GROWTH RELATIONSHIPS AND YIELD OF *Brassica napus*

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ABSTRACT

A detailed analysis of the growth of *Brassica napus* L. was carried out under field conditions during 1975 and 1976 at Saskatoon, Canada. Plant morphology was altered by the use of four planting densities and three water regimes. A comparison of broadcast and drill seeding was also made, using four seeding rates.

The general growth pattern of *B. napus* was similar to that found in Britain and Australia. Both seeding rates and water regimes influenced the amount and distribution of dry matter. High seeding rates and non-irrigated conditions caused a greater proportion of dry matter production to occur prior to flowering. Low seeding rates and irrigated conditions caused greater dry matter production after flowering than before flowering. Leaf area index (LAI) reached a maximum at about the start of flowering. The LAI values recorded were higher than those reported for Britain and Australia.

Growth rates were similar to or slightly higher than those reported in Britain and Australia. There was an increase in the net assimilation rate (NAR) during ripening, which caused a concomitant increase in relative growth rate (RGR) and crop growth rate (CGR).

Seed yield was highest at the high seeding rates. Yield was also markedly increased by irrigation. High seeding rates reduced number of pods per plant but had no effect on number of seeds per pod, and increased 1000-seed weight. Irrigation increased all three yield components compared to rainfed conditions. 1000-seed weight was the only yield component which was positively correlated with yield.

Drill-seeded material out-yielded broadcast-seeded material. The difference was greatest at low seeding rates.

Seeding rates had no effect on seed oil content, but irrigation increased oil content. Seeding rates and water regimes had minor effects on the fatty acid composition of the oil in 1975, but no effect in 1976.

Maximum leaf area was positively correlated with seed yield, particularly in 1976. Leaf area was important during flowering, since leaves constituted the major source of assimilates at this time. The contribution of assimilates from leaves later in seed ripening depended on leaf area duration, which was strongly influenced by water regime.

Measurements of the pod photosynthetic surface area in 1975 showed that maximum pod area was similar in magnitude to maximum leaf area. In 1976, maximum pod area was less than maximum leaf area. Pod area per unit land area was increased by both irrigation and high seeding rates. Correlations between pod area and yield were low, particularly in 1976. Pod photosynthesis seemed to be the most important source of assimilates during the period when number of seeds per pod was established and also during seed filling. Plant and environmental conditions which enhanced assimilate supply during seed filling resulted in greater seed yield.

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I. INTRODUCTION

Rape has become an important alternative to the cereals in western Canada. It generally ranks as the fourth most important crop in terms of acreage, following wheat, barley and oats. *Brassica napus* has been seeded on about 35% of the rape acreage, *B. campestris* on about 65%.

During recent years, rape breeders in Canada have concentrated on improvement of the seed oil and meal quality. Advances in oil quality have been considerable. Improvements in meal quality can make this by-product useful in livestock feeds. To maintain the competitive position of rape in both domestic and world markets, it would be desirable to improve yield through breeding and development of improved management practices.

In recent years, growth analysis studies of *B. napus* have been conducted in Europe, Japan and Australia. These investigations have indicated the general growth patterns of *B. napus* in those environments, and have suggested the importance of pods as photosynthetic organs. Thus far, however, the contributions of the various stages of growth and plant parts to seed yield have not been pin-pointed. Also, there is a lack of information on the effects of environmental conditions on the growth and yield of *B. napus* in Canada.

The objective was first to determine the growth pattern of *B. napus* using appropriate growth analysis techniques, and secondly, to determine the plant growth phases and morphological features influencing the seed yield of the crop under varying environmental conditions.

2. LITERATURE REVIEW

2.1 Quantitative analysis of growth

2.1.1 General concepts

The concepts and techniques of growth analysis were developed in Britain during the period 1919-1952 as a means of quantitatively describing plant growth. Measurements of the change of plant dry weight and leaf area with time are made, from which growth functions can be calculated. These are leaf area index (LAI), leaf area ratio (LAR), relative growth rate (RGR), net assimilation rate (NAR) and crop growth rate (CGR). LAI, introduced by Watson (1947), has become the most commonly used term in the description of leaf canopies. LAI is the unit leaf area per unit soil area.

NAR is defined as the increase of plant material per unit of assimilatory material per unit of time, described mathematically as follows (Radford 1967):

$$NAR = \frac{1}{A}\frac{dW}{dt} \qquad (2.1)$$

(A = leaf area, W = dry weight, t = time) or, for mean NAR between two harvests

$$\overline{NAR} = \frac{W_2 - W_1}{A_2 - A_1} \; \frac{(\log_e A_2 - \log_e A_1)}{t_2 - t_1} \qquad (2.2)$$

Equation 2.2 can be used if A and W are linearly related from t_1 to t_2 and if A and W are not discontinuous functions of time. Radford (1967) presents alternate equations for $\overline{NAR}$ for different A vs W relationships.

Relative growth rate at an instant in time is defined as the increase of plant material per unit of material present per unit of time:

$$RGR = \frac{1}{W}\frac{dW}{dt} \qquad (2.3)$$

and mean RGR is given as:

$$\overline{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \qquad (2.4)$$

The only assumption necessary for the use of equation 2.4 is that W varies without discontinuity throughout the period t_1 to t_2 (Radford 1967).

Crop growth rate at any instant in time is defined as the increase of plant material per unit of time.

$$CGR = \frac{dW}{dt} \qquad (2.5)$$

and mean CGR,
$$\overline{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \qquad (2.6)$$

The use of equation 2.6 requires that W varies without discontinuity from t_1 to t_2.

The leaf area ratio at an instant in time is the ratio of the assimilatory material per unit of plant material present:

$$LAR = \frac{A}{W} \qquad (2.7)$$

Radford (1967) does not recommend calculating mean LAR, since it requires assumptions which are normally not met. He suggests calculation of LAR values for each harvest time.

Equations 2.2, 2.4 and 2.6 are referred to as the classical equations of growth analysis. Vernon and Allison (1963) pioneered an alternate method of calculating the derived growth functions NAR, RGR and LAR. This method involves the determination of the relationship between W and t and A and t using curvilinear regression techniques. NAR, RGR and LAR can then be derived from the equation of the two curves. The use of this method overcomes the assumptions required for the use of the classical equation, and there is no need for arbitrary pairing of samples from the harvest at t_1 with those at t_2 (Radford 1967). The regression technique can reduce variability resulting from sampling error. However, as Buttery and Buzzell (1974) point out, legitimate variation due to changing environmental conditions can also be obscured. They stress the need for carefully choosing the polynomial which best fits the data, since bias can be introduced if the equation is not an accurate representation of the growth of the plant.

2.1.2 Analysis of the growth of rape

There have been relatively few detailed studies of the growth pattern of rape. This lack of information has recently prompted investigation in Britain, Australia and Canada. *B. napus* has been extensively studied in Britain. Preliminary studies of the growth of *B. napus* and *B. campestris* have been made in Australia, and of *B. campestris* in Canada.

Allen and Morgan (1972) found that the total plant dry weight of two *B. napus* cultivars increased in a linear fashion until just before maturity. Leaf area increased rapidly to a maximum near the onset of flowering, and then rapidly declined. A similar pattern of growth was reported by Thurling (1974) in Australia. The growth patterns of *B. campestris* appear to be similar (Thurling 1974a; Krogman and Hobbs 1975).

NAR of the *B. napus* cultivars studied by Allen and Morgan (1972) was high in the seeding stage, and declined with age. CGR followed a similar pattern, although the results were very erratic later in development.

Thurling (1974a) found that about 50% of the total plant dry matter of several *B. napus* varieties was accumulated before anthesis. In winter varieties, Mendham and Scott (1975) found that the plant size at floral initiation had an important bearing on the final seed yield. The cultivars studied by Allen and Morgan (1972, 1975) accumulated 30-40% of their total dry matter before anthesis. Tayo and Morgan (1975) found that dry matter accumulation before and after anthesis were of the same order.

Since total plant dry matter continued to increase after flowering in spite of rapidly declining leaf area, Allen and Morgan (1972) suggested that pods were a major source of assimilates during the post-anthesis period. The role of pods in the yielding ability of several *B. campestris* (Brown Sarson) varieties was investigated by Maiti *et al.* (1970). High correlations between pod surface area and yield were found. Shading of pods reduced seed weight per pod by 68 to 100%. Tayo and Morgan (1975) report that *B. napus* grown under controlled-environment conditions developed a maximum pod surface area comparable in magnitude to the maximum leaf area. Similar results have been reported for field-grown *B. campestris* (Krogman and Hobbs 1975).

Major (1975) studied stomatal distribution and frequency in *B. campestris* var. Span and *B. napus* var. Zephyr. He suggested that there is potential for CO_2 assimilation in pods, beaks, stems and pedicels as well as in leaves. Major and Charnetski (1976) fed $C^{14}O_2$ to field grown *B. napus* during the late flowering phase. Leaves, stems, pods and beaks were found to be capable of assimilating $C^{14}O_2$, but only leaves and stems were found to export assimilates. Roots, pods, seeds, beaks and barren pods acted as sinks. Proximity of the sink to a source influenced the amounts of accumulated labelled assimilates. Hozyo *et al*. (1972) found that when $C^{14}O_2$ was fed to developing *B. napus* pods, the C^{14} photosynthates accumulated in greatest concentration in the seed.

Net photosynthetic rates of *B. napus* pods and leaves were the same during the early phase of ripening (Hozyo *et al*. 1972). The rate in leaves dropped rapidly to zero as ripening proceeded, while that of pods dropped much more slowly. Inanga and Kumara (1974) reported a similar pattern in a field-grown winter *B. napus*. Photosynthesis of the whole plant reached its maximum slightly after maximum LAI was reached. This coincided with the maximum photosynthetic rate of the stem and pod fraction, which at this point constituted 76% of the whole plant rate. The pod and stem photosynthetic rate declined rapidly after this, despite a continued increase in pod surface area. The rate at which plant dry matter accumulated decreased as the photosynthetic rate declined.

Environmental factors were found to influence growth patterns and the derived growth functions of rape and other crops. Allen and Morgan (1972) found that nitrogen increased dry matter production, LAI, and CGR, but decreased NAR of *B. napus*. Krogman and Hobbs (1975) found that irrigation increased leaf area and pod area of *B. campestris*. Plant densities were shown to affect CGR in *Zea mays* L. (Takeda and Akiyama 1973) and NAR and RGR in *Glycine max* L. (Buttery 1969).

2.2 Effect of water regime on rape

2.2.1 Water deficits

In a pot trial in Poland investigating the effects of water deficits on *B. napus*, it was found that water deficits reduced the growth rate and prolonged the rosette phase of growth (Domanska 1958). The plants showed rapid growth after removal of stress conditions, even after two months with soil moisture at 10% of field capacity. Water deficit during flowering and ripening reduced numbers of branches and pods and seed yield, but increased seed size of winter rape grown in pots (Dembinska, 1970). Water deficit during the flowering period produced a similar result. Drought during maturation reduced yield and seed size, although the reduction in seed size was not significant. In spring rape, Jakubowski (1956) reported that drought before flowering had no effect on yield. Drought during flowering and ripening, however, caused reductions in yield of seed and straw, pod numbers, pod size and seed oil content. The drought also shortened the length of the ripening phase.

Mingeau (1974) studied the effect of drought at various stages of development on the spring rape variety Cresus. Drought during the stem elongation and early flowering phases caused a significant reduction in root and stem dry matter. Seed yield was reduced most by drought during flowering and early seed formation. The drought treatments had no effect on leaf dry weight or pod dry weight, although pod numbers were reduced by water stress at late flowering. At this stage there was also a reduction in the number of seeds per pod. 1000-seed weight was reduced by water stress after flowering. Stress at late flowering caused the greatest reduction in pod number and seeds per pod but increased the 1000-seed weight by 16% over that of the non-stressed control.

2.2.2 Irrigation

Decau *et al.* (1973) found that 30 mm of irrigation increased seed yield, seed weight and number of seeds per unit area, but decreased harvest index of *B. napus*: there was no effect on seed oil content. In a greenhouse trial, however, Nuttall (1973) found that oil content of *B. napus* was highest at high soil moisture levels. Krogman and Hobbs (1975) investigated the effects of irrigation on growth from seeding until either stem elongation, early pod formation or pod ripening of *B. campestris*. The irrigation treatments produced progressively more dry matter and increased the leaf area duration compared with non-irrigated plants. Irrigation until early pod formation or pod ripening increased the number of pods per plant, seeds per pod and 1000-seed weight, as compared to the control. Oil content was increased through irrigation up to maturity in two of three years.

2.3 Effect of plant density on rape

In winter *B. napus* grown in Denmark, Larsen and Nordestgard (1971) found no significant differences in seed yield when seeded at 4 or 8 kg/ha. Seed oil and protein content and seed weight were not affected. In addition, row spacings of 50 and 12 cm with a seeding rate of 4 kg/ha were studied. There were no significant differences in yield when weeds were controlled by cultivation in the wide rows. Seed oil content was lower and protein content higher in the 50 cm than in the 12 cm row spacing. Vulliourd (1974) studied the effects of row spacings and seeding rates on winter *B. napus* in Switzerland. Seeding rates of 3, 4, 6, 8, 12 and 16 kg/ha were evaluated for two seasons. Seed yields were highest in the 3-6 kg/ha range. Yields were reduced by as much as 9% at the 12 and 16 kg/ha rate. Lodging was increased at the higher seeding rates. Row spacings of 18 to 40 cm gave similar yields, although the wider rows produced taller plants due to the high intra-row competition. Both seeding rates and row spacings influenced branching, pod number and seeds/pod. Vulliourd concluded that although high yields could be obtained by low seeding rates, the thin stands afforded less competition against weeds. He suggested that seeding rates of 6-8 kg/ha would be preferable.

In Sweden, Ohlsson (1971, 1972) investigated the effects of row spacing and seeding rate on summer rape and summer turnip rape. For _B. napus_, seeding rates of 5, 10 and 20 kg/ha and row spacings of 12, 24 and 48 cm were used. The yield and content of oil was highest at the 20 kg/ha seeding rate planted in 12 cm rows. Oil yield tended to decrease as row spacing was increased, particularly at the high seeding rate. Oil yield of _B. campestris_ was highest at 8 kg/ha in 12 cm rows. In both species, the higher population densities matured earlier.

Helps (1971) studied the effect of seeding rates of 3.4, 6.6 and 10 kg/ha and two seeding methods - drilled in 56 cm rows vs. broadcast - on a _B. napus_ variety in Britain. In drilled rows, the 6.6 and 10 kg/ha rates outyielded the 3.4 kg rate and also had a higher seed oil content. The yield of the broadcast material changed less with seeding rate. Oil content was highest at the low seeding rate. Seed yield and oil content was higher in the broadcast than in the drilled material. Helps concluded that broadcasting at 6 kg/ha was the most suitable practice.

Dhinsda _et al_. (1973) compared row spacings of 30 and 45 cm in irrigated _B. campestris_. Seed yield and oil content were significantly higher in 30 cm rows. Protein content was not affected by row spacing.

Relatively few reports on the effects of seeding rates and row spacings on rape are available in Canada. Downey et al. (1974) recommended seeding rates of 4-6 pounds per acre (4.5 - 6.6 kg/ha) for both B. napus and B. campestris. They reported that in B. campestris, seeding rates between 2.2 and 11.2 kg/ha had no significant affect on seed yield. Kondra (1975) studied the effects of row spacings of 15, 23, 31 and 61 cm and seeding rates of 3, 6 and 12 kg/ha on B. napus var. Zephyr. The narrowest row spacing (15 cm) and the 6 kg/ha seeding rate produced the highest yields. There was no significant effect on oil or protein content. Kondra also found that B. campestris var. Span yielded best at a row spacing of 15 cm and a seeding rate of 2 kg/ha. Oil content was highest at the narrow row spacing. Increased seeding rates tended to reduce oil content. Protein content of the seed was not affected by row spacings or seeding rates. High seeding rates caused increased lodging in both cultivars.

2.4 Factors affecting fatty acid composition of rape oil

Plants grown at lower temperatures tend to produce more highly unsaturated fats than when grown at higher temperatures. This was demonstrated in B. napus by Canvin (1965), who found increasing temperature resulted in reductions in the more highly unsaturated fatty acids and an increase in oleic acid.

In a study of B. napus and B. campestris varieties grown at 7 locations in western Canada, Craig and Wetter (1959) found that varietal differences in fatty acid composition were greater than environmental differences. Gross and Stefansson (1966) reported that delays in planting date of B. napus resulted in a decrease in oil content and an increase in linoleic and linolenic acid content.

The fatty acid compostion of rapeseed oil has also been shown to vary during seed development. Sims (1964) found that in *B. napus* var. Golden, the proportions of oleic and linoleic acids decreased after flowering, while linolenic and erucic acids increased. In zero-erucic material, oleic acid content increased to maturity. Fowler and Downey (1970) reported that relative proportion of oleic acid content increased while that of linoleic and linolenic acid content decreased with increasing maturity in both normal and low-erucic *B. napus*. Similar results were found by Norton and Harris (1975) in a winter variety of *B. napus*.

Bechyne and Kondra (1970) reported that the location of the pod on the plant significantly affected fatty acid composition of *B. campestris* and *B. napus* grown in a controlled environment room but not when grown in the field. In the *B. napus* variety Nugget, linolenic acid content was significantly higher in seeds from pods on the lower branches than in seeds from the main raceme. Erucic acid was significantly lower in seed from lower branches.

Mingeau (1974) investigated the effects of drought treatments at various stages of plant growth on the fatty acid composition of *B. napus* oil. Plants which received drought treatments during early ripening had almost twice as much oleic acid as the control when sampled after 14 days of treatment. Linoleic acid was slightly higher, and linolenic acid slightly lower than the control. The level of erucic acid of the treated plants was about half that of the control: application of the drought treatment at later stages of ripening resulted in progressively less effect. At maturity, the fatty acid composition of plants which had received drought treatments during growth differed little from the non-stressed controls.

2.5 Yield components of rape

2.5.1 Number of pods

Olsson (1960) suggested that since high correlations are observed between number of pods and plant yield, pod number must be strongly influenced by the environment. In a greenhouse study of *B. napus*, Tayo and Morgan (1975) found that only about 45% of the flowers which opened developed pods which developed to maturity. Most of the pods which matured developed from flowers which opened during the early flowering period. They suggested that the ability of the plant to supply assimilates to the inflorescence was of critical importance in establishing the potential number of pods. This could indicate that plant size and leaf area at anthesis are very important in determining yield.

Differences in pod numbers between genotypes have been observed. Allen and Morgan (1975) reported that of four *B. napus* cultivars studied, the highest yielder had a higher number of pods per plant. Similarly, Thurling (1974b) found slight differences in pod number between varieties in both *B. napus* and *B. campestris*. These differences may have reflected differences in response of the varieties to environmental factors affecting some character other than number of pods.

2.5.2 Seeds per pod

Olsson (1960) suggested that number of seeds per pod is not much influenced by environment, but can be changed by selection. Change by selection has been demonstrated in *Sinapis alba* (Olsson 1974). Allen and Morgan (1972, 1975) demonstrated both environmental and genotypic variation in number of seeds per pod in _B. napus_. Krogman and Hobbs (1975) found that irrigation increased seeds per pod in _B. campestris_. Thurling (1974b) noted variation in number of seeds per pod of _B. campestris_ and _B. napus_ varieties.

As pods develop, environmental factors do influence the number of seeds developing in each pod. Mendham and Scott (1975) reported a progressive decline in number of seeds per pod as winter _B. napus_ approached maturity. In another study of winter _B. napus_, Norton and Harris (1975) found that pods initially contained 18-19 seeds. The number declined rapidly to 9 during early pod growth, and was 7 at maturity.

2.5.3 Seed weight

Olsson (1960) considered 1000-seed weight to be much less influenced by environment than number of pods, suggesting that selection for seed size would be effective. Thurling (1974b) demonstrated differences in 1000-seed weight between varieties of _B. napus_ and _B. campestris_. Krogman and Hobbs (1975) found that irrigation increased 1000-seed weight of the _B. campestris_ variety Span.

2.5.4 Yield component compensation

Adams (1967) has suggested that the negative correlations between yield components which are widespread among crop plants are a reflection of yield component compensation. Adams and Grafius (1971) suggest that the balance among components of yield is achieved through the oscillatory response to environmental stress of sequentially developing components. In rapeseed, the effect of low pod number can be offset by changes in number of seeds per pod or by changes in seed weight. Thurling (1974b) found highly significant negative correlations between pod number and seeds per pod in both *B. campestris* and *B. napus*. There was also a highly significant negative correlation between pod number and seed weight in *B. campestris* but not in *B. napus*. 1000-seed weight was strongly negatively correlated with number of pods in *B. campestris* but not in *B. napus*.

3. MATERIALS AND METHODS

3.1 General procedure

3.1.1 Design of experiments

One field experiment was conducted in 1975, and three in 1976. These experiments investigated the effects of irrigation and seeding rate on growth and yield, the effects of seeding method and seeding rate on yield, and the effects of defoliation on the yield of *B. napus* var. Tower.

The experiment investigating the effects of irrigation and seeding rate on growth and yield was conducted over two years (1975 and 1976). The experiments were laid out in a split-plot in randomized complete block design, with four replications in 1975 and six in 1976. The three main plots (rainfed, low irrigation, high irrigation) were assigned non-randomly across all replications. The main plots were separated by 15 m to allow for sprinkler irrigation. Sub-plots (seeding rates) were assigned randomly within replicates. Each sub-plot was 4.9 x 4.9 m.

The investigation of the effect of seeding method and rate was undertaken in 1976. This experiment was laid out as a split-plot, with the main plots arranged in a 2 x 3 factorial (seeding methods and fertilizer rates) and six replications. The sub-plots (seeding rates) were 1.2 x 4.9 m.

The defoliation experiment was carried out in 1976. Treatments were laid out in a split-plot in randomized block design, with four replications. Whole plots (seeding rates) were assigned randomly within replications. Sub-plots (time of defoliation) were assigned randomly within the main plots. Each sub-plot consisted of two 4.9 m rows spaced 30 cm apart.

3.1.2 Location

Both the 1975 and 1976 field trials were conducted in the Investigations Field of the Department of Crop Science, University of Saskatchewan. The soil belonged to the Tuxford Soil Association and consisted of a silty clay loam overlying a silty clay. All experiments were seeded on land which had been summerfallowed one year. Soil tests indicated high levels of available N, P and K in both years.

3.1.3 Seeding methods and rates

A powered 4-row (30 cm spacing) v-belt seeder was used to seed all experiments. The seed for each row was individually packaged to provide the appropriate seeding rate. Seed was treated with carbofuran granules (1975) or lindane/captan powder (1976) to control flea beetles.

The seeder was equipped with double-disc furrow openers, which were used for the drilled seedings. Broadcast seedings were made with the same seeder, using a deflector attachment in place of each of the disc furrow openers. A 1.2 m wide section of tine harrows was mounted behind the deflectors to cover the seed. Both the deflectors and the tine harrows could be raised and lowered by the furrow opener lift mechanism.

The irrigation/seeding rate experiment was broadcast-seeded at rates of 2.5, 5, 10 and 20 kg/ha in both years. In the 1976 seeding methods and rates experiment, broadcast and drilled seedings of 2.5, 5, 10, and 20 kg/ha were included. The defoliation experiment was drill-seeded at rates of 5 and 20 kg/ha.

The 1975 experiment was seeded May 12. The 1976 experiments were seeded May 8-10, with the exception of the defoliation experiment, which was seeded May 27.

3.1.4 Fertilizer rates

On the basis of soil test recommendations, 44 kg/ha of 11-48-0 (ammonium phosphate) fertilizer was applied to all experiments, with the exception of the 1976 seeding methods/rates experiment. In this latter experiment, rates of 0, 45 and 90 kg/ha 11-48-0 were applied. In all cases the fertilizer for each row was individually packaged and spread on the seeder belts with the seed at the time of seeding.

3.1.5 Irrigation

Irrigation water was applied with sprinklers set on a 12 x 12 m grid. In 1975, the irrigations were scheduled by the use of tensiometers to estimate soil water tension. For the high irrigation treatment, water was applied when the tensiometer reading (average of eight instruments) at 20 cm depth reached -0.5 bar. In the low irrigation treatment, water was applied when the reading of instruments placed at a 40 cm depth gave a reading of -0.5 bar. In 1976, irrigations were scheduled on the basis of leaf osmotic potential measurements. Water was applied when osmotic potential dropped below -10.5 bars (high irrigation) or -12.5 bars (low irrigation). It was not possible to follow a strict irrigation schedule due to unavilability of irrigation equipment and occasional periods of windy weather.

3.1.6 Osmotic potential measurements

Osmotic potential measurements of leaf cell sap were made on material from the irrigation/seeding rates experiment in 1975 and 1976. Measurements were started in early June of each year. For each sub-plot treatment (seeding rate) 1-2 leaves were taken from each replication and bulked in a 20 cc disposable syringe with a plug of glass wool in the bottom of the barrel. In all cases, the leaves selected were the newest fully expanded leaves on the plant. The samples in the syringes were frozen and then thawed to rupture the leaf cells. Sap was expressed by pressing the plunger of the syringe. The glass wool served to strain the leaf tissue from the sap. Osmotic potential of the sap was determined with a cryoscopic osmometer (Knauer, Berlin) in 1975 and a vapour pressure osmometer (Model 5130, Wescor Inc., Logan, Utah) in 1976.

3.2 Quantitative analysis of growth

3.2.1 Sampling procedure

The plant material for the growth measurements was obtained from the 1975 and 1976 irrigation/seeding rates experiment. After the plants had emerged, each 4.9 x 4.9 m sub-plot was divided into areas for growth analysis sampling and for seed yield determination. In 1975, fifteen 0.5 x 0.5 m sites were designated for growth analysis sampling, and marked with a 30 cm wooden peg in one corner. Six-cm strips of fluorescent orange plastic tape were stapled to the top of each peg to make them easier to find as the crop grew larger. A 0.6 x 4.4 m area was left on one side of each sub-plot for seed yield determination. In 1976, there were 10 growth analysis sites, five on each side of a 1.2 x 4.9 m strip left for seed yield determination. In both years all sampling sites were bordered by 0.5 m of discard area.

Sampling was started 2-3 weeks after emergence. In 1975, samples were taken at five day intervals during the first part of the season, and at seven day intervals for the last few harvests. Throughout the 1976 season samples were taken at seven day intervals. In both years sampling was continued to within two weeks of harvest. Prior to the start of each season's sampling, sample numbers were randomly assigned to each available sampling site. At each sampling time, the designated site was located, and a 0.5 x 0.5 m metal quadrat with 90 cm adjustable legs was put down next to the peg. All plants within the quadrat were cut at the soil level and placed in labelled plastic bags for transport to the laboratory. In 1975 and early 1976 it was possible to complete all sampling and measuring in one day. During the later part of the 1976 season, however, it was necessary to spread the sampling and measuring over two days.

In 1975, all of the plants in the cut samples were counted, and 10 withdrawn from each for leaf area determination. The remainder, or a representative portion, was used for dry weight measurements. In 1976, total fresh weight of each sample was determined, and 1/3 to 2/3 was sub-sampled for the leaf area and dry weight determinations. The number of plants in each sample was counted on three occasions during the season to determine the stand density of the crop.

3.2.2 Leaf area determinations

Leaf area was measured with an electronic planimeter with a continuous belt feed (Model LI 3000, Lambda Instruments Corp., Lincoln, Nebraska). Leaves which were greater than 50% necrotic or yellowed were not included in the measurements. The cotyledons were included in the leaf area measurements. The area-meter belts were cleaned frequently, and after each sample if the leaf material was wet.

Total leaf area per 0.25 m^2 was calculated on the basis of plant numbers in 1975. In 1976, it was calculated using the specific leaf area (cm^2/g) and total leaf dry weight per 0.25 m^2. Leaf area duration after flowering was calculated by integrating the LAI with respect to time from 10% flowering until leaf area had dropped to zero.

3.2.3 Dry matter determinations

In 1975, dry matter determinations were made on 5-10 whole plants at each sampling, with the exception of the July 11 harvest. On this date the plant components (stem, leaf, pod) were dried separately. In 1976, the plant components were dried separately throughout the season. In both years, a final determination of dry weight of the plant components was made just prior to harvest. After drying, the pod samples were threshed and the seed weighed. All dry matter samples were dried for 24 h at 100°C in forced-air ovens. The dry weight values of the subsamples were converted to values per 0.25 m^2 quadrat on the basis of plant number (1975) or dry matter percentage (1976).

3.2.4 Pod area

The initial measurement of pod area was made in 1975 immediately after the cessation of flowering. Pod area should have been at or near its maximum at this time, since most pods which mature are produced during the early flowering period (Tayo and Morgan, 1975). Six plants were pulled from the border regions of each sub-plot. The number of pods on each plant was counted, and 10 pods were removed from the mid-sections of the main inflorescence and the primary branches. The pods were placed in labelled envelopes and refrigerated until measurements could be made (usually within 24 h). Pod diameter and length (from the base to 1/3 of the way up the beak) were measured with a vernier caliper.

Several measurements of pod area were made during the 1976 experiment starting one week after flowering and continuing to the assumed maximum pod area at the end of flowering. Ten pods were randomly selected from each of the six replicates of each plant-density subplot. Diameter and length of each of these 60 pods were determined and the pods were dried individually in labelled envelopes (24 h at 100^{o}C). After drying, the pods were weighed to the nearest 0.001 g.

Pod areas were calculated as the surface area of a cylinder (including the ends) of like dimensions. Similar methods of measurement of rape pods have been used by Tayo and Morgan (1975) and Krogman and Hobbs (1975). In 1975, pod area per 0.25 m^2 quadrat was calculated for each treatment on the basis of the mean pod area, the number of pods per plant, and the number of plants per 0.25 m^2. In 1976 a linear regression through the origin of pod area on pod weight was calculated for each treatment. Pod area per 0.25 m^2 was then calculated using the appropriate regression equation and the dry weight of pods per 0.25 m^2 as determined from the growth analysis samples.

3.2.5 Defoliation

The treatments consisted of two times of defoliation - at 10% flowering and at the end of flowering. All leaves were hand-stripped from the plants. Growth analysis samples were taken from 1240 cm^2 quadrats as described above. Samples were taken at approximately two week intervals until maturity.

3.3 Yield and yield components

3.3.1 Sampling procedure

In the irrigation/seeding rate experiments of 1975 and 1976, the plants in a 0.25 m^2 quadrat were cut at ground level at maturity. A sub-sample of 10 plants was withdrawn for yield component determinations. Yield components were studied on 10 plants pulled randomly from border areas in the 1976 defoliation experiment. For the seeding methods/rates experiment, 10 plants were pulled from the yield area. In all experiments (1975, 1976), the 10 plant samples were separated into stem and pod fractions, dried and weighed. The pods were then threshed and the weight of seed determined.

3.3.2 Branch and pod numbers

Branch numbers were counted on all 10 plants in all experiments. The main raceme was included in the counts. Only branches bearing more than two seed-containing pods were counted. The numbers were recorded for each plant, and a plot mean calculated from these.

All pods which contained seeds were counted on the 10 plants. The observed pod numbers on each plant were recorded, and the totals and means calculated.

3.3.3 Number of seeds per pod

For the 1975 experiments, 10 pods were removed from the mid-sections of the racemes of each of 10 plants and initially placed in labelled envelopes. Later they were hand-threshed and the number of seeds per pod recorded. In 1976 the number of seeds per pod was determined indirectly by calculation from the number of pods per 10 plants, the weight of seed per 10 plants and the weight per seed.

3.3.4 Seed weight

In all experiments weight of 1000 seeds was calculated from the weight of 250 hand-counted seeds. These seeds were randomly drawn from the bulk seed yield samples from each plot.

3.3.5 Seed weight-pod position study

Four-plant samples were withdrawn from each of the six replications of the 5 and 20 kg/ha seeding rates of the low irrigation treatment of the 1976 irrigation/seeding rate experiment. Plants with three branches in addition to the main raceme were sampled from the 5 kg/ha rate, and plants with one branch from the 20 kg/ha rate. The number of pods on each branch was counted and recorded. Branch positions were then designated within the groups of plant sizes. Each main raceme was divided in half, with the upper half being numbered as position 1, the lower as position 2. Each subtending branch down the stem was numbered as a specific position. The 5 kg/ha rate had five positions in total; the 20 kg rate had three.

Five pods were removed from each branch position and placed in labelled envelopes. These samples were later hand- threshed, and the number of seeds per pod counted. Sub-samples of 50 seeds were weighed to the nearest 0.001 g, and from these, weights per seed were calculated.

3.3.6 Seed yield

The 1975 experiment and the 1976 defoliation experiment were cut by hand when 30% of the seeds had started to turn brown. The cut material was placed in cotton sacks for air-drying. The material was later threshed, and the seed cleaned and weighed.

