons to the development of the first and second true leaves.

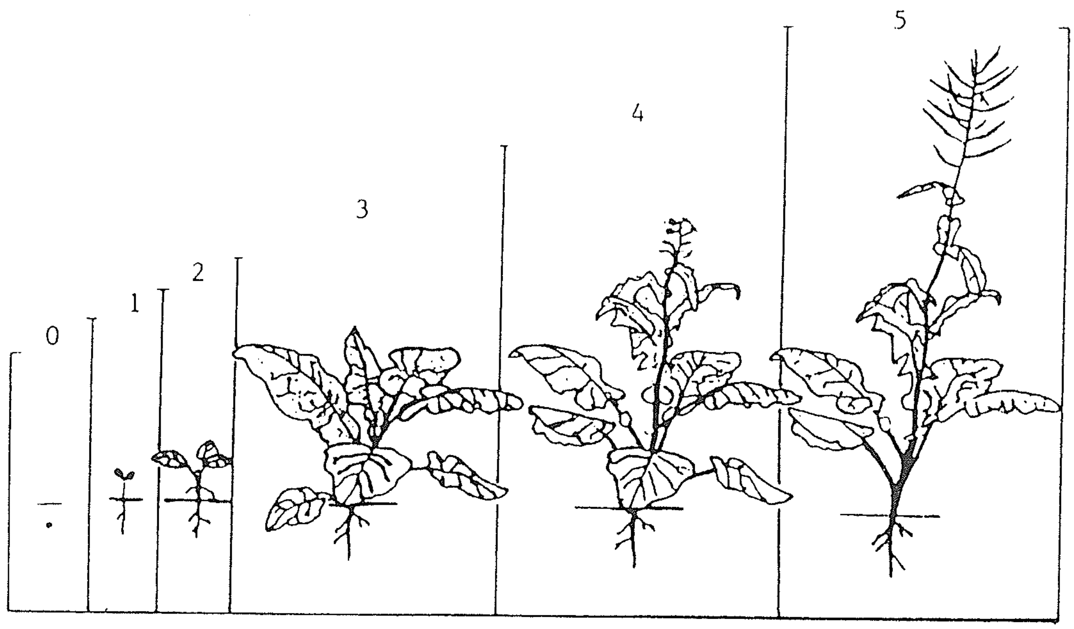


Figure 2. Harper and Berkenkamp (1975) growth stage key.

These leaves quickly senesce. The rosette stage is described by stage 2, adding a substage for each expanded true leaf. Stage 3 monitors the development of the bud and inflorescence as the plant bolts. Stage 4 describes the flowering stage, while the ripening process is described by stage 5.

Growth stages were monitored on the Winnipeg treatments three times per week, and once per week on the Portage site. The plants were measured from emergence until harvest. An analysis of variance was performed to determine treatment differences with respect to day to first flower.

3.3.2 Stomatal Resistance

Stomatal resistance was measured using the Licor portable photosynthesis system. An active photosynthesizing and respiring leaf was enclosed in a leaf chamber. The leaf was then excised. Leaf area was then measured in the laboratory using a Decagon leaf area meter.

Stomatal resistance was measured for Westar, Pivot, and Global. These cultivars were chosen because they represented early, middle, and late maturity groups. Stomatal resistance was measured on the irrigated and on the nonirrigated treatments, while the plants were at the flowering to early ripening stage. In 1985 measurements were taken from 62 days after sowing to 83 days after sowing. Measurements were taken in 1986 from 52 days to 73 days after sowing. Three plants per plot were measured at random in three of the six replicates. Ten readings were taken per plant over a 30 second interval. This technique is limited because measurements can only be taken during extended periods free of cloud cover. In 1986 measurements could only be taken on four days over a period of three weeks. It was also necessary that measurements were completed before noon in order to ensure that the stomata were physiologically active.

3.3.3 Yield Components

Flower and pod development was determined by randomly selecting five plants per plot per cultivar in three of the six replicates at each location. Each individual inflorescence was tagged and numbered. During flowering, the number of buds on each inflorescence was counted. The day prior to harvest, the total number of mature pods was counted. The percent pod abortion was then determined for each plant by dividing the number of mature pods by the number of buds. Buds that failed to open were included in the count of aborted pods. This technique also gave an analysis of the number of inflorescences per plant. The tagged plants were individually harvested and hand threshed to provide a measure of the number of seeds per pod.

3.3.4 Seed Yield

At maturity, the center 4.5 m of the middle two rows of a four row plot were hand harvested when approximately 50% of the seeds in that plot had begun to turn brown or black in color. This corresponded to growth stage 5.3 in the Harper and Berkenkamp (1975) scale. The entire above-ground plant material of the harvested plot was placed in burlap sacks and air dried for several weeks before thrashing. In 1986 harvest index was determined. The plants were dried for 48 hours, and were then reclimatized by removing the plants in their sacks from the drying chamber and placing them in an unheated shed for 24 hours. This was done to prevent excess shattering. The total dry matter was measured. Total seed weight was then divided by the total dry matter to provide a measurement of harvest index. Thousand seed weight was determined in 1986.

3.3.5 Quality Analysis

Seed samples from each plot were analyzed for oil and protein content. Oil percentage was determined using the Nuclear Magnetic Resonance technique (Robertson and Morrison, 1979) using 25 g oven dried seed samples. Protein percentage was determined on the oil free meal using the Kjeldahl procedure. Titanium dioxide was used as the catalyst in the digestion (Williams, 1973).

3.4 STATISTICAL ANALYSIS

Data sets were analysed as randomized complete block design experiments using analysis of variance. Means were compared using Duncan's Multiple Range test. Pearson product-moment correlation was used for all correlation analyses. Statistical analysis were performed on the University of Manitoba AMDAHL 5858 mainframe computer. Data analysis for available soil moisture was performed on a MacIntosh microcomputer using the database program Excel.

Chapter IV

RESULTS

4.1 SOIL MEASUREMENTS

4.1.1 Soil Physical Properties

The total moisture of the soil at field capacity on the nonirrigated treatment was 476 mm, the irrigated treatment was 559 mm, and the Portage location was 572 mm. The permanent wilting percentage of the 0 - 15 cm surface soil for all soils was determined to be 20.18% by weight. The permanent wilting percentage for soil depths greater than 15 cm was estimated at 21.3%. This estimation was based on a Manitoba soil survey undertaken by Zwarich in 1963.

Particle size analysis of the soil sample from the irrigated treatments was composed of 39% silt, 60% clay, and 1% sand. The soil on the nonirrigated and late treatment was composed of 3% silt, 74% clay, and 23% sand. The higher sand content on these treatments was the result of an old creek bed that was once situated on this plot. The Point soils were determined to be high clay soils, and are classified as a Riverdale floodplain soil. The Portage treatment was 80% silt, 6% clay, and 14% sand. The Portage soil was classified as a Newhorst soil, and from particle size analysis was determined to be a silty loam.

4.1.2 Available Soil Moisture

4.1.2.1 Irrigated vs. Nonirrigated Treatments

The available moisture over the growing season in the irrigated and nonirrigated treatments in 1985 and 1986 are illustrated in Fig. 3. The irrigated treatment received 56 mm of irrigation 63 days after sowing in 1985. At this time the irrigated treatment was considered to be moisture stressed because the soil water was 69% of field capacity. Rainfall in the week following this period of irrigation contributed a further 61 mm. In the following four weeks a total of 134 mm of rain fell. These inputs of water lead to flooding on the irrigated treatment. Seasonal (Table 1) and weekly (Appendix Table 1) differences in soil moisture between the nonirrigated and irrigated treatment were significant. However, differences between these two treatments for the total water used were not significant.

In 1986 33 mm of irrigation was applied to the irrigated treatment 15 days after sowing. The available soil moisture was not below 70% field capacity, but irrigation was necessary as the soil surface was very dry and the young plants had begun to wilt visibly after 15 days of high temperatures without precipitation. The treatment remained at or near 70% field capacity for the remainder the summer. No further irrigation was applied. There were significant differences between the irrigated and the nonirrigated treatments when comparisons were made between the weekly available moisture over the two treatments (Appendix Table 1). The irrigated treatment had a greater volume of available water than the nonirrigated treatment. However, there was no difference in the total volume of water used between these treatments (Table 1).

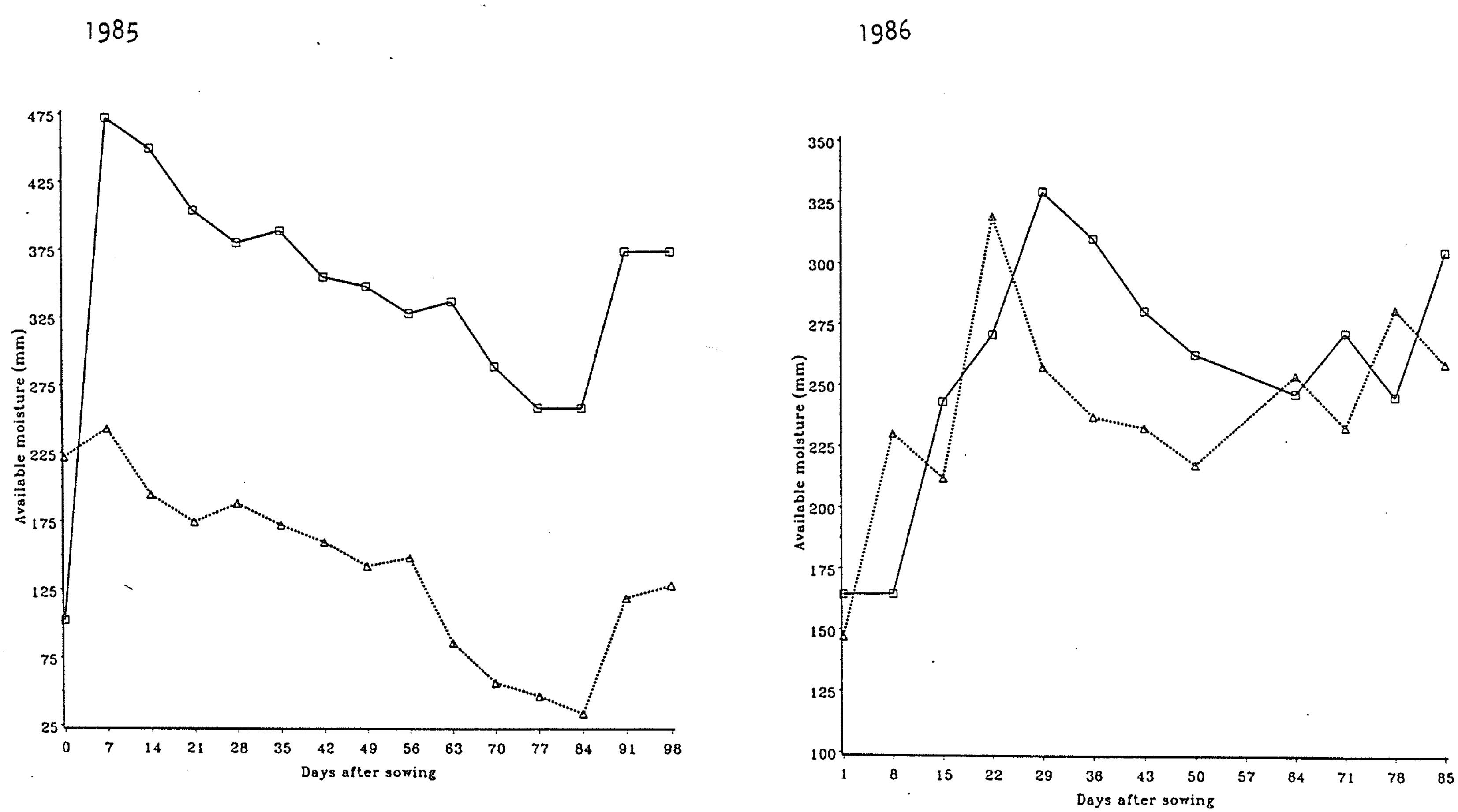


Figure 3. Available soil moisture for the irrigated (-) and nonirrigated (---) treatments 1985 and 1986.

Table 1. Available moisture, total water used, and precipitation for the four treatments in 1985 and 1986.

	1985			1986		
Treatment	Available moisture (mm)	1. Total water used (mm)	Precipitation (mm)	Available moisture (mm)	2. Total water used (mm)	Precipitation (mm)
Irrigated	343	387 a	348	258	224 b	286
Nonirrigated	141	364 ab	293	240	203 b	254
Late	161	326 b	377	264	217 b	256
Portage	259	389 a	425	250	312 a	292

Values followed by the same letter(s) within 1 and 2 are not significantly different $P<0.05$.

4.1.2.2 Early vs. Late Treatments

A comparison of available moisture between the early and late sowings in 1985 (Fig. 4) indicated that the differences in available water between these treatments were significant from day 78 to day 105 after sowing (Appendix Table 2). During this period, there was a significantly greater volume of available moisture in the late treatment. There were no significant differences between the early and late sowing with regard to total available moisture throughout the summer, or for the total volume of water used (Table 1).

A comparison of available moisture between sowing dates in 1986 is illustrated in Fig. 4. The volume of available moisture was greater on the late treatment (Table 1). The total water used was not significantly different. From day 36 through to day 63 after sowing there was a greater amount of available moisture on the late treatment (Appendix Table 2). There was a significantly greater volume of available moisture on the early treatment during the period from day 71 until day 84.