In 1976, the irrigation/seeding rate experiment (with the exception of the high irrigation treatment) and the seeding methods/ rates experiment were harvested by combine when the seed moisture content was in the 10-15% range. The high irrigation treatment was cut by hand when 30% of the seeds had turned brown. The material was laid on the ground to air-dry, following which it was threshed by the combine. The seed was cleaned, dried and weighed.

3.3.7 Harvest index

Harvest index of the 1976 defoliation experiment was determined by weighing the yield samples prior to threshing. The weight of seed was then divided by the total straw + seed weight to give the harvest index. In the other experiments, harvest index was determined using the 10-plant yield component samples.

3.4 Oil determinations

3.4.1 Oil content

In 1975, seed oil content was determined by Soxhlet extraction with petroleum ether. Duplicate determinations were made on each plot. In 1976, oil percentage of dry seed was determined by means of nuclear magnetic resonance spectroscopy using duplicate readings from each plot. Oil content was calculated by comparison with standards of known oil content.

3.4.2 Fatty acid composition

Fatty acid composition was determined by gas-liquid chromatography, using the technique and equipment described by McGregor (1977). In 1975, the oil samples used were obtained by Soxhlet extraction. In 1976, oil was extracted from finely ground seed samples by petroleum ether. Two g samples of ground seed were mixed with 10 ml petroleum ether on a vortex mixer for 30 sec, allowed to stand for 2 min, and remixed. The samples were then centrifuged at 30,000 g for 5 minutes. The supernatant was transferred to a distillation apparatus, and the petroleum ether distilled off to yield the oil sample.

4. RESULTS

4.1 Weather

Mean air temperatures of the 1975 season were near normal, with the exception of April and August, which were considerably below normal (Table 1). In 1976, April and May temperatures were considerably above normal, followed by below normal temperatures in June and July. August temperatures were also above normal.

Precipitation during the April-September period of 1975 was slightly above the 30 year average for this period (Table 1). April-June precipitation was above normal, while that of July and August was below normal. Precipitation for the April - September period of 1976 was below normal. August precipitation was very much below normal.

4.2 Stand establishment

The May 1975 rainfall distribution and amount was particularly favorable for the establishment of the plots. 61 of the 76 mm of precipitation came within 10 days after seeding. This provided excellent conditions for germination and early growth of the crop. Conditions in May of 1976 were less favorable. Precipitation was much lower, while temperatures and wind were higher. Despite sprinkler application of 18 mm of water, germination was not uniform until after the rains of early June. An intense thunderstorm on June 4 caused some erosion and flooded a portion of the plot area. The standing water was pumped off within 12 hours.

Flea beetle damage occurred to some extent in both years. Damage was slight in 1975, due to the rapid early growth of the plants.

Table 1. Weather data for the 1975 and 1976 growth periods at Saskatoon .

Year	Month	Air temperature, ^{o}C		Precipitation, mm	
		Monthly mean	Normal*	Monthly total	Normal*
1975	April	-0.1	3.6	34.6	19.8
	May	10.0	10.7	75.7	36.3
	June	14.8	15.6	81.3	66.3
	July	19.7	19.6	27.7	62.2
	August	14.7	17.7	35.1	43.7
	September	11.7	11.3	23.1	34.6
				278	263
1976	April	7.1	3.6	22.6	19.8
	May	12.5	10.7	20.8	36.3
	June	15.0	15.6	85.3	66.3
	July	18.3	19.6	75.2	62.2
	August	18.3	17.7	8.9	43.7
	September	13.4	11.3	14.7	34.6
				228	263

* Normal temperature and precipitation based on the 1941-70 average.

Source - Monthly Weather Summary, Saskatchewan Research Council.

The slow growth due to the dry conditions in 1976 resulted in relatively more damage. The plants recovered during the more favorable growing conditions of early June.

4.3 General growth pattern of *B. napus*

4.3.1 Dry weight

The pattern of dry matter accumulation was similar for 1975 and 1976 (Fig. 1). In 1975, 60% of the dry weight was accumulated before flowering; 56% in 1976. In both years the dry weight of plants at maturity was less than the maximum dry weight attained by these plants during their development.

Leaf dry weight in 1976 reached a maximum at flowering, and declined slightly to maturity. The increase in dry weight from one week after flowering to maturity was due to the pod + seed fraction.

The distribution of dry matter at maturity differed in each year. In 1975 48, 27, and 25% of the total dry matter was in the stem, pod and seed fractions, respectively (Fig. 1a). The corresponding values for 1976 were 31, 37 and 31% (Fig. 1b).

4.3.2 Leaf Area

Leaf area index reached its maximum near flowering in both years (Fig. 2). In 1976 leaf area index did not decline as rapidly after the start of flowering as it did in 1975. Maximum leaf area index in 1975 was 3.5, compared with 2.9 in 1976.

4.3.3 Growth functions

Mean net assimilation rate was high early in the season and declined in a near linear manner to flowering (Fig. 3). There was a sharp increase

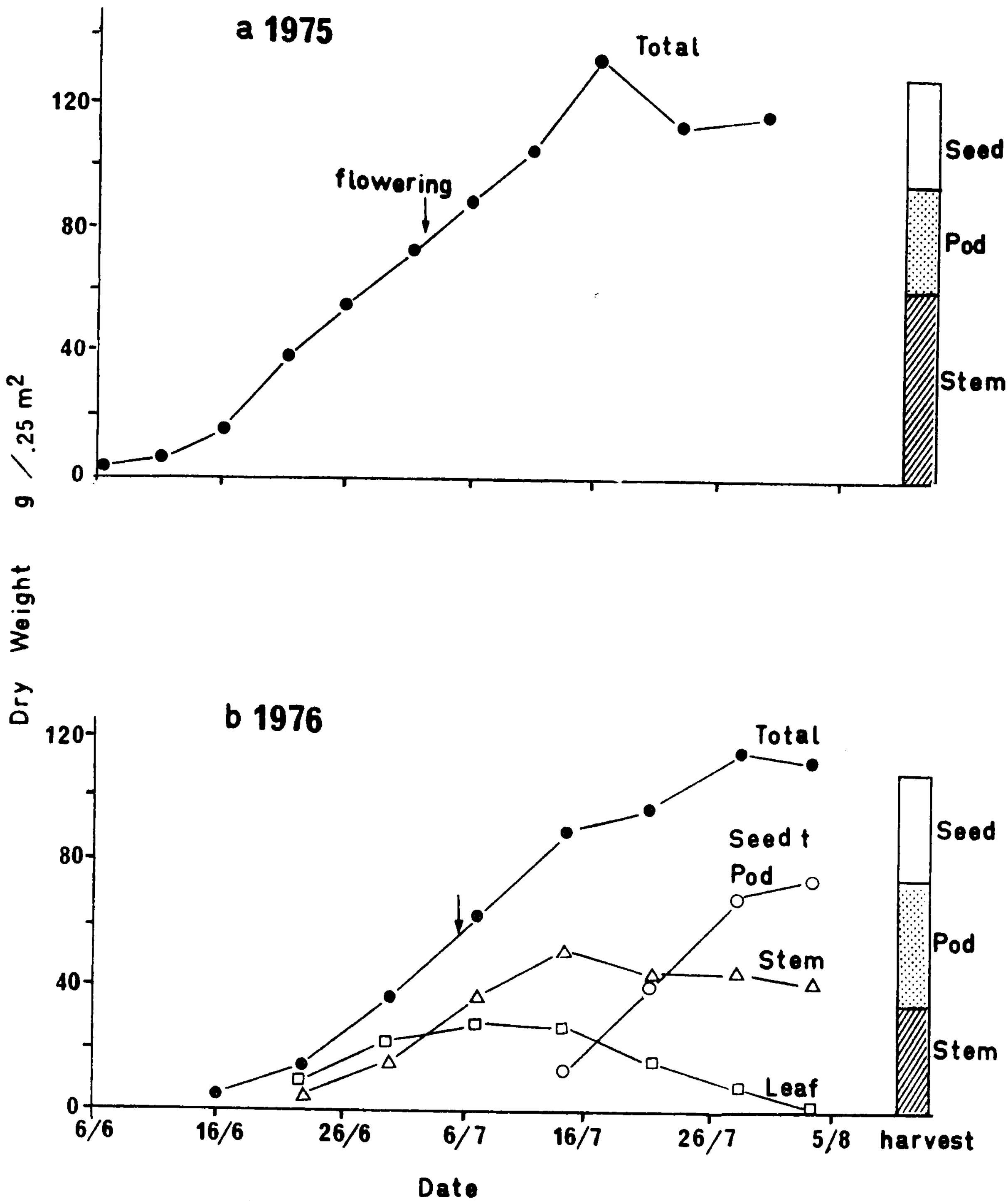

Figure 1. Dry weight accumulation of rainfed B. napus; mean of four seeding rates, 1975 and 1976.

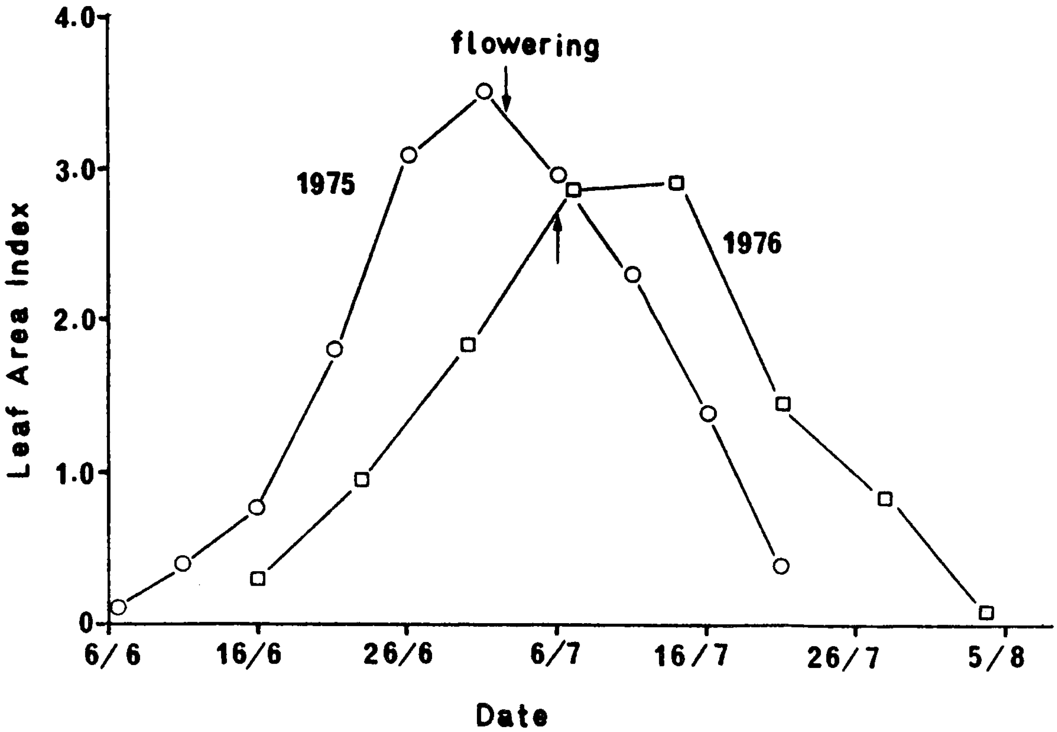

Figure 2. Leaf area index of rainfed *B. napus*; mean of four seeding rates, 1975 and 1976.

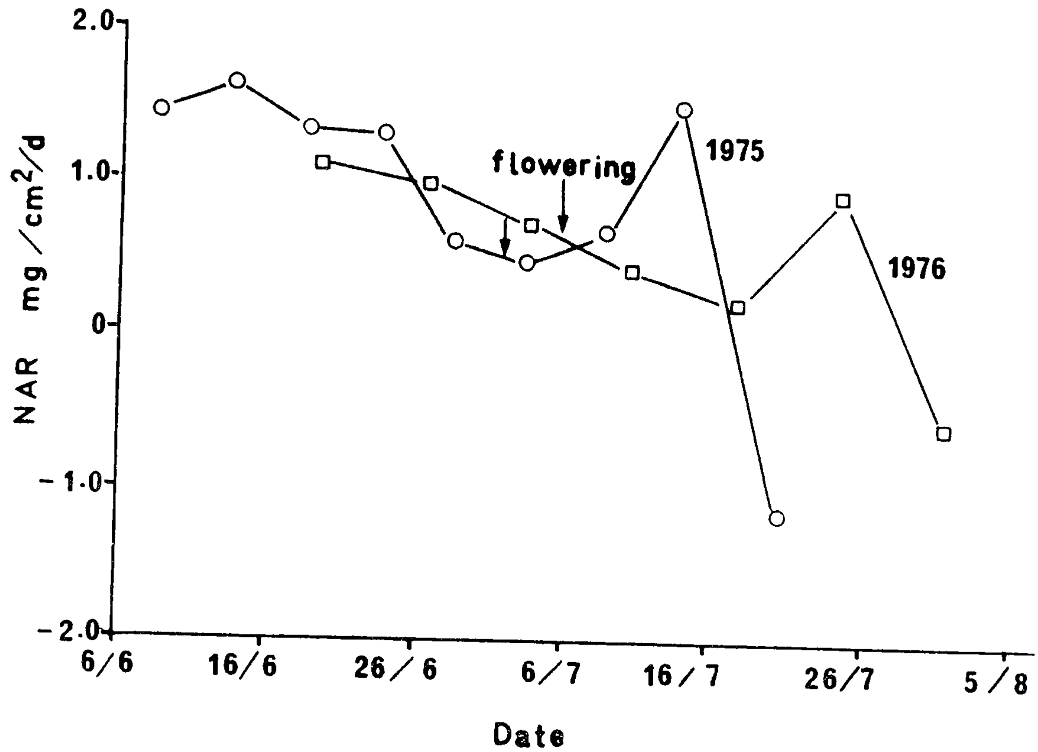

Figure 3. Mean net assimilation rate of rainfed B. napus; mean of four seeding rates, 1975 and 1976.

after flowering in both years, followed by a rapid decline to negative values. Mean relative growth rate followed a similar pattern (Fig. 4).

Mean crop growth rate was low early in the season, reached a maximum near flowering, and declined thereafter (Fig. 5). There was a tendency for the rate to increase near the end of the season in both years.

4.4 Effect of irrigation and seeding rate on growth of *B. napus*

4.4.1 Stand

The plant stands obtained at the 2.5 and 5 kg/ha seeding rates were similar in each of the two years (Table 2). However, at the 10 and 20 kg/ha rates the 1976 stands were considerably lower. Potential stand, based on 100% germination and survival would have been 75, 150, 300 and 600 plants/m^2 for the 2.5, 5, 10 and 20 kg/ha seeding rates, respectively. The actual stands were in the region of 50% of these values in most cases.

4.4.2 Irrigation

In 1975, the first irrigation of the high irrigation treatment was made just before flowering (Table 3). The low irrigation treatment was irrigated twice, once at the beginning of flowering and once at the end. In 1976, the high irrigation treatment was first irrigated two weeks prior to flowering, while the low irrigation treatment was not irrigated until the end of flowering.

The excess of evaporation over precipitation was similar for June of 1975 and 1976 (Table 4). In 1975, however, July had a greater water deficit than in 1976.

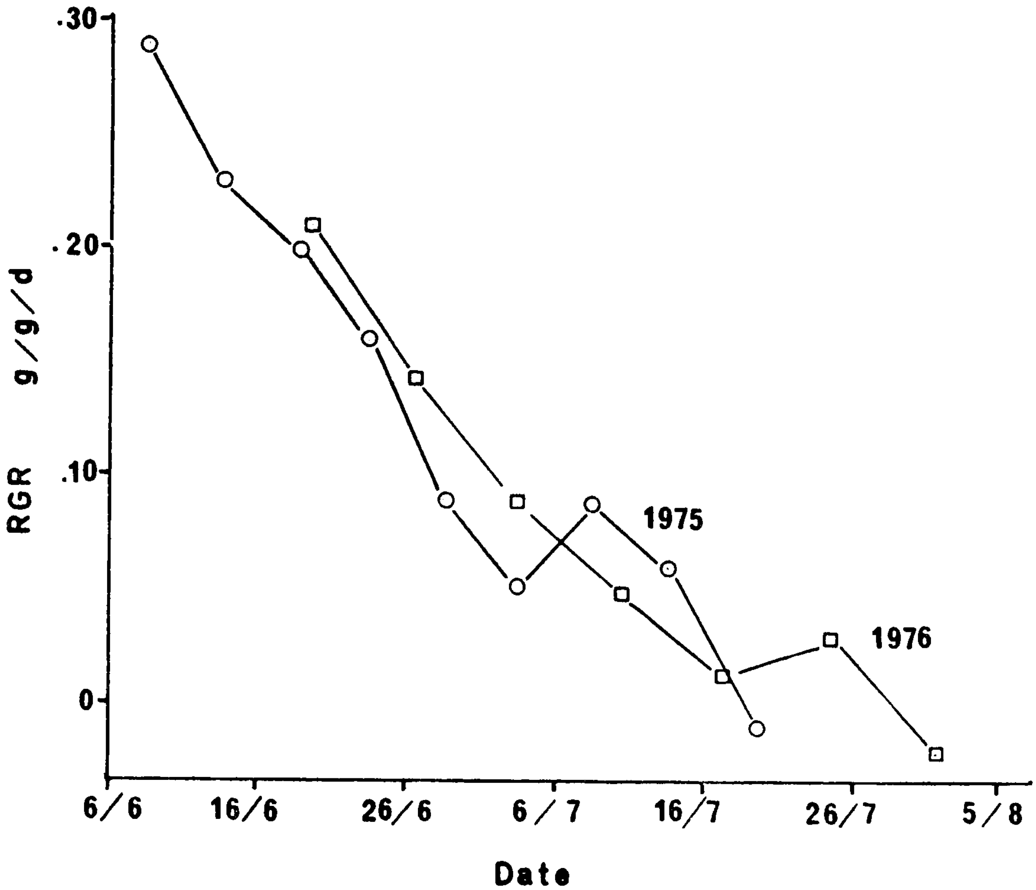

Figure 4. Mean relative growth rate of rainfed *B. napus*; mean of four seeding rates, 1975 and 1976.

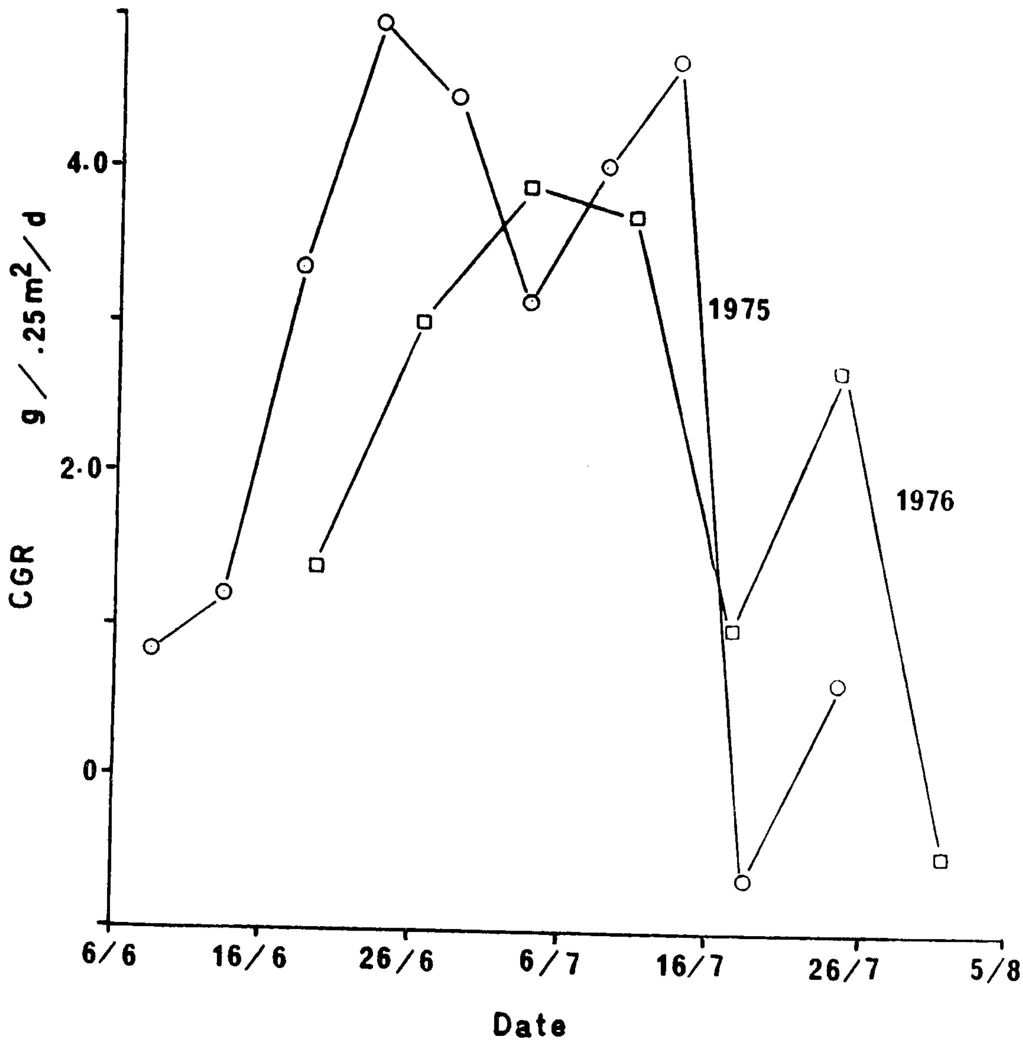

Figure 5. Mean crop growth rate of rainfed B. napus; mean of four seeding rates, 1975 and 1976.

Table 2. Establishment of *B. napus* under irrigation and seeding rate treatments.

Year	Seeding Rate (kg/ha)	Stand (plants/m^2)		
		Rainfed	Low irrigation	High irrigation
1975	2.5	44	44	44
	5	82	80	82
	10	164	156	164
	20	312	308	304
1976	2.5	36	44	40
	5	72	76	76
	10	120	128	132
	20	240	180	248

Table 3. Timing and amounts of irrigation.

Year	Date	Water applied (mm)	
		Low irrigation	High irrigation
1975	June 30	-	30
	July 6	30	30
	12	-	30
	17	41	41
	27	-	41
	Total	71	202
1976	June 17	-	15
	July 1	-	15
	17	36	30
	23	36	36
	August 4	-	20
	Total	72	116

Table 4. Water deficit as measured by evaporation minus precipitation and irrigation for June and July of 1975 and 1976.

Year	Month	Evap.* - (precip. + irrigation), mm		
		Rainfed	Low irrigation	High irrigation
1975	June	100	100	70
	July	199	128	57
1976	June	108	108	93
	July	142	70	60

* evaporation from Class A pan.

4.4.3 Osmotic potential

Leaf osmotic potential (ψ_s) in early June of 1975 was about -9 bars, and fell to -11 bars by the end of June (Fig. 6). The rate of decline of ψ_s of the rainfed plots was very rapid during July. Irrigation prevented some of the decline in ψ_s.

The leaf osmotic potential responded to precipitation and irrigation (Fig. 6). In cases where ψ_s measurements were made just prior to rainfall or irrigation and again just after, the resultant increase in ψ_s could be easily seen. For the high irrigation treatment, irrigation increased ψ_s to -10 to -11 bars. The amount of the increase was somewhat less as the season progressed.

The trend of ψ_s was similar in 1976 (Fig. 7). The rapid decline of ψ_s of the rainfed treatment did not occur until later in July of 1976 than in 1975. Leaf osmotic potential again was responsive to rainfall and irrigation.

4.4.4 Curve fitting

In 1975, seven out of eight sets of dry weight data fitted a cubic polynomial with time:

$$\log_e \text{dry weight} = a + bT + cT^2 + dT^3$$

where a, b, c, and d are constants, and T is time from planting in days. The r^2 values ranged from 0.88 to 0.96 (Table 5). The data set in which the cubic term was non-significant gave the lowest r^2 value (0.88). Fitted data removed the wild fluctuation of the actual data (Fig. 8).

In two out of eight sets of dry weight data in 1976, the cubic term was non-significant (Table 6). The r^2 values ranged from 0.93 to 0.97.

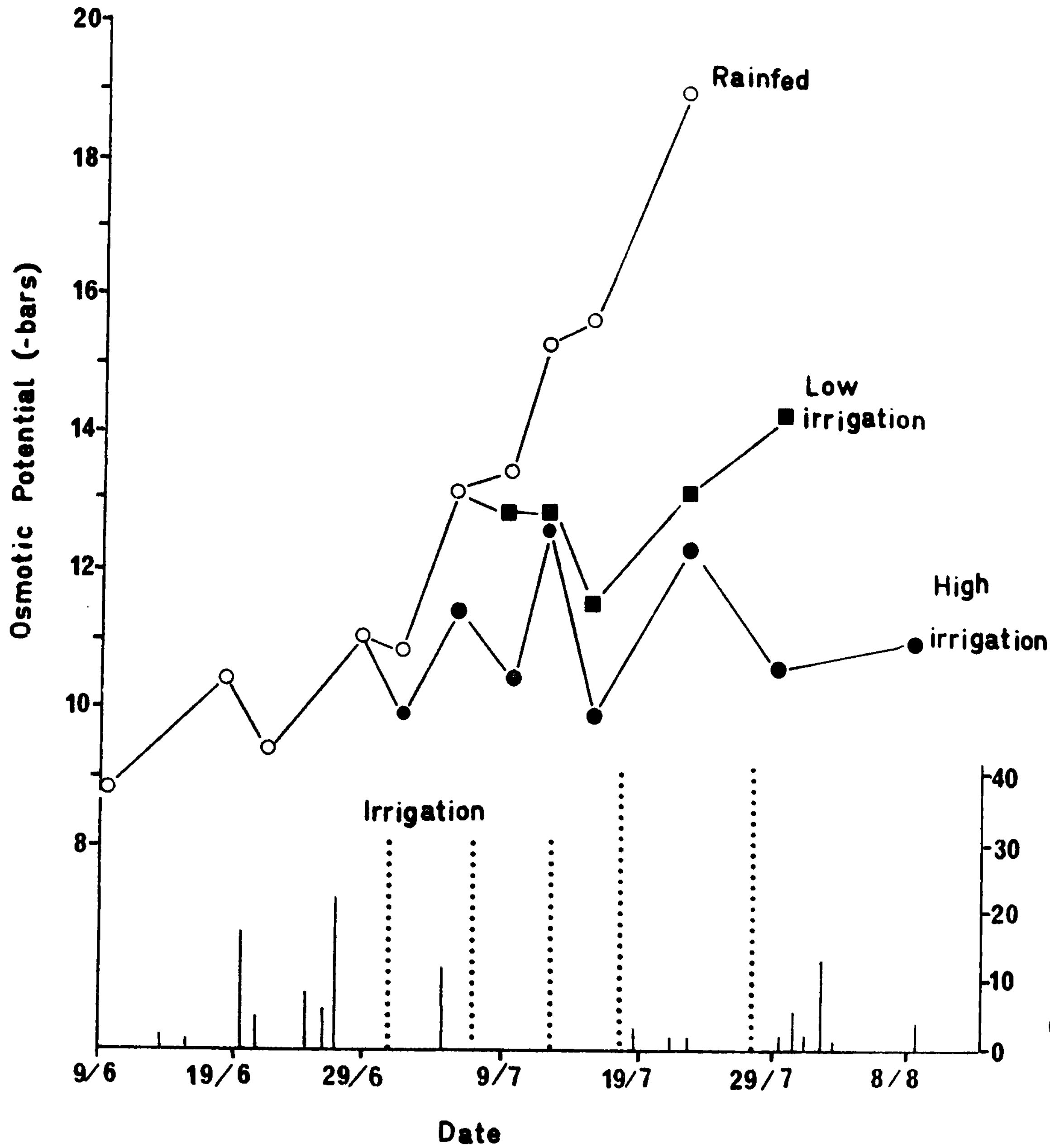

Figure 6. Leaf osmotic potential of B. napus, 1975.

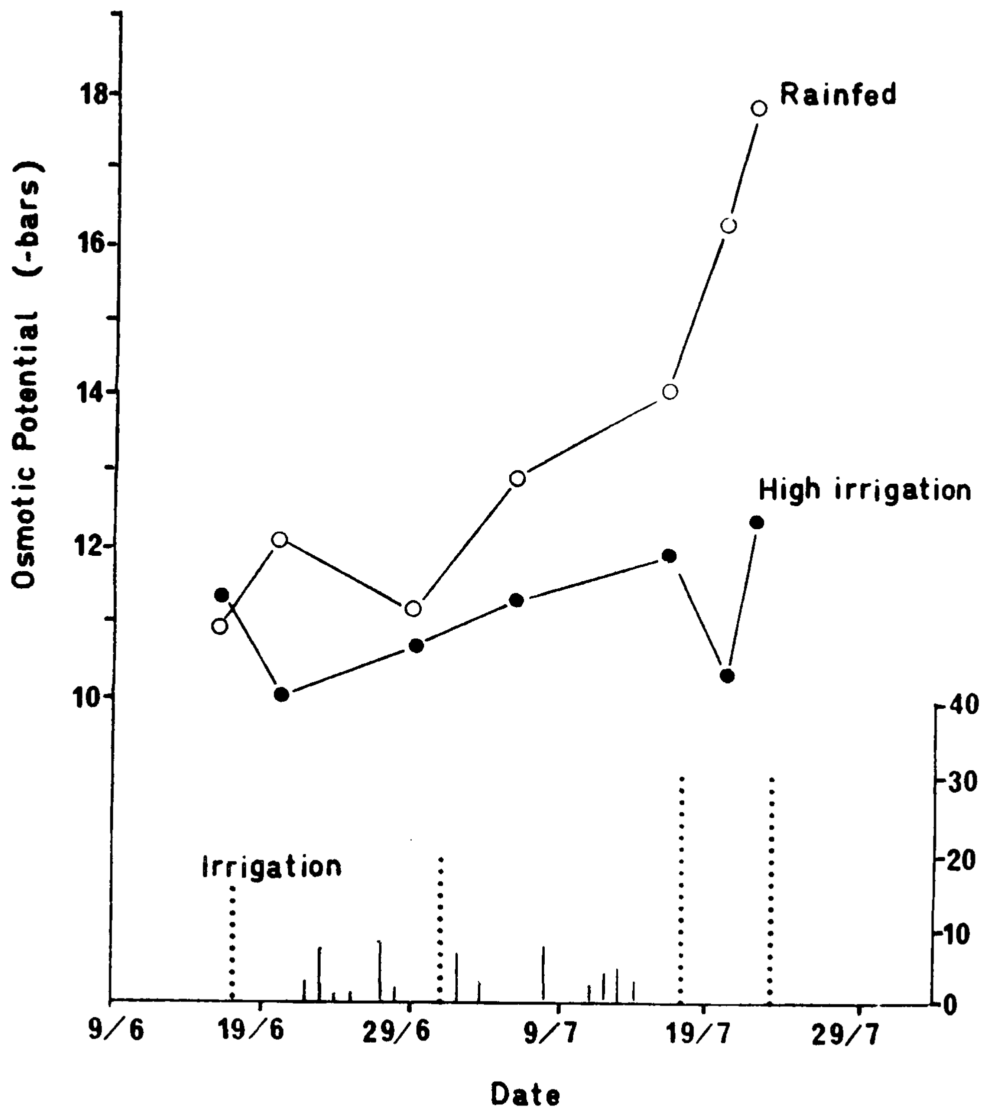

Figure 7. Leaf osmotic potential of B. napus, 1976.

Table 5. Regression coefficients and standard errors for dry weight fitted to cubic polynomials of the form $\log_e DW = a + bT + cT^2 + dT^3$, 1975.

Seeding rate Kg/ha		Rainfed coefficient	Rainfed S.E.	r^2	High irrigation coefficient	High irrigation S.E.	r^2
2.5	Constant (a)	-19.4990	1.98483	.94	-16.3663	1.5786	.94
	Time (b)	1.0047	.1170		.7946	.0894	
	$Time^2$ (c)	.0139	.0022		- .0097	.0015	
	$Time^3$ (d)	.000064	.000013		.000040	.0000083	
5	Constant	-13.4275	1.5048	.95	-9.9433	2.0965	.88†
	Time	.7167	.0903		.4884	.1187	
	$Time^2$	-.0094	.0017		-.0050	.0021	
	$Time^3$	.000041	.0000097		.000016	.000011	
10	Constant	-11.6239	1.1252	.96	-9.8633	.9526	.96
	Time	.6818	.0676		.5640	.0539	
	$Time^2$	-.0094	.0013		-.0070	.0009	
	$Time^3$	.000043	.0000072		.000030	.000005	
20	Constant	-7.9292	1.1458	.94	-7.7330	.9291	.94
	Time	.5160	.0688		.4980	.0526	
	$Time^2$	-.0068	.0013		-.0064	.0009	
	$Time^3$	.000030	.0000074		.000028	.000005	

† data set fitted a quadratic rather than a cubic.

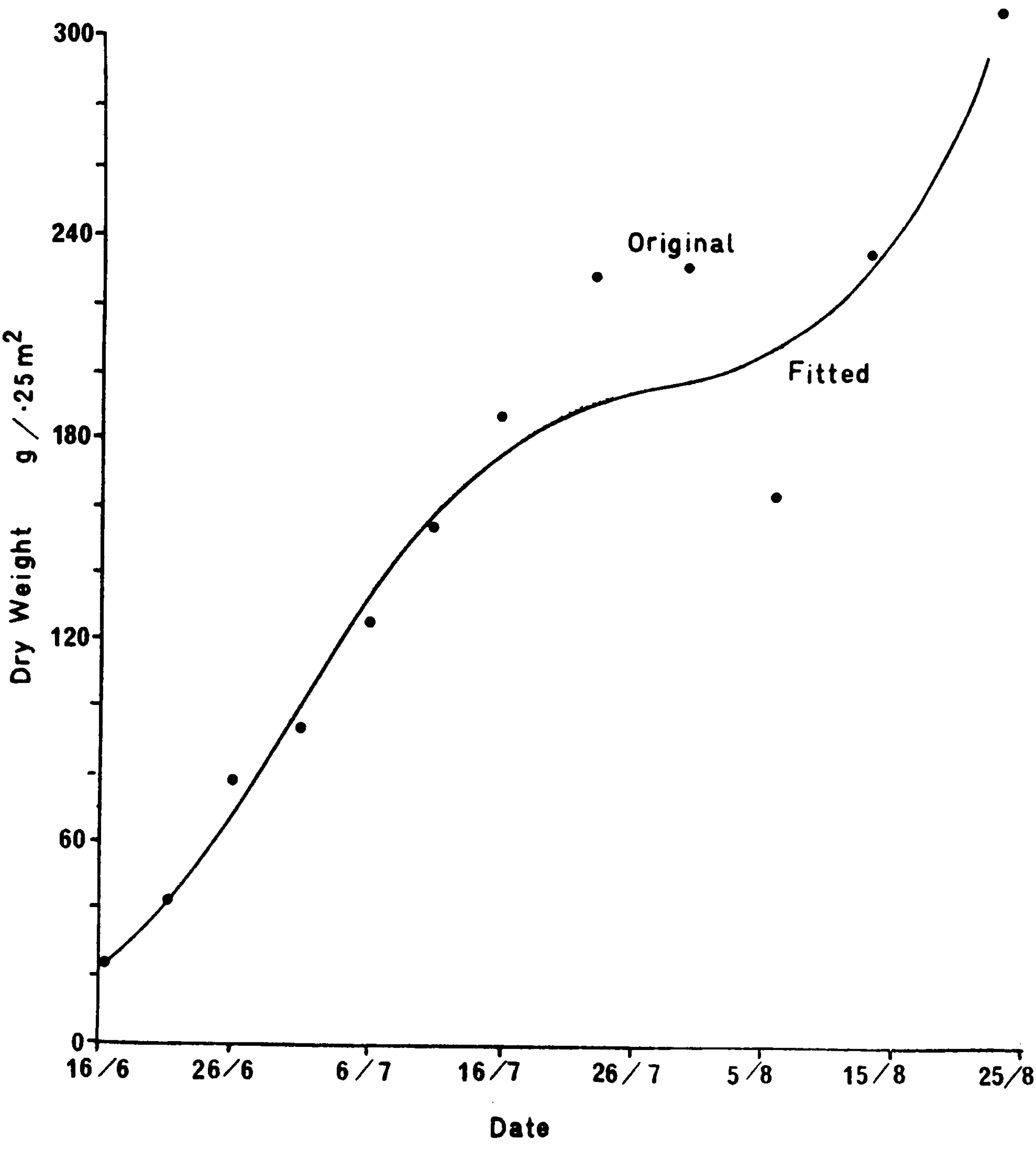

Figure 8. Comparison of original and fitted ($\log_e DW = a + bT + cT^2 + dT^3$) dry weight of B. napus; 20 kg/ha seeding rate, high irrigation, 1975.

Table 6. Regression coefficients and standard errors for dry weight fitted to cubic polynomials of the form $\log_e = a + bT + cT^2 + dT^3$, 1976.

Seeding rate Kg/ha		Rainfed coefficient	Rainfed S.E.	r^2	High irrigation coefficient	High irrigation S.E.	r^2
2.5	Constant	-42.9088	6.3187	.93	-31.3932	4.4500	.94
	Time	1.8609	.3191		1.2532	.2151	
	$Time^2$	-.0244	.0052		- .01459	.0033	
	$Time^3$	.00011	.00003		.000057	.000016	
5	Constant	-15.0166	3.5838	.95†	-13.6323	2.2889	.97†
	Time	.6346	.1810		.5601	.1106	
	$Time^2$	-.0068	.0029		-.0056	.0017	
	$Time^3$	.000024	.000015		.000018	.0000085	
10	Constant	-21.374	3.4934	.94	-18.0948	2.2799	.96
	Time	.9934	.1764		.8183	.1102	
	$Time^2$	-.0127	.0029		-.0098	.0017	
	$Time^3$	.000054	.000015		.000040	.0000084	
20	Constant	-12.7180	2.5066	.95	-12.3747	1.9425	.95
	Time	.6359	.1266		.6221	.0939	
	$Time^2$	-.0078	.0021		-.00757	.00145	
	$Time^3$	.000032	.000011		.000031	.0000072	

† data did not fit a cubic polynomial

Even though two of the data sets did not fit cubic polynomials statistically, the fit was closer to the original than was the quadratic polynomial (Fig. 9). Data fitted to the quadratic produced a curve which tailed off excessively near maturity. The original dry weight continued to increase during this time. When crop growth rate was calculated from the data fitted to the quadratic, the resultant curve was considerably different from that produced from the original data (Fig. 10a). The cubic-fitted data gave a result closer to the original. Similarly, when relative growth rate was calculated from the quadratic data, the result was a linear decline in RGR with time (Fig. 10b). The original data and that fitted to the cubic polynomial produced higher RGR values at both the beginning and the end of the season than did the quadratic data.

Attempts to fit leaf area to quadratic polynomials using all plots of each treatment were not successful due to the high degree of variability. However, reasonably good fits were obtained when the treatment means were fitted. The quadratic was of the form:

$$\log_e \text{ leaf area} = a' + b'T + c'T^2$$

where a', b' and c' are constants and T is time from planting in days. The r^2 values ranged from 0.92 to 0.99 in both 1975 (Table 7) and 1976 (Table 8). In both years the fit tended to be best for the lower seeding rates of the rainfed material. The higher seeding rates, particularly under irrigated conditions, gave a poorer fit, with high standard errors. This trend is particularly clear in the 1976 results (Table 8).

As in the case of dry weights, the curve fitting for leaf area smoothed out the fluctuations in the original data (Fig. 11a).

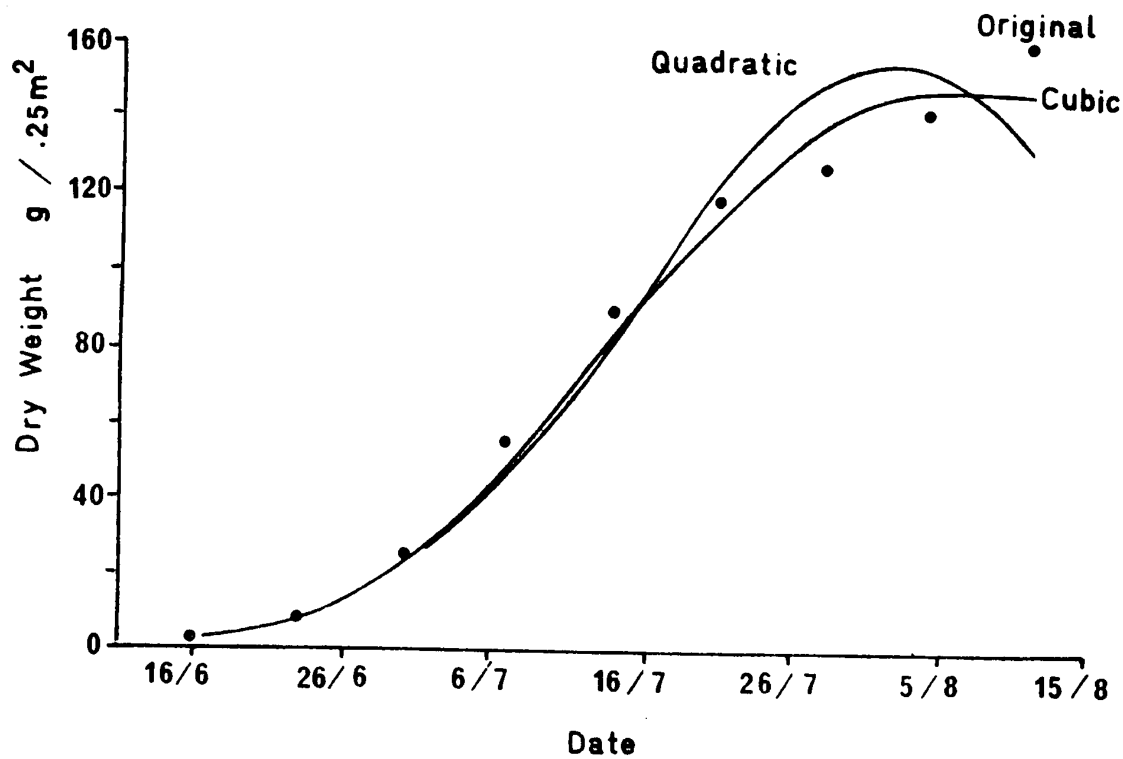

Figure 9. Comparison of B. napus dry weight curve fitting to cubic and quadratic polynomials in a case where the cubic term was non-significant; 5 kg/ha seeding rate, high irrigation, 1976.

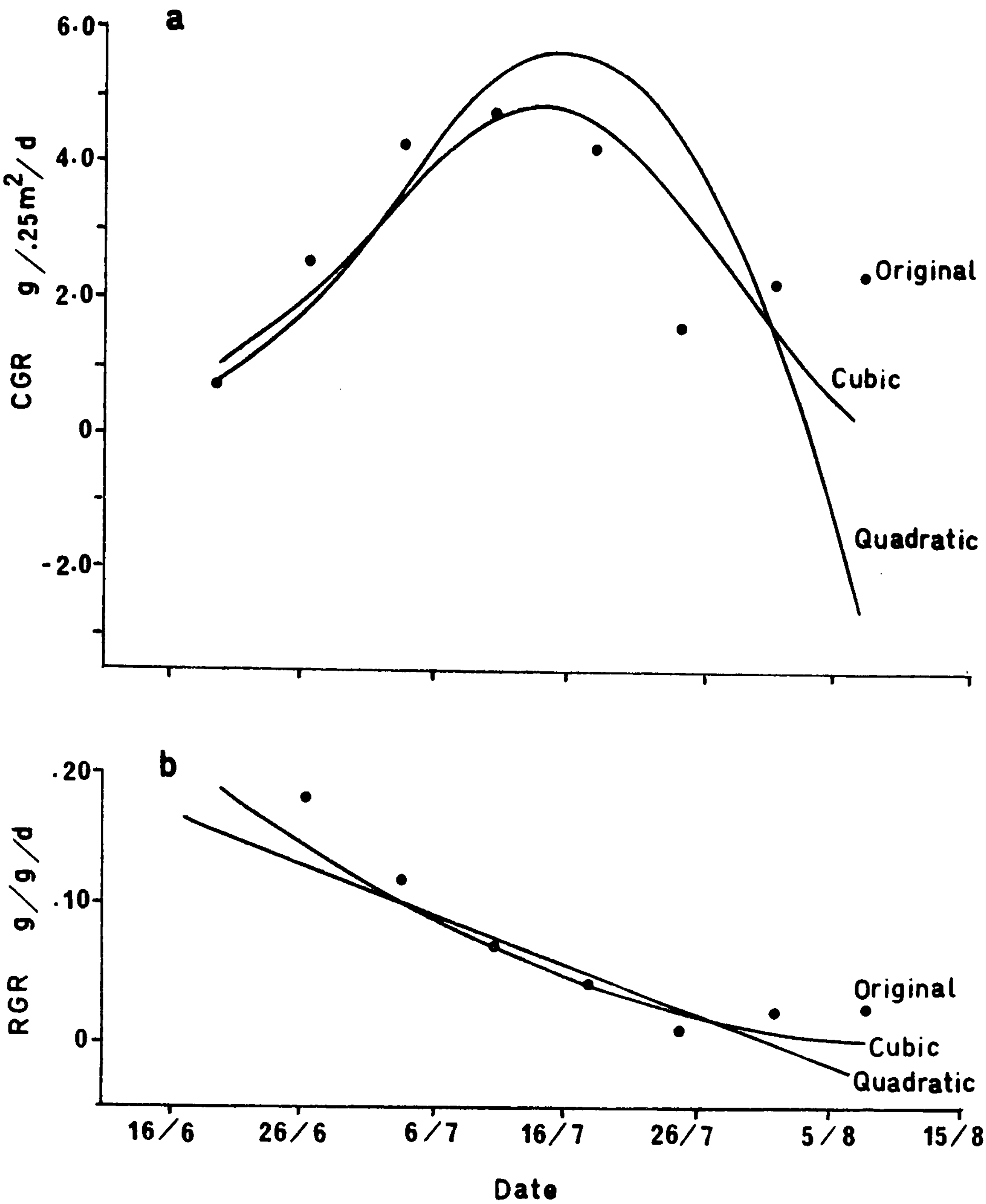

Figure 10. Comparison of crop growth rate (a) and relative growth rate (b) of B. napus calculated from original dry weight data and from dry weights fitted to quadratic and cubic polynomials; 5 kg/ha seeding rate, high irrigation, 1976.

Table 7. Regression coefficients and standard errors for leaf area fitted to a quadratic polynomial of the form $\log_e A = a' + b'T + c'T^2$, 1975.

Treatment	Seeding rate		Coefficient	S.E.	r^2
Rainfed	2.5	Constant	-10.7348	1.0498	.98
		Time	.7258	.0462	
		Time^2	-.0067	.00048	
	5	Constant	-8.1321	.6790	.99
		Time	.6542	.0299	
		Time^2	-.0063	.00031	
	10	Constant	-4.1380	1.2647	.93
		Time	.5100	.0557	
		Time^2	-.0049	.00057	
	20	Constant	-1.3036	.6195	.97
		Time	.4231	.0273	
		Time^2	-.0042	.00028	
High irrigation	2.5	Constant	-4.9375	.9501	.95
		Time	.4309	.0351	
		Time^2	-.0032	.00030	
	5	Constant	-2.7606	.7285	.96
		Time	.3782	.0269	
		Time^2	-.0030	.00023	
	10	Constant	-1.0000	.8254	.93
		Time	.3448	.0305	
		Time^2	-.0029	.00026	
	20	Constant	-.6161	1.0240	.92
		Time	.3695	.0379	
		Time^2	-.0033	.00032	

Table 8. Regression coefficients and standard errors for leaf area fitted to a quadratic polynomial of the form $\log_e A = a' + b'T + c'T^2$, 1976.

Treatment	Seeding rate		Coefficient	S.E.	r^2
Rainfed	2.5	Constant	-13.1184	.9877	.99
		Time	.6716	.0325	
		Time^2	-.0052	.00025	
	5	Constant	-7.8684	1.0838	.98
		Time	.5156	.0356	
		Time^2	-.0040	.00028	
	10	Constant	-12.2376	2.5083	.95
		Time	.7029	.0825	
		Time^2	-.0058	.00065	
	20	Constant	-7.8586	2.7146	.93
		Time	.5766	.0893	
		Time^2	-.0049	.0007	
High irrigation	2.5	Constant	-7.9330	1.3602	.98
		Time	.4560	.0426	
		Time^2	-.0031	.00032	
	5	Constant	-4.2164	1.2626	.95
		Time	.3656	.0396	
		Time^2	-.0025	.00029	
	10	Constant	-3.6763	1.4289	.92
		Time	.3702	.0448	
		Time^2	-.0026	.00033	
	20	Constant	.2772	1.0137	.92
		Time	.2684	.0318	
		Time^2	-.0020	.00024	

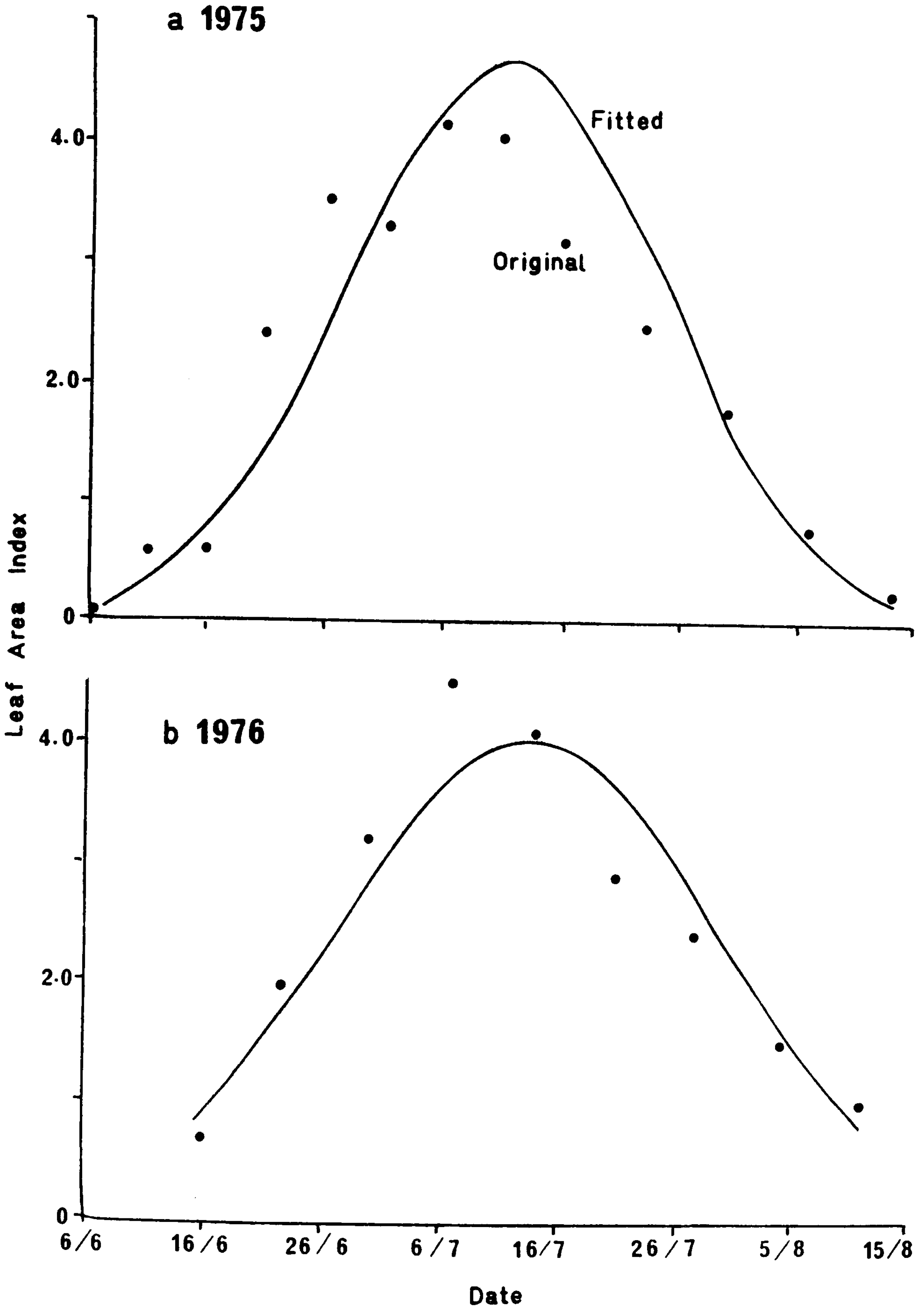

Figure 11. Comparison of original and fitted ($\log_e L = a' + b'T + c'T^2$) leaf area index data of B. napus; high irrigation, seeded at 10 kg/ha (1975) and 20 kg/ha (1976).

The fitted data followed the original data closely early in the season and late in the season (Fig. 11 and Fig. 12). There were considerable differences between the fitted and original data in the area of maximum LAI, with over-estimates and under-estimates of maximum LAI being evident in the fitted data.

4.4.5 Dry weight

Irrigation had a substantial effect on both the total amount of dry matter produced and the pattern of its production (Fig. 13 and 14). Under rainfed conditions, there was rapid production of dry matter during the bolting, flowering and early ripening phases (Fig. 13a and 14a). A plateau was reached during the late ripening phase. Under irrigation, the rate of dry matter production continued at a high rate until the late ripening phase (Fig. 13b and 14b).

Seeding rates affected the amount of dry matter produced, but had little effect on its pattern of production (Fig. 13 and 14). With the exception of the 1975 irrigated material, the dry matter increased as the seeding rate was increased. In the 1975 irrigated material, this held true early in the season, but not after flowering (Fig. 13b).

Both irrigation and seeding rate affected the proportion of the total dry matter produced before flowering (Table 9). Irrigated material produced more of its dry matter after flowering than did non-irrigated material. As seeding rate was increased, the proportion of the dry weight produced after flowering decreased. This trend was particularly evident in the 1976 data. The range between low and high seeding rates was greater under rainfed than under irrigated conditions.

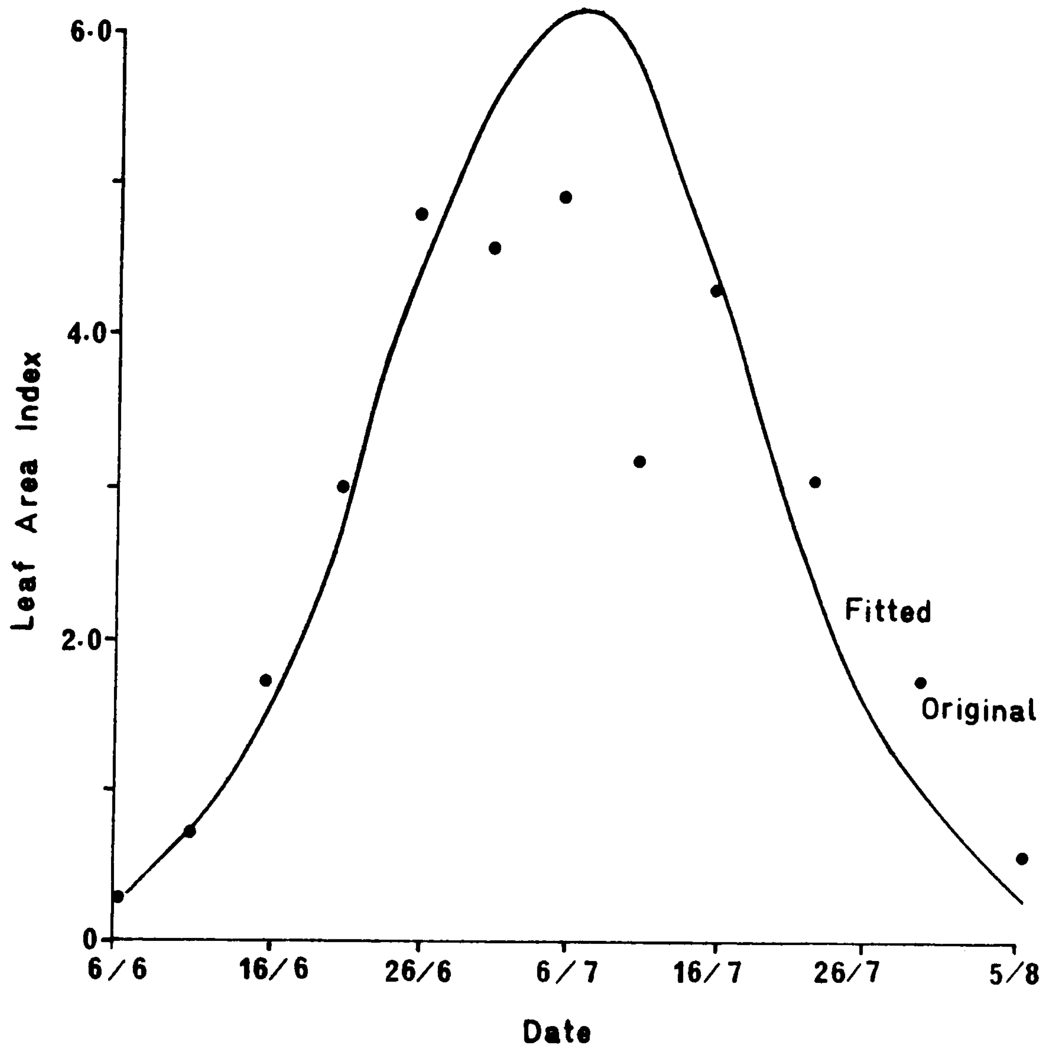

Figure 12. Comparison of original and fitted ($\log_e L = a' + b'T + c'T^2$) leaf area index data of B. napus; 20 kg/ha seeding rate, high irrigation, 1975.

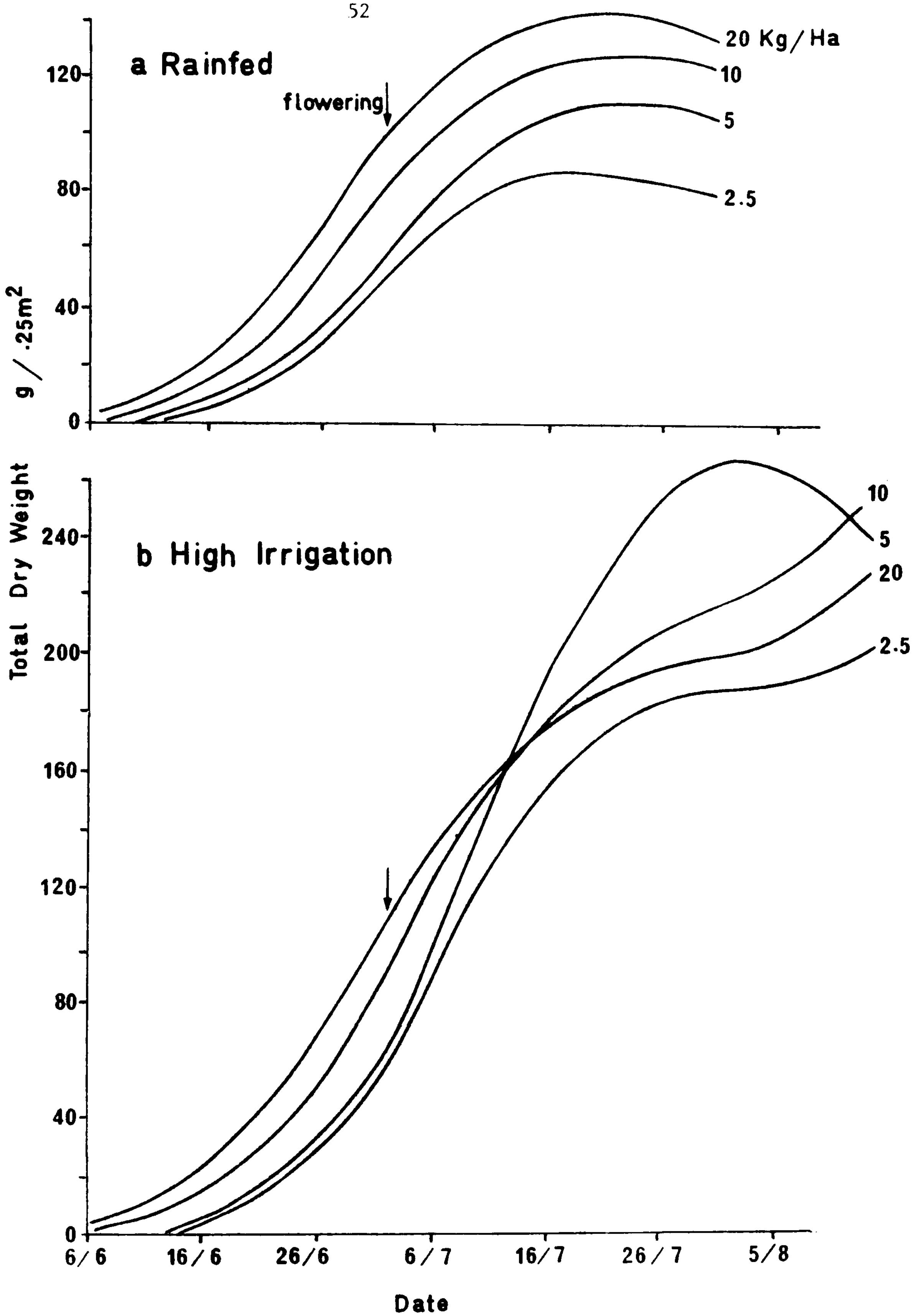

Figure 13. Effect of irrigation and seeding rate on dry matter production of B. napus; fitted data, 1975.

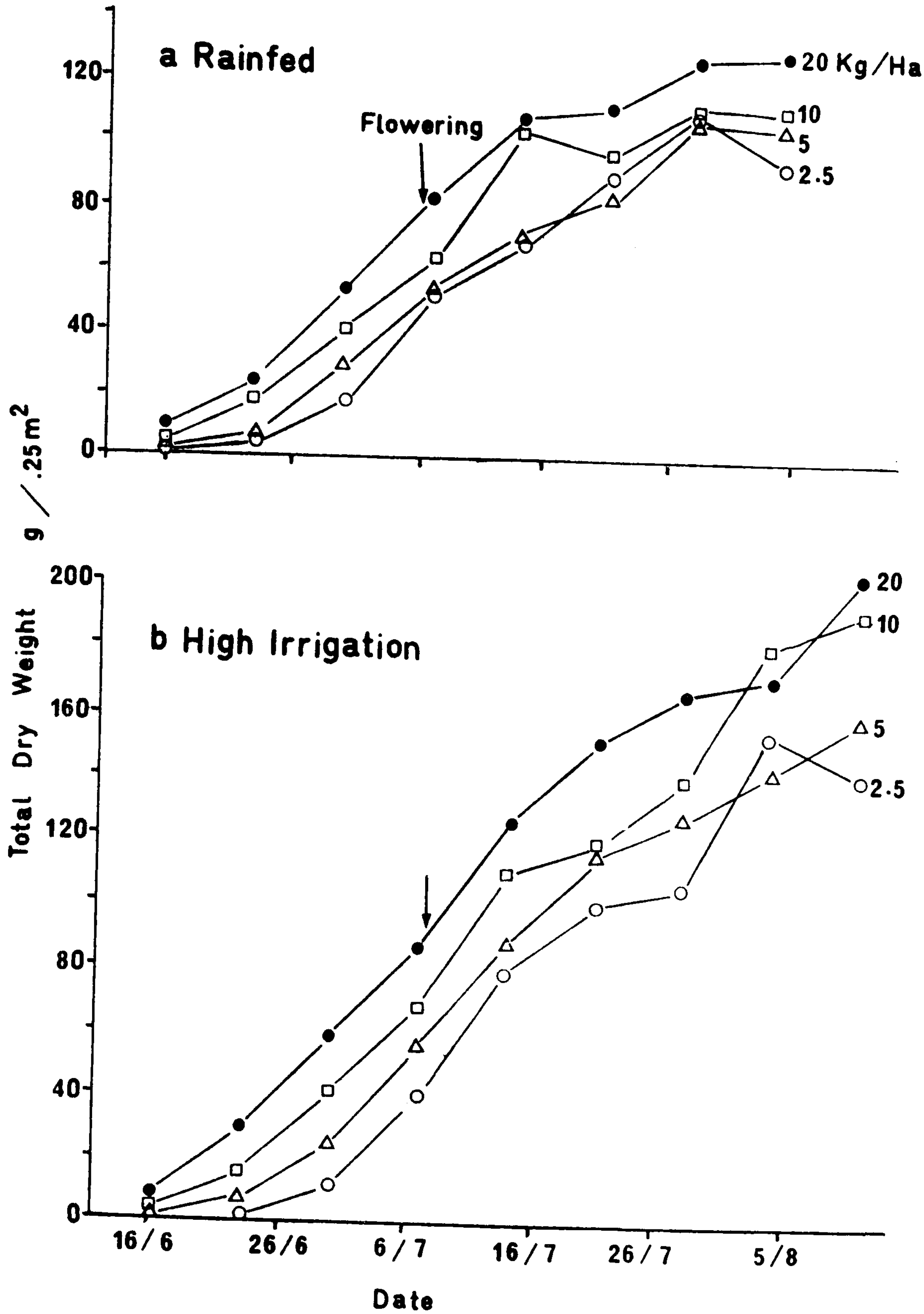

Figure 14. Effect of irrigation and seeding rate on dry matter production of B. napus, 1976.