4.1.2.3 Portage Treatment

In 1985 available moisture at the Portage location decreased as the summer progressed (Fig. 5). This trend continued until the last four weeks of the summer. There was an increased volume of available moisture during this time as a result of the heavy rainfall during the later portion of the 1985 summer (Appendix Table 3). The Portage location had a greater volume of available moisture than the early and

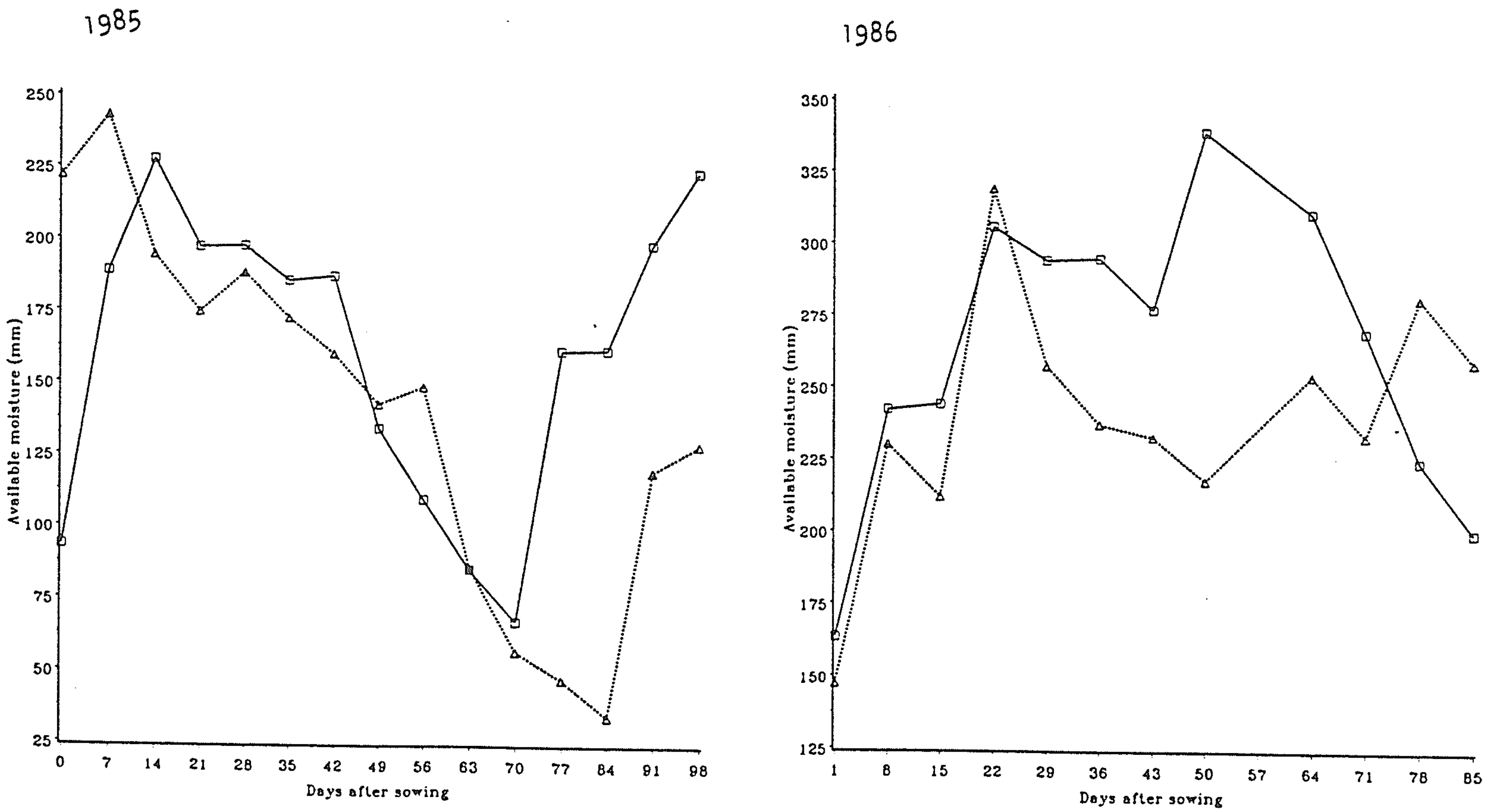


Figure 4. Available soil moisture for the early (---) and late (-) treatments in 1985 and 1986.

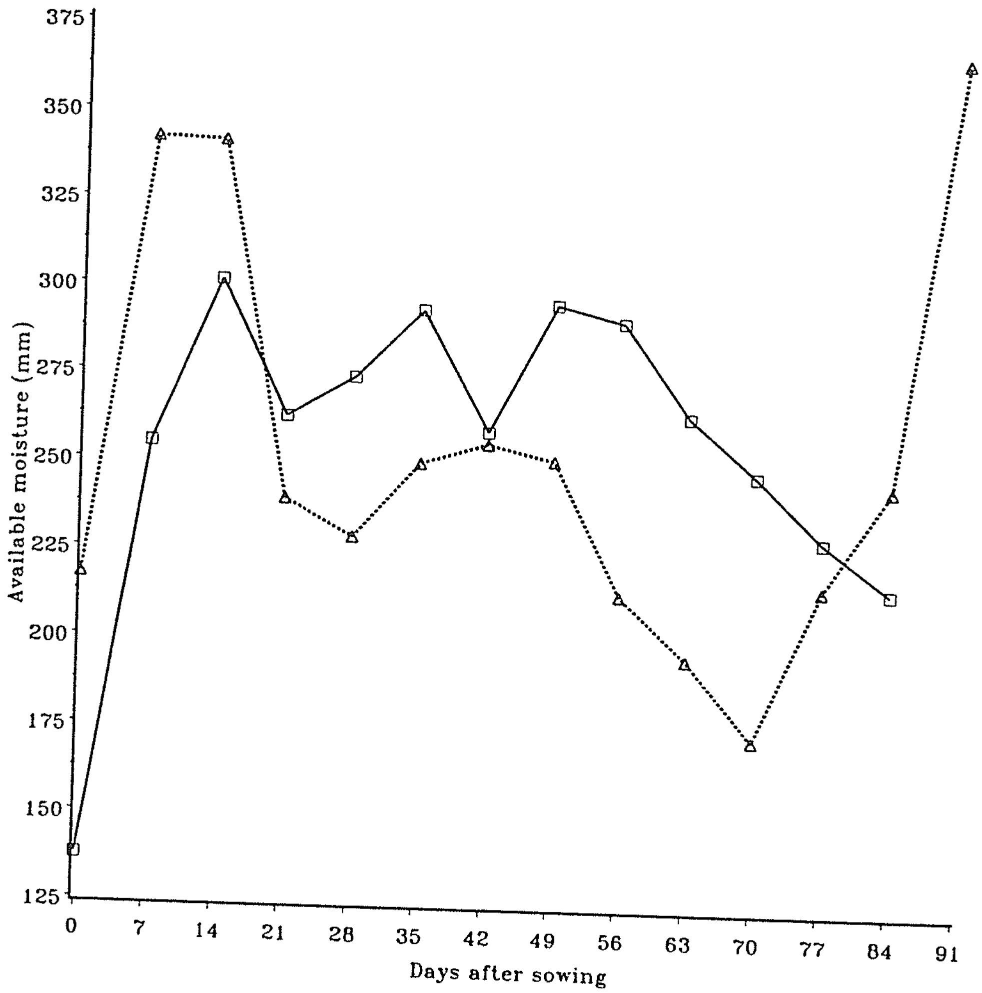


Figure 5. Available soil moisture for the Portage location in 1985 (---) and 1986 (-).

late Point treatments, but less available moisture than the irrigated Point treatment (Table 1). The total volume of water used was significantly higher than the late treatment. In 1986 available moisture was high throughout the summer. The driest period occurred during the three week period prior to harvest (Appendix Table 3). Available moisture on the Portage treatment was similar to the three Point treatments, although the total volume of water used on the Portage location was significantly greater than the Point treatments.

4.2 METEOROLOGICAL DATA

Mean daily temperatures and precipitation in 1985 and 1986 for the three Point locations are illustrated in Appendix Fig.1. The Portage location is illustrated in Appendix Fig. 2. A comparison with the 30 year means is presented in Table 2. In August, 1985 precipitation was three times greater than normal and temperatures were relatively low. In 1986 the month of July had unusually high precipitation. 137 mm were recorded, which was almost double the 30 year average of 76 mm.

Table 2. Monthly precipitation and temperatures for 1985 and 1986 in Winnipeg[1] and Portage la Prarie[2] compared to the 30 year average[3] of these locations.

		May		June		July		August	
Location	Year	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
Winnipeg	1985	15.1	64.0	16.1	64.4	20.7	34.0	16.7	218.0
Portage la Prairie	1985	11.7	87.0	14.0	81.2	19.0	11.1	16.2	222.2
Winnipeg	1986	16.6	32.5	17.3	109.3	20.2	136.8	18.4	19.4
Portage la Prairie	1986	13.4	45.9	16.6	92.8	19.5	149.1	17.7	20.8
Winnipeg	30 year	11.3	65.7	16.8	80.1	19.6	75.9	18.3	75.2
Portage la Prairie	average	11.2	62.3	17.0	75.7	19.7	76.3	18.4	81.0

[1] From University of Manitoba, Winnipeg

[2] From CFB Portage la Prairie, Manitoba

[3] From Environment Canada, 1951-1980.

4.3 PLANT MEASUREMENTS

4.3.1 Stomatal Resistance

Stomatal resistance was measured for the cultivars Westar, Pivot, and Global to determine if there were differences between these cultivars representing the different maturity classes. Results for stomatal resistance are summarized on Table 3 and Figure 6. In 1985 and 1986 there were significant differences for stomatal resistance between cultivars on different treatments, and between the different cultivars on the same treatments. However, it was not possible to explain these relationships with respect to limited moisture availablity. Day 66 in 1985, the day prior to irrigation, was the only period that moisture streass was known to occur on the nonirrigated treatment and not on the irrigated treatment. At this time, Pivot had a significantly lower stomatal resistance on the irrigated treatment.

Differences between the days on which stomatal resistance was measured on were significant between the treatments in 1985 (Appendix Table 4). In 1985 stomatal resistance was higher on the nonirrigated treatment on day 76. This period corresponded to the period following irrigation on the irrigated treatment. Stomatal resistance was higher on the irrigated treatment on day 62, the day prior to irrigation when the irrigated treatment was determined to be water stressed. Periods of high stomatal resistance correspond to the periods when available water was lowest.

Table 3. Stomatal resistance for three B. napus cultivars on the irrigated (I) and nonirrigated (NI) treatments in 1985 and 1986.

Year	Days after sowing	Stomatal resistance (s/cm)					
		Westar		Pivot		Global	
		I	NI	I	NI	I	NI
1985	62	1.18 b	2.56 a	1.17 b	2.08 ab	1.45 ab	1.88 ab
	66	1.79 ab	2.15 a	1.25 c	2.06 a	1.32 bc	1.68 abc
	69	1.75 a	2.88 a	1.95 a	2.26 a	2.48 a	1.62 a
	73	1.82 a	1.75 ab	1.80 a	1.53 abc	1.12 bc	0.93 c
	76	2.62 b	2.23 b	2.69 b	7.76 a	2.32 b	6.04 a
	80	6.15 ab	1.62 c	8.04 a	3.79 bc	4.59 bc	3.19 bc
	83	5.71 ab	4.10 b	4.91 ab	4.54 b	6.26 a	5.38 ab
	92	2.20 a	4.01 a	2.75 a	4.17 a	1.76 a	5.03 a
1986	52	1.77 b	2.19 ab	1.77 b	1.05 c	1.63 bc	2.70 a
	56	2.21 a	0.62 b	0.87 b	0.66 b	0.86 b	0.24 b
	70	3.31 a	1.92 ab	2.16 ab	2.42 ab	3.38 a	1.20 b
	73	1.82 a	1.75 ab	1.80 a	1.53 abc	1.12 bc	0.93 c

Values followed by the same letter within each day are not significantly different $P<0.05$.

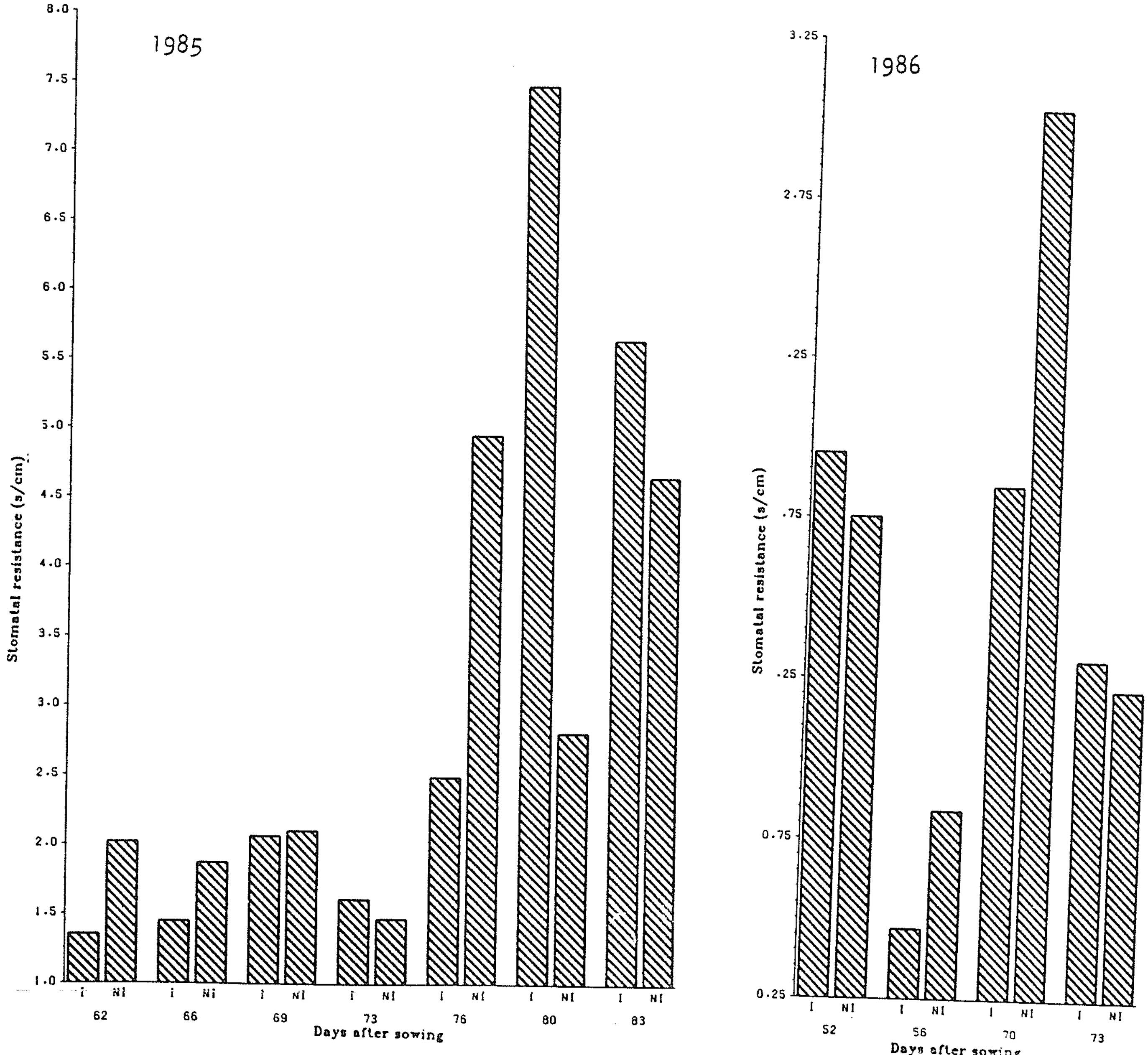


Figure 6. Stomatal resistance for the irrigated (I) and nonirrigated (NI) treatments in 1985 and 1986.