Table 9. Effect of irrigation and seeding rate on dry weight accumulation of B. napus before flowering.

Year	Seeding rate (kg/ha)	Dry weight at flowering (% of total) Rainfed	High irrigation
1975	2.5	61	36
	5	54	32
	10	42	44
	20	75	41
1976	2.5	43	21
	5	52	26
	10	63	36
	20	71	43

Irrigation also affected the pattern of accumulation of dry matter of plant parts (Fig. 15 and 16). Dry weight accumulation of the stem and leaf fractions was essentially the same under both rainfed and irrigated conditions. Leaf dry weight remained higher during the ripening phase under irrigated than under rainfed conditions. Dry weight accumulation of the seed + pod fraction was substantially changed by irrigation. Under rainfed conditions, dry weight of the seed + pod fraction increased linearly after flowering and then reached a plateau during the late ripening phase. Under irrigated conditions, the linear increase in dry weight of the seed + pod fraction continued for a longer period of time than under rainfed conditions. Under both rainfed and irrigated conditions, plant dry weight changes during the ripening phase were due to changes in the seed + pod dry weight.

Due to the high variability in the dry weight data, no significant differences were detected between treatments at maturity. There were, however, some obvious differences in the contributions of the stem, pod and seed fractions to the total dry weight (Table 10). Irrigation reduced the proportion of stems, and increased the proportion of pods and seeds. This effect was more pronounced in 1975 than in 1976. In 1975, the proportion of seeds was greater than that of pods, while the reverse was true in 1976.

4.4.6 Leaf area

Irrigation resulted in a higher maximum LAI than rainfed in both 1975 and 1976 (Fig. 17). LAI was also maintained longer and at a higher level after flowering. Under rainfed conditions maximum LAI was reached

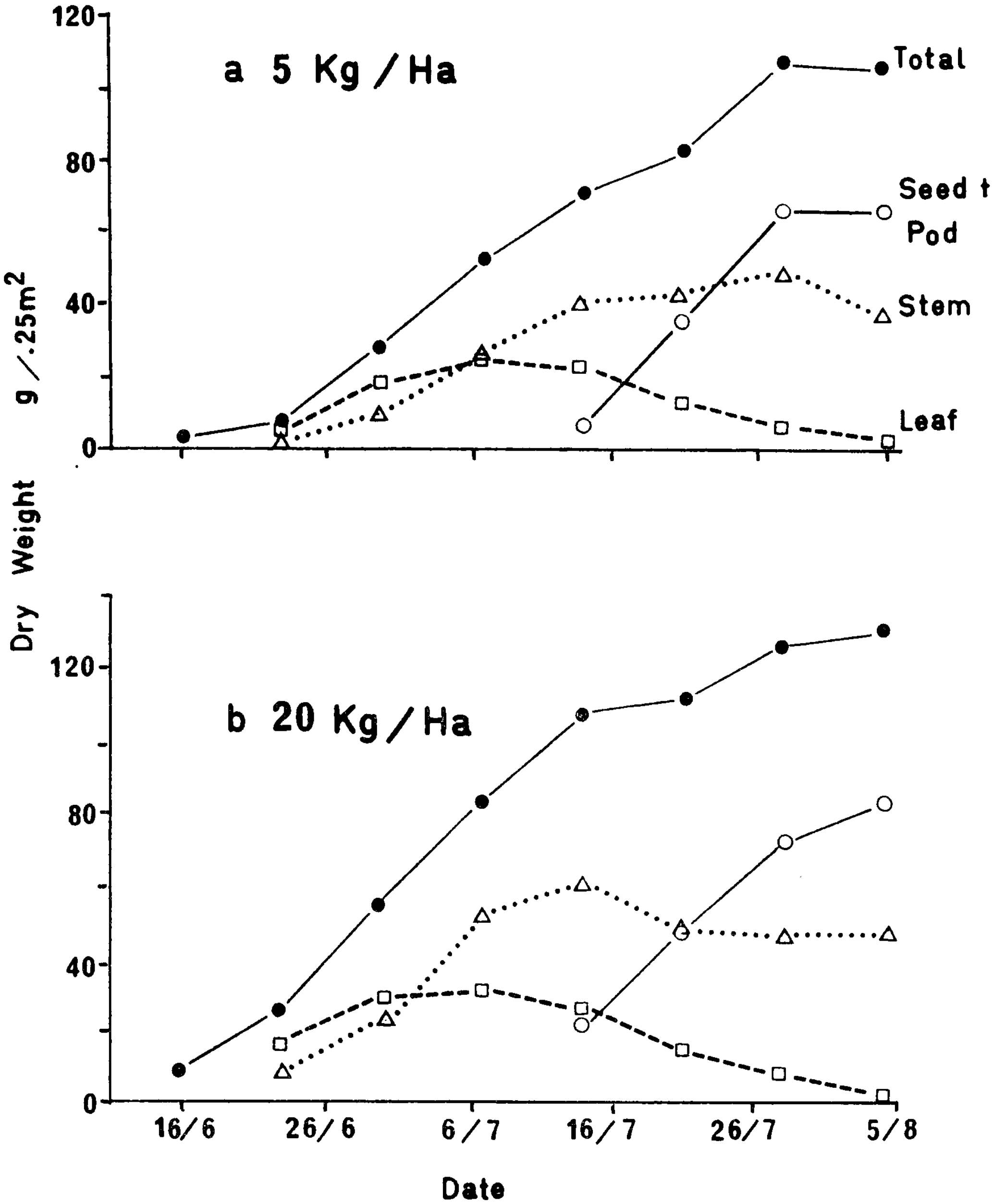

Figure 15. Dry weights of plant parts of B. napus seeded at two rates under rainfed conditions, 1976.

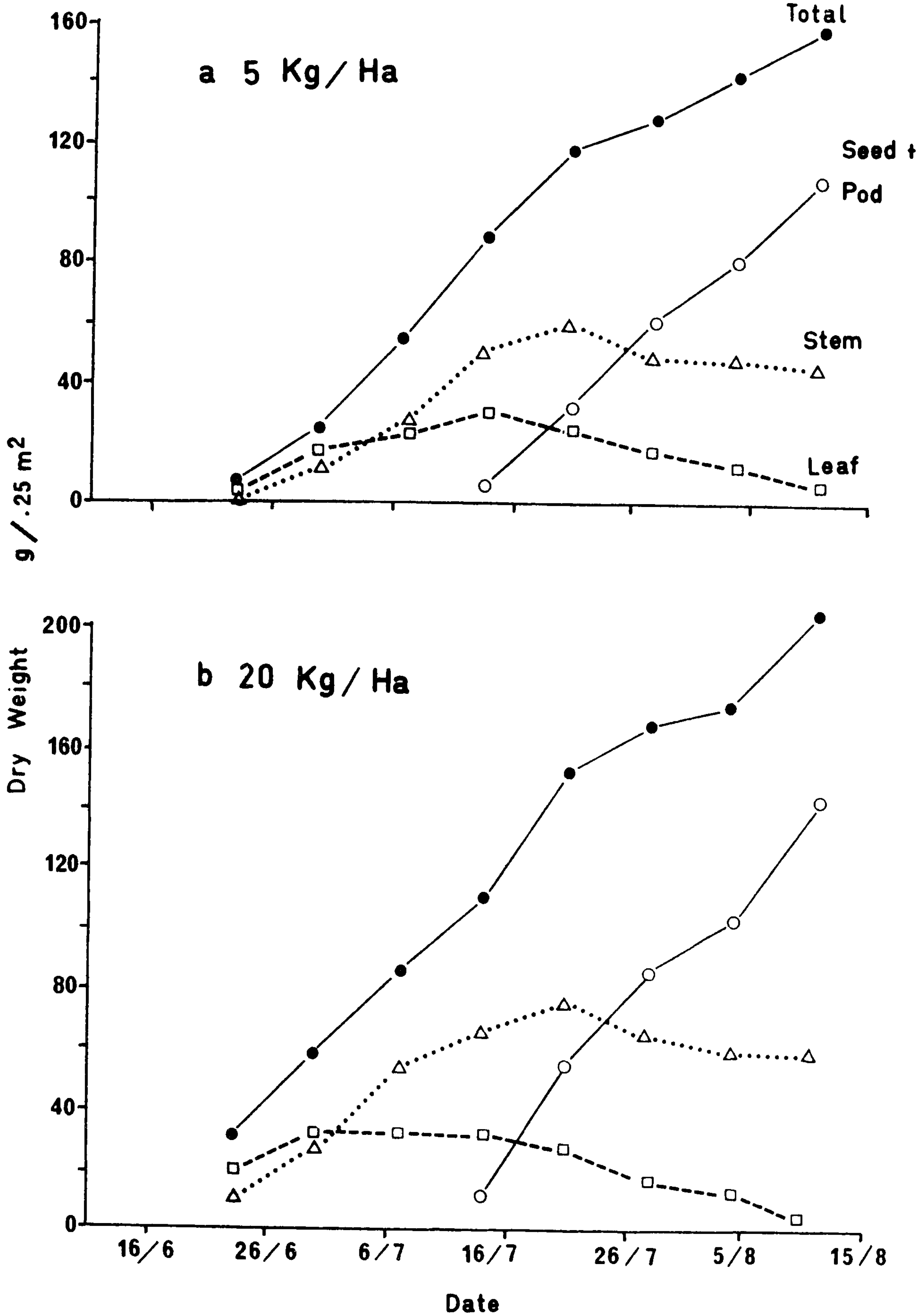

Figure 16. Dry weights of plant parts of B. napus seeded at two rates under irrigated conditions, 1976.

Table 10. Effect of irrigation and seeding rate on dry weight components of *B. napus* at maturity.

		% of total dry weight								
	Seeding	Rainfed			Low irrigation			High irrigation		
Year	Rate (kg/ha)	stem	pod	seed	stem	pod	seed	stem	pod	seed
1975	2.5	44	29	27	33	32	35	28	34	38
	5	45	27	28	34	31	35	31	32	37
	10	48	28	24	36	29	35	29	33	38
	20	52	22	26	37	29	34	29	30	41
1976	2.5	31	36	28	22	42	35	28	40	33
	5	33	38	30	24	42	35	28	39	32
	10	30	38	31	25	41	34	29	40	31
	20	31	37	32	27	39	34	28	41	31

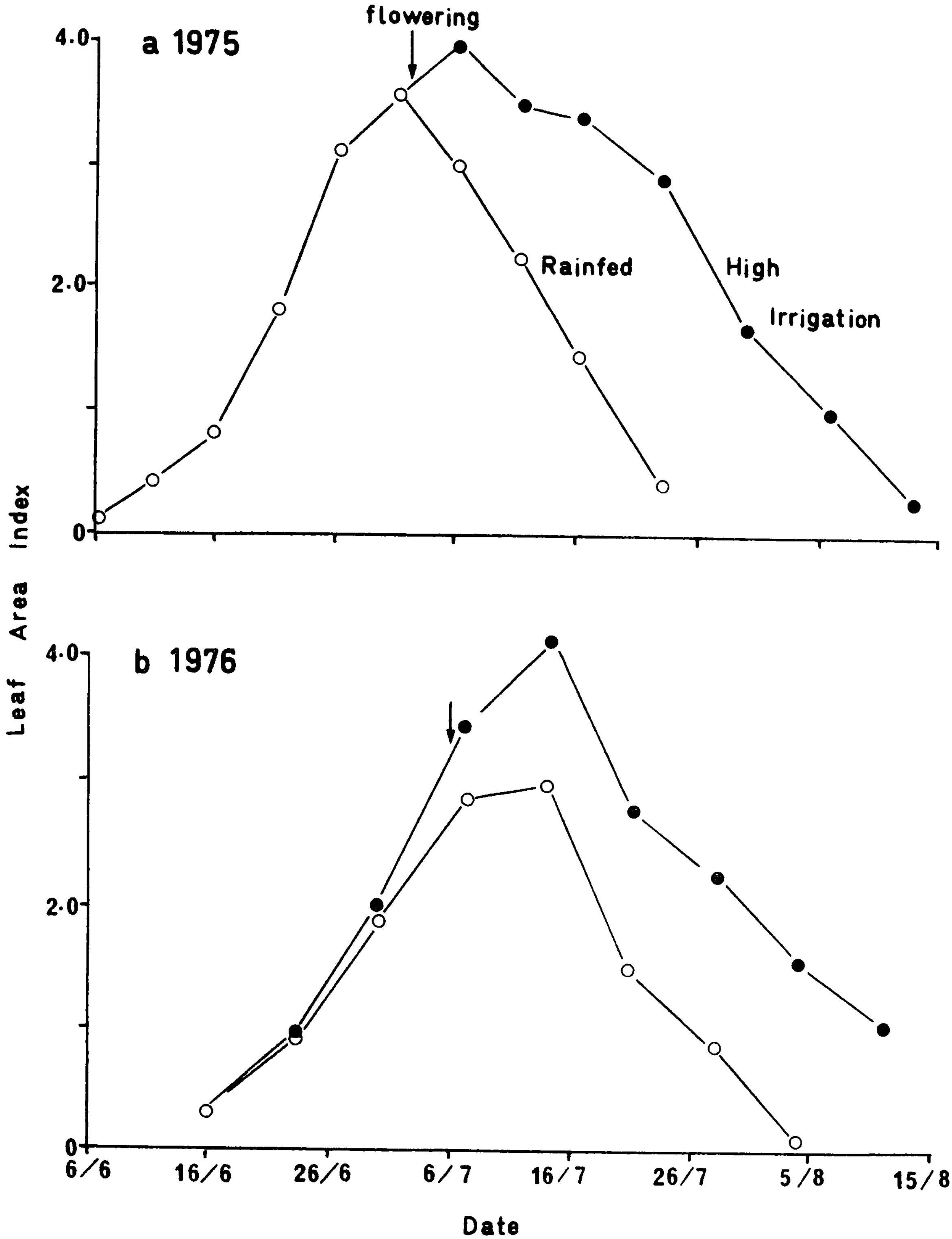

Figure 17. Effect of irrigation on leaf area index of _B. napus_ in 1975 and 1976.

at flowering, while under irrigation it was not reached until 5-7 days later.

Seeding rate affected LAI during the period of growth up to maximum LAI (Fig. 18 and 19). LAI increased with increasing seeding rate during this period. From maximum LAI to the disappearance of leaves there was virtually no difference in LAI among seeding rates. The highest seeding rate reached maximum LAI slightly earlier than the lower seeding rates.

There were significant differences in LAI between seeding rates at 10 percent flowering (Table 11). The LAI of the 20 kg/ha seeding rate was significantly higher than that of the 2.5 kg rate in 1975. In 1976, LAI of the 20 kg rate was significantly greater than both the 5 and 2.5 kg rates under rainfed and irrigated conditions. Under irrigated conditions the 10 kg rate had significantly higher LAI than the 2.5 kg rate.

Irrigation and seeding rates also affected LAD (Table 12). Irrigation, particularly the high level, increased LAD. LAD increased with increasing seeding rate at the high irrigation level. LAD was shorter in 1976 than in 1975.

4.4.7 Flowering

Both irrigation and seeding rate influenced the number of days to flowering (Table 13). There was no irrigation effect in 1975, since the first irrigation was applied a few days prior to flowering. In 1976, irrigation delayed flowering by about two days. Flowering tended to be earlier at the higher than at the lower seeding rates. Under the irrigated conditions of 1976 this trend was particularly clear,

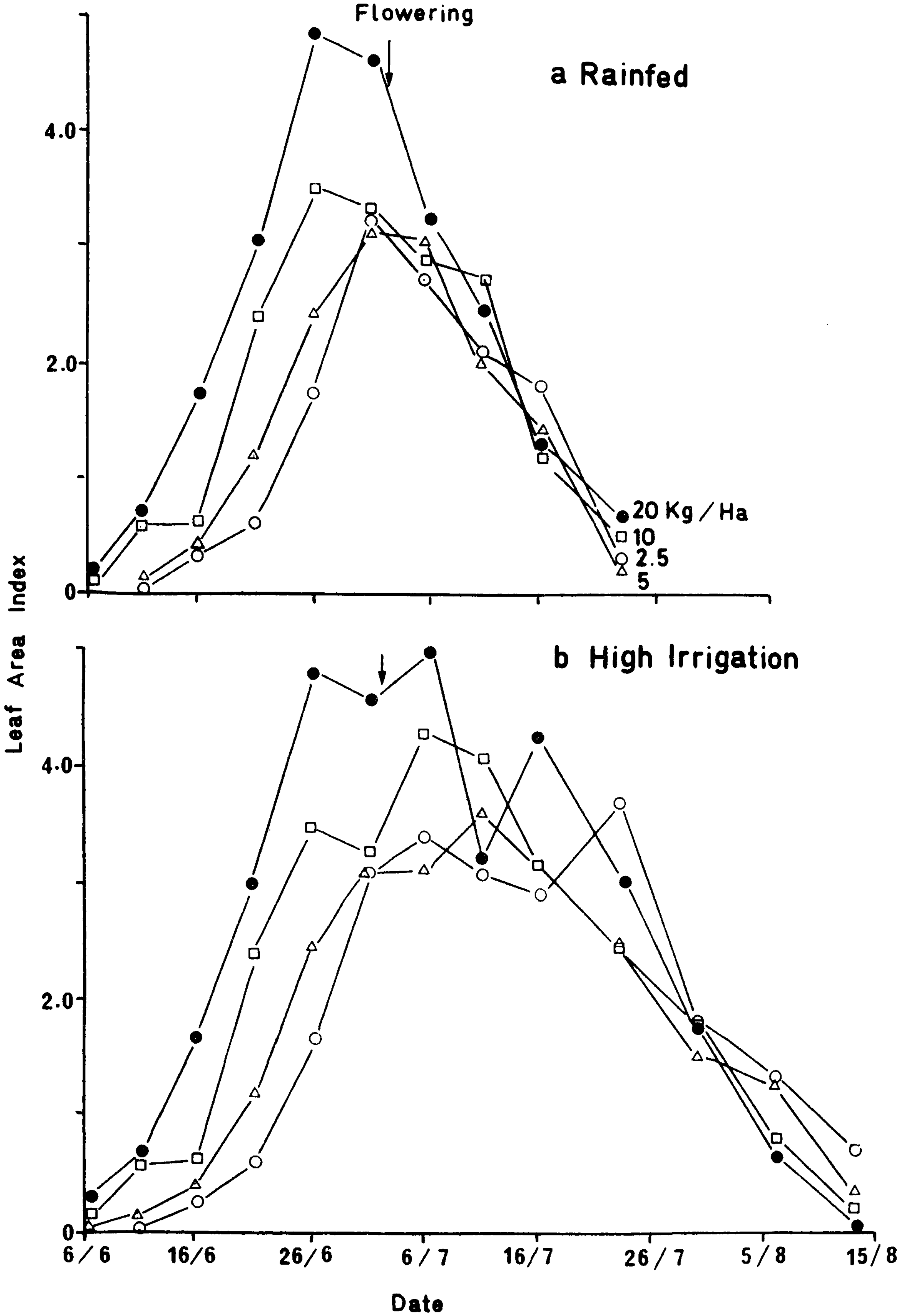

Figure 18. Effect of seeding rate on leaf area index of *B. napus* under rainfed and irrigated conditions, 1975.

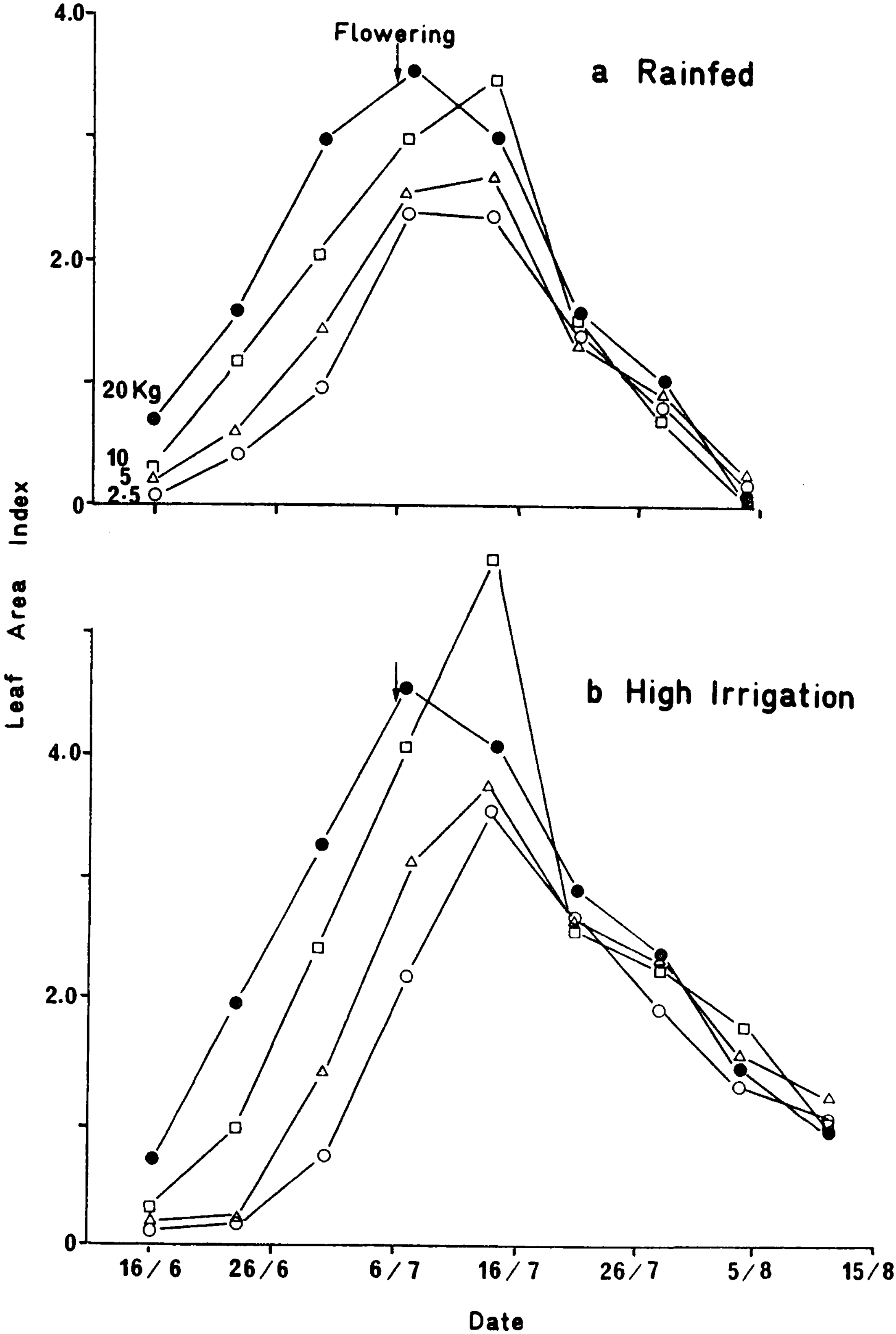

Figure 19. Effect of seeding rate on leaf area index of B. napus under rainfed and irrigated conditions, 1976.

Table 11. Effect of irrigation and seeding rate on leaf area index of *B. napus* at 10 percent flowering.

Year	Seeding rate (kg/ha)	Leaf Area Index Rainfed	Leaf Area Index High irrigation
1975	2.5	3.15 b	3.15 b
	5	3.13 ab	3.13 ab
	10	3.32 ab	3.32 ab
	20	4.55 a	4.55 a
	Mean	3.54	3.54
	SE	.16	.16
1976	2.5	2.42 b	2.29 c
	5	2.49 b	3.13 bc
	10	2.99 ab	4.00 ab
	20	3.53 a	4.53 a
	Mean	2.86	3.49
	SE	.08	.08

Means within years and irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 12. Effect of seeding rate and irrigation on leaf area duration (LAD) of *B. napus*.

Year	Seeding Rate (kg/ha)	LAD (weeks)		
		Rainfed	Low irrigation	High irrigation
1975	2.5	7.37 a	7.90 a	18.26 ab
	5	7.25 a	8.67 a	16.66 b
	10	7.65 a	9.11 a	18.61 ab
	20	8.28 a	9.45 a	20.77 a
	Mean	7.64	8.78	18.58
	SE	.41	.41	.41
1976	2.5	6.08 a	7.25 a	12.07 b
	5	6.55 a	8.07 a	13.50 ab
	10	7.67 a	8.42 a	15.70 a
	20	7.60 a	8.98 a	14.32 ab
	Mean	6.98	8.18	13.90
	SE	.39	.39	.39

Means within years and irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 13. Effect of seeding rate and irrigation on days to 10 percent flowering of *B. napus*.

Year	Seeding Rate (kg/ha)	Days to flowering: Rainfed	Days to flowering: High irrigation
1975	2.5	51.3 a	51.8 a
	5.0	51.3 a	50.8 b
	19.0	50.3 b	50.0 b
	20.0	50.5 ab	50.3 b
	Mean	50.9	50.7
	SE	.12	.12
1976	2.5	58.5 a	62.0 a
	5	58.7 a	61.3 b
	10	58.2 ab	60.5 c
	20	57.8 b	59.2 d
	Mean	58.3	60.8
	SE	.11	.11

Means within years and irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

with each seeding rate, from highest to lowest, flowering significantly earlier than the next lowest.

Detailed records of the length of the flowering period were not kept in 1975. However, it was noted that the last flowers on the rainfed and low irrigation plots had disappeared by July 16, and those on the high irrigation plots by July 23. The length of the flowering period was thus about 14 days for the rainfed and low irrigation treatments, and 21 days for the high irrigation treatment. Observations on the length of the flowering period in 1976 showed a seeding rate as well as an irrigation effect (Table 14). The flowering period was longer at the lower seeding rates than at the higher rates. Irrigation, particularly the high level, also increased the length of the flowering period.

4.4.8 Pod area

In 1976, enough measurements of pod area were made on the high irrigation treatment to give an indication of the development of pod area. Pod area increased rapidly during the flowering period and reached its maximum at about the time flowering ceased (Fig. 20). The increasing pod area more than off-set the decline in leaf area after flowering, resulting in an increase in total leaf + pod area. The total leaf + pod area reached its maximum at the end of flowering, and then declined.

Irrigation and seeding rate influenced the maximum pod area attained (Table 15). Maximum pod area of the high irrigation was almost double that of the rainfed treatment in both 1975 and 1976. Significant differences in pod area between seeding rates were detected in 1975.

Table 14. Effect of seeding rate and irrigation on length of the flowering period of *B. napus* (1976).

Seeding Rate (kg/ha)	Length of flowering (days)		
	Rainfed	Low irrigation	High irrigation
2.5	19.7 a	19.5 a	24.0 a
5	17.8 b	19.0 a	22.0 b
10	16.3 c	16.7 b	21.5 b
20	16.3 c	17.0 b	21.8 b
Mean	17.5	18.1	22.3
SE	.24	.24	.24

Means within years and irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

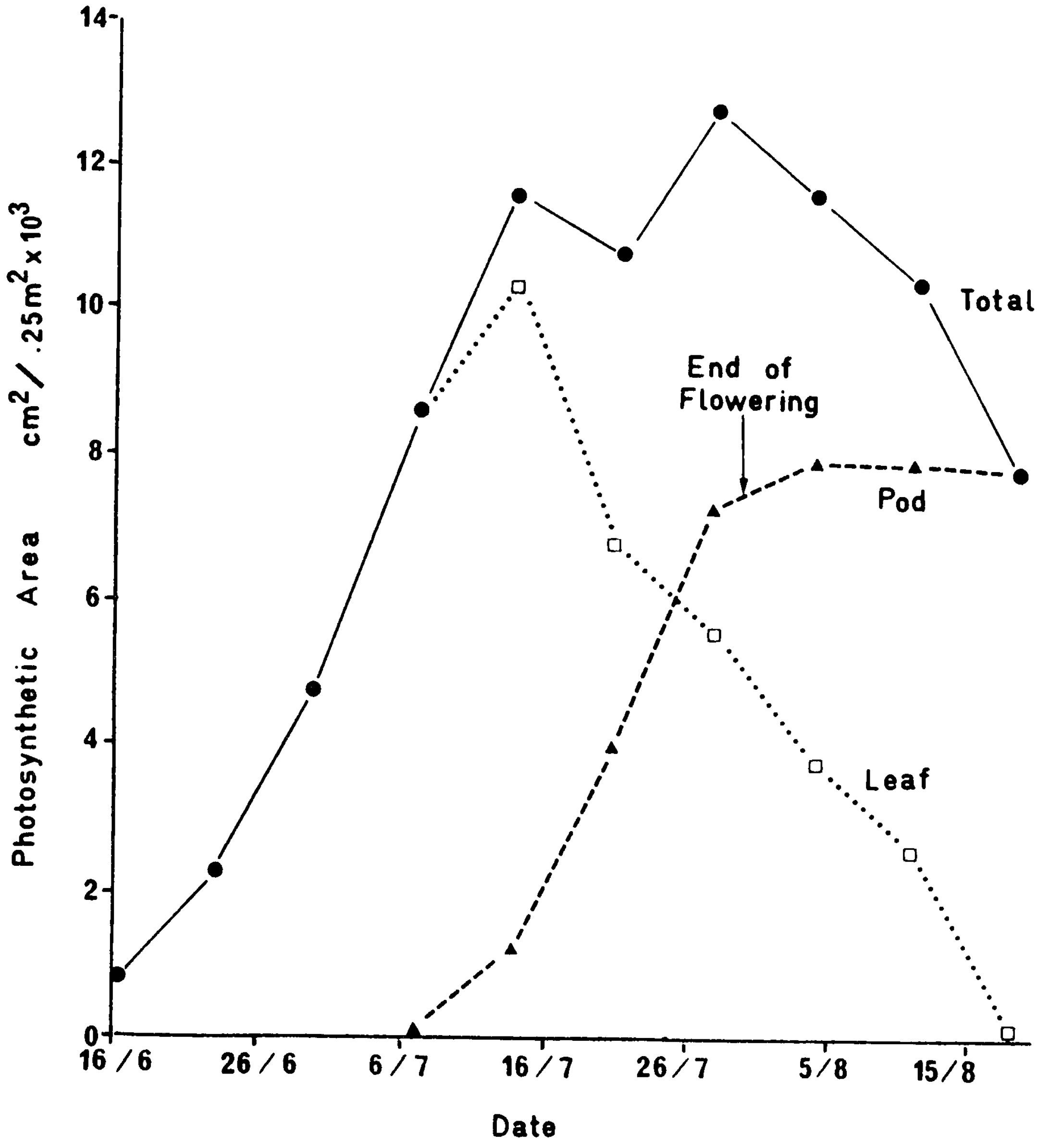

Figure 20. Total leaf and pod surface area of B. napus; high irrigation 1976.

Table 15. Effect of seeding rate and irrigation on maximum pod area of *B. napus*.

Year	Seeding Rate (kg/ha)	Pod Area ($cm^2/.25m^2$)		
		Rainfed	Low irrigation	High irrigation
1975	2.5	5280 b	6863 b	11843 a
	5	6193 ab	7982 ab	14056 a
	10	6521 ab	11619 a	13601 a
	20	9788 a	11743 a	14153 a
	Mean	6946	9552	13413
	SE	630.66	630.66	630.66
1976	2.5	3268 a	7613 a	7683 a
	5	3603 a	7250 a	7082 a
	10	4931 a	6213 a	7689 a
	20	4592 a	6922 a	8830 a
	Mean	4099	7000	7821
	SE	297.81	297.81	297.81

Means within years and irrigation treatments followed by the same letter do not differ significantly according to Duncan's Multiple Range Test.

The high seeding rates had higher pod area than the low rate in the rainfed and low irrigation treatments. Differences were not significant in the high irrigation treatment or in any of the 1976 treatments. Due to the differences in area measurement techniques, a comparison of the magnitude of pod area between the two years was not made.

4.4.9 Growth functions

Leaf area ratio was high at the beginning of the season and declined to zero during ripening (Fig. 21). Irrigation increased LAR and maintained it at a higher level after flowering. LAR at flowering in the rainfed treatment was the same in 1975 as it was in 1976 (120 cm^2/g).

Seeding rate had little effect on LAR, except perhaps in the very early stages of growth. In 1975, the 10 and 20 kg/ha seeding rates tended to have a higher LAR before flowering than did the 2.5 or 5 kg/ha rates (Fig. 22). After flowering there were no consistent differences between the seeding rates in either the rainfed or irrigated treatments. In 1976, the 2.5 kg/ha seeding rate had the highest LAR at the first harvest under both rainfed and irrigated conditions (Fig. 23). After this, differences between seeding rates in the rainfed and irrigated treatments were very small.

Net assimilation rate was high early in the season, declined until early ripening, increased for a short period and again declined. Irrigation tended to increase NAR (Fig. 24). NAR during early growth was higher in 1975 than in 1976. At flowering, NAR of the rainfed treatments of both years was in the order of 0.5 $mg/cm^2/day$.

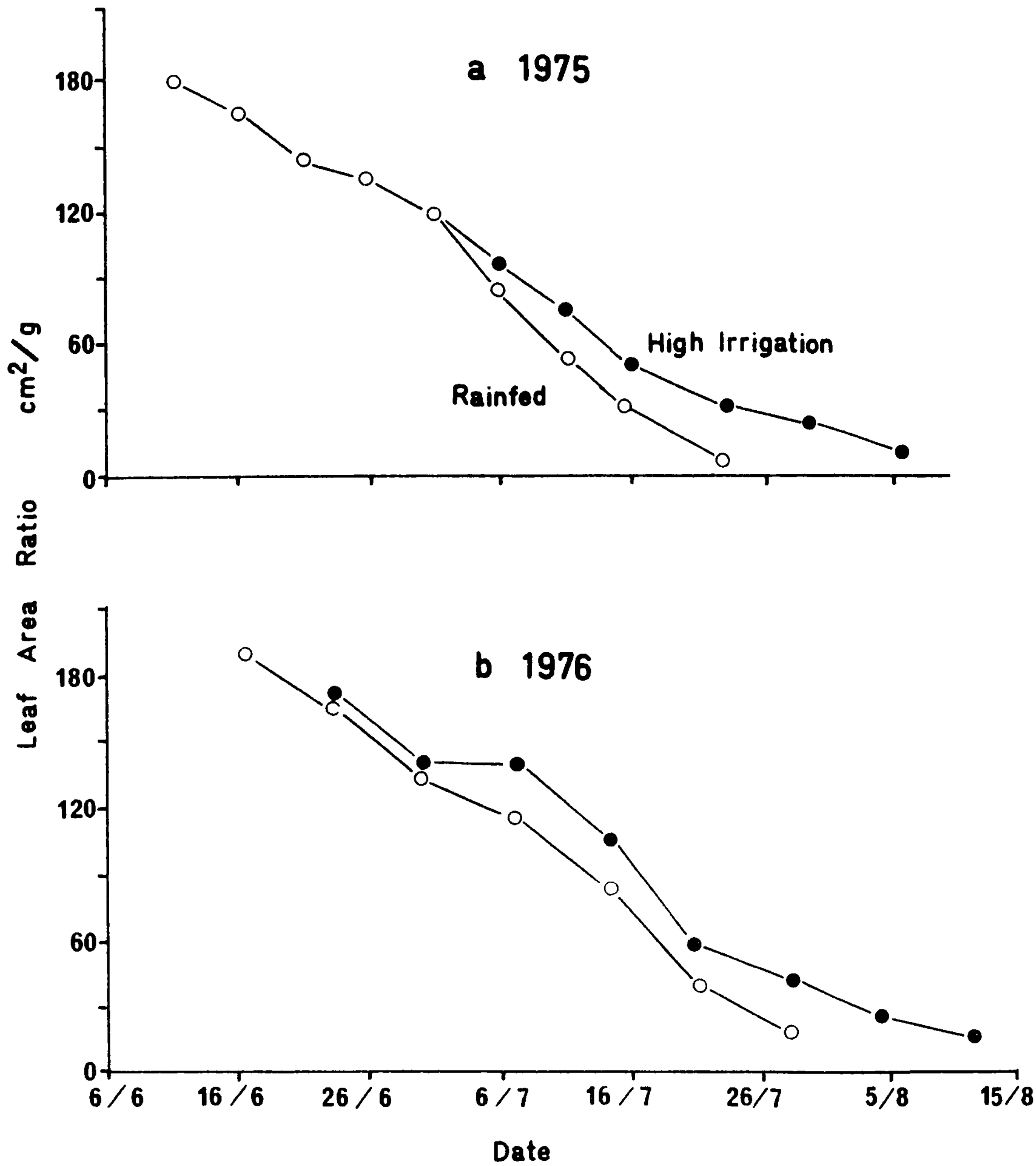

Figure 21. Effect of irrigation on leaf area ratio of B. napus in 1975 and 1976.

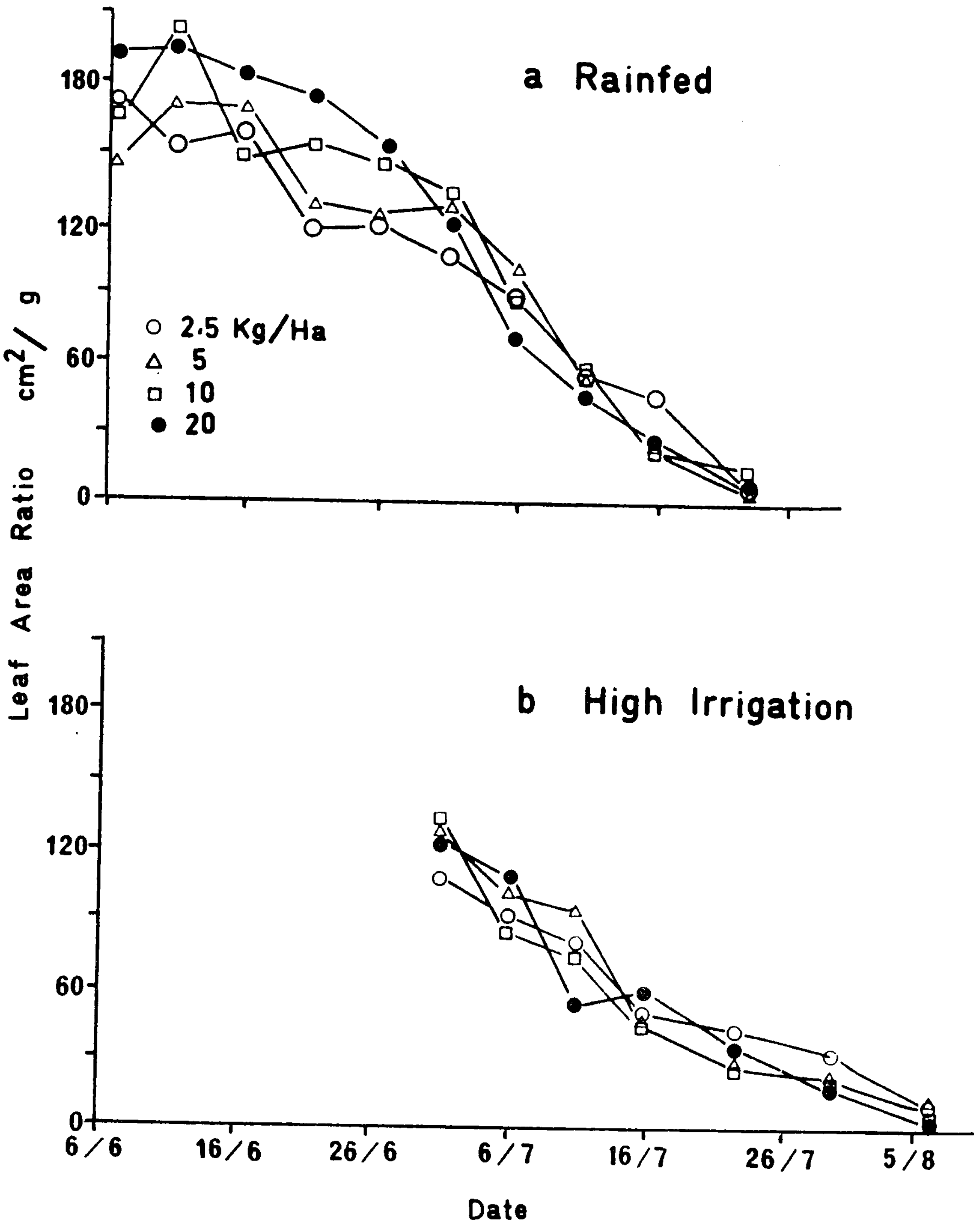

Figure 22. Effect of seeding rate on leaf area ratio of B. napus under rainfed and irrigated conditions, 1975.

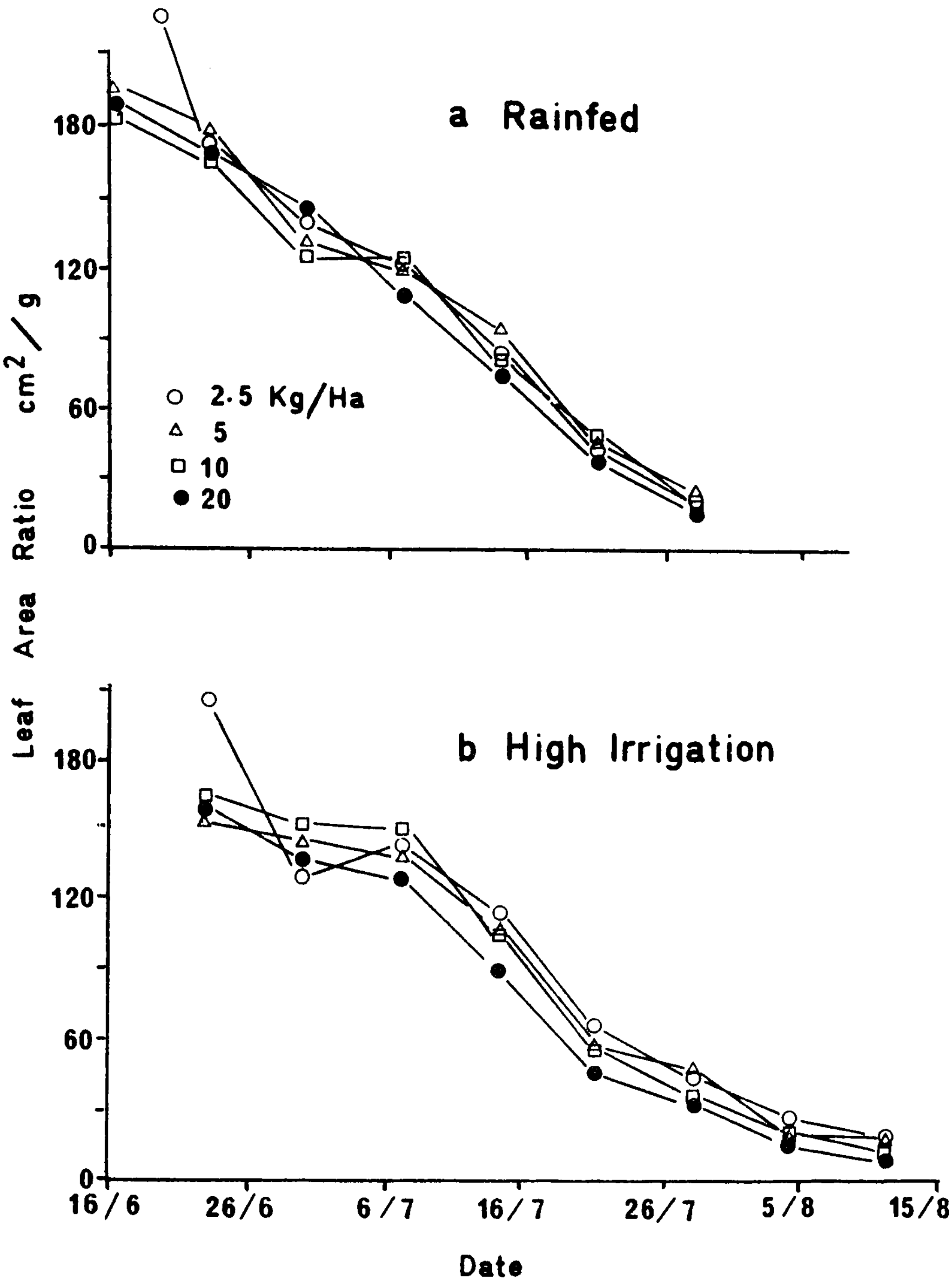

Figure 23. Effect of seeding rate on leaf area ratio of *B. napus* under rainfed and irrigated conditions, 1976.

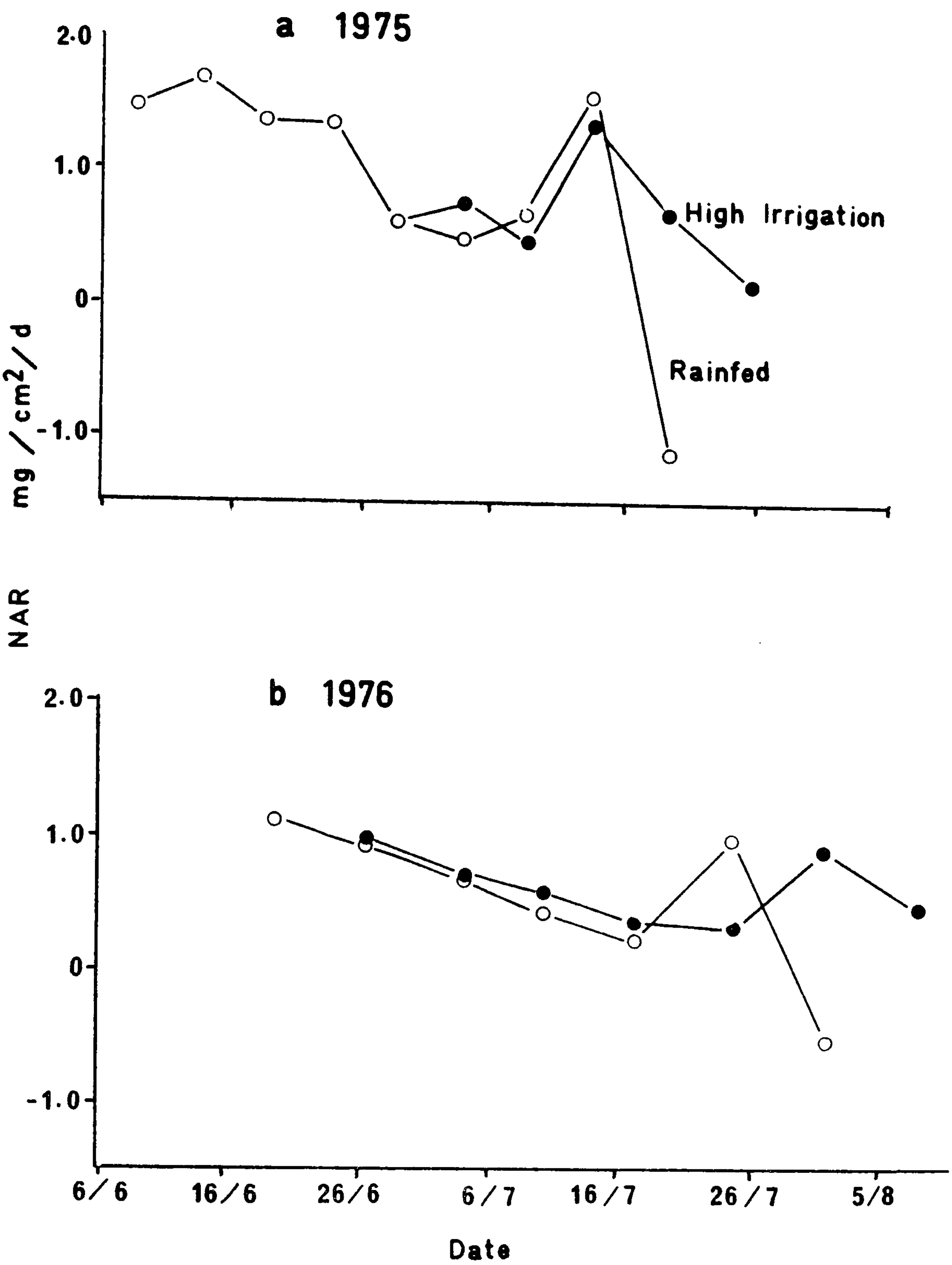

Figure 24. Effect of irrigation on mean net assimilation rate of *B. napus* in 1975 and 1976.

The late-season upswing in NAR occurred earlier in 1975 than in 1976. In 1975 it occurred just prior to the end of flowering in both the rainfed and irrigated treatments. NAR declined to a negative value after this in the rainfed treatment. In the high irrigation treatment, NAR declined to near zero, then increased. The upswing in NAR came just prior to the end of flowering in the 1976 rainfed treatment, and just after the end of flowering in the high irrigation treatment.

Seeding rates also influenced NAR. In 1975, NAR was highest at the 2.5 kg/ha seeding rate and lowest at the 20 kg/ha rate throughout most of the season in the rainfed treatment (Fig. 25). Irrigation caused NAR to be highest at the 10 and 20 kg/ha rates, and lowest in the 2.5 and 5 kg/ha rates in the latter part of the season. In 1976, NAR was again highest in the low seeding rate early in the season in both rainfed and irrigated treatments (Fig. 26). During the late spring phase, NAR was highest in the high seeding rate in the rainfed treatment (Fig. 26a). In the high irrigation treatment, the reversal in ranking of the NAR values came just after flowering (Fig. 26b).

Relative growth rate reached its maximum early in the season and then declined rapidly. Irrigation tended to increase RGR (Fig. 27). RGR decreased rapidly until flowering, and more slowly during the flowering and ripening phases. There was a brief increase in RGR during the early ripening phase in the 1975 high irrigation treatment and near the end of flowering in the 1976 rainfed and high irrigation treatments.

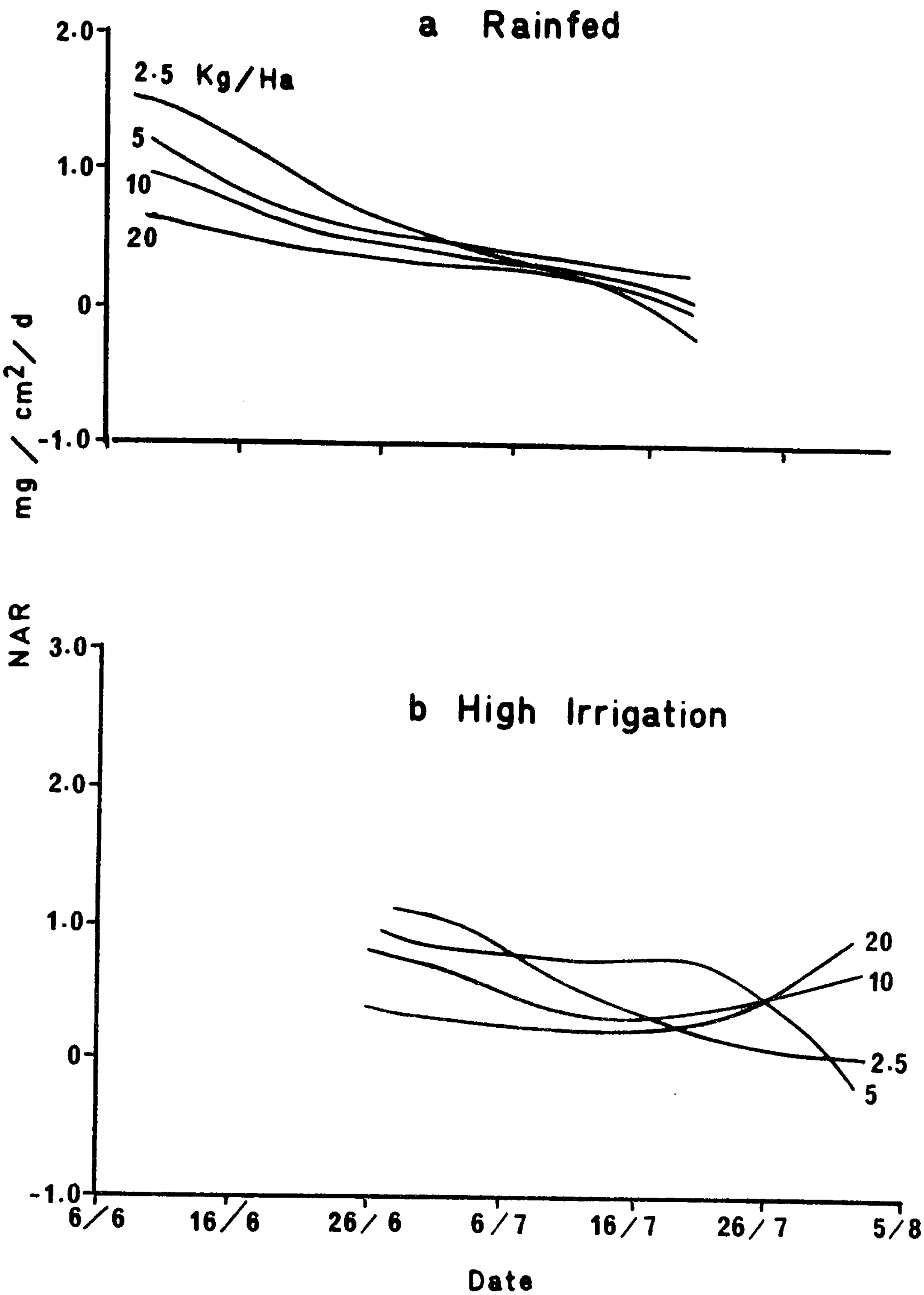

Figure 25. Effect of seeding rate on mean net assimilation rate of *B. napus* grown under rainfed and irrigated conditions, 1975 (calculated from fitted dry weight and leaf area data).

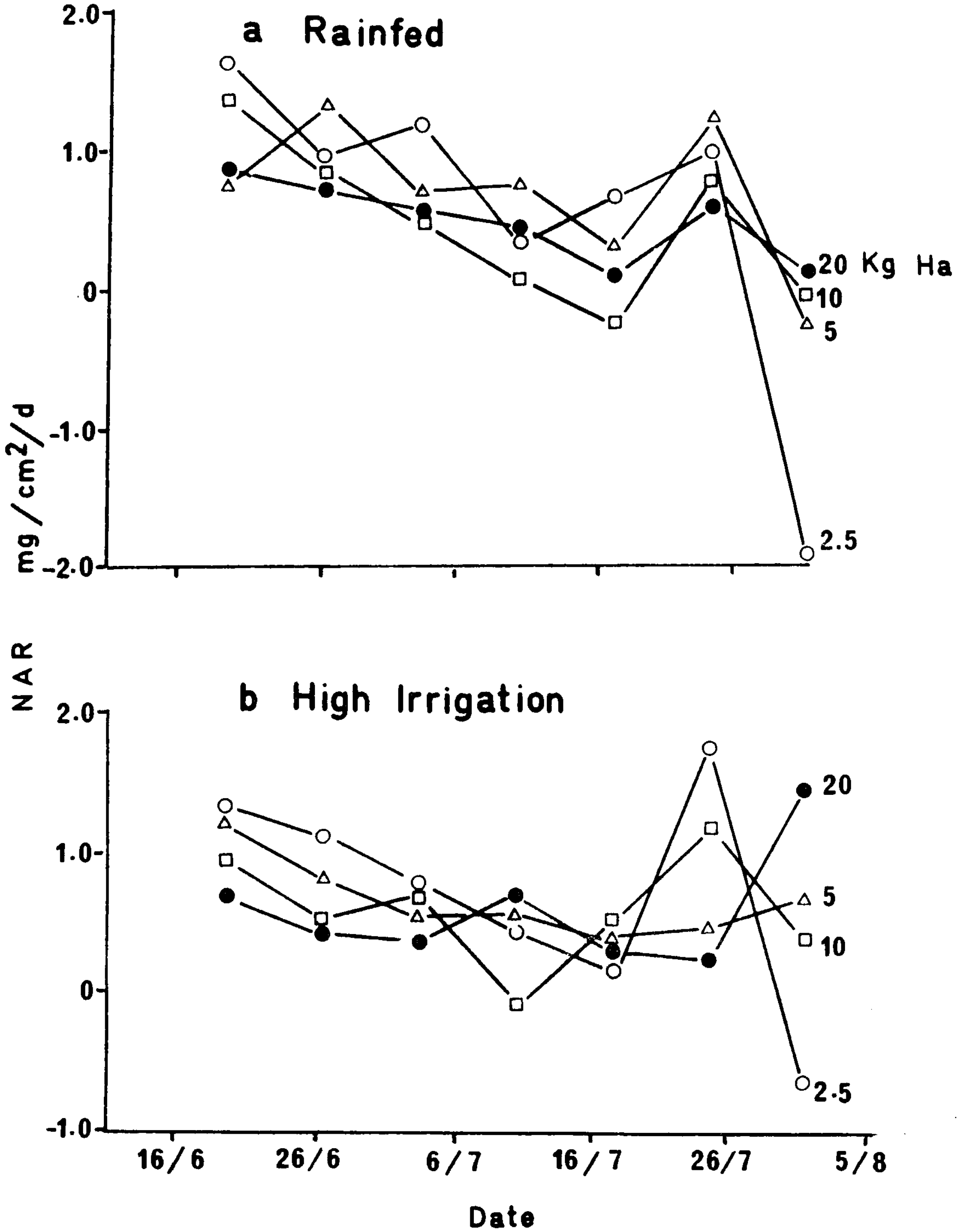

Figure 26. Effect of seeding rate on mean net assimilation rate of *B. napus* under rainfed and irrigated conditions, 1976.

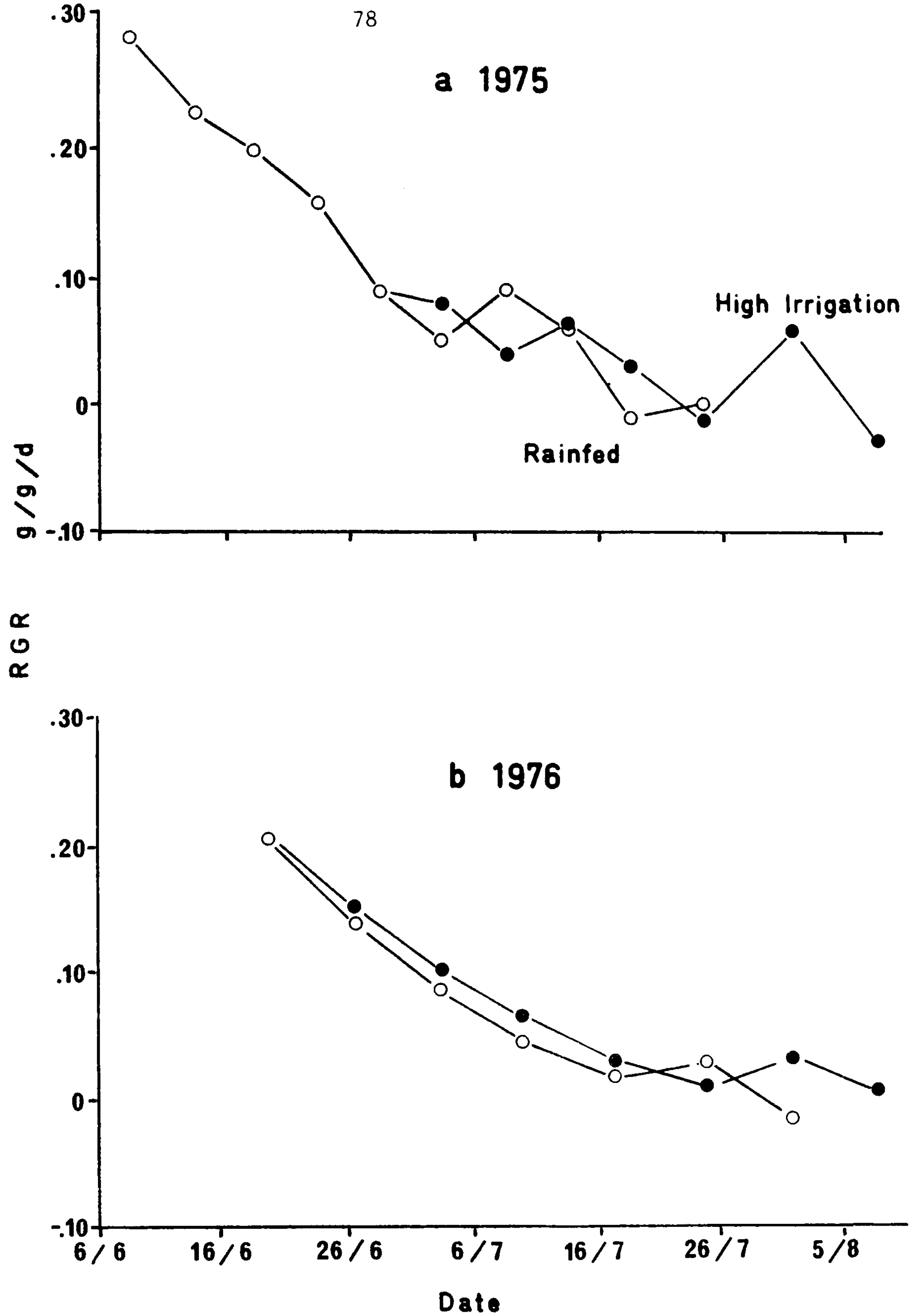

Figure 27. Effect of irrigation on mean relative growth rate of B. napus, 1975 and 1976.

Seeding rate influenced RGR relatively more than irrigation (Figs. 28 and 29). RGR increased as the seeding rate was decreased from 20 kg/ha to 2.5 kg/ha. RGR of the 2.5 kg/ha seeding rate was much higher than that of the other seeding rates early in the season, particularly in 1976. The RGR's of all seeding rates converged later in the season. In the 1975 rainfed treatment this convergence took place early in the flowering phase, while in the high irrigation treatment it occurred somewhat later (Fig. 28). In 1976, the convergence also took place earlier in the rainfed than in the high irrigation treatment (Fig. 29). An upswing in RGR at the end of the season was evident in all but the 1975 rainfed treatment.

Crop growth rate was low at the beginning of the season, increased to a maximum near flowering, declined after flowering and made another brief upswing near the end of flowering (Fig. 30). Irrigation increased CGR both years.

The CGR was highest at the highest seeding rate during the early part of the season in both years (Figs. 31 and 32). The maximum CGR tended to be reached earlier in the higher seeding rates. Maximum CGR was similar for all seeding rates, with the exception of the 1975 rainfed treatment where it was highest at the high seeding rates. The 5 kg/ha seeding rates in the 1975 high irrigation treatment and in the 1976 rainfed treatment did not follow the pattern of the other seeding rates (Figs. 31b and 32a). An upswing in CGR at the end of the season was evident in all but the 1975 rainfed treatment. The relationship between CGR and LAI was asymptotic, with CGR approaching a maximum near LAI 4, particularly in the irrigated material (Fig. 33).

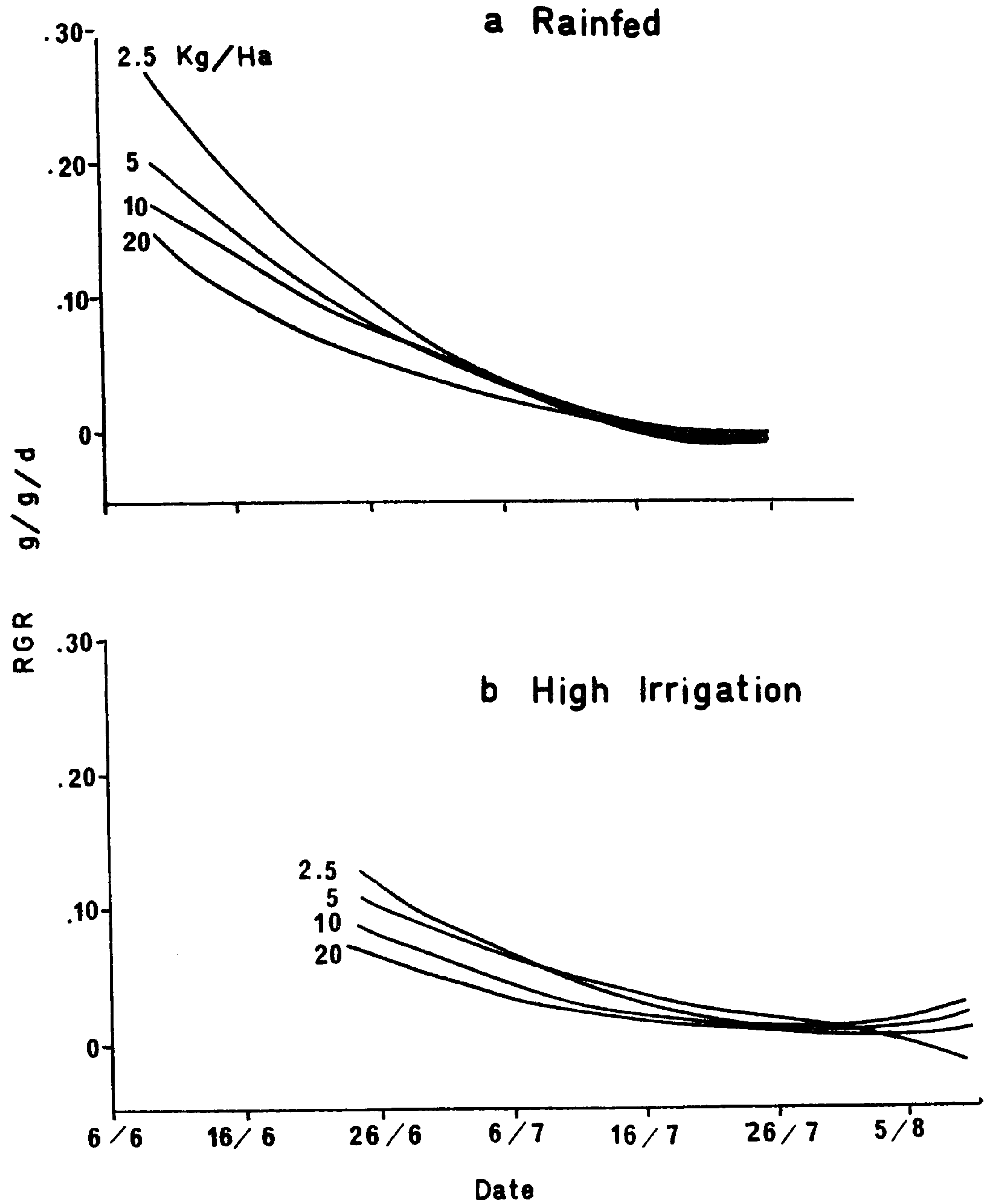

Figure 28. Effect of seeding rate on mean relative growth rate of *B. napus* under rainfed and irrigated conditions, 1975 (calculated from fitted dry weight data).