4.3.2 Growth Stages

The vegetative growth stages (stages 0 to 2) and reproductive growth stages (3 to 5) were scored for the six cultivars using the Harper and Berkenkamp (1975) scale. There were large differences in days to first flower over the four treatments (Table 4). In 1985 the cultivars on the late treatment flowered in the least number of days, followed by Portage, the irrigated, and the nonirrigated treatment. In 1986 the same rankings occurred for the late and Portage treatment. The nonirrigated treatment reached flowering before the irrigated treatment.

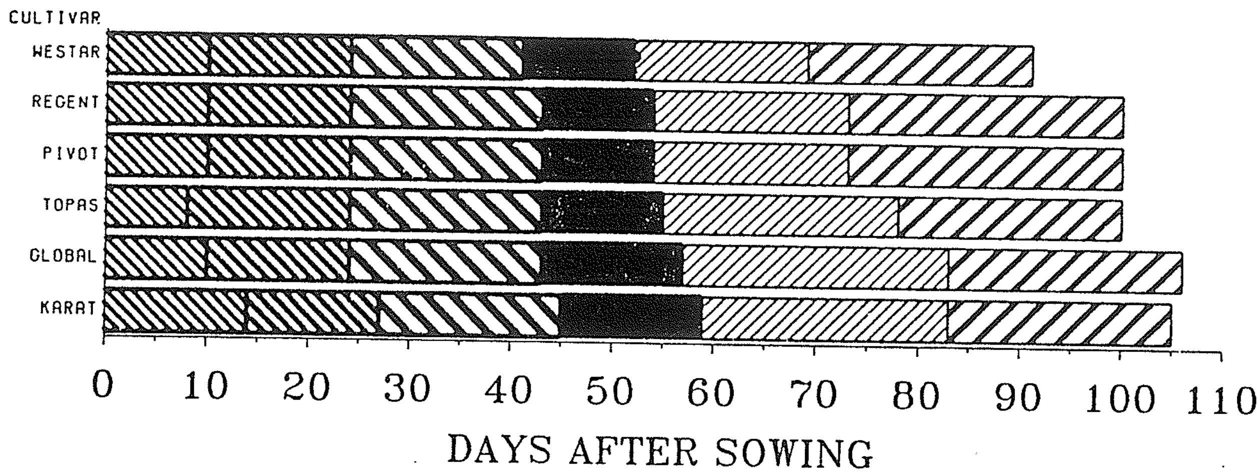
Growth stages of the six cultivars for the Point treatments are illustrated for the 1985 summer in Fig. 7 and 8, and for the 1986 summer in Fig. 9 and 10. The growth stages of the cultivars on the Portage location in 1985 and 1986 are illustrated in Fig. 11. Westar was the first cultivar to reach each growth stage, while the cultivars Global and Karat required a greater length of time to reach each stage. Regent, Pivot, and Topas reached each stage at an intermediate rate. These observations apply to all treatments and for both 1985 and 1986.

In 1985 Westar, Global, and Karat flowered significantly earlier on the irrigated treatment (Table 5). In 1986 there were no significant differences between flowering dates for cultivars except for Topas, which flowered earlier on the nonirrigated treatment (Table 5). All cultivars flowered in significantly fewer days on the late seeded treatment compared to the early seeded treatment in 1985 and 1986 (Table 6). At the Portage location Global required significantly more days to flower than the earlier cultivars in 1985 and 1986 (Table 7).

Table 4. Day to first flower for the four treatments in 1985 and 1986.

	1985	1986
Treatment	Day to first flower	Day to first flower
Irrigated	53.5	46.1
Nonirrigated	54.6	45.4
Late	31.9	40.6
Portage	51.1	44.1

Nonirrigated



Irrigated

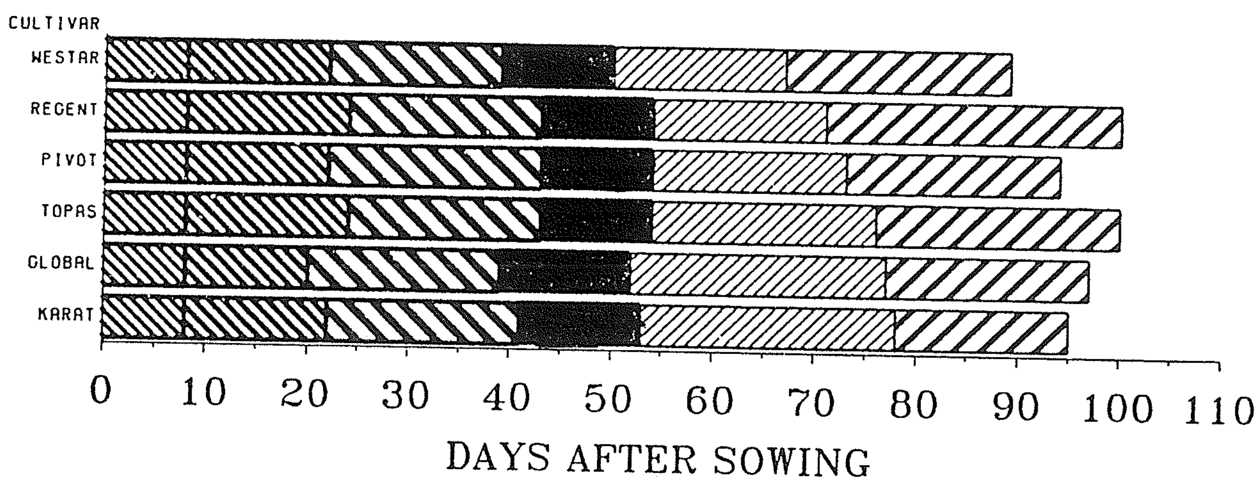


Figure 7. Growth stages for the irrigated and nonirrigated treatments in 1985.

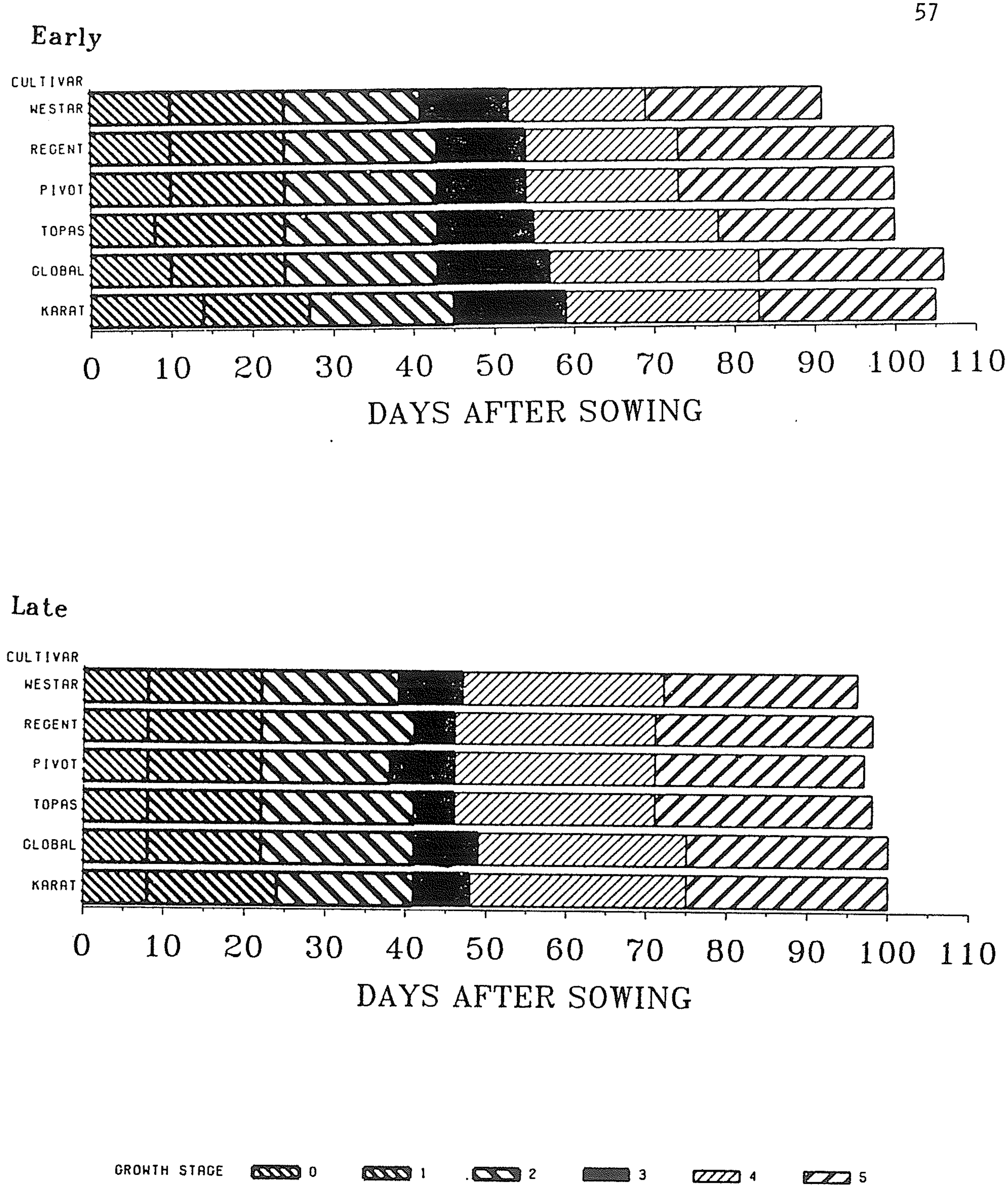


Figure 8. Growth stages of the early and late treatments in 1985.

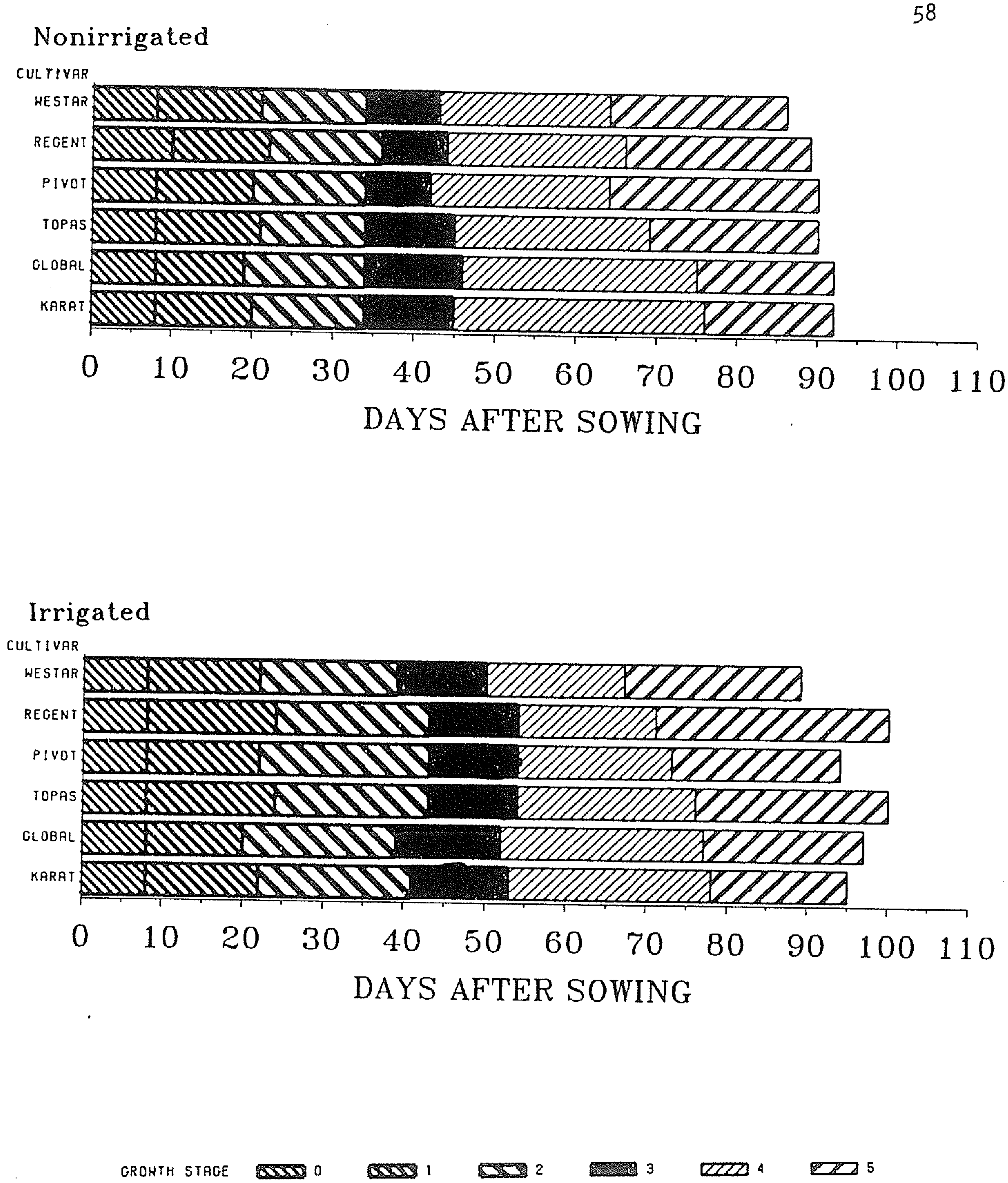
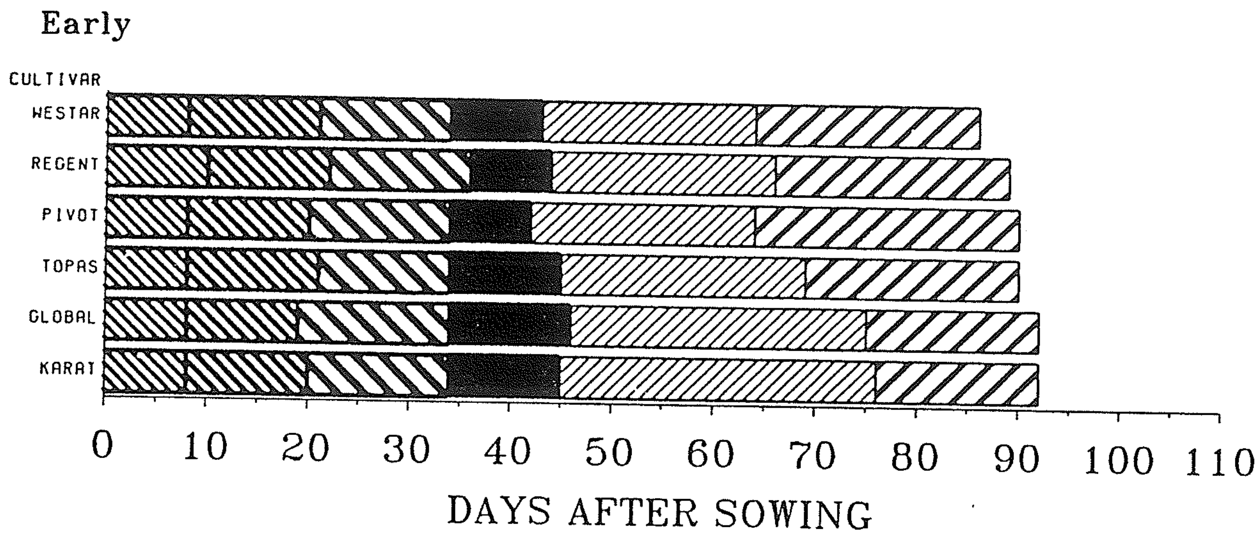