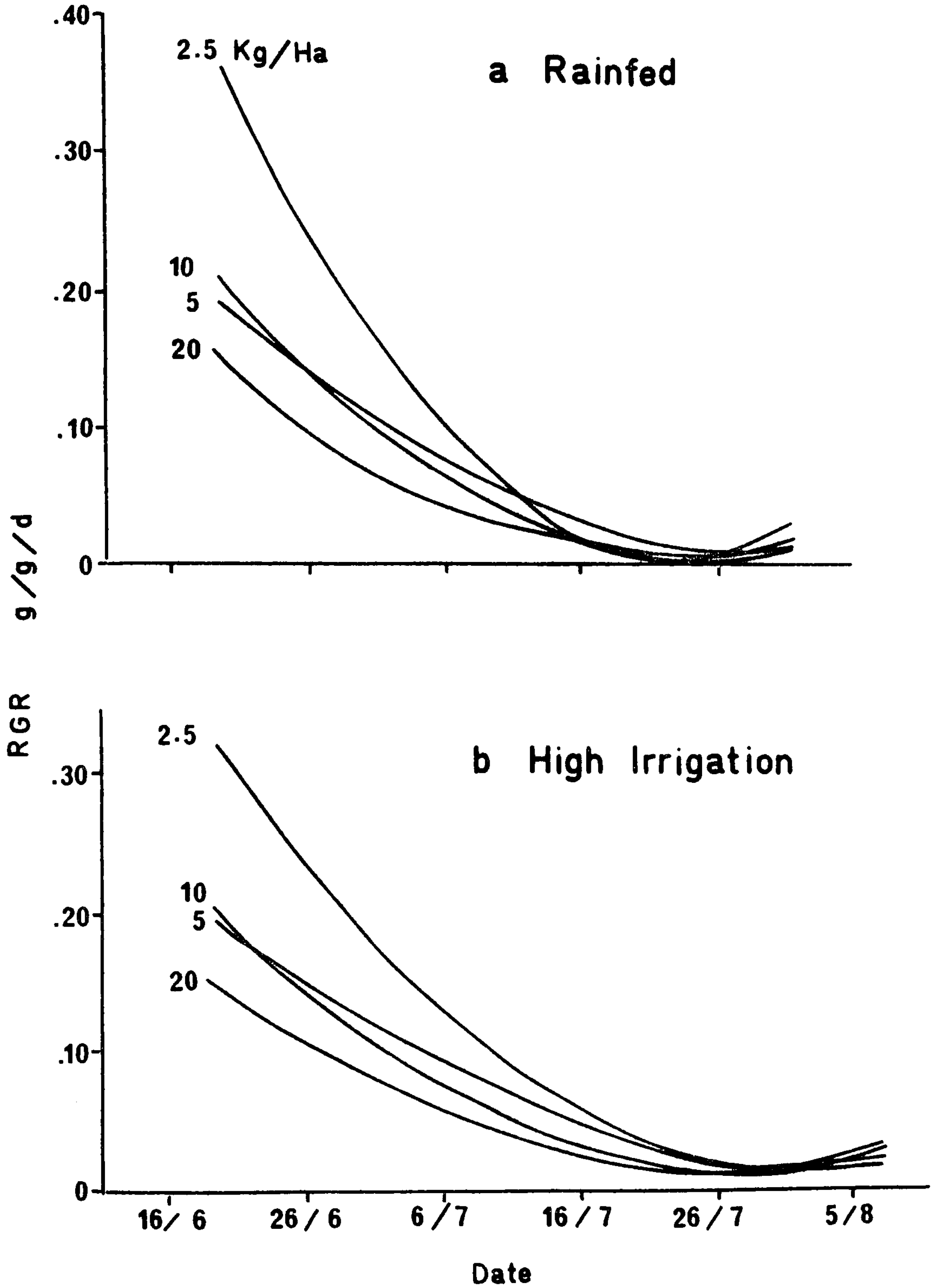

Figure 29. Effect of seeding rate on mean relative growth rate of *B. napus* under rainfed and irrigated conditions, 1976 (calculated from fitted dry weight data).

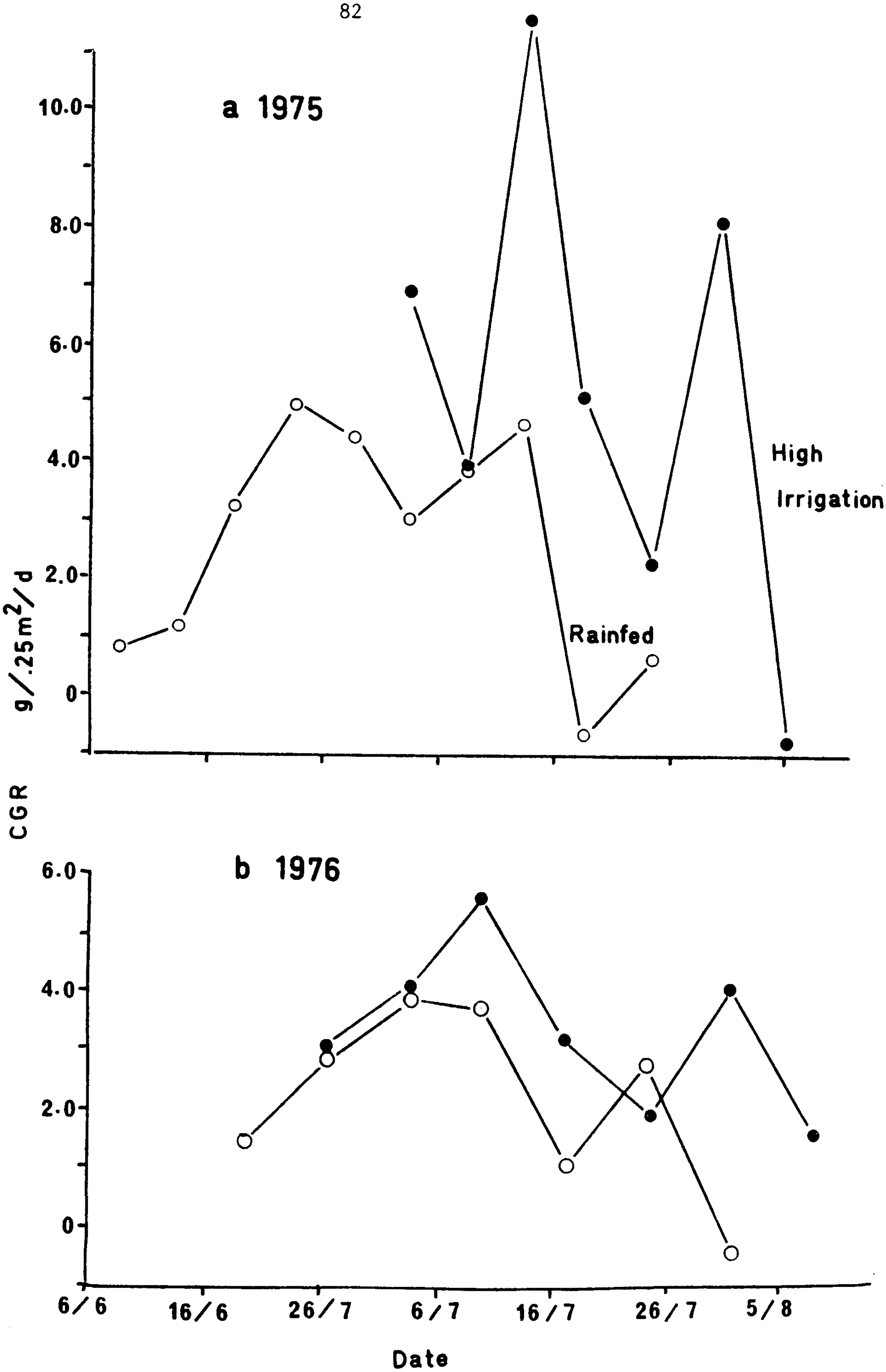

Figure 30. Effect of irrigation on mean crop growth rate of <u>B. napus</u> in 1975 and 1976.

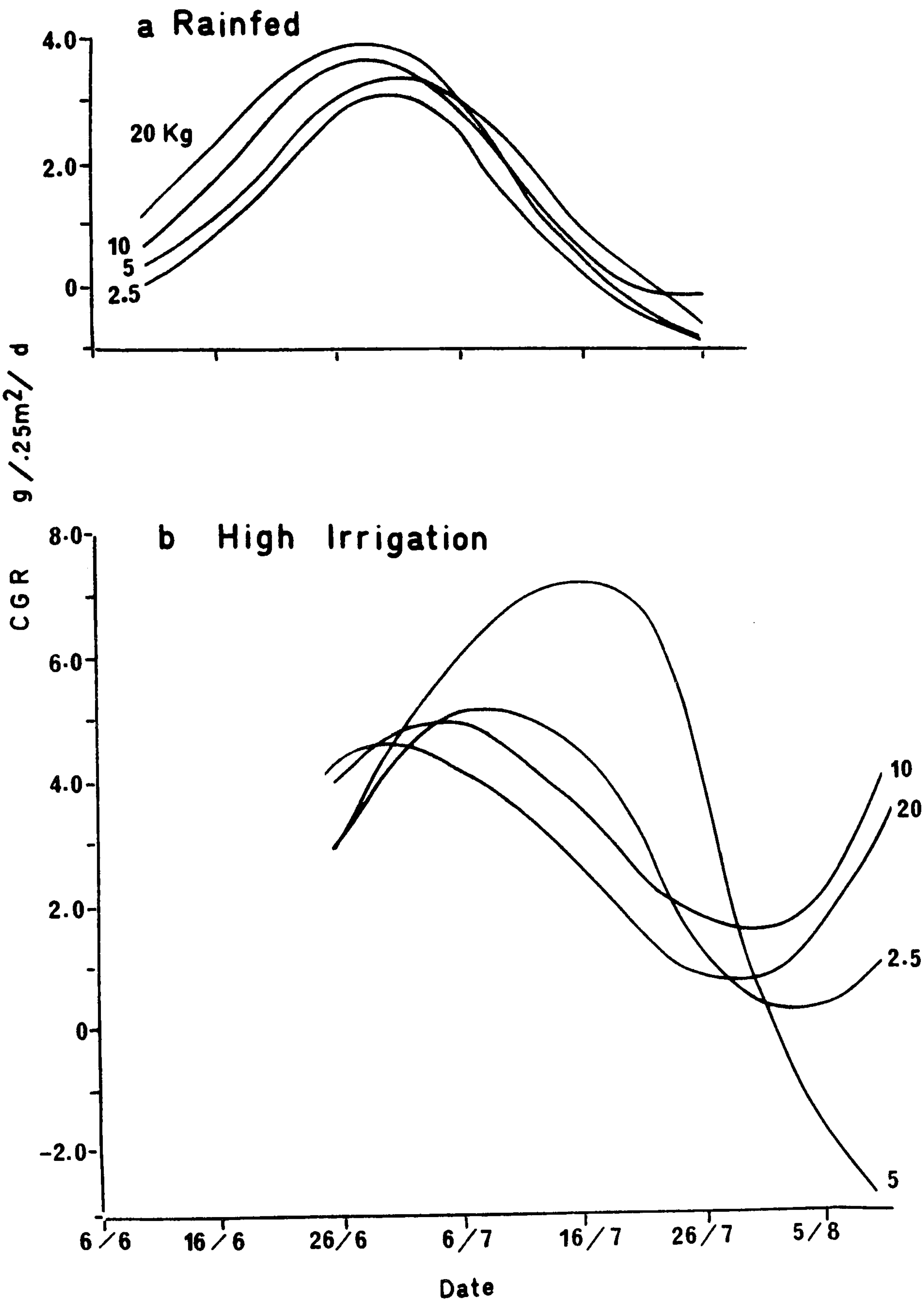

Figure 31. Effect of seeding rate on mean crop growth rate of B. napus under rainfed and irrigated conditions, 1975 (calculated from fitted dry weight data).

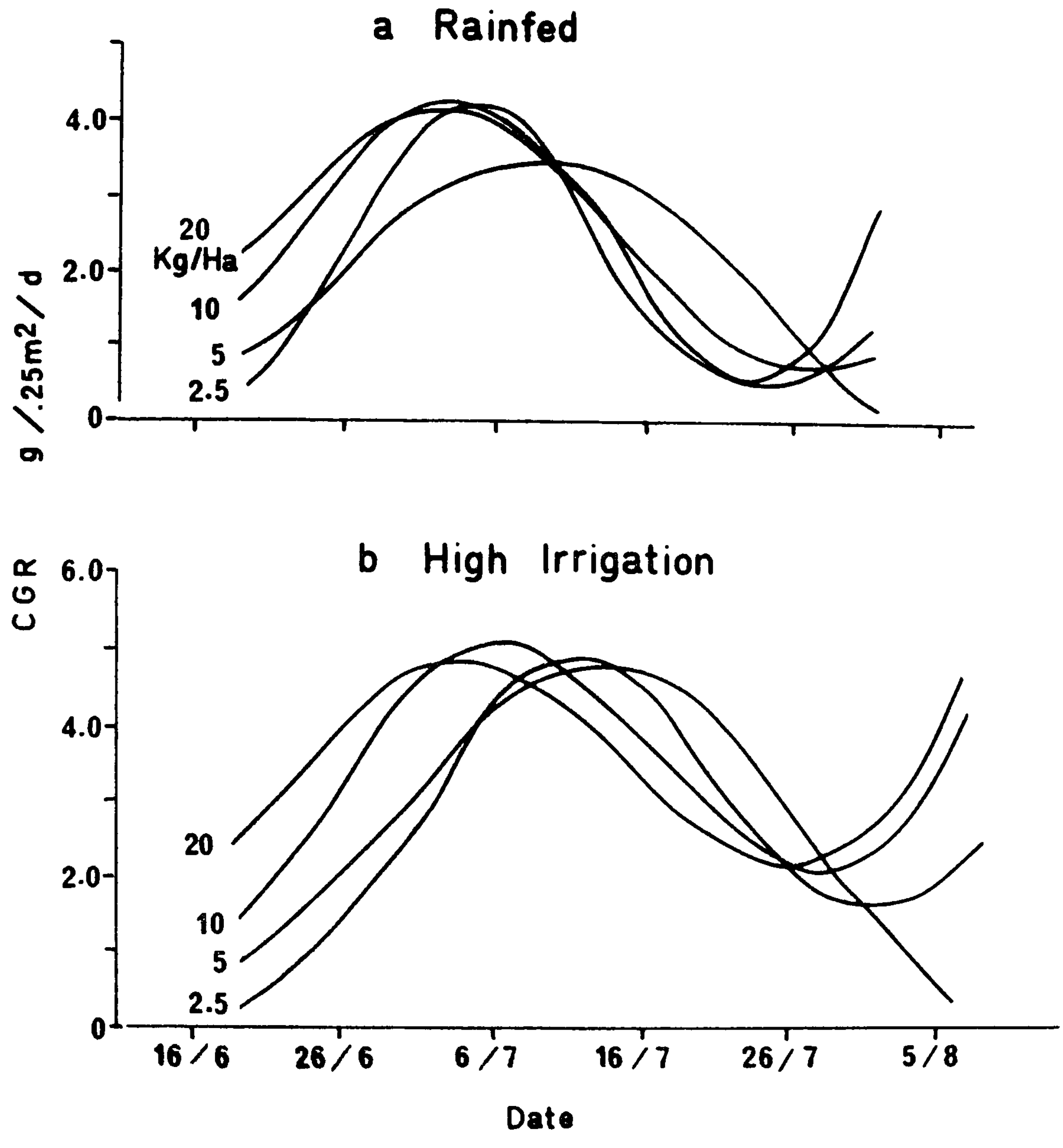

Figure 32. Effect of seeding rate on mean crop growth rate of B. napus under rainfed and irrigated conditions, 1976 (calculated from fitted dry weight data).

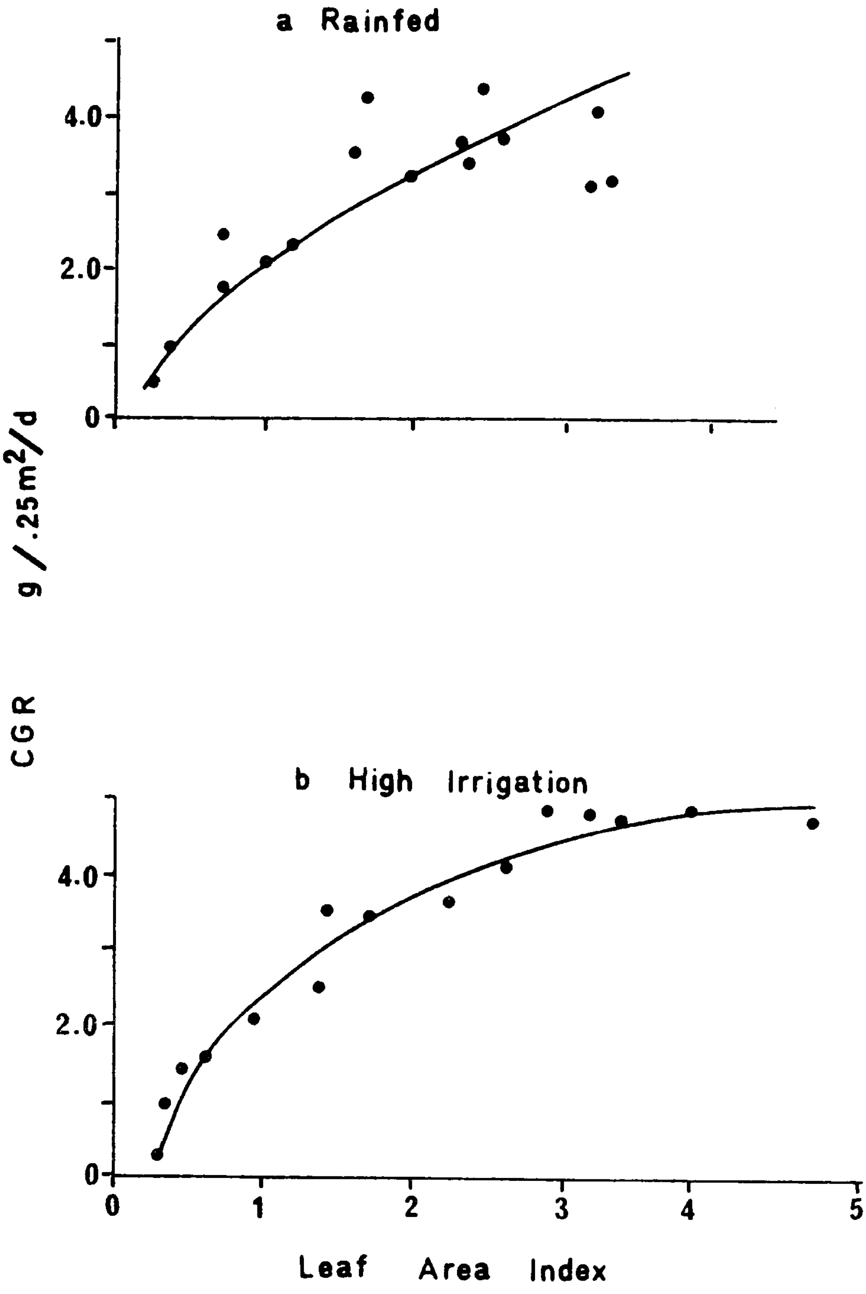

Figure 33. Relationship between leaf area index and crop growth rate of *B. napus*, 1976.

4.5 Relationship between photosynthetic area and yield

4.5.1 Leaf removal

Removal of leaves at the start of flowering (July 12) resulted in reduced total dry matter through the rest of the growth period as compared to the control (Table 16). The effect was more pronounced in the 5 kg/ha seeding rate than in the 20 kg/ha rate. Defoliation at the end of flowering (July 26) caused no significant changes in dry matter even though the control plants had a substantial leaf dry weight at this time, with leaf area indices of 3.8 and 2.6 for the 5 and 20 kg/ha seeding rates, respectively. At maturity, the dry weights of stem and seed + pod were significantly higher in the control and late defoliation than in the early defoliation at the 5 kg/ha seeding rate, but not at the 20 kg rate.

Leaf removal had no effect on the number of branches per plant or the number of seeds per pod (Table 17). At the 5 kg/ha seeding rate, the early defoliation resulted in significantly fewer pods per plant than in the control or the later defoliation. Also in the 5 kg/ha rate, the early defoliation treatment resulted in a significantly higher 1000-seed weight than in the control or late defoliation treatments.

The seed yield of the early defoliation treatment was significantly lower than that of either the control or the late defoliation at the 20 kg/ha seeing rate, and lower than the control yield at the 5 kg rate (Table 18). The yield of the control and the late defoliation did not differ significantly at either of the two seeding rates.

Table 16. Effect of defoliation on dry weight of B. napus in 1976. 1 = control, 2 = defoliation at start of flowering, 3 = defoliation at end of flowering.

Seeding rate and Harvest date	Dry weight ($g/1240\ cm^2$)											
	Stem			Leaf			Pod			Total		
	1	2	3	1	2	3	1	2	3	1	2	3
5 kg/ha												
12/7	27.4	-	-	21.2	0	-	0	-	-	48.6	-	-
26/7	41.4	27.1	-	17.2	0	0	33.2a	15.2b	-	91.8a	42.2b	-
6/8	26.2	17.2	26.6	3.6	0	0	38.8a	20.1b	36.2ab	68.6	37.3	62.9
17/8	39.7a	26.5b	32.6ab	0	0	0	75.7a	48.7b	64.2ab	115.a	75.4b	97.0ab
20 kg/ha												
12/7	40.4	-	-	28.0	0	-	0	0	0	68.5	-	-
26/7	39.5	34.9	-	12.8	0	0	33.2	18.1	-	85.4a	52.9b	-
6/8	30.9	24.4	29.5	3.8	0	0	43.4	24.5	33.7	78.1	48.8	63.2
17/8	37.1	30.1	43.5	0	0	0	60.2	49.3	73.6	97.3	79.4	116.8

Means within rows, within components and sharing the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 17. Effect of timing of defoliation on yield components of *B. napus* in 1976. 1st defoliation = defoliation at 10% flowering; 2nd defoliation = defoliation at end of flowering.

Component	Seeding Rate (kg/ha)	Control	1st defoliation	2nd defoliation
Branches/plant	5	4.0 a	3.3 a	3.8 a
	20	2.0 a	1.5 a	2.0 a
	Mean	3.0	2.4	2.9
	SE	.36	.36	.36
Pods/plant	5	62.8 a	42.3 b	53.8 a
	20	22.5 a	18.0 a	25.5 a
	Mean	42.7	30.2	39.7
	SE	5.21	5.21	5.21
Seeds/pod	5	12.5 a	11.5 a	12.3 a
	20	12.0 a	11.0 a	9.5 a
	Mean	12.3	11.3	10.9
	SE	1.05	1.05	1.05
1000-seed weight (g)	5	3.14 b	3.40 a	3.19 b
	20	3.29 a	3.36 a	3.33 a
	Mean	3.21	3.38	3.26
	SE	.04	.04	.04

Means within rows followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 18. Effect of timing of defoliation on seed yield of *B. napus* seeded at two rates in 1976. 1st defoliation = defoliation at 10% flowering; 2nd defoliation = defoliation at end of flowering.

Seeding rate (kg/ha)	Seed yield (g/plot)		
	Control	1st defoliation	2nd defoliation
5	237 a	167 b	216 ab
20	236 a	165 b	262 a
Mean	237	166	239
SE	20.97	20.97	20.97

Means within rows followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

4.5.2 Correlations with seed yield

There was a significant positive correlation between seed yield and maximum LAI in all but the 1975 rainfed treatment (Table 19). This was also the case for LAD. LAD was negatively correlated with seed yield in the 1975 rainfed treatment. There was a significant positive correlation between seed yield and maximum pod area in the 1975 rainfed treatment. The correlation was near zero in both 1976 treatments.

Path coefficient analysis revealed a larger direct relationship between seed yield and maximum LAI in 1975 than was indicated by correlation, particularly in the rainfed treatment (Table 20). This direct effect was masked by the negative contribution of LAD. The significant positive correlation between seed yield and LAD in the high irrigation treatment was the result of the correlation with LAI, the direct effect being near zero.

In 1976, the direct effect of maximum LAI on seed yield in the high irrigation treatment was shown to be smaller than indicated by the correlation (Table 21). Over half of the correlation value was contributed via LAD. The correlation between seed yield and LAD in the rainfed treatment was mostly due to the effect of LAI on seed yield. The direct effects of maximum pod area and plant size at maturity on seed yield were little different than the correlation values.

4.6 Effect of irrigation and seeding rate on yield and its components

4.6.1 Agronomic characters

Irrigation delayed maturity in both years (Table 22). The rainfed treatment matured 14 days earlier than the high irrigation treatment

Table 19. Correlations between seed yield and other parameters.

Parameter	Year	Rainfed	High irrigation
Maximum LAI	1975	.140	.504*
	1976	.682**	.411*
Leaf area duration	1975	-.390	.477*
	1976	.485*	.594**
Maximum Pod Area	1975	.524*	.347
	1976	.021	-.044
Dry weight at maturity	1975	-.300	-.010
	1976	.217	.115

*significant P = .05, **significant P = .01 (n=16, 1975; n=24, 1976).

Table 20. Partial correlation analysis of the relationship between seed yield and photosynthetic parameters in 1975.

	Rainfed	High irrigation
Maximum LAI		
Direct effect	.470	.675
via pod area	.042	.076
via LAD	-.342	-.067
via dry weight	-.030	-.179
Total	.140	.504
Leaf area duration		
Direct effect	-.551	-.077
via pod area	-.075	.123
via LAI	.291	.591
via dry weight	-.056	-.139
Total	-.390	.499
Maximum pod area		
Direct effect	.301	.315
via LAD	.138	-.030
via LAI	.066	.162
via dry weight	.020	-.099
Total	.524	.347
Dry weight at maturity		
Direct effect	-.138	-.381
via pod area	-.044	.082
via LAD	-.222	-.028
via LAI	.103	.317
Total	-.300	-.010

Table 21. Partial correlation analysis of the relationship between seed yield and photosynthetic parameters in 1976.

	Rainfed	High irrigation
Maximum LAI		
Direct effect	.644	.198
via pod area	.000	-.033
via LAD	.070	.236
via dry weight	-.031	.011
Total	.682	.411
Leaf area duration		
Direct effect	.124	.543
via pod area	-.001	-.027
via LAI	.363	.086
via dry weight	.000	-.007
Total	.485	.594
Maximum pod area		
Direct effect	.076	-.185
via LAD	-.002	.079
via LAI	-.005	.035
via dry weight	-.049	.027
Total	.021	-.044
Dry weight at maturity		
Direct effect	.297	.158
via pod area	-.012	-.031
via LAD	.000	-.025
via LAI	-.067	.014
Total	.217	.115

Table 22. Effect of seeding rate and irrigation on days to maturity of *B. napus*.

Year	Seeding Rate (kg/ha)	Days to Maturity		
		Rainfed	Low irrigation	High irrigation
1975	2.5	90.5 a	94.3 a	106.5 a
	5	89.5 a	91.5 a	102.5 b
	10	89.8 a	90.5 a	105.3 ab
	20	89.5 a	92.8 a	103.3 ab
	Mean	89.8	92.3	104.4
	SE	.55	.55	.55
1976	2.5	97.3 a	100.0 a	105.8 a
	5	96.7 a	98.0 b	105.3 ab
	10	94.0 b	96.0 c	103.5 bc
	20	94.3 b	96.0 c	102.5 c
	Mean	95.6	97.5	104.3
	SE	.48	.48	.48

Means within years within irrigation treatments followed by the same letter do not differ at the 5% level according to Duncan's Multiple Range Test.

in 1975, 8 days earlier in 1976. The high seeding rates were earlier maturing than the low seeding rates in the 1975 high irrigation treatment and in all 1976 treatments. Visual observation indicated that the maturity pattern within seeding rates became less uniform when the amount of irrigation was increased, particularly in the 2.5 and 5 kg/ha seeding rates. Pods on the main raceme would be fully ripe and prone to shattering, while those on the lower branches would still be completely green.

Plant height was increased by irrigation, more so in 1975 than in 1976 (Table 23). The higher seeding rates caused significant reductions in plant height in the 1975 irrigated treatments and in the 1976 high irrigation treatment.

Lodging was more severe in 1975 than in 1976 (Table 24). In 1976, there was slight lodging in the 20 kg/ha seeding rate in the high irrigation treatment. Loding was increased by both irrigation and high seeding rates in 1975. The 10 and 20 kg/ha seeding rates were almost completely lodged in the high irrigation treatment.

4.6.2 Branch number

Irrigation caused a slight increase in the number of branches per plant (Table 25). Seeding rates had a much greater effect on branch number than irrigation. Branch number decreased as seeding rate was increased. The number of branches per plant was higher in 1976 than in 1975.

4.6.3 Number of pods

There was an increase in number of pods per plant with irrigation,

Table 23. Effect of seeding rate and irrigation on plant height at harvest of *B. napus*.

Year	Seeding Rate (kg/ha)	Height (cm) Rainfed	Low irrigation	High irrigation
1975	2.5	86.5 a	90.8 ab	103.5 a
	5	86.0 a	95.0 a	101.3 ab
	10	86.5 a	92.3 ab	96.0 bc
	20	80.0 a	86.0 b	90.0 c
	Mean	84.8	91.0	97.7
	SE	1.16	1.16	1.16
1976	2.5	82.3 a	82.8 a	91.7 ab
	5	84.0 a	81.5 a	92.8 a
	10	80.5 a	79.0 a	90.8 ab
	20	81.3 a	81.2 a	87.3 b
	Mean	82.0	81.1	90.7
	SE	.97	.97	.97

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 24. Effect of seeding rate and irrigation on lodging of *B. napus*. Scale 1 = no lodging to 9, completely lodged.

Year	Seeding Rate (kg/ha)	Rainfed	Low irrigation	High irrigation
1975	2.5	1.0 a	1.5 b	3.0 c
	5	1.0 a	1.8 b	5.0 b
	10	1.0 a	2.3 b	7.3 a
	20	2.3 a	4.3 a	8.5 a
	Mean	1.3	2.4	5.9
	SE	.35	.35	.35
1976	2.5	1.0 a	1.0 a	1.0 b
	5	1.0 a	1.0 a	1.0 b
	10	1.0 a	1.0 a	1.2 b
	20	1.0 a	1.0 a	1.8 a
	Mean	1.0	1.0	1.3
	SE	.05	.05	.05

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 25. Effect of seeding rate and irrigation on branches/plant at harvest of *B. napus*.

Year	Seeding Rate (kg/ha)	Branches/plant Rainfed	Low irrigation	High irrigation
1975	2.5	4.5 a	4.8 a	6.0 a
	5	3.5 b	4.0 a	3.8 b
	10	2.0 c	2.5 b	2.8 c
	20	1.3 c	1.0 c	2.0 c
	Mean	2.8	3.1	3.7
	SE	.15	.15	.15
1976	2.5	4.8 a	5.0 a	7.2 a
	5	3.5 ab	3.8 ab	4.2 b
	10	3.3 bc	3.0 bc	2.8 b
	20	2.2 c	2.3 c	2.7 b
	Mean	3.5	3.5	4.2
	SE	.23	.23	.23

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

particularly the highest irrigation (Table 26). The effect of irrigation was more pronounced in 1975 than in 1976. All treatments had higher pod numbers in 1976 than in 1975. The number of pods per plant decreased with increasing seeding rate.

4.6.4 Number of seeds per pod

Irrigation increased the number of seeds per pod in both 1975 and 1976 (Table 27). The difference in seed numbers between rainfed and highly irrigated conditions was greatest in 1975. A significant effect of seeding rate on number of seeds per pod was detected in the 1975 low irrigation treatment, where the 2.5 and 5 kg/ha seeding rates had more seeds per pod than the 10 and 20 kg/ha seeding rates.

4.6.5 1000-seed weight

The 1000-seed weight was increased by irrigation in both years (Table 28). 1000-seed weight also tended to increase with seeding rate. Significant differences in 1000-seed weight between seeding rates occurred in the rainfed and low irrigation treatments in 1975, but not in the high irrigation treatment. In 1976, significant differences occurred in the two irrigation treatments, but not in the rainfed treatment.

4.6.6 Relationship between components of yield and position on the plant

In 1976, the relationship between pod number, number of seeds per pod and seed size was investigated at the 5 and 20 kg/ha seeding rates. At the 5 kg/ha rate, the main raceme had significantly more pods than

Table 26. Effect of seeding rate and irrigation on number of pods per plant at harvest of *B. napus*.

Year	Seeding Rate (kg/ha)	Pods/plant Rainfed	Low irrigation	High irrigation
1975	2.5	62 a	71 a	106 a
	5	45 b	50 b	56 b
	10	24 c	29 c	45 b
	20	14 c	15 d	24 c
	Mean	36	41	58
	SE	3.04	3.04	3.04
1976	2.5	76 a	85 a	120 a
	5	50 b	58 b	66 b
	10	41 b	40 c	43 c
	20	25 c	26 c	35 c
	Mean	48	52	66
	SE	3.79	3.79	3.79

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 27. Effect of seeding rate and irrigation on number of seeds per pod at harvest of B. napus.

Year	Seeding Rate (kg/ha)	Seeds/pod Rainfed	Low irrigation	High irrigation
1975	2.5	17.0 a	22.3 a	25.5 a
	5	16.8 a	22.3 a	22.8 a
	10	12.5 a	15.5 b	21.0 a
	20	11.5 a	15.8 b	20.0 a
	Mean	14.5	19.0	22.3
	SE	.91	.91	.91
1976	2.5	15.7 a	17.0 a	17.8 a
	5	13.5 a	15.5 a	17.7 a
	10	13.2 a	14.2 a	15.0 a
	20	13.7 a	16.3 a	15.0 a
	Mean	14.0	15.8	16.4
	SE	.62	.62	.62

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 28. Effect of seeding rate and irrigation on 1000-seed weight of *B. napus*.

Year	Seeding Rate (kg/ha)	1000-seed weight (g) Rainfed	Low irrigation	High irrigation
1975	2.5	2.93 b	2.98 b	3.40 a
	5	3.03 b	3.05 b	3.50 a
	10	3.50 a	3.33 ab	3.73 a
	20	3.35 ab	3.73 a	3.55 a
	Mean	3.20	3.27	3.55
	SE	.06	.06	.06
1976	2.5	3.05 a	3.28 c	3.23 c
	5	3.15 a	3.38 bc	3.46 b
	10	3.07 a	3.48 ab	3.54 ab
	20	3.18 a	3.53 a	3.67 a
	Mean	3.11	3.42	3.48
	SE	.05	.05	.05

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

the side branches (Table 29). The lowest branch had the lowest number of pods. At the 20 kg/ha seeding rate, the main raceme had three times as many pods as the subtending branch.

The number of seeds per pod was greatest in the lower half of the main raceme at the 5 kg/ha seeding rate. Numbers of seeds per pod in the upper half of the main raceme and on the first and second branches did not differ significantly. The third branch had the lowest number. At the 20 kg/ha seeding rate, the number of seeds per pod on both halves of the main raceme was significantly higher than that of the side branch.

Weight per seed was greatest in the lower half of the main raceme at the 5 kg/ha seeding rate. The weight per seed on the lowest branch was significantly lower than that of seeds from the main raceme. At the 20 kg/ha rate the weight per seed on the lower half of the main raceme was significantly higher than that of the branch, but did not differ from that of the upper portion of the main raceme.

In the 5 kg/ha seeding rate, 47% of the plant's seed yield was produced by the main raceme, and 21, 20 and 12% by the first, second and third branches, respectively. The main raceme produced 79% of the seed in the 20 kg/ha rate, while the side branch contributed the remaining 21%.

4.6.7 Seed yield

Irrigation increased seed yield in both years (Table 30). In 1975, the increase in yield of the low and high irrigation treatments over the rainfed treatment was 89 and 213%, respectively. The corresponding increases for 1976 were 59 and 128%.

Table 29. Relationship between branch position and each of the parameters pod number, number of seeds per pod and seed weight.

Seeding rate (kg/ha)	Position	Pod number	Seeds/pod	Seed weight (mg)
5	1	31 a	24 b	3.30 b
	2		28 a	3.45 a
	3	16 b	24 b	3.26 bc
	4	16 b	23 b	3.23 bc
	5	12 c	18 c	3.14 c
20	1	21 a	23 a	3.49 ab
	2		25 a	3.52 a
	3	7 b	20 b	3.38 b

Position 1 = top half of main raceme

2 = bottom half of main raceme

3 = 1st branch down

etc.

Means within seeding rates within components followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 30. Effect of seeding rate and irrigation on seed yield of *B. napus*.

Year	Seeding Rate (kg/ha)	Seed yield (kg/ha)		
		Rainfed	Low irrigation	High irrigation
1975	2.5	725 a	1392 a	2821 a
	5.0	878 a	1605 a	2570 a
	10.0	868 a	1927 a	3102 a
	20.0	1116 a	1852 a	2742 a
	Mean	897	1694	2809
	SE	106.59	106.59	106.59
1976	2.5	748 b	1344 c	1916 b
	5.0	965 b	1468 bc	2356 a
	10.0	954 b	1731 ab	2366 a
	20.0	1364 a	1877 a	2558 a
	Mean	1007	1605	2299
	SE	78.5	78.5	78.5

Means within years within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

In 1975, no significant differences in seed yield were detected between seeding rates. In 1976, however, yield increased with seeding rate. Under rainfed conditions, the 20 kg/ha seeding rate yielded more than the lower three seeding rates. In the high irrigation treatment, the top three seeding rates did not differ significantly, but all three yielded significantly more than the 2.5 kg/ha rate.

4.6.8 Harvest index

In 1975, irrigation tended to increase harvest index, while in 1976 it had little effect (Table 31). There were no significant differences in harvest index between seeding rates in either year.

4.6.9 Relationship between yield and its components

In 1975, only a few of the correlations between yield and its components were significant (Table 32). The correlation between yield and number of pods per plant was -0.570* in the low irrigation treatment. Yield and 1000-seed weight were positively correlated, +0.498* and +0.719** in the low and high irrigation, respectively. The correlation was positive but non-significant in the rainfed treatment.

Most correlations between yield and its components were significant in 1976 (Table 32). There was a highly significant positive correlation between yield and stand in all three environments. Yield and branches per plant and yield and pods per plant were negatively correlated in the three environments. The correlation between yield and number of seeds per pod was negative in all three, but reached significance only in the high irrigation treatment. There was a highly significant positive

Table 31. Effect of seeding rate and irrigation on harvest index of *B. napus*.

Year	Seeding Rate (kg/ha)	Harvest index ($\frac{\text{seed DW}}{\text{total DW}} \times 100$) Rainfed	Low irrigation	High irrigation
1975	2.5	27 ns	35 ns	38 ns
	5	28	35	37
	10	24	35	38
	20	26	34	41
	Mean	26	35	39
	SE	.70	.70	.70
1976	2.5	28 ns	35 ns	32 ns
	5	29	33	32
	10	30	34	31
	20	32	34	31
	Mean	30	34	32
	SE	.72	.72	.72

ns = non-significant

Table 32. Correlations between yield and its components for three water regimes (top line = rainfed, middle line = low irrigation, bottom line = high irrigation).

	Branches/plant		Pods/plant		Seeds/pod		1000-seed wt.		Stand	
	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976
Pods/plant	.955**	.921**								
	.965**	.958**								
	.950**	.952**								
Seeds/pod	.651**	.262	.400	.411*						
	.709**	.194	.706**	.165						
	.783**	.349	.770**	.399						
1000-seed wt.	-.647**	-.165	-.647**	-.228	-.220	-.134				
	-.648**	-.483*	-.649**	-.466*	-.490	-.110				
	-.221	-.450*	-.096	-.538**	.446	-.487*				
Stand	-.908**	-.871**	-.827**	-.813**	-.701**	-.117	.449	.240		
	-.934**	-.789**	-.901**	-.811**	-.590*	-.281	.674**	.447*		
	-.821**	-.657**	-.816**	-.738**	-.620*	-.449*	.189	.650**		
Yield	-.280	-.614**	-.341	-.572**	.343	-.102	.499*	.543**	.226	.690**
	-.465	-.452*	-.570*	-.414*	-.011	-.370	.499*	.283	.488	.472**
	.080	-.451*	.183	-.509*	.055	-.516**	.719**	.812**	-.021	.551**

* P = .05, ** P = .01 n = 16 1975; n = 24 1976

correlation between yield and 1000-seed weight in the rainfed and high irrigation treatments.

Correlations between pods per plant and 1000-seed weight were negative both years (Table 32). The correlation between number of seeds per pod and 1000-seed weight was also negative, but only reached significance in the 1976 high irrigation treatment. 1000-seed weight was positively correlated with stand. In 1976, the correlation was highest in the high irrigation treatment and lowest in the rainfed treatment.

Path coefficient analysis of the 1975 correlations revealed substantial differences between the observed correlations and the direct effects. The direct effect of stand on yield was high in the rainfed treatment (.548), and near zero in the two irrigated treatments (Table 33). In the rainfed treatment, the effect of pods per plant on yield was zero. In the low irrigation treatment the effect of pod number was strongly negative. The effect of pod number on yield was positive in the high irrigation treatment, but this was masked by negative contributions to yield via seeds per pod and stand. The number of seeds per pod had a high direct effect on yield in the rainfed and low irrigation treatments. This effect was masked by the negative contribution of stand in the rainfed treatment, and by the negative contribution of number of pods in the low irrigation treatment. The correlation between yield and 1000-seed weight in the low irrigation treatment was mainly due to the effect of number of pods per plant. In the high irrigation, the high correlation between yield and 1000-seed weight was mainly a direct effect.

Table 33. Partial correlation analysis of the relationship between yield and its components in 1975.

Component	Rainfed	Low irrigation	High irrigation
Stand			
Direct effect	.548	-.017	.150
via 1000 seed wt.	.143	.127	.139
via seeds/pod	-.464	-.339	.164
via pods/plant	0	.716	-.474
Total	.226	.488	-.020
Pods/plant			
Direct effect	.001	-.795	.581
via 1000 seed wt.	-.194	-.123	-.070
via seeds/pod	.433	.332	-.204
via stand	-.453	.015	-.122
Total	-.214	-.570	.183
Seeds/pod			
Direct effect	.656	.575	-.266
via 1000 seed wt.	-.071	-.064	-.033
via pods/plant	0	-.460	.447
via stand	-.388	.010	-.093
Total	.197	.060	.055
1000-seed weight			
Direct effect	.318	.189	.734
via seeds/pod	-.147	-.196	.012
via pods/plant	0	.516	-.056
via stand	.246	-.011	.028
Total	.417	.498	.719

In 1976, a very high direct effect of stand on yield in the low irrigation treatment was partially masked by a negative contribution via pods per plant (Table 34). The observed positive correlation between yield and stand in the high irrigation treatment was mainly due to the contribution of 1000-seed weight - the direct effect was near zero. The direct effects of number of pods per plant on yield were considerably different from the correlation values in all three environments. The difference was greatest in the low irrigation, where the direct effect was positive and the correlation was negative due to a highly negative contribution via stand. Much of the observed negative correlation between yield and number of seeds per pod in the high irrigation treatment was contributed via 1000-seed weight. The correlations between yield and 1000-seed weight in the rainfed and high irrigation treatments were mainly direct effects, while in the low irrigation it was mainly due to the contribution of stand.

4.7 Effect of seeding method and rate on *B. napus*

Fertilizer rates had no significant effect, so means were calculated across fertilizer rates to give 18 replications for seeding methods and rates.

4.7.1 Stand establishment

At the 2.5 and 5 kg/ha seeding rates, the number of plants established was essentially the same for both broadcast and drilled material (Table 35). There were considerably more plants in the 10 and 20 kg/ha seeding rates of the drilled treatment than in the broadcast treatment. In the broadcast treatment 76, 75, 49 and 45% of the potential stand was achieved in the 2.5, 5, 10 and 20 kg/ha seeding rates, respectively. The corresponding figures for the drilled treatment were 76, 68, 56 and 54%.

54%.

Table 34. Partial correlation analysis of the relationship between yield and its components in 1976.

Component	Rainfed	Low irrigation	High irrigation
Stand			
Direct effect	.581	1.125	-.074
via 1000 seed wt.	.097	.004	.471
via seeds/pod	-.003	.039	.075
via pods/plant	.015	-.427	.079
Total	.690	.742	.551
Pods/plant			
Direct effect	-.019	.526	-.107
via 1000 seed wt.	-.092	-.004	-.390
via seeds/pod	.012	-.023	-.067
via stand	-.472	-.912	.055
Total	-.572	-.414	-.509
Seeds/pod			
Direct effect	.028	-.140	-.167
via 1000 seed wt.	-.054	-.001	-.340
via pods/plant	-.008	.087	-.043
via stand	-.068	-.316	.033
Total	-.102	-.370	-.516
1000-seed weight			
Direct effect	.403	.009	.724
via seeds/pod	-.004	.015	.078
via pods/plant	.004	-.245	.058
via stand	.139	.503	-.048
Total	.543	.283	.812

Table 35. Stand establishment of the experiment to evaluate rates and methods of seeding of *B. napus* in 1976.

Seeding rate (kg/ha)	Stand (plants/m^2) Seeding method	
	Broadcast	Drilled
2.5	56	56
5	111	100
10	144	167
20	267	322

4.7.2 Days to flowering and maturity

The drilled treatments flowered one day earlier on the average than did the broadcast treatments (Table 36). In both seeding methods, flowering was earlier at the high seeding rates than at the low rates. Average maturity was one day earlier in the drilled than in the broadcast treatment (Table 37). The high seeding rates matured earlier than the low rates.

4.7.3 Height

Seeding method had no significant effect on plant height at maturity (Table 38). Height was reduced as seeding rate was increased in both seeding methods. The lower seeding rates were significantly taller than the 20 kg/ha rate in both broadcast and drilled treatments.

4.7.4 Branch number

The broadcast material had more branches per plant than did the drilled material (Table 39). In both seeding methods there were significant reductions in number of branches as the seeding rate was increased.

4.7.5 Pod number

The number of pods per plant was considerably greater in the broadcast than in the drilled treatment (Table 40). As seeding rate increased, the number of pods was significantly reduced. In the drilled treatment, the 10 and 20 kg/ha seeding rates did not differ significantly.

Table 36. Effect of method and rate of seeding on days to 10 percent flowering of _B. napus_ in 1976.

Seeding rate (kg/ha)	Days to flower	
	Broadcast	Drilled
2.5	53.5 a	52.7 a
5	52.9 b	52.1 b
10	52.6 b	51.1 c
20	51.9 c	50.1 d
Mean	52.7 i	51.5 j
SE	.15	.15

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 37. Effect of method and rate of seeding on time to maturity of *B. napus* in 1976.

Seeding rate (kg/ha)	Days to mature	
	Broadcast	Drilled
2.5	96.8 a	95.6 a
5	95.3 b	94.1 b
10	94.3 c	93.4 b
20	93.7 c	92.6 c
Mean	95.0 i	93.9 j
SE	.36	.36

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 38. Effect of method and rate of seeding on plant height of *B. napus* in 1976.

Seeding rate (kg/ha)	Height (cm)	
	Broadcast	Drilled
2.5	86.0 ab	85.3 a
5.0	87.2 a	84.7 a
10.0	84.9 bc	83.3 a
20.0	83.5 c	80.3 b
Mean	85.4 i	83.4 i
SE	1.30	1.30

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 39. Effect of method and rate of seeding on number of branches per plant at harvest of *B. napus* in 1976.

Seeding rate (kg/ha)	Seeding method Broadcast	Drilled
2.5	7.2 a	6.4 a
5	5.7 b	4.8 b
10	4.2 c	3.7 c
20	3.4 c	2.8 d
Mean	5.1 i	4.4 j
SE	.14	.14

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 40. Effect of method and rate of seeding on number of pods per plant at harvest of *B. napus* in 1976.

Seeding rate (kg/ha)	Seeding method	
	Broadcast	Drilled
2.5	134 a	115 a
5	97 b	77 b
10	64 c	49 c
20	42 d	36 c
Mean	84 i	69 j
SE	3.36	3.36

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

4.7.6 Seeds per pod

Seeding method had no significant effect on number of seeds per pod (Table 41). The number of seeds per pod tended to decrease as seeding rate increased. In the broadcast treatment, the only significant difference was between the 2.5 and 20 kg/ha seeding rate. The range between the high and low seeding rates was greater in the drilled material. As a result, both the 2.5 and the 5 kg/ha rates had significantly more seeds/pod than the 20 kg rate.

4.7.7 1000-seed weight

Seeding method had no significant effect on 1000-seed weight (Table 42). There was some increase in 1000-seed weight at the higher seeding rates. In the broadcast treatment, the 20 kg/ha rate had significantly higher 1000-seed weight than the lower three rates. The 10 and 20 kg/ha rates in the drilled treatment had significantly higher 1000-seed weight than did the 2.5 and 5 kg rates.

4.7.8 Seed yield

The drilled material yielded more than the broadcast material (Table 43). In both seeding methods, each increase in seeding rate caused a significant increase in yield. The difference in yield between the lowest and highest seeding rate was greater in the broadcast than in the drilled treatment. The difference between the broadcast and drilled treatments was greatest at the lower seeding rates. The drilled material yielded 32, 28, 12 and 5% more than the broadcast material at the 2.5, 5, 10 and 20 kg/ha seeding rates, respectively.

Table 41. Effect of method and rate of seeding on number of seeds per pod at harvest in *B. napus* in 1976.

Seeding rate (kg/ha)	Seeding method Broadcast	Drilled
2.5	19.0 a	18.9 a
5	18.2 ab	17.8 ab
10	17.8 ab	17.2 bc
20	17.2 b	16.3 c
Mean	18.1 i	17.8 i
SE	.27	.27

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 42. Effect of method and rate of seeding on 1000-seed weight of *B. napus* in 1976.

Seeding rate (kg/ha)	1000-seed wt. (g) Seeding method Broadcast	Drilled
2.5	3.33 b	3.41 b
5	3.29 b	3.36 b
10	3.36 b	3.51 a
20	3.49 a	3.51 a
Mean	3.37 i	3.45 i
SE	.03	.03

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 43. Effect of method and rate of seeding on seed yield of *B. napus* in 1976.

Seeding rate (kg/ha)	Seed yield (kg/ha) Seeding method	
	Broadcast	Drilled
2.5	1149 d	1520 d
5	1455 c	1859 c
10	1779 b	2000 b
20	2095 a	2194 a
Mean	1620 j	1893 i
SE	67.2	67.2

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

4.7.9 Harvest index

Seeding method had no effect on harvest index (Table 44). Seeding rate affected harvest index in the broadcast material, where harvest index was higher at the 20 kg/ha seeding rate than at the 2.5 kg rate.

4.7.10 Relationship between yield and its components

Yield was positively correlated with stand and 1000-seed weight in both the broadcast and drilled treatments (Table 45). The correlation between yield and number of branches per plant and number of pods per plant was negative. There was also a negative but non-significant correlation between yield and number of seeds per pod.

When correlations were calculated within each seeding rate, few of them were significant (Table 46). The correlation between yield and 1000-seed weight remained strongly positive in all seeding rates. Differences between seeding rates in the correlations between characters were evident. The correlation between pods per plant and seeds per pod tended to become less negative as seeding rate increased. The correlation between pods per plant and 1000-seed weight was positive at the lower seeding rates and negative at the higher seeding rates.

Path coefficient analysis revealed some differences between direct effects and observed correlations. The direct effect of stand on yield in the broadcast treatment was considerably smaller than the correlation value (Table 47). The high correlation value resulted from contributions via number of pods per plant and 1000-seed weight. In the drilled treatment, the direct effect of stand on yield was near zero,

Table 44. Effect of method and rate of seeding on harvest index of *B. napus* in 1976.

Seeding rate (kg/ha)	Harvest index ($\frac{\text{seed DW}}{\text{total DW}}$ x 100)	
	Broadcast	Drilled
2.5	25.5 b	26.4 a
5	25.9 ab	26.1 a
10	25.9 ab	26.6 a
20	26.6 a	26.7 a
Mean	26.0 i	26.5 i
SE	.20	.20

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 45. Correlations between yield and its components for broadcast and drilled *B. napus*, 1976 (upper line, broadcast; lower line, drilled).

	Branches/plant	Pods/plant	Seeds/pod	1000-seed wt.	Stand
Pods/plant	.941** .931**				
Seeds/pod	.280* .402**	.238* .312**			
1000-seed wt.	-.288* -.124	-.277* -.044	.076 -.073		
Stand	-.771** -.775**	-.792** -.708**	-.240* -.410**	.394** .209	
Yield	-.671** -.529**	-.643** -.455**	-.157 -.159	.603** .533**	.680** .478*

* P = .05, ** P = .01; n = 72.

Table 46. Correlations between yield and its components within each of 4 seeding rates (upper line 2.5 kg/ha, second line 5 kg, third line 10 kg and lower line 20 kg).

	Branches/plant	Pods/plant	Seeds/pod	1000-seed wt.
Pods/plant	.771**			
	.876**			
	.883**			
	.889**			
Seeds/pod	-.174	-.184		
	.041	-.076		
	.243	.114		
	.210	-.032		
1000-seed wt.	.108	.286	-.044	
	.222	.219	.256	
	-.283	-.256	.059	
	-.058	-.039	.149	
Yield	-.325*	-.174	.069	.590**
	-.250	-.091	.095	.491**
	-.179	-.191	.192	.565**
	-.166	-.049	-.004	.642**

* P = .05, ** P = .01, n = 36

Table 47. Partial correlation analysis of the relationship between yield and its components.

Component	Seeding method	
	Broadcast	Drilled
Stand		
Direct effect	.254	.005
via pod number	.248	.227
via seeds/pod	.013	.143
via 1000-seed wt.	.165	.103
Total	.680	.478
Number of pods/plant		
Direct effect	-.313	-.321
via stand	-.201	-.004
via seeds/pod	-.013	-.109
via 1000-seed wt.	-.117	-.022
Total	-.643	-.455
Number of seeds/pod		
Direct effect	-.054	-.349
via stand	-.061	-.022
via pod number	-.074	.227
via 1000-seed wt.	.032	-.036
Total	-.157	-.159
1000-seed weight		
Direct effect	.420	.492
via stand	.100	.001
via pod number	.086	.014
via 1000-seed wt.	-.004	.025
Total	.603	.533

with the correlation resulting from contributions via number of pods per plant, number of seeds per pod and 1000-seed weight.

In the broadcast material, about half the observed correlation between yield and number of pods per plant was contributed via stand and 1000-seed weight. In the drilled treatment, the direct effect was the largest, with 1000-seed weight contributing the rest.

There was little direct effect of number of seeds per pod on yield in the broadcast treatment. In the drilled treatment, the direct effect was greater than the observed correlation. The direct effect was partially masked by a positive contribution via number of pods per plant. The direct effect of 1000-seed weight on yield was close to the correlation value in the drilled material, but about one third of the correlation value in the broadcast material was contributed via stand and number of pods per plant.

4.8 Oil determinations

4.8.1 Seed oil content

Irrigation resulted in an increase in seed oil content, particularly in 1975 (Table 48). Both irrigation treatments in 1975 increased actual seed oil by about 4% compared to the rainfed treatment. Oil content in the irrigated treatments in 1976 were not as high as in 1975. Seeding rates had no effect on seed oil content in either 1975 or 1976.

Seeding method had some effect on seed oil content (Table 49). Rate of seeding did not affect oil content in the broadcast treatment. In the drilled treatment, seed oil content of the 2.5 and 5 kg/ha seeding rates was significantly higher than that of the 20 kg/ha rate.

Table 48. Effect of seeding rate and irrigation on seed oil content of *B. napus*.

Year	Seeding rate (kg/ha)	Seed oil content (%) Rainfed	Low irrigation	High irrigation
1975	2.5	37.3 ns	42.5 ns	42.9 ns
	5.0	39.8	41.8	42.7
	10.0	37.3	41.9	42.3
	20.0	38.3	41.8	41.1
	Mean	38.2	42.0	42.2
	SE	.32	.32	.32
1976	2.5	38.9 ns	38.3 ns	38.9 ns
	5.0	39.1	38.9	39.6
	10.0	38.5	38.3	40.1
	20.0	38.9	38.2	40.6
	Mean	38.8	38.4	39.8
	SE	.37	.37	.37

ns = non-significant

Table 49. Effect of method and rate of seeding on seed oil content of *B. napus* in 1976.

Seeding rate (kg/ha)	Seed oil content (%) Broadcast	Drilled
2.5	41.7 a	41.5 a
5	41.3 a	41.5 a
10	41.3 a	41.4 ab
20	41.2 a	40.9 b
Mean	41.4 i	41.3 i
SE	.16	.16

Means within seeding methods or methods means followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

4.8.2 Fatty acid composition

In 1975, both irrigation and seeding rates influenced the relative amounts of the 18-carbon fatty acids oleic, linoleic and linolenic (Table 50). The amount of oleic acid decreased with irrigation, while that of linoleic and linolenic increased. In the low irrigation treatment, the amount of oleic acid in the 2.5 kg/ha seeding rate was significantly lower than that of the higher seeding rates. The 20 kg/ha seeding rate of the rainfed and high irrigation treatments had a higher proportion of linoleic acid than did the lower seeding rates. In the low irrigation treatment, there was a reduction in linolenic acid content with increased seeding rate.

There was no consistent effect of irrigation on fatty acids in 1976 (Table 51). The only significant effect of seeding rate occurred in the high irrigation treatment, where linolenic acid content increased with increasing seeding rate. Oleic acid comprised an average of 64% of the total fatty acids in 1976, as compared to 70% in 1975. Linoleic acid was higher in 1976, 21% vs. 14% in 1975. The linolenic acid content was about 1% lower in 1976 than in 1975.

Table 50. Effect of irrigation and seeding rates on relative proportions of 18-carbon fatty acids of *B. napus* in 1975.

Fatty acid	Seeding rate (kg/ha)	Rainfed	Low irrigation	High irrigation
		% of total fatty acids		
Oleic	2.5	71.1 a	69.6 b	68.5 a
	5	71.1 a	70.6 a	69.0 a
	10	71.4 a	70.9 a	69.1 a
	20	70.5 a	70.9 a	67.7 a
	Mean	71.0	70.5	68.6
	SE	.12	.12	.12
Linoleic	2.5	13.7 b	14.3 a	14.8 b
	5	13.6 b	14.0 a	14.5 b
	10	13.5 b	13.9 a	14.5 b
	20	14.2 a	13.9 a	15.8 a
	Mean	13.8	14.0	14.9
	SE	.09	.09	.09
Linolenic	2.5	9.0 a	9.6 a	10.3 a
	5	9.0 a	9.4 ab	10.1 a
	10	8.8 a	9.1 bc	10.1 a
	20	8.9 a	9.0 c	10.0 a
	Mean	8.9	9.3	10.1
	SE	.06	.06	.06

Means within fatty acids within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

Table 51. Effect of irrigation and seeding rates on relative proportions of 18-carbon fatty acids of B. napus in 1976.

Fatty acid	Seeding rate (kg/ha)	% of total fatty acids		
		Rainfed	Low irrigation	High irrigation
Oleic	2.5	64.4 a	62.7 a	65.1 a
	5	63.8 a	63.5 a	64.7 a
	10	64.0 a	63.3 a	65.0 a
	20	64.4 a	63.7 a	64.5 a
	Mean	64.2	63.3	64.8
	SE	.21	.21	.21
linoleic	2.5	21.1 a	22.2 a	20.6 a
	5	21.2 a	22.0 a	20.4 a
	10	21.4 a	22.1 a	20.5 a
	20	21.0 a	21.9 a	20.7 a
	Mean	21.2	22.1	20.6
	SE	.15	.15	.15
Linolenic	2.5	8.0 a	7.8 a	7.8 c
	5	7.9 a	7.9 a	7.9 bc
	10	8.2 a	8.1 a	8.1 ab
	20	8.1 a	8.0 a	8.3 a
	Mean	8.1	8.0	8.0
	SE	.05	.05	.05

Means within fatty acids within irrigation treatments followed by the same letter do not differ significantly at the 5% level according to Duncan's Multiple Range Test.

5. DISCUSSION

5.1 Dry matter accumulation and distribution

The production of dry matter in *Brassica napus* was not limited by lack of water before flowering, but it was clearly influenced by planting density. The high NAR of low density material was not capable of fully compensating for low plant numbers.

The results of this study show that the proportion of dry matter produced before flowering is very dependent on environmental conditions. Irrigation resulted in a greater proportion of dry matter production after flowering, while increased seeding rates increased the proportion produced before flowering. In Australia, the dry weight accumulation of *B. napus* before and after anthesis was found to be nearly equal (Thurling, 1974a).

Seasonal patterns of dry weight accumulation in plant parts were affected very little by irrigation or seeding rate. The amount of dry matter produced and the duration of production were affected by irrigation, but relatively less by seeding rate. The seasonal pattern of accumulation - maximum leaf dry weight at flowering, maximum stem dry weight near the end of flowering, and increases in pod and seed dry weight to near maturity - was similar to that found in Britain (Allen and Morgan 1972, 1975; Tayo and Morgan 1975).

At maturity, the proportions of the total plant dry matter in pods, seeds and stems was influenced by irrigation, but not as much by seeding rate. Irrigated material had proportionately more seed and less stem, and thus a higher harvest index, than rainfed material. The longer growth period of the irrigated material, as well as greater photosynthetic area (both leaf and pod), resulted in fuller development of the seeds than where water was limiting. Harvest index increased with seeding rate in the broadcast treatment of the seeding methods trial. Since a greater proportion of the dry weight was accumulated before flowering in the high seeding rates, there must have been greater diversion of the assimilates produced after flowering into the seed fraction than occured at the lower seeding rates.

The harvest index values reported here are considerably higher than those reported for *B. napus* grown in Australia (Thurling 1974a). This is perhaps due to daylength and temperature combinations, since Canadian spring varieties were being grown as a winter crop in Australia. In the present study, high seeding rates limited the dry matter production per plant and restricted dry matter production after flowering, producing plants which used the available environmental resources effectively, resulting in high dry matter and seed yields.

5.2 Photosynthetic area

The highest LAI's measured in this study were 5.0 in 1975, and 5.5 in 1976. Both maxima occured in irrigated material. These values are slightly higher than those reported for *B. napus* grown in Britain (Allen and Morgan 1972, 1975) and considerably above those reported in Australia (Thurling 1974a).

There was no indication of an optimum LAI in the present study of *B. napus*. As LAI increased, there was an asymptotic approach to maximum CGR. An asymptotic relationship between LAI and CGR has been reported in corn (Williams *et al*. 1965) and in alfalfa (Wilfong *et al*. 1967). In barley, net photosynthesis was found to be optimum over a broad range of LAI values, but declined at very high LAI values (Pearce *et al*. 1967). Similarly in *Brassica oleracea* (kale), Watson (1958) reported decreases in CGR when LAI surpassed 4. In the present study, there was no drop in CGR at high LAI values since there was not an excessive production of leaf area. Indeed, excessive leaf area is not expected under normal conditions since *B. napus* is not able to go on increasing leaf area much beyond the start of flowering.

The degree of post-anthesis contribution of leaves to the yield of rape has been disputed. The results of the defoliation experiment reported here show that leaves were making a significant contribution at early anthesis but not at the end of flowering. It is probable that environmental factors affect the point at which leaves become non-functional. Irrigation, for example, caused a much longer LAD, so that the leaves probably continued to supply assimilates to developing seeds and pods.

In 1975, maximum pod surface area and maximum leaf area were very similar, as reported for greenhouse-grown *B. napus* (Tayo and Morgan 1975). In 1976, however, maximum pod surface area was considerably lower than maximum leaf area, a condition reported in winter *B. napus* (Inanga and Kumara 1974). The differences between the two years' results are at least partly due to the different systems of measurement used. Irrigation caused marked increases in pod area, which is consistent with reports in *B. campestris* (Krogman and Hobbs 1975).