Figure 9. Growth stages of the irrigated and nonirrigated treatments in 1986.



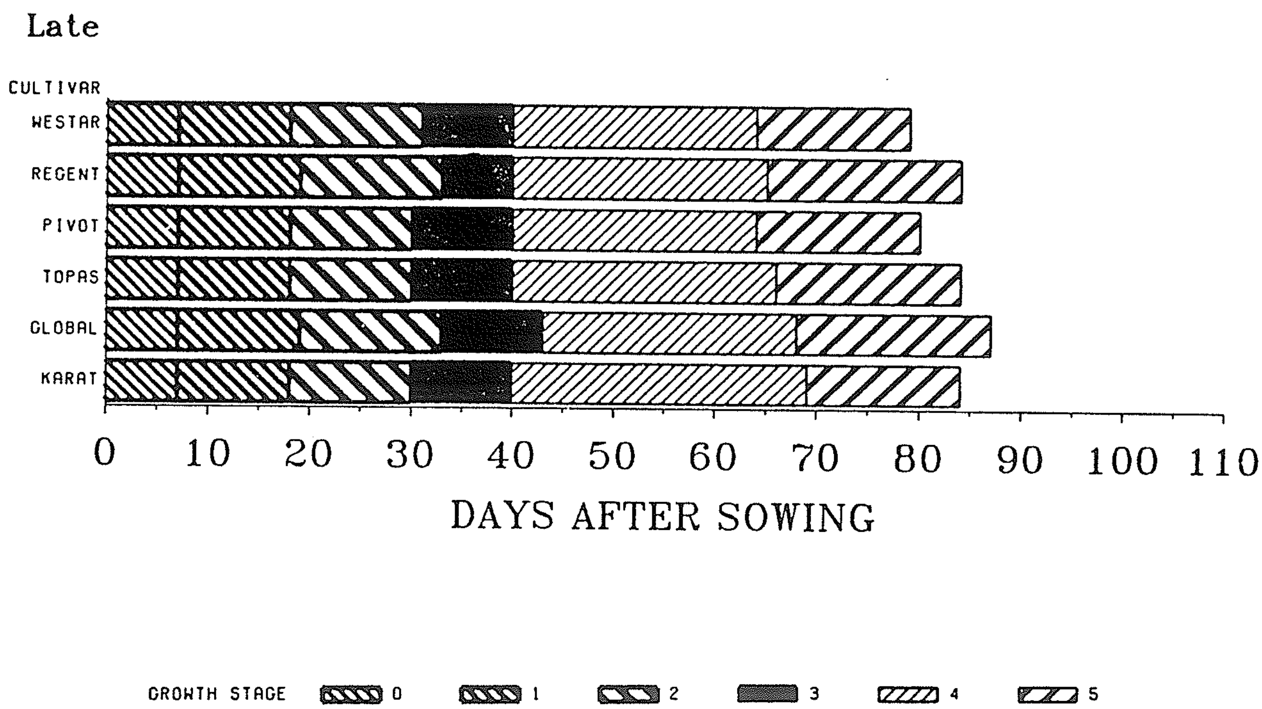


Figure 10. Growth stages of the early and late treatments in 1986.

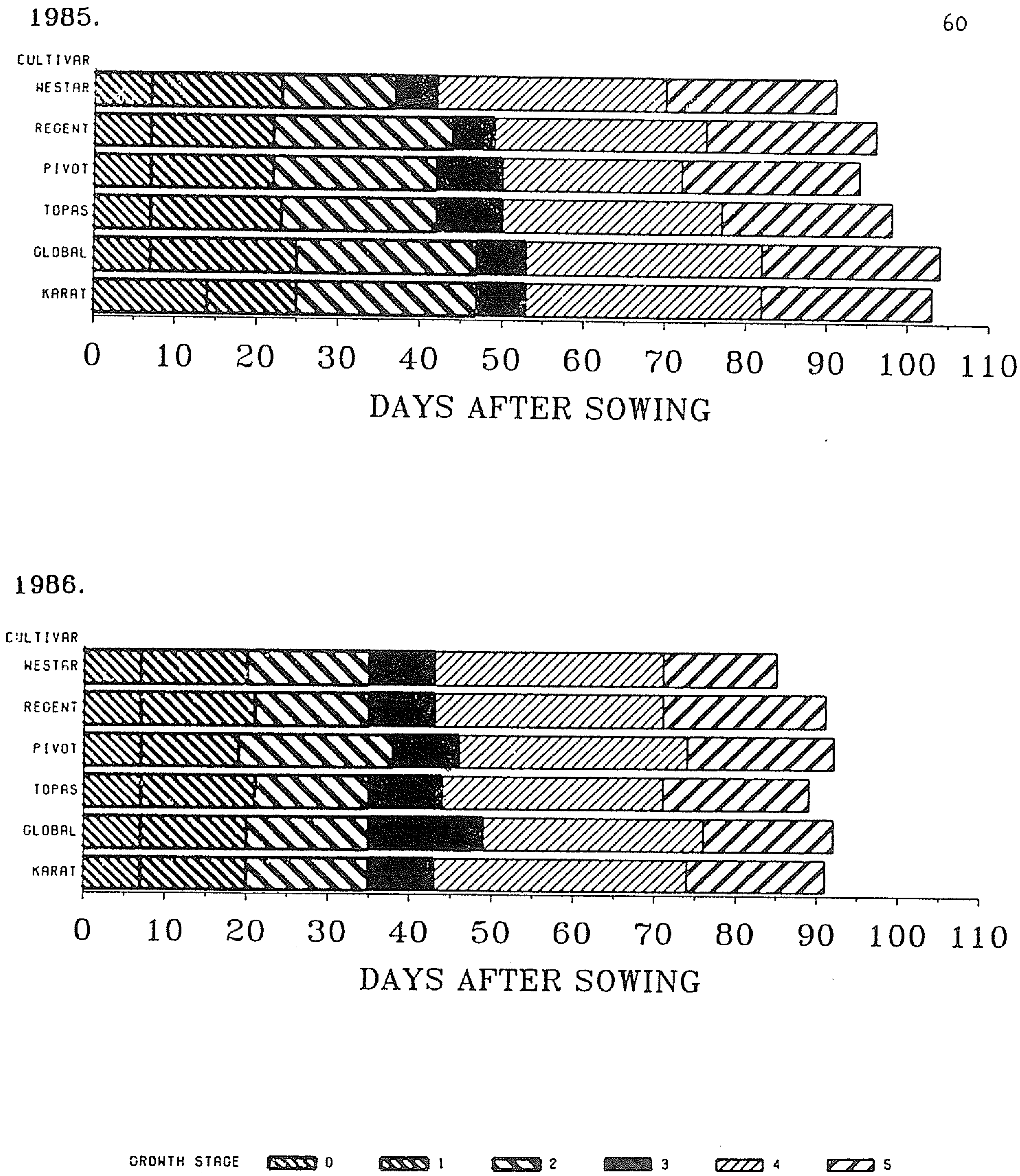


Figure 11. Growth stages of the Portage location in 1985 and 1986.

Table 5. Day to first flower for the six B. napus cultivars on the irrigated (I) and nonirrigated (NI) treatments in 1985 and 1985.

	1. Days to first flower 1985		2. Days to first flower 1986	
Cultivar	NI	I	NI	I
Westar	51.3 f	50.3 g	43.2 e	43.3 de
Regent	53.0 e	52.7 e	44.5 c	45.2 c
Pivot	54.2 cd	53.3 de	44.3 cd	45.3 c
Topas	55.0 c	54.2 cd	45.3 c	46.7 b
Global	57.0 a	54.8 c	48.0 a	48.3 a
Karat	57.3 a	56.0 b	47.3 ab	48.0 a

Values followed by the same letter(s) within 1 and 2 are not significantly different $P<0.05$.

Table 6. Day to first flower of the six *B. napus* cultivars on the early (E) and late (L) treatments in 1985 and 1986.

	1. Days to first flower 1985		2. Days to first flower 1986	
Cultivar	E	L	E	L
Westar	51.3 d	46.0 f	43.2 d	40.0 e
Regent	53.0 c	46.3 f	44.5 bc	40.3 e
Pivot	54.2 c	46.2 f	44.3 c	40.0 e
Topas	55.0 b	46.0 f	45.3 b	40.0 e
Global	57.0 a	54.8 e	48.0 a	43.3 d
Karat	57.3 a	48.0 e	47.3 a	40.0 e

Values followed by the same letter(s) within 1 and 2 are not significantly different $P<0.05$.

Table 7. Day to first flower for the six B. napus cultivars on the Portage location in 1985 and 1986.

Cultivar	1. Days to first flower 1985	2. Days to first flower 1986
Westar	45.0 d	42.7 b
Regent	50.2 c	42.5 b
Pivot	50.3 c	42.7 b
Topas	51.3 b	44.0 b
Global	55.0 a	49.2 a
Karat	55.0 a	43.3 b

Values followed by the same letter(s) within 1 and 2 are not significantly different $P<0.05$.

In 1985 Westar was the first cultivar to flower on all treatments. Karat was the last to flower on the irrigated and the nonirrigated treatment. Global flowered last on the late and Portage treatments. In 1986 Westar was observed to flower first on the nonirrigated, the irrigated, and on the late treatments. Regent flowered first on the Portage treatment. In 1986 Global flowered last on all treatments.

4.3.3 Yield and Yield Components

4.3.3.1 Yield

In 1985, yield for the four treatments were similar. The Portage treatment yielded higher than the the three Point treatments. In 1986 (Table 9) differences of yield between the irrigated and the nonirrigated treatments were similar. Differences between the early and late treatments were substantial. The early treatment had a higher yield than the late treatment. Yield of the Portage treatment was lower than the irrigated treatment.

Seed yields were significantly higher for the cultivars Westar and Pivot in the nonirrigated treatment compared to the irrigated treatment in 1985 (Table 10) and 1986 (Table 11). Comparisons between the early and late treatments in 1985 (Table 12) and 1986 (Table 13) indicated that average seed yield was higher for all cultivars for the ' early treatment but these differences were not significant. Seed yields of the Portage location in 1985 and 1986 are presented in Table 14. In both years Westar and Pivot were the high yielding cultivars on the early and late treatments. Regent and Karat had the lowest yields on

Table 8. Yield, pod abortion and the yield components pods/plant and seeds/pod of the four treatments in 1985.

Treatment	Yield gm/plot	% Pod Abortion	Pods/ plant	Seeds/ pod
Irrigated	580.6	51.6	90.2	19.5
Nonirrigated	625.8	53.6	99.6	22.7
Late	589.1	52.4	98.1	22.3
Portage	665.0	51.9	110.0	18.2

Table 9. Yield, pod abortion, the yield components pods/plant, seeds/pod and 1000 seed weight and harvest index of the four treatments in 1986.

Treatment	Yield gm/plot	% Pod Abortion	Pods/ plant	Seeds/ pod	1000 seed weight (gm)	Harvest index
Irrigated	667.1	48.8	84.8	16.9	1.02	26.0
Nonirrigated	647.3	49.5	80.6	16.6	1.04	27.0
Late	538.6	55.8	75.6	16.3	1.01	22.5
Portage	600.6	50.3	119.1	18.2	0.92	25.1

Table 10. Yield, pod abortion, and the yield components pods/plant and seeds/pod of the six _B_. _napus_ cultivars on the nonirrigated (NI) and irrigated (I) treatments in 1985.

	1. Yield gm/plot		2. % Pod Abortion		3. Pods/ plant		4. Seeds/ pod	
	NI	I	NI	I	NI	I	NI	I
Westar	690.6 a	559.6 bcd	59.6 a	55.7 abc	89.0 ab	84.7 ab	26.8 a	18.7 bcd
Regent	591.9 abcd	559.6 abcd	54.0 abcd	53.4 bcde	107.2ab	78.5 b	22.1 b	21.6 bc
Pivot	698.8 a	502.5 d	53.7 abcd	52.6 bcde	114.3 a	97.0 ab	27.1 a	21.2 bc
Topas	613.8 abcd	631.4 abc	48.7 def	47.6 ef	81.8 ab	84.7 ab	20.4 bcd	17.1 d
Global	604.1 abcd	673.5 ab	56.4 ab	55.0 abc	96.2 ab	103.4ab	21.9 bc	21.3 b
Karat	555.9 bcd	529.5 cd	49.8 cdef	46.0 f	108.3ab	92.5 ab	18.0 cd	17.1 d

Values followed by the same letter(s) within 1, 2, 3 and 4 are not significantly different.

Table 11. Seed yield, the yield components pods/plant, seeds/pod, 1000 seed weight and harvest index of the six *B. napus* cultivars on the nonirrigated (NI) and irrigated (I) treatments in 1986.

	1. Yield gm/plot		2. % Pod Abortion		3. Pods/ plant		4. Seeds/ pod		5. 1000 seed weight (gm)		6. Harvest index	
	NI	I	NI	I	NI	I	NI	I	NI	I	NI	I
Westar	782.6 a	620.3 bc	54.3 a	59.5 c	58.2 c	59.5 c	20.5 a	19.7 ab	1.12 ab	1.18 a	28.9 a	27.9 ab
Regent	590.9 c	635.4 abc	52.9 ab	50.7 abc	74.8 ab	95.6 ab	14.4 de	15.7 cde	1.12 ab	1.10 ab	27.7 ab	25.0 ab
Pivot	624.7 bc	658.6 abc	51.3 ab	54.6 a	74.5 abc	76.9 abc	18.2 abc	17.5 bcd	1.14 ab	1.09 ab	28.2 ab	26.4 ab
Topas	641.2 abc	680.8 abc	42.8 cd	41.5 d	73.1 bc	82.4 abc	15.3 cde	15.4 cde	0.90 c	0.87 c	27.4 ab	27.1 ab
Global	649.7 abc	772.4 ab	49.7 abc	43.3 cd	103.1a	97.7 ab	17.1 bcd	17.4 bcd	1.10 ab	1.04 b	27.3 ab	25.7 ab
Karat	594.4 c	635.2 abc	45.9 bcd	48.5 abcd	99.9 ab	97.6 ab	13.9 e	15.3 cde	0.84 c	0.84 c	22.6 b	24.0 ab

Values followed by the same letter(s) within 1, 2, 3, 4, 5, and 6 are not significantly different.

Table 12. Yield, pod abortion, and the yield components pods/plant and seeds/pod of the six B. napus cultivars on the early (E) and late (L) treatments in 1985.

	1. Yield gm/plot		2. % Pod Abortion		3. Pods/ plant		4. Seeds/ pod	
	E	L	E	L	E	L	E	L
Westar	690.6 a	636.3 ab	59.5 a	55.3 abcd	89.0 abcd	61.8 ab	26.8 a	24.8 ab
Regent	591.9 ab	573.7 ab	54.0 abcde	47.9 de	107.2abc	78.7 cd	22.1 ab	22.5 abc
Pivot	698.8 a	636.8 ab	52.7 abcde	51.4 bcde	114.3ab	107.3abc	27.1 a	21.9 abc
Topas	613.8 ab	610.5 ab	43.7 abc	50.6 cde	81.8 bcd	115.6abc	20.4 bc	20.5 bc
Global	604.1 ab	571.5 ab	56.4 abc	47.8 ab	96.2 abc	106.5abc	21.7 abc	23.8 ab
Karat	555.9 ab	506.1 b	49.8 cde	51.5 bcde	108.3abc	118.9a	18.0 c	20.3 bc

Values followed by the same letter(s) within 1, 2, 3 and 4 are not significantly different.

Table 13. Seed yield, the yield components pods/plant, seeds/pod, 1000 seed weight and harvest index of the six *B. napus* cultivars on the early (E) and late (L) treatments in 1986.

	1. Yield gm/plot		2. % Pod Abortion		3. Pods/ plant		4. Seeds/ pod		5. 1000 seed weight (gm)		6. Harvest index	
	E	L	E	L	E	L	E	L	E	L	E	L
Westar	782.6 a	630.4 abc	54.3 bc	56.0 abc	58.2 a	18.3 ab	20.5 a	18.3ab	1.12 a	1.14 a	28.9a	23.7abc
Regent	590.9 abc	549.8 bc	53.0 bcd	58.8 ab	74.8 b	63.5 b	14.4 cd	14.7 cd	1.12 a	0.99 c	27.7 bc	22.4ab
Pivot	624.7 abc	618.9 abc	51.3 bcd	54.5 abc	74.5 b	75.8 b	18.2 ab	17.3 bc	1.14 a	1.05 b	28.2a	27.6ab
Topas	641.2 ab	511.2 bc	53.1 b	48.5 cde	73.1 b	68.2 b	15.3 bcd	15.5 bcd	0.90 d	0.90 d	27.4ab	24.4ab
Global	649.7 ab	530.2 bc	49.7 cde	62.0 a	101.1a	72.9 b	17.1 bcd	15.1 bcd	1.10 ab	1.06 b	27.3ab	18.6 c
Karat	594.4 abc	441.0 c	45.9 de	55.2 abc	99.9 a	105.2a	13.9 d	16.2 bcd	0.84 e	0.91 d	22.6 bc	18.6 c

Values followed by the same letter(s) within 1, 2, 3, 4, 5, and 6 are not significantly different.

the nonirrigated and Portage treatments in 1985, and on the early, irrigated, and late treatments in 1986. Under irrigation Global and Topas outyielded other cultivars in both years.

Correlation coefficients between days to first flower and yield (Table 15) revealed negative correlations between these variables for Westar and Pivot on the nonirrigated treatment in 1985. In 1985 and 1986 a negative correlation were found for Regent on the late treatment. On the Portage location in 1986, a negative correlation was found between these variables for the cultivar Pivot. Negative correlations were also found for days to first flower with yield over all varieties on the 1985 late treatment, and the 1985 and 1986 Portage treatment. A positive correlation was found on the 1986 irrigated treatment. Stand counts were measured in order to determine if yield/stand correlations existed. However, significant yield/stand correlations were not found for any treatments in either year. In 1985 the late treatment had a significantly higher stand count than other treatments. There were no significant stand differences between the irrigated and nonirrigated treatments in 1985 and 1986. In all but the 1986 irrigated treatment in 1986, Karat and Topas had the highest stand counts. Pivot and Global had significantly lower stand counts for all but the early treatments in 1985 and 1986.

4.3.3.2 Pod Abortion

The % pod abortion was lower in all cultivars on the irrigated compared to the nonirrigated treatment in 1985 (Table 8). On all Point treatments Westar and Global had the highest % pod abortion, while Topas

Table 14. Yield, pod abortion, the yield components pods/plant, seeds/pod, and 1000 seed weight of the six B. napus cultivars on the Portage location in 1985 and 1986.

	1985				1986					
	1. Yield gm/plot	2. % Pod abortion	3. Pods/ plant	4. Seeds/ pod	5. Yield gm/plot	6. % Pod abortion	7. Pods/ plant	8. Seeds/ pod	9. 1000 seed wt	10. Harvest index
Westar	847.9 a	60.0 a	76.2 b	25.5 a	625.7 b	55.6 a	109.0 a	19.6 ab	0.95 ab	25.5 ab
Regent	569.9 c	45.6 c	99.2 ab	13.2 d	630.9 b	48.7 b	110.7 a	17.5 ab	0.94 b	27.6 a
Pivot	757.1 ab	47.8 bc	116.5a	18.6 b	622.2 b	51.9 ab	105.4 a	16.6 b	0.92 b	25.1 ab
Topas	591.0 c	52.1 abc	101.6ab	14.5 cd	644.2 b	49.0 b	126.3 a	16.2 b	0.84 c	25.7 ab
Global	649.4 bc	53.3 abc	131.2a	20.0 b	688.7 a	48.3 b	133.1 a	21.6 a	1.02 a	23.4 b
Karat	575.3 c	53.8 ab	136.6a	17.3 bc	691.6 a	48.2 b	130.6 a	17.9 ab	0.82 c	23.1 b

Values followed by the same letter(s) within 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 are not significantly different.

Table 15. Correlation coefficients between days to first flower and yield.

Treatment	Year	Westar	Regent	Pivot	Topas	Global	Karat	Overall
Nonirrigated	1985	-.936	-.001	.963	.288	0.00	.210	-.311
Pr>R		.01	1.00	.002	.58	1.00	.69	.07
Nonirrigated	1986	.123	-.169	.401	.540	0.00	.494	-.080
Pr>R		.82	.75	.43	.27	1.00	.32	.64
Irrigated	1985	-.528	-.299	.410	-.382	.043	-.485	.016
Pr>R		.28	.57	.42	.46	.94	.33	.93
Irrigated	1986	.466	-.625	-.077	.340	.68	0.00	.342
Pr>R		.35	.19	.89	.51	.14	1.00	.04
Late	1985	.000	-.821	-.562	0.00	0.00	.008	-.321
Pr>R		1.00	.05	.25	1.00	1.00	.99	.06
Late	1986	.000	-.952	0.00	0.00	.503	0.00	-.048
Pr>R		1.00	.003	1.00	1.00	.31	1.00	.78
Portage	1985	.158	-.078	.262	.440	0.00	0.00	-.463
Pr>R		1.00	.88	.62	.38	1.00	1.00	.01
Portage	1986	.158	.595	.893	.617	.400	-.426	.405
Pr>R		.77	.21	.02	.19	.43	.40	.01

and Karat had generally the lowest % pod abortion. At the Portage location Westar had the lowest % pod abortion and Karat had the greatest (Table 14).

In 1986 all treatments had similar %pod abortion (Table 9). Pod abortion was significantly higher for the cultivar Westar on the irrigated compared to the nonirrigated treatment (Table 11), and significantly lower for the cultivars Topas, Global, and Karat on the early compared to the late treatment (Table 13). On all treatments pod abortion was highest for the cultivar Westar, and generally lowest for Topas.

4.3.3.3 Harvest Index

Harvest index was measured in 1986. The early treatment had a greater harvest index than the Portage and late treatments (Table 9). There was little difference between the Portage and irrigated treatments. These two treatments both had a higher harvest index than the late treatment.

On the nonirrigated treatment (Table 11) Westar had a higher harvest index than Karat. Other than this there were no significant differences among cultivars on the irrigated treatment, or among the same cultivars on the nonirrigated and irrigated treatments. On the late treatment (Table 13) Pivot had a higher harvest index than Regent and Global. While cultivars had a higher harvest index on the early treatment compared to the late treatment, Global was the only cultivar to be significantly higher. On the Portage treatment (Table 14) Regent had a significantly higher harvest index than Global and Karat.

4.3.3.4 Yield Components

In 1985 the Portage location had a higher number of pods per plant than the irrigated and late treatment, but the Portage and the irrigated treatment had fewer seeds per pod than the early and late treatments. In 1986 the Portage location had a higher number of pods per plant and seeds per pod than the Point treatments (Table 9). Yield components for each cultivar - seeds per pod, pods per plant, and 1000 seed weight are summarized in Tables 10 to 14. In general pods per plant were significantly higher and seeds per pod significantly lower in the later maturing cultivars Global and Karat compared to Westar.

The yield component 1000 seed weight was not measured in 1985. Of the four treatments in 1986, the Portage location had a lower 1000 seed weight than the three Point treatments. Westar had the greatest seed weight on the irrigated and late treatments. There were no significant differences between Westar and cultivars of greater seed weight on the Portage and late treatments (Tables 11, 13 and 14). In all treatments the cultivars Karat and Topas had significantly lower 1000 seed weights than other cultivars.

4.3.3.5 Yield Component Correlation

Pearson's correlation analysis was performed to compare all yield components. Few significant correlations were found. Significant negative correlations were found between the variables pods/plant and seeds/pod for the cultivar Karat on the nonirrigated treatment in 1985 and for Regent on the irrigated treatment in 1986 (Table 16). Positive correlations were found between for these variables for the cultivars Regent on the nonirrigated treatment in 1985, for Karat at the Portage location in 1985 and 1986. There were no significant correlation between the yield components seeds/pod and 1000 seed weight, or between pods/plant and 1000 seed weight (Table 16).

4.4 OIL AND PROTEIN

4.4.0.6 Oil

In 1985 there were no differences in % oil content on the three treatments at the Point (Table 17). The Portage treatment had a lower mean oil content than the Point treatments. In 1986 the irrigated treatment had a higher mean oil content than the nonirrigated treatment, which in turn had a higher mean oil content than the late treatment. The Portage treatment did not greatly differ from the nonirrigated treatment.

In 1985 Westar had a significantly higher oil content than the other five cultivars, while Karat generally had the lowest oil content. In 1986 Karat had the lowest oil content of the six cultivars while Topas had generally the highest mean oil content.

Table 16. Correlation coefficients between the yield components pods/plant, seeds/pod and 1000 seed weight.