Path coefficient analysis indicated that LAI was more associated with seed yield than was LAD in all but the 1976 high irrigation treatment. The observed correlations between LAD and seed yield were caused indirectly by maximum LAI - the higher maximum LAI resulted in higher LAD. In the 1976 high irrigation treatment, LAD was correlated with yield because LAI was high at flowering, and continued to increase somewhat after flowering. LAD would be expected to be related to yield in the high irrigation treatment, since leaves remained on the plants longer, and proportionately more dry matter was produced after flowering than before flowering.

The correlation between seed yield and maximum LAI is possibly due to the effect of LAI on number of pods formed. Maximum LAI occurs near the start of flowering and would have an effect on size and nutritional status of plants, two factors which could influence pod set. The effect of plant size at flowering would be particularly important at high seeding rates, since flowering and pod formation occur over a relatively short time period, and there is no potential for further branching and pod formation.

The correlations between pod area and seed yield were low, particularly in 1976. More accurate measurements of pod area might show a better relationship between pod area and seed yield. In *B. campestris*, correlations of +0.97 and +0.87 between pod area and seed yield were found in two years of study (Maiti *et al*. 1970).

High seeding rates are able to produce more photosynthetic area than are low seeding rates. This increased photosynthetic area results in superior seed yields of the material seeded at high rates. Low seeding rates, despite higher assimilation rates per unit leaf area, are unable to fully compensate for their lower photosynthetic areas.

5.3 Growth functions

In the early part of the season, NAR was considerably greater in the low densities than in the high densities. Buttery (1969) found the same relationship in soybean. Watson (1958) has attributed the decline in NAR with increasing LAI to increases in mutual shading of leaves, resulting in reduced photosynthesis. As Buttery (1969) notes, however, mutual shading should not be a factor when LAI is below one. At the same time, competition for water or soil-supplied nutrients at this stage seems even less likely. It is possible that the effect was due to light interception - perhaps at the lower densities light interception of the hypocotyl was high, resulting in increased photosynthesis by the plants.

The most interesting feature of NAR values after flowering was their tendency to increase for a short period before maturity. The phenomenon is evident in other *B. napus* studies (Allen and Morgan 1972, 1975). Similar occurrences are found in soybean (Buttery 1969; Wallace and Munger 1965; Koller *et al*. 1970). In the present work this upswing was observed in both fitted and original data, in a manner similar to that observed in Buttery's (1969) data.

Koller *et al*. (1970) suggested that the observed upswing in NAR was the response of the photosynthetic apparatus to increased demand for assimilates by the rapidly growing seed fraction. Eastin and Gritton (1969) suggested the same reason for late season upswings in CGR of

Pisum sativum. Indeed, recent results of Thorne and Koller (1974) have shown that assimilate demand has a marked influence on source-leaf photosynthesis and carbohydrate formation and export in soybean.

In *B. napus*, the observed increase in NAR could be due to three factors: 1) translocation of stored carbohydrates from roots to tops; 2) pod photosynthesis; 3) an increase in photosynthetic activity. Measurements of root dry weight by Allen and Morgan (1972, 1975) did not indicate any reduction in root dry matter at the time when NAR was increasing. Indeed, root dry matter was still increasing at this time. If the root growth of *B. napus* followed a similar pattern to the above in this study, translocation of carbohydrates from roots to tops could be eliminated as a cause of the increase in NAR. The upswing in NAR occurred at or near maximum pod surface area. Inanga and Kumara (1974) reported that maximum total plant and pod photosynthetic rate occurred before the attainment of maximum pod area. If the increase in NAR was due to pod photosynthesis, it would be expected to increase gradually as pod surface area increased, rather than increase abruptly near or beyond maximum pod area. By the process of elimination, this would leave increased photosynthetic rate as the reason for the increase in NAR. Norton and Harris (1975) found that there was a rapid increase in seed dry weight of *B. napus* just prior to maturity. This would constitute high sink demand, which could then result in increased photosynthetic activity.

This upswing in assimilation rate when seeds start to develop implies that sink capacity may be limiting photosynthetic rates prior to this point in development. The reason for this is not apparent. More knowledge about the source and distribution of assimilates during early pod and seed growth is required. Also, futher information on the factors affecting number of seeds per pod is needed.

In rape, as in many other plants, the calculation of NAR after the vegetative phase of growth produces over-estimates if only leaf areas are measured. This is because the dry weight changes are being attributed to a fraction of the true assimilating surface. Also, as noted by Watson (1952), the change in NAR with plant age is difficult to assess because respiration rates in plant parts other than leaves may be changing. Since the respiration of the whole plant is being attributed to leaves in the calculation of NAR, changes in respiration rate in plant parts other than leaves can result in changes in the observed NAR which are not caused by actual changes in the assimilation rate of leaves. These difficulties are overcome by the use of CGR as the main growth function. CGR represents the net result of the photosynthesis, respiration and canopy area interactions, and as noted by Williams _et al._ (1965), represents the most common agronomic measurement - i.e. yield of dry matter per unit land area. An added advantage of using CGR as an index of growth is that it requires only the measurement of dry matter changes with time. This makes it relatively easy to get accurate estimates of CGR to compare large numbers of treatments. This is not possible with NAR determinations, which require time-consuming leaf area measurements.

5.4 Yield components and yield

5.4.1 Effect of irrigation and seeding rate

The number of branches per plant was much more influenced by seeding rate than by irrigation. Reduction of the assimilate supply by defoliation at the start of flowering did not affect the branch number either. The number of branches is probably determined before flowering by the same plant and environmental factors which govern floral initiation.

Both irrigation and seeding rate influenced the number of pods per plant. The number of pods per plant was low at the high seeding rates because of few branches and a short flowering period. Pod number in winter rape was very sensitive to planting density (Huhn and Schuster 1975). Irrigation lengthened the flowering period, resulting in the formation of more pods per plant than under non-irrigated conditions.

Allen and Morgan (1972) suggested that the ability of the rape plant to supply assimilates during flowering is important in determining the number of pods formed. In the present work plants in the lower seeding rates developed more pods per branch than the higher seeding rates, possibly due to a more favorable assimilate supply in the low density plantings. Indeed, maximal CGR occurred later in the low than in the high densities and coincided with the flowering period. Leaves played an important role in determining pod numbers in the low but not in the high seeding rates, since defoliation at flowering reduced number of pods per plant at the 5 kg/ha seeding rate but not at the 20 kg/ha rate. Pod numbers in high density plantings may be determined before flowering by limitations to the numbers of flowers initiated.

The number of seeds per pod was affected very little by seeding rate, but was increased by irrigation. Huhn and Schuster (1975) have reported that the number of seeds per pod of winter B. napus is insensitive to variations in plant density. In the present work, the results of the defoliation experiment suggest that number of seeds per pod is determined fairly late in the ripening phase, since number of seeds per pod was not affected by a reduction in assimilate supply through defoliation at the end of flowering. The number of seeds per pod may be determined primarily by the ability of the individual pod to supply assimilates at the time when number of seeds per pod is being determined. Irrigation could have increased seed number through its effect on pod surface area, which would in turn create a greater assimilate supply.

Seeding rate affected 1000-seed weight, probably due to a combination of the effects of assimilate supply and distribution within the plant. At the high seeding rates, most of the pods were on the main raceme, and thus in a favorable position for the interception of radiant energy for photosynthesis. In addition, there were fewer pods on the plant, making more assimilate available for seed growth. At the lower seeding rates, the pods were distributed over a greater depth in the canopy. Light for assimilate production could have been a factor limiting seed size at lower branch positions. Seed size was greatest on the lower portion of the main raceme at both high and low densities, perhaps since pods in this region were receiving the assimilates being exported by the few remaining upper leaves of the plant.

Seed yield of B. napus was influenced by seeding rate; yield was increased by increased seeding rates. Similar results have been reported by Ohlsson (1972). Most other reports have shown either no difference between seeding rates, or yield reductions at high seeding rates (Vulliourd, 1974). The failure to detect significant yield differences between the 2.5, 5 and 10 kg/ha seeding rates in the 1976 rainfed material may not represent the true relationship. Broadcast material in the methods of seeding experiment exhibited significant differences between all seeding rates, with the 2.5 kg rate yielding least and the 20 kg rate most. In both years the difference between seeding rates was smaller in the high irrigation treatment. This suggests that under these more favorable environmental conditions, the low seeding rates were able to compensate for having fewer plants per unit area.

Further research on seeding rates should be conducted to determine any genotypic differences in response to seeding rate. Other planting configurations, such as narrow rows, should also be investigated. The present results indicate that _B. napus_ can benefit from higher seeding rates, both in terms of increased yield and hastened maturity. The yield increases obtained by high seeding rates would probably be greatest in the drier southern regions of the rape growing area. High seeding rates would also be an advantage in areas with a limited length of growing season due to hastened and more uniform maturity. High seeding rates may also be useful in seed production due to increased seed size. The benefits of higher seeding rates must be balanced against higher seed costs and an increased risk of lodging.

Irrigation produced substantial yield increases, similar to those reported for _B. campestris_ (Krogman and Hobbs 1975). The increases in yield from irrigation would make B. napus a useful rotation crop in irrigated areas. Irrigation during the period of flowering was particularly important, and should also be continued as late in the season as possible in order to realize the full yield potential. The need for late-season irrigation must be balanced against the resultant delay in maturity. High seeding rates (>10 kg/ha) should be used in order to promote uniform maturity and thus reduce harvest losses. Investigation of the irrigation x fertilizer requirement interaction would be warranted.

5.4.2 Effect of seeding method

The more even occupation of land area by broadcast material compared with drilled material permitted increased branching and subsequent development of increased numbers of pods per plant. There was enough intra-row competition in the drilled material to reduce branch and pod numbers. Seeding method did not affect either number of seeds per pod or 1000-seed weight.

Seed yield of broadcast material was below that of drilled material at all rates of seeding. This effect was not due to fertilizer placement, since there was no response to fertilizer. The superior yield of drilled material was perhaps due to the effect of intra-row competition on the morphology of the plant: fewer pods were formed, which could have resulted in more assimilates for seed growth. Increases in yield and seed size in Sorghum bicolor when plant competition was promoted have been reported (Blum and Naveh 1976). In the present study, the yield difference between the two seeding methods narrowed at the high seeding rates, perhaps because the intra-row competition was becoming too severe in the drilled material.

Broadcast seeding of *B. napus* is feasible under certain conditions, although higher seeding rates than those used for drilling may be required. Dry seedbeds or conditions of low soil fertility would be situations where drill-seeding is preferable, due to placement of seed into moisture and placement of fertilizer near the seed. Broadcast seeding is faster and, therefore, less costly than drill seeding.

5.4.3 Yield component interrelationships

Yield was positively correlated with 1000-seed weight and stand density in this study. Thurling (1974b), however, concluded that number of pods per plant was the most important yield component in three *B. napus* varieties. This correlation was possibly only a reflection of the ability of the three varieties to yield in the particular conditions under which they were grown. Number of pods per plant is not normally an important component of yield because of its sensitivity to environment (Ohlsson 1960; Huhn and Schuster 1975). In addition less than half of the potential pod numbers of *B. napus* normally reach maturity (Tayo and Morgan 1975).

Correlations between pod number and number of seeds per pod were positive when calculated for the 4 seeding rates. When the correlations were calculated within seeding rates the relationship between pod number and seed number was low and negative. These relationships suggest that some degree of compensation can occur, since the number of seeds per pod was reduced on plants having high numbers of pods. The correlation between pod number and 1000-seed weight was positive at the low densities, but negative at the high densities, indicating that compensation occurred as competition increased. Adams (1967) reported a similar occurrence in *Phaseolus vulgaris*.

Adams (1967) postulated that compensation is inevitable when sequentially developing yield components share a common metabolic pool. In the present study, there was not much compensation between seeds per pod and number of pods. This could be because seed number was more influenced by assimilate production in the pods themselves, whereas pod number was influenced by assimilate supplied by leaves during the flowering period. A greater degree of compensation was evident in 1000-seed weight relationships to pod and seed number. For example, defoliation at flowering caused a decrease in number of pods with a subsequent increase in 1000-seed weight. Similar compensation in 1000-seed weight for low pod or seed numbers has been reported in winter *B. napus* (Dembinska 1970; Mingeau 1974).

Since there is little evidence to suggest that there are genetic limitations on potential pod number, number of seeds per pod or seed size, selection for these characters would not be of much direct value in yield improvement. There could be some indirect benefits of selecting for seed size, since it could produce plants better able to supply photosynthate during seed filling. On the other hand, the same selection could lead to concomitant reductions in seed number per pod or numbers of pods per plant. As Adams and Grafius (1971) have suggested, the best avenue for yield improvement would be to improve the supply of metabolic inputs during the development of the yield components. In B. napus this would mean increasing leaf area and duration of leaf area to supply assimilates for pod growth and early seed growth and increase pod area or photosynthetic rate to supply the final seed growth. In the present work these changes were achieved by manipulating plant morphology through changes in seeding density.

5.5 Effect of irrigation and seeding rate on oil

Irrigation increased seed oil content, particularly in 1975. This is consistent with the results of Krogman and Hobbs (1975) for *B. campestris* and of Nuttall (1973) for greenhouse-grown *B. napus*.

Seeding rate did not affect seed oil content of the broadcast-seeded material. However, in the drilled material oil content was reduced by the 20 kg/ha seeding rate. Ohlsson (1971) has found that high seeding rates reduced seed oil content of *B. napus* in widely spaced but not in narrowly spaced rows. This indicates that oil content of seeds is sensitive to plant competition. In the broadcast-seeded material, competition was not severe enough to reduce oil content.

Irrigation and seeding rates had small effects on fatty acid composition in 1975, but had essentially no effect in 1976. The effect of seeding rates on linolenic acid content in 1975 could have been due to differences in the level of this fatty acid caused by pod position on the plant, as reported by Bechyne and Kondra (1970). At the lower seeding rates there was more branching and thus a greater yield contribution by the lower regions of the plant than at the high seeding rates. This resulted in high linolenic acid levels at the low seeding rates.

The level of oleic acid was higher in 1975 than in 1976, which is inconsistent with the normal trend toward more highly unsaturated fats at lower temperatures (Canvin, 1965); August of 1976 was considerably warmer than August of 1975. Fowler and Downey (1970) and Rakow and McGregor (1975), however, reported the proportions of the fatty acids changed very little after 28 days from pollination. If a similar developmental trend existed in the present study, the fatty acid proportions would have been established in July. July of 1975 was slightly warmer than July of 1976, but it seems improbable that the difference was great enough to cause the rather large difference in fatty acid composition. It is possible that the difference was caused by a combination of temperature and moisture effects. July was wetter in 1976 than in 1975, and increases in moisture following irrigation decreased oleic acid content in 1975.

The effects of irrigation and seeding rate on fatty acid composition noted in this study are relatively minor compared to genotypic differences or differences caused by temperature. Plant breeding, therefore, is the only practical means of altering fatty acid composition.

5.6 Growth analysis methodology

To obtain accurate results in a formal growth analysis of *B. napus*, large sample sizes and at least 6 replications are required. The amount of material which can be handled is limited by the available time and labour for leaf area measurements. Despite advances in leaf area measuring devices, this remains a tedious operation.

The use of small sample sizes in conjunction with curve fitting techniques has been suggested as a means of reducing the labour requirement of growth analysis (Radford 1967; Hughes and Freeman 1967; Nicholls and Calder 1973). The present study demonstrates that the fitting of data to polynomials solely on a statistical basis can result in growth curves which are not representative of the original data. Curve fitting may be of some use for comparative purposes or for removing small sampling errors from data. The use of curve fitting, however, is not possible unless a detailed growth analysis is first performed to determine the appropriate polynomial expression. A further drawback of curve fitting is that it may mask genuine environmental and developmental variations in the data.

Growth analysis of larger numbers of treatments could be handled if the seasonal trend in dry weight was measured, which would allow the calculation of CGR. This would provide sufficient information for most agronomic purposes. Leaf area measurements must continue to be made if information on photosynthetic rates or assimilate sources is required.

5.7 Summary of environmental effects on *B. napus*

The growth phases and suggested source-sink interrelationships of *B. napus* are summarized in Figure 34. Leaves are suggested as the assimilate source for pod growth, and perhaps for seed development under some conditions. Pods are probably the major assimilate source for seed growth. Further research is required to complete the model.

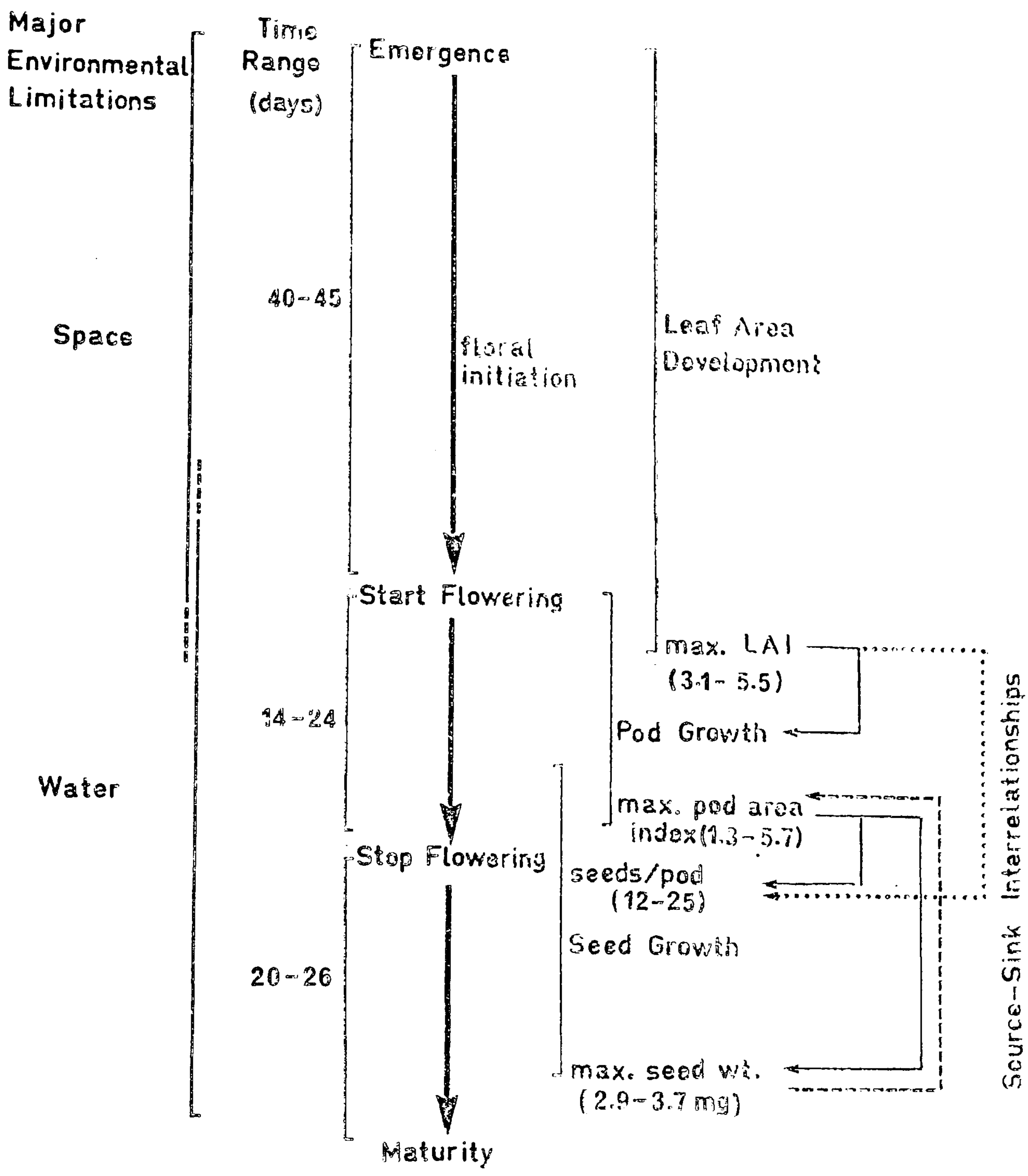

Figure 34. The growth phases of B. napus and suggested source-sink interrelationships.

6. SUMMARY

The general growth pattern of B. napus was found to be the same in Canada as that reported in Europe and Australia. Leaf area reached a maximum just after the start of flowering and then declined. Maximum leaf area index was greater and growth rates were equal to or greater than those reported in other countries.

Irrigation and variations in seeding rate caused substantial changes in the accumulation of dry matter, and subsequently the yield of seed. Changes in planting density caused substantial morphological changes during the vegetative phase of growth. High plant density reduced leaf area per plant and number of branches per plant, which in turn limited flower numbers and number of pods. From flowering onward, water availability had a major effect on growth and subsequently, seed yield.

The ability of the plant to supply assimilates during the reproductive and ripening phases was the major factor affecting yield. Water had a direct effect on this distribution of assimilates, while spacing affected it indirectly through the alterations in plant morphology. Leaves were major suppliers of assimilates during flowering, with pods becoming increasingly important as they developed. An increase in photosynthetic rate may have occurred during the late ripening phase, probably due to increased sink demand. The seed yield of B. napus is most strongly limited by the ability of the plant to supply assimilates from the photosynthetic areas during the reproductive and ripening phases, particularly during seed filling. There was no suggestion of limitation of sink capacity.

High plant densities produced morphological changes which improved assimilate production and distribution, particularly during seed filling. These plants diverted more of the post-flowering assimilates into seed than did plants grown at lower densities.

Growth analysis procedures were a logical approach to the study of the growth of *B. napus*. However, the labour requirement of detailed analyses of growth limits the scale of such experiments, mainly due to the slowness of making leaf area measurements. For comparative purposes, it is suggested that CGR would be the most meaningful growth function to measure. Determination of CGR merely requires dry weight measurements so that larger amounts of material can be handled. Leaf area would have to be measured in cases where information on photosynthetic rates or assimilate source was desirable. Curve-fitting techniques can be of some use in growth analysis of *B. napus*, but must be used with caution.

Further studies of seeding rates and planting configurations aimed directly at determining optimum plant density would provide valuable agronomic information. Varietal differences in response to plant density should also be assessed. In addition, more detailed studies of the environmental effects on assimilate supply and yield component development, particularly number of seeds per pod, should be conducted. An assessment of genotypic differences in growth rates and response to environment is also warranted. Increased knowledge in these areas would be of use in predicting yield, or in assessing yield losses, and in breeding for improved yield of *B. napus*.

7. REFERENCES

Adams, M.W. 1967. Basis of yield component compensation in crop plants with special reference to the field bean, Phaseolus vulgaris. Crop Sci. 7: 505-510.

Adams, M.W. and Grafius, J.E. 1971. Yield component compensation - alternative interpretations. Crop Sci. 11: 33-35.

Allen, E.J. and Morgan, D.G. 1972. A quantitative analysis of the effects of nitrogen on the growth, development and yield of oilseed rape. J. Agric. Sci. 78: 315-324.

Allen, E.J. and Morgan, D.G. 1975. A quantitative comparison of the growth, development and yield of different varieties of oilseed rape. J. Agric. Sci. 85: 159-174.

Bechyne, M. and Kondra, Z.P. 1970. Effect of pod location on the fatty acid composition of seed oil from rapeseed (Brassica napus and B. campestris). Can. J. Plant Sci. 50: 151-154.

Blum, A. and Naveh, M. 1976. Improved water-use efficiency in dryland grain sorghum by promoted plant competition. Agron. J. 68: 111-116.

Buttery, B.R. 1969. Analysis of the growth of soybeans as affected by plant population and fertilizer. Can. J. Plant Sci. 49: 675-684.

Buttery, B.R. and Buzzell, R.I. 1974. Evaluation of methods used in computing net assimilation rates of soybeans (Glycine max (L.) Merrill.). Crop Sci. 14: 41-44.

Canvin, D.T. 1965. The effect of temperature on the oil content and fatty acid composition of the oils from several oil seed crops. Can. J. Bot. 43: 63-69.

Craig, B.M. and Wetter, L.R. 1959. Varietal and environmental effects on rapeseed. II. Fatty acid composition of the oil. Can. J. Plant Sci. 39: 437-442.

Decau, J., Lencrerot, P., Marty, J.R., Puech, J. and Pujol, B. 1973. Influences des conditions climatiques et de l'irrigation sur la production oleoproteique de trois oleangineaux (Colza, Tournesol, Soja) dans la sud-ouest de la France. Acad. Agric. Fr. C.R. Seances. 59: 1464-1474.

Dembinska, H. 1970. Influence of water deficiency in autumn and spring on development and structure of winter rape yield. Roczniki Nauk Rolniczych 96: 73-94. (Pol., Eng. Summary).

Dhindsa, K.S., Gupta, S.K., Chaudhry, M.S. and Singh, B.P. 1973. Effect of date of sowing, spacings and fertility levels on yield and chemical composition of Toria (Brassica campestris var. Toria Duthie and Full.). Indian J. Agric. Res. 7: 153-158.

Domanska, H. 1958. Growth and development of spring rape as depending upon the soil moisture content. Roczniki Nauk Rolniczych 78: 579-619. (Pol., Eng. Summary).

Downey, R.K., Klassen, A.J. and McAnsh, J. 1974. Rapeseed: Canada's "Cinderella" crop. Publ. No. 33, Rapeseed Assoc. of Can. 52 pp.

Eastin, J.A. and Gritton, E.T. 1969. Leaf area development, light interception, and the growth of canning pea (Pisum sativum L.) in relation to plant population and spacing. Agron. J. 61: 612-615.

Fowler, D.B. and Downey, R.K. 1970. Lipid and morphological changes in developing rapeseed, Brassica napus. Can. J. Plant Sci. 50: 233-247.

Gross, A.T.H. and Stefansson, B.R. 1966. Effect of planting date on protein, oil and fatty acid content of rape seed and turnip rape. Can. J. Plant Sci. 46: 389-395.

Helps, M.B. 1971. Methods of sowing, seed rate and nitrogen level for oil seed rape. Exp. Husb. 20: 69-72.

Hozyo, Y., Kato, S. and Kobayashi, H. 1972. Photosynthetic activity of the pods of rape plants (Brassica napus L.) and the contribution of the pods to the ripening of rape-seeds. Proc. Crop Sci. Soc. Japan 41: 420-425. (Jap., Eng. Summary).

Hughes, A.P. and Freeman, P.R. 1967. Growth analysis using frequent small harvests. J. Appl. Ecol. 4: 553-560.

Huhn, M. and Schuster, W. 1975. Untersuchungen zur quantitativen Einschatzung von Konkurrenzeffekten in Winterrapsbestanden. Z. Pflanzenzuchtg. 75: 217-236.

Inanga, S. and Kumara, A. 1974. Studies on matter production of rape plant (Brassica napus L.) 1. Changes with growth in rates of photosynthesis and respiration of rape plant population. Proc. Crop Sci. Soc. Japan 43: 267-277. (Jap., Eng. Summary).

Jakubowski, E. 1956. The influence of various soil moisture conditions on yields of spring rape. Roczniki Nauk Rolniczych. 73: 81-103. (Pol., Eng. Summary).

Koller, H.R., Nyquist, W.E. and Chorush, I.S. 1970. Growth analysis of the soybean community. Crop Sci. 10: 407-412.

Kondra, Z.P. 1975. Effects of row spacing and seeding rate on rapeseed. Can. J. Plant Sci. 55: 339-341.

Krogman, K.K. and Hobbs, E.H. 1975. Yield and morphological response or rape (Brassica campestris L. cv. Span) to irrigation and fertilizer treatments. Can. J. Plant Sci. 55: 903-909.

Larsen, A. and Nodestgard, A. 1971. Row spacing experiments with winter rape. Tidsskrift fur Planteavl 75: 90-95. (Dan., Eng. Summary).

Maiti, S., Bhattacharya, K. and Chatterjee, B.N. 1970. Growth analysis of Brown Sarson (Brassica campestris) varieties. Indian J. Agron. 15: 318-321.

Major, D.J. 1975. Stomatal frequency and distribution in rape. Can. J. Plant Sci. 55: 1077-1078.

Major, D.J. and Charnetski, W.A. 1976. Distribution of ^{14}C-labelled assimilates in rape plants. Crop Sci. 16: 530-532.

McGregor, D.I. 1977. A rapid and simple method of screening rapeseed and mustard seed for erucic acid content. Can. J. Plant Sci. (in press).

Mendham, N.J. and Scott, R.K. 1975. The limiting effect of plant size at inflorescence initiation on subsequent growth and yield of oilseed rape (Brassica napus). J. Agric. Sci. 84: 487-502.

Mingeau, M. 1974. Comportment du colza de printemps à la secheresse. Inf. Tech. (Paris) 36: 1-11.

Nicholls, A.O. and Calder, D.M. 1973. Comments on the use of regression analysis for the study of plant growth. New Phytol. 72: 571-581.

Norton, G. and Harris, J.F. 1975. Compositional changes in developing rape seed (Brassica napus L.). Planta 123: 163-174.

Nuttall, W.F. 1973. Influence of soil moisture tension and amendments on yield, oil, and protein content of Target rape grown on Grey Wooded soils in the greenhouse. Can. J. Soil Sci. 53: 87-93.

Ohlsson, I. 1971. Higher yield and quality in spring-sown oil crops sown at close row spacings. Svensk Frotiding 40: 40-43. (Swedish).

Ohlsson, I. 1972. Spring rape and spring turnip rape need sowing at close row spacings. Svensk Frotidning 41: 25-27. (Swedish, Eng. Summary).

Olsson, G. 1960. Some relationships between number of seeds per pod, seed size, and oil content and effect of selection of these characters in Brassica and Sinapis. Hereditas 46: 29-70.

Olsson, G. 1974. Continuous selection for seed number per pod and oil content in white mustard. Hereditas 77: 197-204.

Pearce, R.B., Brown, R.H. and Blaser, R.E. 1967. Net photosynthesis of barley seedlings as influenced by leaf area index. Crop Sci. 7: 545-546.

Radford, P.J. 1967. Growth analysis formulae - their use and abuse. Crop Sci. 7: 171-175.

Rakow, G. and McGregor, D.I. 1975. Oil, fatty acid and chlorophyll accumulation in developing seeds of two "linolenic acid lines" of low erucic acid rapeseed. Can. J. Plant Sci. 55: 197-203.

Sims, R.P.A. 1964. Changes in the fatty acid composition of the seeds of three oil-bearing species during increasing seed maturity. Can. J. Plant Sci. 44: 217-218.

Takeda, T. and Akiyama, T. 1973. Studies on dry matter production in corn plant. II. Dry matter production of seedlings as affected by dense planting. Proc. Crop Sci. Soc. Japan 42: 302-306. (Jap., Eng. Summary).

Tayo, T.O. and Morgan, D.G. 1975. Quantitative analysis of the growth, development and distribution of flowers and pods in oil seed rape (Brassica napus L.). J. Agric. Sci. 85: 103-110.

Thorne, J.H. and Koller, H.R. 1974. Influence of assimilate demand on photosynthesis, diffusive resistance, translocation, and carbohydrate levels of soybean leaves. Plant Physiol. 54: 201-207.

Thurling, N. 1974a. Morphological determinants of yield in rapeseed (Brassica campestris and Brassica napus). I. Growth and morphological characters. Aust. J. Agric. Res. 25: 697-710.

Thurling, N. 1974b. Morphological determinants of yield in rapeseed (Brassica campestris and Brassica napus). II. Yield components. Aust. J. Agric. Res. 25: 711-721.

Vernon, A.J. and Allison, J.C.S. 1963. A method of calculating net assimilation rate. Nature (London) 200: 814.

Vulliourd, P. 1974. Influence de la densite de semis, de l'ecartement des lignes et de la fumure azotee sur le developpement et le rendement du colza d'automne. Rev. Suisse Agric. 6: 4-8.

Wallace, D.M. and Munger, H.M. 1965. Studies on the physiological basis for yield differences. I. Growth analysis of six dry bean varieties. Crop Sci. 5: 343-348.

Watson, D.J. 1947. Comparitive physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. Ann. Bot. N.S. 11: 41-76.

Watson, D.J. 1952. The physiological basis of variation in yield. Advan. Agron. 4: 101-145.

Watson, D.J. 1958. The dependence of net assimilation rate on leaf area index. Ann. Bot. N.S. 22: 37-54.

Wilfong, R.T., Brown, R.H. and Blaser, R.E. 1967. Relationships between leaf area index and apparent photosynthesis in alfalfa (Medicago sativa L.) and ladino clover (Trifolium repens L.). Crop Sci. 7: 27-30.

Williams, W.A., Loomis, R.S. and Lepley, C.R. 1965. Vegetative growth of corn as affected by population density. II. Components of growth, net assimilation rate and leaf area index. Crop Sci. 5: 215-219.