Yield components	Treatment	Cultivars	Correlation	Pr>R
Pods/plant v seeds/pod	Nonirrigated 1985	Westar	.080	.79
		Regent	.600	.02
		Pivot	-.125	.66
		Topas	.044	.88
		Global	.254	.36
		Karat	-.571	.03
	Nonirrigated 1986	Westar	.571	.03
		Regent	-.588	.02
		Pivot	.278	.32
		Topas	.647	.01
		Global	.002	.99
		Karat	.360	.19
	Irrigated 1985	Westar	.460	.11
		Regent	-.352	.20
		Pivot	-.204	.47
		Topas	.204	.47
		Global	.204	.47
		Karat	.637	.01
	Irrigated 1986	Westar	-.118	.68
		Regent	-.610	.02
		Pivot	.352	.20
		Topas	.240	.39
		Global	.050	.86
		Karat	.412	.14
	Late 1985	Westar	.004	.99
		Regent	-.255	.36
		Pivot	-.292	.15
		Topas	.455	.09
		Global	-.256	.36
		Karat	-.099	.73
	Late 1986	Westar	.449	.09
		Regent	.415	.12
		Pivot	-.445	.10
		Topas	-.295	.28
		Global	-.397	.14
		Karat	.295	.29
	Portage 1985	Westar	-.45	.17
		Regent	-.010	.98
		Pivot	.074	.83
		Topas	-.120	.70
		Global	.263	.41
		Karat	.640	.05

Table 16. cont.

Yield components	Treatment	Cultivars	Correlation	Pr>R
	Portage 1986	Westar	-.404	.14
		Regent	-.245	.36
		Pivot	.351	.22
		Topas	.192	.49
		Global	-.052	.85
		Karat	.725	.005
Seeds/pod v 1000 seed wt	Nonirrigated 1986	Westar	-.907	.28
		Regent	-.082	.95
		Pivot	.803	.41
		Topas	-.792	.42
		Global	.756	.45
		Karat	-.237	.85
	Irrigated 1986	Westar	-.680	.52
		Regent	-.327	.79
		Pivot	.292	.81
		Topas	.872	.33
		Global	-.697	.51
		Karat	.869	.33
	Late 1986	Westar	-.339	.78
		Regent	.911	.01
		Pivot	.436	.39
		Topas	.366	.48
		Global	-.621	.19
		Karat	.504	.31
	Portage 1986	Westar	.760	.45
		Regent	.966	.17
		Pivot	-.269	.83
		Topas	-.051	.97
		Global	-.191	.88
		Karat	-.050	.97
Pods/plant v 1000 seed wt	Nonirrigated 1986	Westar	-.071	.96
		Regent	-.846	.36
		Pivot	.639	.56
		Topas	.518	.65
		Global	.745	.67
		Karat	-.075	.95
	Irrigated 1986	Westar	-.977	.14
		Regent	.421	.72
		Pivot	.898	.28
		Topas	-.600	.59
		Global	-.823	.39
		Karat	.176	.89

Table 16. cont.

Yield components	Treatment	Cultivars	Correlation	Pr>R
	Late 1986	Westar	-.339	.78
		Regent	0.00	1.00
		Pivot	.883	.31
		Topas	.028	.98
		Global	-.416	.73
		Karat	-.119	.92
	Portage 1986	Westar	-.204	.87
		Regent	-.115	.93
		Pivot	-.725	.48
		Topas	.489	.68
		Global	.379	.75
		Karat	.074	.95

Table 17. Oil and protein content of the four treatments in 1985 and 1986.

	1985		1986	
Treatment	% Oil	% Protein	% Oil	% Protein
Irrigated	46.4	23.1	45.7	24.4
Nonirrigated	46.6	24.7	44.8	25.3
Late	46.8	23.3	43.7	26.4
Portage	44.2	26.0	45.2	25.3

In 1985 there were no significant cultivar differences between the irrigated and nonirrigated treatments, or between the early and late treatments (Tables 18-20). In 1986 Regent, Pivot, Global, and Karat had significantly lower oil contents on the nonirrigated compared to the irrigated treatment. Westar, Topas, Karat, and Global had significantly higher oil contents on the early treatment compared to the late treatment in 1986. Westar had the highest oil content at the Portage location in 1985, while Global had the highest in 1986 (Table 20).

Pearson's correlation was used to analyze days to first flower and % oil content to determine if a correlation between these two variables existed. In 1985 there was a significant negative correlation between these two variables on the nonirrigated treatment (Pr>R 0.005), the irrigated treatment (Pr>R 0.0006), and the Portage treatment (Pr>R 0.001). There were no significant correlations in 1986.

4.4.0.7 Protein

Protein content was highest in the Portage treatment and lowest on the irrigated treatment in 1985. In 1986, the late treatement had a significantly higher protein content than the nonirrigated/early treatment which was higher than the irrigated treatment for protein content. Protein content had the same ranking for the four treatments in 1986 (Table 18).

For all treatments in both years Global had the lowest protein content. In both 1985 and 1986 all cultivars had a lower protein content on the irrigated compared to the nonirrigated treatment (Table

Table 18. Oil and protein content of the six B. napus cultivars on the nonirrigated (NI) and irrigated (I) treatment.

	1985 1. % oil		2. % protein		1986 3. % oil		4. % protein	
Cultivar	NI	I	NI	I	NI	I	NI	I
Westar	48.2 a	47.2 abc	26.5 a	22.8 ab	45.6 ab	45.7 ab	24.8 de	24.1 ef
Regent	46.4 bcd	46.5 bc	23.9 ab	22.6 ab	43.9 d	45.4 b	26.7 a	24.9 cde
Pivot	46.7 bc	47.4 ab	24.9 ab	22.7 ab	44.5 c	45.4 b	26.5 ab	25.8 bc
Topas	46.3 bcd	46.2 bcd	24.4 ab	24.9 ab	45.6 ab	46.1 a	24.4 ef	24.2 ef
Global	46.1 cd	46.0 cd	23.5 ab	22.0 ab	45.2 b	46.1 a	23.7 f	22.8 fg
Karat	46.1 cd	45.2 d	24.8 ab	24.0 ab	44.1 cd	45.3 b	25.6 bcd	24.9 cde

Values followed by the same letter(s) within 1, 2, 3, and 4 are not significantly different $P<0.05$.

Table 19. Oil and protein content of the six _B_. _napus_ cultivars on the early (E) and late (L) treatments.

	1985 1. % oil		2. % protein		1986 3. % oil		4. % protein	
Cultivar	E	L	E	L	E	L	E	L
Westar	48.2 a	47.8 ab	26.5 a	22.6 a	45.6 a	43.6 de	26.5 a	22.6 a
Regent	46.4 bc	46.2 c	23.9 a	22.6 a	43.9 cd	43.7 de	26.7 ab	26.6 ab
Pivot	46.7 bc	46.8 c	24.9 a	23.9 a	44.5 b	44.3 bc	26.5 ab	27.1 a
Topas	46.3 c	47.2 abc	24.4 a	24.0 a	45.6 a	43.9 cd	24.4 de	26.5 ab
Global	46.1 c	46.8 bc	23.5 a	23.2 a	45.2 a	43.3 e	23.7 e	25.3 cd
Karat	46.1 c	46.3 c	24.8 a	23.5 a	44.1 cd	43.3 e	25.6 bc	26.4 ab

Values followed by the same letter(s) within 1, 2, 3, and 4 are not significantly different P<0.05.

Table 20. Oil and protein content of the six B. napus cultivars on the Portage location.

Cultivar	1985	1. % oil	2. % protein	1986	3. % oil	4. % protein
Westar		45.7 a	27.7 a		44.6 bc	24.6 bc
Regent		43.8 bc	26.2 a		45.4 ab	25.5 abc
Pivot		44.6 b	25.9 a		45.4 ab	25.5 abc
Topas		43.3 bc	26.0 a		45.6 ab	25.8 ab
Global		43.9 bc	24.3 a		46.2 a	24.3 c
Karat		43.8 bc	25.7 a		44.3 c	26.2 a

Values followed by the same letter(s) within 1, 2, 3, and 4 are not significantly different $P<0.05$.

18). In 1985 all cultivars had a higher mean protein content on the early compared to the late treatment. There were no significant cultivar differences between these two treatments (Table 19). In 1986 Regent was the only cultivar to have a significantly higher protein content on the early compared to the late treatment.

Correlation analysis between oil and protein content revealed negative correlations on the 1986 nonirrigated treatment, the 1985 and 1986 irrigated treatment, the 1985 and 1986 late treatment, and the 1986 Portage location (Table 21). Negative correlations between oil and protein were found for all cultivars over the four treatments.

Table 21. Correlation coefficients between oil and protein content.

Treatment	Year	Westar	Regent	Pivot	Topas	Global	Karat	Overall
Nonirrigated	1985	-.012	-.970	-.964	-.945	-.576	-.967	-.077
Pr>R		.98	.001	.002	.004	.23	.002	.66
Nonirrigated	1986	-.074	-.639	.122	-.409	.281	-.397	-.603
Pr>R		.89	.17	.82	.42	.59	.44	.0001
Irrigated	1985	-.692	-.104	-.716	-.917	-.690	-.717	-.550
Pr>R		.13	.84	.11	.01	.13	.11	.0005
Irrigated	1986	-.681	-.624	-.552	-.754	-.516	-.996	-.614
Pr>R		.14	.19	.26	.08	.29	.0001	.0001
Late	1985	-.855	-.730	-.962	-.908	-.993	-.908	-.875
Pr>R		.03	.10	.002	.01	.0001	.01	.0001
Late	1986	-.617	-.423	-.512	-.878	-.957	-.661	-.509
Pr>R		.19	.40	.23	.02	.003	.15	.002
Portage	1985	-.620	-.616	-.403	-.499	.048	-.582	-.023
Pr>R		.20	.98	.43	.31	.93	.03	.90
Portage	1986	-.973	-.861	-.654	-.586	-.840	-.470	-.657
Pr>R		.001	.03	.16	.22	.04	.35	.0001

Chapter V

DISCUSSION

5.1 COMPARISON BETWEEN TREATMENTS

5.1.1 Irrigated and Nonirrigated Experiment

In 1985 the amount of available water was greater on the irrigated treatment compared to the nonirrigated treatment for the entire growing season. The irrigated treatment also flowered earlier than the nonirrigated treatment and the time required to reach final maturity was shortened. A reduction in time to reach maturity on the irrigated treatment, implies the presence of an environment stress since stress reduces the duration of vegetative development. The stress was imposed by high soil moisture as there was a three week period of rainfall during ripening (growth stage 5). For over one week, water covered this treatment. Flooding of soil results in anaerobic stress which brings about a reduced rate of transpiration and water absorption. This occurs because soil water is displaced with air causing a deficiency of oxygen and an accumulation of carbon dioxide. Either of these conditions can seriously damage the root system (Kramer and Jackson, 1953). Decreased water absorption results in chlorotic leaves. Flooding stops downward translocation of carbohydrates and auxins, which accumulate at the water line. Injury and death of the leaves also occurs by toxic substances moving up from the dead roots (Kramer, 1951). Yields can also be substantially reduced (Jones and Qualset, 1984). Yield, pod abortion, pods per plant and protein content were all reduced on the irrigated treatment, although the reduction was not significant. There were reductions in number of seeds per pod on this treatment compared to the nonirrigated treatment.

In 1986, although there were some differences between the irrigated and nonirrigated treatment for the amount of available water, it is likely that there were no sustained periods of moisture stress on the nonirrigated treatment. This was due to the high rainfall throughout the 1986 summer. Absence of stress was evidenced by the lack of significant differences between the two treatments for total water used and the absence of treatment differences for stomatal resistance. Significant differences between the treatments with respect to available moisture were reflected in the time required to reach first flower. Plants flowered in a shorter period of time on the nonirrigated treatment.

Lack of moisture stress resulted in similar overall yields between treatments. Although available moisture was not different between these treatments, the yield components pod per plant, seeds per pod, 1000 seed weight and yield were higher on the irrigated treatment. The percent pod abortion was lower. Differences were also noted between these two treatments for percent oil and protein. The irrigated treatment had a higher oil content and a lower protein content.

Irrigation has been shown to increase seed yield and yield components (Krogman and Hobbs, 1975, Richards and Thurling, 1978b, Clarke and Simpson, 1978b, Singh and Yusef, 1979). Oil content has also been shown to increase by irrigation (Krogman and Hobbs, 1975, Singh and Yusef, 1979). In this study, the yield of each cultivar was increased under irrigation, but this increase was not significant. In the 1986 growing season there was more available water on the irrigated treatment. However, the amount of available water used was quite similar for these treatments. It appears that there is an optimum amount of water used by rapeseed over the growing season. Any increases above this amount are not reflected in increases of yield or yield components. In particular the major yield component pod abortion was not significantly reduced on the irrigated treatment.

5.1.2 Early and Late Experiment

In 1985 there were no differences between the early and late treatments with respect to available moisture or total water used over the growing season. Days to first flower and maturity were considerably earlier on the late treatment. In Manitoba (Gross and Stefansson, 1966) and in Alberta (Kondra, 1976), late plantings of *B. napus* result in a decrease in days to maturity, decreased yield, and decreased oil content. The optimum planting date for rapeseed in Manitoba was indicated by Gross (1964) to be approximately May 8. In this experiment late planting had little effect on yield. There were no yield or yield component differences. However, yield, pod abortion and the yield components pods per plant and seeds per pod were higher on the early treatment. Oil content was not different on the two treatments, but protein content was higher on the early treatment. The primary motivation for early planting is to avoid the normally dry portion of the Prairie summer occuring from the time of flowering to harvest, as well as to avoid an early frost at the end of the growing season. However, the high rainfall of July and August eliminated the detrimental effects that would normally occur by a two week delay in planting.

In 1986 the late treatment was sown three weeks later than the early treatment, but due to the unusually high rainfall of July the available moisture on the later treatment was significantly greater than the early treatment. This difference was not reflected in the total water used over the two treatments, which was not significantly different. Days to first flower was reduced as a result of higher temperatures during ripening. Pod abortion was higher on the late treatment despite the higher available moisture. Harvest index, yield, and time to maturity were reduced. Oil content was also lower. This indicates a stress imposed on the late sowing likely due to the higher temperatures during flowering on the late treatment.

5.1.3 Portage Location

In 1985 the Portage location had a greater amount of available water than the nonirrigated early and late treatments, but there was less available water than on the irrigated treatment. The differences between the Portage treatment and the nonirrigated Point soils were due to the Portage soil having a higher silt content, which is the most important factor influencing available moisture for rapeseed (Thomas, 1984). In addition there was higher of precipitation at the Portage location compared to all Point treatments.

Day to first flower at the Portage location was earlier than the irrigated and nonirrigated treatments, and later than the late treatment in 1985 and 1986. Yield was higher on the Portage location than on any of the Point treatments. The number of pods per plant was higher than the irrigated and late treatments, seeds per pod was lower than on the early and late treatments, while there were few differences between locations for pod abortion. Oil content was lower on the Portage location, and protein content was higher. An increase in yield and yield components over the Point location was associated with ample available moisture coupled with rapid soil drainage. The Portage location was seeded one week later than the irrigated and nonirrigated treatments, and one week earlier than the late treatment. The time to maturity reflected these planting dates. Earlier seeded treatments took longer to reach maturity due to cooler temperatures early in the growing season.

In 1986 the Portage location did not have different available moisture compared to the three Point treatments, although the ranking between the four treatments showed that the Portage location had less available water than the irrigated and late treatment and more available water than the nonirrigated treatment. The Portage treatment did however use significantly more water than the Point treatments. This can be attributed to the greater moisture inputs and the high silt content of the soil.

The Portage location had a lower yield compared to the irrigated treatment, a higher number of pods per plant than the Point treatments, and fewer seeds per pod and 1000 seed weight than the Point treatments.

Pod abortion was lower compared to the late treatment, but not different from the irrigated and nonirrigated treatments. Harvest index was lower than the nonirrigated treatment, and higher compared to the late treatment. From these results, the higher precipitation and greater volume of water used at the Portage location had few, if any, positive effects on yield and the components of yield. Oil and protein content also remained unaffected by the greater volume of water used. Both quality components were intermediate compared to the Point treatments.

It appears that other environmental conditions such as different soil fertility levels were influencing these characters. The high volume of water used and the higher precipitation at the Portage location were not reflected in a prolonged maturation period or increased yields. It is also likely that the later planting dates had a detrimental effect on the time required to reach maturation.

5.2 COMPARISON BETWEEN CULTIVARS

5.2.1 Irrigated and Nonirrigated Experiment

In 1985, weekly comparisons between the irrigated and nonirrigated treatments indicated that there was a greater volume of available moisture on the irrigated treatment for every week measurements were taken. In 1986 there was significantly more available moisture on the irrigated treatment from the fifth through the sixth week after sowing. There was also an overall higher volume of available moisture on the irrigated treatment.

The greater volume of available water on the irrigated treatment was not reflected in differences in stomatal resistance. Cultivars Westar, Pivot, and Global were not significantly different from one another within or between treatments in 1985 and in 1986. These results were consistent with other works attempting to differentiate between drought resistant and drought susceptible cultivars. Dedio, Stewart and Green (1976) were unable to screen for drought resistance in wheat when measuring actual photosynthesis. Kaul (1969) also failed to find cultivar differences with regards to drought tolerance by measuring water potential of wheat. Harris, Schapaugh and Kanemasu (1984) attempted to screen soybean cultivars for drought resistance using leaf canopy temperatures. They were unable to do so. Their conclusions were that the use of such a technique in a breeding program was limited to years in which the evaporative demands are high and when water stress treatments can be imposed. This work also attempted to correlate canopy temperature deviations with yield, but no correlation were significant. It is therefore possible that the low overall temperatures of 1985 and 1986 combined with the unusually high rainfall resulted in low evaporation demands. Since there was little drought stress, even on the nonirrigated treatment, stomatal resistance measurements did not provide any indications of drought conditions in rapeseed cultivars brought about by either drought avoidance or drought tolerance. Stomatal resistance measurements did reflect drought or heat stress. The days of greatest stomatal resistance corresponded to periods when available water was low and temperatures were high.

In 1985 and 1986 Westar matured earlier than the other cultivars. Regent, Pivot, and Topas had intermediate maturity, while Global and Karat were late maturing. In 1985 irrigation did not affect the order of maturity of these cultivars. Early flowering cultivars flowered early regardless of larger quantities of available moisture. In 1986 however, irrigation lengthened the time required to reach maturity. This is consistent with previous work (Clark and Simpson, 1978b). Days to first flower did reflect the time required to reach full maturity, as suggested by Campbell and Kondra (1978).

In 1985 the early cultivars Westar and Pivot were high yielding, while the late cultivar Karat was the low yielding cultivar. There appears to be a yield disadvantage for those later maturing cultivars. Topas, Global and Karat are Swedish cultivars, but because Topas had quite high yields, the difference in yield is likely due to late maturity rather than pedigree.

On the nonirrigated treatment in 1985 there was a negative correlation between days to first flower and yield for the cultivar Westar, and a positive correlation for Pivot. There were no significant cultivar correlations for days to first flower and yield on the irrigated treatment. Campbell and Kondra (1978) found negative correlations between earliness of growth stages and vegetative yield, indicating that growth characters associated with early maturity were associated with higher yield. Correlations in this study varied with cultivars. Under stressed conditions Westar was high yielding and matured rapidly. This suggests that the high yields of Westar are due in part to drought avoidance. Pivot showed drought tolerance through yield increases when the time to reach maturity increased. The cultivars Karat and Global displayed yield component compensation on the nonirrigated treatment.

It was not possible to determine the positive effects of irrigation from this study. In 1985 the plant injury on the irrigated treatment due to flooding resulted in a yield decrease for each cultivar. In 1986 high rainfall maintained a high level of available moisture throughout the summer, eliminating the need to irrigate. Previous studies have indicated that yield increased with irrigation as did number of pods per plant, number of seeds per pod, 1000 seed weight (Krogman and Hobbs, 1975, Clarke and Simpson, 1978b).

The earlier cultivars Westar and Pivot had the highest oil content in 1985 while Global and Karat had the lowest. In 1986 Westar, Topas and Global had the highest oil content, while Karat and Regent had the lowest. There were no differences between the treatments for each cultivar.

In 1985 Regent and Pivot had higher oil contents on the irrigated treatment, although these differences were not significant. In 1986 oil content was significantly higher on the irrigated treatment for the cultivars Regent, Pivot, Global, and Topas. There were no significant differences for oil content between the two treatments for Westar and Topas, although oil content for both cultivars was marginally higher on the irrigated treatment. These results agree with the studies by Krogman and Hobbs (1975) and Singh and Yusef (1979) in which oil content was shown to increase under irrigation.

Negative correlations between days to first flower and percent oil content in 1985 indicated that oil content increased when the vegetative growth period lengthened.

Negative correlations were found between oil and protein content for the cultivars Regent, Pivot, Topas and Global on the nonirrigated treatment, and for Topas on the irrigated treatment in 1985. Topas therefore seems to be the cultivar most sensitive to environmental stress with respect to quality. Soil moisture on the nonirrigated treatment was below 70% of available moisture at field capacity during flower initiation, while soil moisture on the irrigated treatment was suboptimal during ripening. Stress on the nonirrigated treatment was more severe and occured at a more vital time in the plant's development.

In 1986 there was no moisture stress on either treatment. The only cultivar to show a negative correlation between the two components oil and protein, was Global on the irrigated treatment.

5.2.2 Early and Late Experiment

In 1985 there was no difference in available moisture between the early and late sowings. A seeding delay of two weeks on the late treatment meant that much of the soil moisture had evaporated. The high volume of available moisture on the late treatment was the result of the high precipitation throughout August. The early treatment had been harvested prior to the period of heavy precipitation in August. At this period, the late treatment was ripening. In 1986 during the two weeks prior to harvest there was more available moisture on the early treatment. There were no differences between the early and late treatment for the total volume of water used in 1985 or 1986.

In 1985 and 1986 Westar flowered significantly earlier than other cultivars on the early treatment. On the late treatment in 1985 Westar, Regent, Pivot and Topas flowered significantly earlier than Global and Karat. In 1986, only Global flowered significantly later than the five cultivars.

Delayed seeding significantly reduced the time required to flower and reach maturity for all cultivars in both seasons. This is consistent with the findings of earlier research (Gross and Stefansson, 1966).

Yield was not significantly different between the early and late treatments for each cultivar. An increase in growth rate brought about by delayed seeding did not significantly reduce the yield. Yield was highest in the earlier cultivars Pivot and Westar, and lowest in the late cultivar Karat. Harvest index was generally lower on the late treatment with the exception of Regent. In contrast, Global had a significantly lower harvest index on the late treatment indicating a higher yield in relation to total dry matter.

Delayed sowings increase the main stem contribution to seed production, the percent of damaged pods (Scarisbrick, Daniels, and Alcock, 1981) and the vegetative yield, but decrease harvest index and racemes per plant (Degenhardt and Kondra, 1981). Delayed seedings have been shown to reduce seed yield (Richards and Thurling, 1978b) which is attributed to the dry weight accumulation pattern in B. napus. Most of the dry weight accumulation occurs prior to flowering. A reduction in time to reach flowering effectively reduces the reserves accumulated by flowering that are used during pod filling. In this study the overall low temperatures and high precipitation throughout the growing season meant that the plants did not need to fall back on reserves in short supply. Had there been drought stress following flowering, the accumulated reserve would have been rapidly depleted.

Regent was the only cultivar to display a negative correlation between days to first flower and yield. The early maturation of the late treatment due to increased temperatures resulted in a yield loss for the cultivar Regent in both 1985 and 1986.

Westar had the highest pod abortion on both treatments in 1985 and 1986, as well as the highest number of seeds per pod and highest 1000 seed weight. This distribution resulted in high seed yields on both treatments in both years. Karat had the lowest yields in both years on both treatments. This was the result of lowest number of seeds per pod, a low 1000 seed weight, and a low harvest index.

Lower 1000 seed weights and lower pods per plant with delayed sowings agree with the results obtained by Scarisbrick, Daniels, and Alcock (1981), but disagrees with the results obtained by Degenhardt and Kondra (1981). In this study late seeding decreased pod abortion, decreased the number of pods per plant and 1000 seed weight for two of the six cultivars in 1986, but not 1985. The effects of delayed sowings appear to influence each cultivar differently, for example cultivars Westar and Topas were not affected. Care must therefore be taken when stating effects of delayed sowings since all cultivars are not affected in the same manner.

There were no negative correlations between number of seeds per pod and number of pods per plant found on the late treatment. This was quite unusual. Earlier maturity leads to a reduction in vegetative growth, which decreases the plant's photosynthetic area. There will therefore be a lower assimilate availability, leading to component compensation.

Protein content was generally highest in the cultivar Pivot. There appeared to be no gain in protein content at the loss of oil content for this cultivar. Global had the lowest protein content for both treatments in both seasons. Oil content significantly decreased with delayed seeding for cultivars Westar, Topas, Global and Karat in 1986. Protein content significantly increased with delayed seeding for Westar, Topas, and Global in 1986. These results are consistent with those of Gross and Stefansson (1966). They too found that oil content was negatively associated with date of planting, and that protein content varied, increasing or decreasing with delayed sowing, depending on the year.

There were significant negative interaction between these variables for the cultivars Westar, Topas, and Karat on the late treatment in both years. Of these cultivars, only Topas had a negative correlation on the early treatment in 1985. Karat and Topas seem to be particularly susceptible to quality component compensation when seedings are delayed. Negative correlations were also found in Westar, Pivot, and Global on the late treatment in 1985.

5.2.3 Portage Location

In 1985 the Portage location had a greater volume of available moisture, than the nonirrigated and late point treatments. Total water used reflected available moisture. Days to first flower was intermediate, as was yield. Component compensation occurred between pods/plant and seeds/pod for the cultivar Karat. In 1986 there were no significant differences between the Portage location and the three Point treatments with respect to available moisture, although the Portage location used significantly more water. The yield was lower and component compensation was more common for both yield and quality components.

Differences between 1985 and 1986 compared to the Point treatments are likely due to precipitation. In 1985 the Portage location received a minimum of 50 mm more precipitation than the Point treatments, but in 1986 the Portage location received only 6 mm more precipitation than the irrigated treatment. This suggests that increased precipitation increases yield and decreases the degree with which component compensation occurs.

In six of eight treatments over 1985 and 1986 the high yielding cultivars Westar and Pivot were characterized by a relatively high percent pod abortion while the yield components pods per plant and seeds per pod were high. Karat had a lower percent pod abortion and lower seeds per pod. In the two treatments (irrigated 1986 and Portage 1986) where Karat surpassed Westar in yield, the lower percent pod abortion contributed higher pods per plant and the other yield components.

Chapter VI

CONCLUSIONS

Flooding of the irrigated treatment in 1985 made it difficult to determine the effects of moisture stress on maturity, yield, and yield components of rapeseed. In 1986 irrigation was necessary only once early in the growing season, making it difficult once again to draw conclusions on the effects of moisture stress on six B. napus cultivars.

Although there was a greater volume of water on the irrigated treatment in both 1985 and 1986, stomatal resistance measurements did not indicate behavioral differences for cultivars with respect to drought stress or drought tolerance. The use of measurements such as stomatal resistance is limited, as are other measurements attempting to measure drought resistance through physiological parameters. These techniques are limited to years in which the evaporative demand is high, and when water stress can be imposed.

In this study there was a significant difference between the irrigated and nonirrigated treatment for the time to first flower. In 1986 irrigation caused a lengthening of the vegetative growth phases, which was reflected in a longer time required to reach maturity. A longer maturation period should increase the plant's ability to acquire photosynthates, which increases the plant's nutritional status, leading to yield increases. This however was not the case. There were no yield or yield component increases on the irrigated treatment. The plentiful water supply on the nonirrigated treatment did not result in lower nutrient availability.

Yield component compensation was found between number of seeds per pod and number of pods per plant for the late maturing cultivars Karat and Global.

In 1986 the higher available moisture on the irrigation treatment increased the oil content of the six cultivars, while protein content decreased. Negative correlations between oil and protein on both treatments indicates that compensation occurs between quality components.

High precipitation throughout the summer of 1985 resulted in no differences in available moisture or total water used between the early and late treatment. Unusually high precipitation during August 1986 led to a higher volume of available moisture on the late treatment, although there was no difference in the total volume of water used.

Delayed seedings reduced the time required to reach maturity in both 1985 and 1986. A shorter maturation period should have decreased the plant's nutritional status leading to yield decreases. This did not occur. There were no cultivar differences between the early and late treatments in either year. In 1986 the overall yield on the late treatment was reduced. Decreased yield occurred through an overall increase in pod abortion and a decrease in harvest index. There were no negative correlations between number of seeds per pod and number of pods per plant. The shorter maturation period did not substantially reduce the plant's nutritional status. Yield reductions did not occur, and there was no evidence of yield component compensation.

Delayed sowings did not affect yield components of each cultivar in the same manner. Previous studies involving three _B_. _napus_ cultivars (Scarisbrick, Daniels, and Alcock, 1981) and five _B_. _napus_ cultivars (Degenhardt and Kondra, 1981) reached opposing conclusions regarding the way in which delayed sowing influenced yield components. The six cultivars used in this study differed in their responses, and there was evidence to support both views.

Delayed sowings resulted in decreased oil content, while protein content increased or decreased, depending on the year and the cultivar. Negative correlations between oil and protein content occurred on the late sowing in both years for most cultivars. Quality component compensation occurred much more frequently with delayed sowings. The cause was a limited nutrient supply brought about by delayed sowing.

In 1985 the Portage location had less available moisture and used less water than the irrigated treatment, but there was a greater volume of available water and a greater volume of water used than on the early and late treatments. However this treatment had the highest yield and protein content, but lowest oil content. Days to reach first flower was relatively short, explaining the low oil content.

In 1986 the Portage location used a greater volume of water than the Point treatments. This was a result of the greater precipitation and the higher silt content of the Newhorst soil type. The yield, as well as oil and protein content, did not reflect the greater volume of water used. Differences in soil type contribute to differences in fertility, and climatic differences between the locations will affect the performance of the cultivars.

The results indicate that the later flowering cultivars tended to have a lower rate of pod abortion and a lower number of pods per plant. Seeds per pod and 1000 seed weight were, however, lower. Higher yields were found in cultivars Westar and Pivot. Component compensation among yield components occurred for all cultivars but no cultivar performed consistently with regard to which components showed compensation in response to different treatments.

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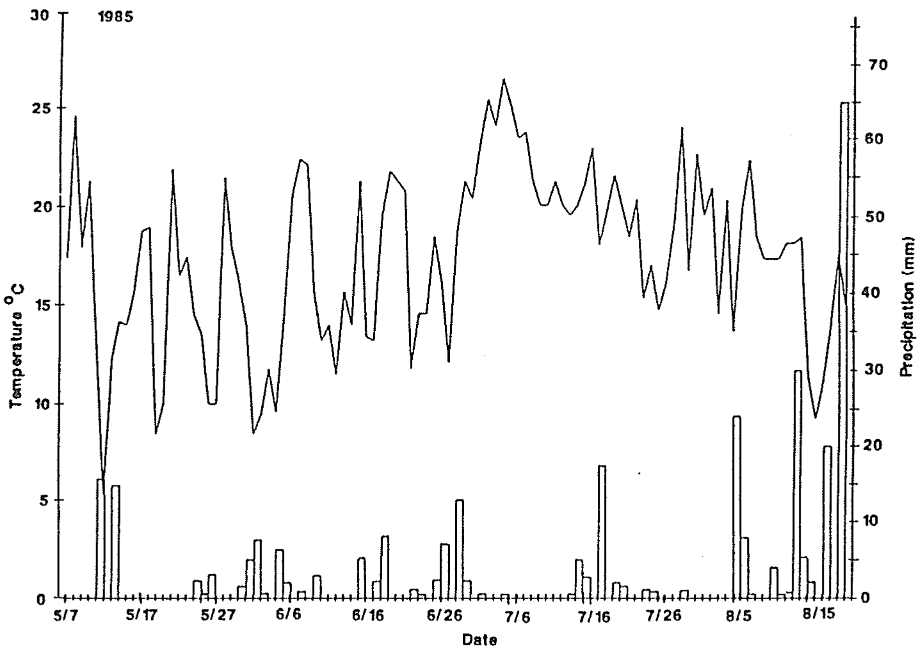
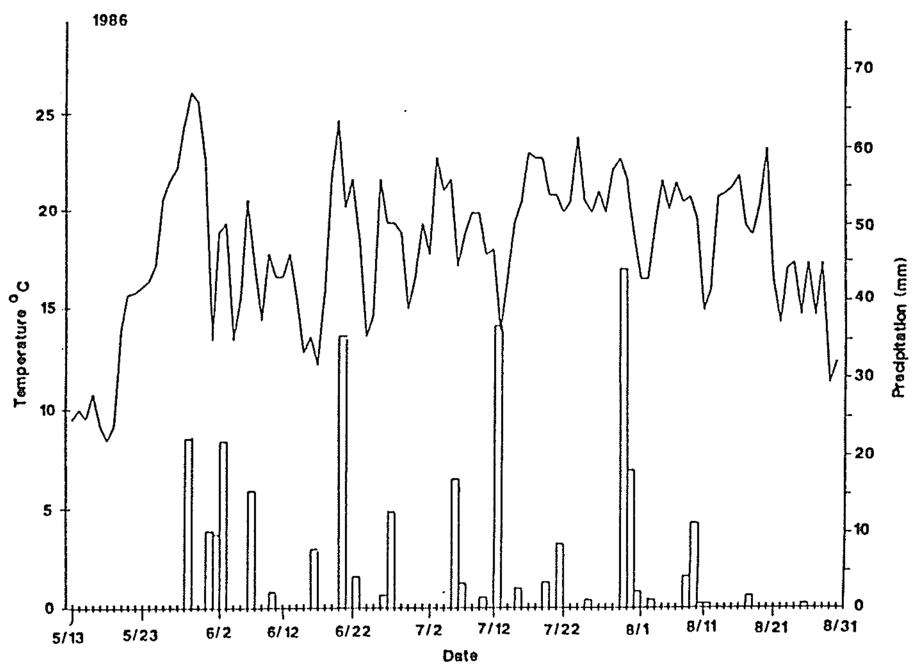
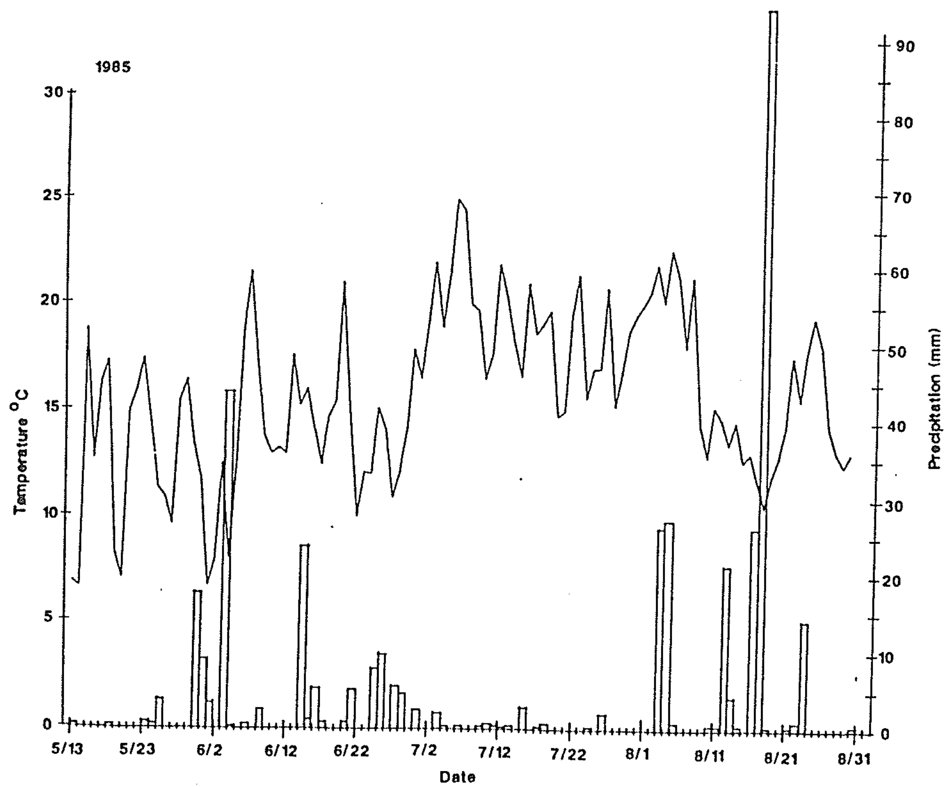
Chapter VII

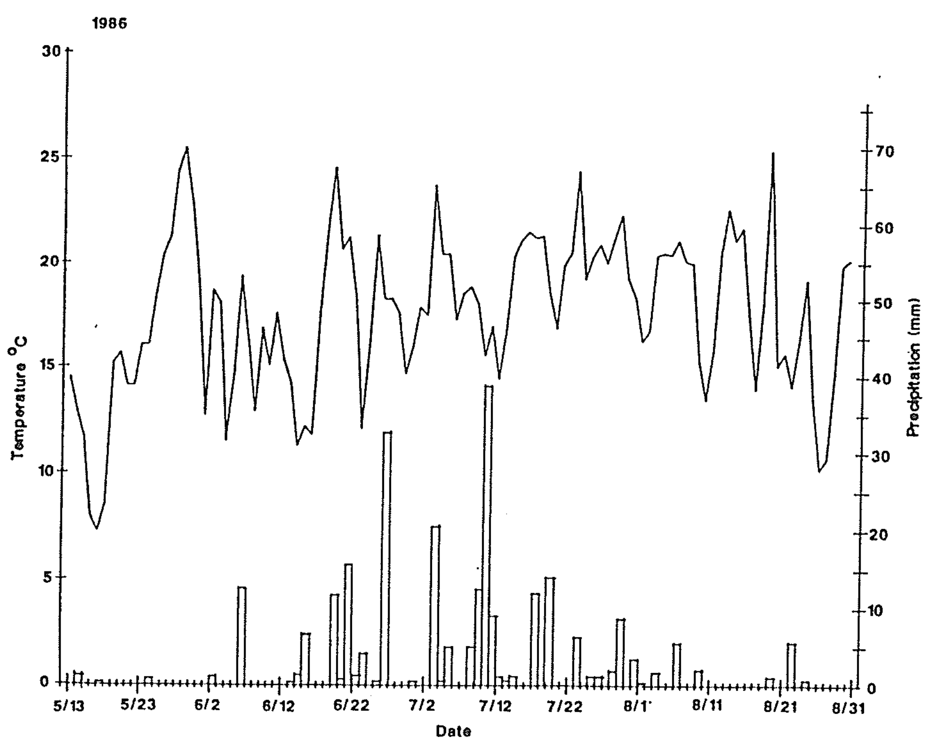
APPENDIX





Appendix Figure 1. Daily temperature and precipitation measurements at the Point location in 1985 and 1986.





Appendix Figure 2. Daily temperature and precipitation measurements at the Portage location in 1985 and 1986.

Appendix Table 1. Weekly available moisture for the nonirrigated (NI) and irrigated (I) treatments in 1985 and 1986.

	Available moisture (mm) 1985		Available moisture (mm) 1986	
Days after sowing	NI	I	NI	I
0	222 fgh	102 klmn	162 g	164 g
7	243 fgh	472 a	230 ef	165 g
14	194 ghij	450 ab	212 f	243 ef
21	188 ghij	380 bc	319 ab	271 bcde
28	172 hilk	389 bc	257 def	329 a
35	160 ijkl	355 cd	237 ef	310 abc
42	142 jkl	348 cd	233 ef	280 bcde
49	148 ijkl	328 cde	218 f	263 cdef
56	86 mno	337 cd	254 ef	247 ef
63	57 no	289 def	233 ef	272 bcde
70	47 no	281 def	281 bcde	246 ef
77	34 no	258 efg	259 def	305 abcd
84	119 jklm	374 bc		
91	128 jklm	375 bc		

Appendix Table 2. Weekly available moisture for the early (E) and late (L) treatments in 1985 and 1986.

	Available moisture (mm) 1985		Available moisture (mm) 1986	
Days after sowing	E	L	E	L
0	222 abc	93 jkl	162 k	163 k
7	243 a	189 bcde	230 ghij	242 efghij
14	194 bcd	228 ab	212 ij	244 efghij
21	188 bcde	197 abcd	319 ab	306 abc
28	172 def	185 bcde	257 defghi	294 bcd
35	160 defg	187 bcde	237 efghij	295 bcd
42	142 efgh	134 fghi	233 fghij	277 bcdef
49	148 defgh	109 ijk	218 hij	339 a
56	86 jkl	85 jkl	254 defghi	311 abc
63	57 lm	67 klm	233 fghij	269 cdefg
70	47 lm	161 defg	281 bcde	224 ghij
77	34 m	161 defg	259 defgh	200 jk
84	119 ghij	198 abcd		
91	128 fghij	223 abc		

Appendix Table 3. Weekly available moisture for the Portage location in 1985 and 1986.

Days after sowing	Available moisture (mm) 1985	Available moisture (mm) 1986
0	217 bcd	137 d
7	342 a	255 abc
14	341 a	301 a
21	330 a	263 abc
28	230 bc	274 ab
35	250 bc	294 a
42	256 b	259 abc
49	252 bc	296 a
56	214 bcd	291 a
63	196 cd	265 abc
70	173 d	248 abc
77	216 bcd	230 bc
84	245 bc	216 c
91	368 a	

Appendix Table 4. Weekly stomatal resistance measurements for the nonirrigated (NI) and irrigated (I) treatments in 1985 and 1986.

	Stomatal resistance (s/cm) 1985			Stomatal resistance (s/cm) 1986	
Days after sowing	1. NI	I	Days after sowing	2. NI	I
62	2.02 d	4.41 abc	52	1.75 bc	1.94 b
66	1.87 d	1.35 d	56	.84 de	.47 e
69	2.10 d	1.42 d	70	3.03 a	1.85 bc
73	1.47 d	2.06 d	73	1.21 cd	1.31 bcd
76	4.95 a	1.61 d			
80	2.86 bcd	2.49 cd			
83	4.65 ab	6.38 a			

Values followed by the same letter within 1 and 2 are not significantly different.