AGRONOMIC STUDIES IN SUMMER RAPE F1 HYBRID CULTIVARS (BRASSICA NAPUS L.)

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Allen Emile Van Deynze

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AGRONOMIC STUDIES IN SUMMER RAPE F_1 HYBRID CULTIVARS (*Brassica napus* L.)

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ABSTRACT

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The effect of hybridity, seeding rate and fertilizer rate on the performance and quality of summer rape F_1 hybrid cultivars was examined over three years (1986-1988).

Two F_1 hybrid cultivars were blended with 0 to 80% male sterile line (A-line) and 0-20% restorer line in two locations over two years. Contamination with the restorer line did not significantly affect hybrid cultivar performance or quality. Thirty percent or greater A-line contamination delayed earliness to flowering and maturity by about 1 day. The number of male sterile plants in the contaminated plots was not reduced by competition as indicated by the percent male sterility determined at flowering. Seed yield was reduced by 20% A-line contamination under heat and moisture stressed growing conditions, however, up to 80% A-line contamination did not change the seed yield of summer rape hybrid cultivars with adequate moisture conditions. Harvest index and oil concentration of the hybrid cultivars were reduced as percent male sterility in the plot increased due to relative differences between the A-line and the hybrid cultivars. Since percent male sterility in the plot was not substantially reduced by competition from the F_1 hybrid cultivars, only low levels of incomplete male sterility in the hybrid production field can be tolerated to maintain high levels of hybridity, yield and oil concentrations.

Four summer rape F_1 hybrid and two open pollinated cultivars were seeded at 1.5, 3.0, 4.5, 6.0 and 9.0 kg ha^{-1} at two locations in 1986 and 1987. Hybrid and open

pollinated cultivars responded similarly to seeding rate as indicated by the lack of cultivar x seeding rate interaction. Generally hybrid cultivars were later flowering and later maturing than open pollinated cultivars, both by approximately 1 day. They were taller and produced significantly more total dry matter. Seed yields of the hybrid cultivars were equal to or higher than the open pollinated cultivars. Hybrid cultivars had lower harvest indices and 1-3% lower seed oil concentrations than the open pollinated cultivars.

Increasing seeding rate hastened earliness to flowering and maturity by approximately 1 day. Percent survival decreased with increasing seeding rate because of increased interplant competition. Plant height was reduced, and lodging was more severe due to thinner plant stems at high seeding rates. The highest overall seed yields were at the 3.0 kg ha^{-1} seeding rate but 1.5 kg ha^{-1} produced similar yields with irrigation. Seeding rate did not affect oil, protein or chlorophyll concentrations. A lowering of the presently recommended seeding rates of 6-8 kg ha^{-1} for summer rape in Canada may be in order.

Three summer rape F_1 hybrid cultivars and the open pollinated cultivar Regent were seeded at 3 and 6 kg ha^{-1} with 0, 60, 120 and 240 kg ha^{-1} nitrogen fertilizer. The hybrid cultivars were later maturing than Regent by 1 to 2 day(s). They produced higher total dry matter yields and similar oil and protein concentrations as Regent. Seeding rate did not change the direction of the nitrogen fertilizer response for performance and quality traits of the cultivars tested, therefore, it was concluded that seeding rate did not affect the nitrogen fertilizer response of summer rape hybrid or open pollinated cultivars.

Nitrogen fertilizer did not affect plant density characters, height, harvest index or seed weight. Increasing nitrogen fertilizer delayed flowering and maturity, and prolonged seed formation period by 2, 4 and 2 days, respectively. The highest seed yields were achieved at 120 kg ha^{-1} nitrogen fertilizer due to the highest number of pods $plant^{-1}$ and seeds pod^{-1} at that nitrogen fertilizer rate. Oil concentration was reduced but

protein concentration increased, resulting in a 1.3% increase in total oil and protein concentration with 240 kg ha^{-1} nitrogen fertilizer. Although nitrogen fertilizer raised chlorophyll concentration, it remained below the Canadian standard limit of 24 ppm.

The results of this study suggest that the nitrogen fertilizer rates (150-200 kg ha^{-1}) presently recommended for summer rape open pollinated cultivars may be used for summer rape F_1 hybrid cultivars.

FOREWORD

The following thesis was written in manucript style. The three manuscripts will be submitted to the Canadian Journal of Plant Science for publication.

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1. INTRODUCTION

Canola is the term used for low erucic acid (<2%), low glucosinolate (<30 μmols glucosinolates per g meal) cultivars of turnip rape (B. campestris) and rape (B. napus). It was first adopted by Canada in 1978 (Canola Council 1987) and is now a registered trademark in 16 countries.[1] In 1988, Canada produced 4.2 million tonnes of canola yielding approximately 1160 kg ha^{-1} over 3.65 million hectares.[2] Since canola rapeseed oil has low saturated fat content, its demand has increased with the increase in health consciousness. The production of high yielding F_1 hybrid cultivars is a means of meeting this demand.

Heterosis for yield must be sufficient to proceed in a F_1 hybrid program. F_1 hybrid, denoting the product of the initial cross between parents, will be referred to as simply hybrid hereafter. High parent heterosis for yield of intercultivar hybrid cultivars averaged 40-60% in winter rape (Shiga 1976) and summer rape (Sernyk and Stefansson 1983, Grant and Beversdorf 1985). In winter and summer rape, inbred line derived hybrid cultivars yielded 23% (Buson 1980) and up to 120% (Brandle 1989) more than their parent inbred lines, respectively. These reports show that the requirement for heterosis in hybrid rapeseed is fulfilled.

Pollination control mechanisms are essential to ensure hybridization of the parents. Heyn (1973) developed a genic male sterility system in rape. Self incompatibility was used to produce rape hybrid cultivars in China (Fu 1981b) and the United Kingdom (Thompson 1983). The mur (Hinata and Konno 1979, Shiga 1980), ogu

1. Canola Council of Canada. Canola Digest - Vol. 21 No. 5 1987
2. Statistics Canada. Field Crop Reporting Series - No. 8 1988

(Ogura 1968, Bannerot et al. 1977), nap (Thompson 1972, Shiga and Baba 1971, 1973) and the pol (Fu 1981a) cytoplasmic male sterility (CMS) systems have been discovered in summer and winter rape. Of these, the nap (Sernyk 1982) and the pol (Sernyk and Stefansson 1983, Fang and McVetty 1987) CMS systems show the most promise for hybrid seed production in summer rape.

Seed production on a commercial scale is essential for the exploitation of hybrid rape. The honeybee (Apis mellifera) has been identified as an efficient pollen vector in rape (Renard and Mesquida 1979, Eisikowitch 1981). Row ratios of 14:2 and 10:1 male sterile to male fertile genotypes were proposed for the production of hybrid winter rape (Renard and Mesquida 1979) and hybrid summer rape (Pinnisch 1988), respectively. Preliminary studies have therefore shown that it may be possible to produce hybrid rape on a commercial scale.

Hybrid seed must have high levels of hybridity to qualify for hybrid status and perhaps to ensure adequate agronomic performance of the hybrid cultivar. In Japan, parental contamination of 50% in hybrid winter rape populations was tolerated without a loss in yield (Murakami et al. 1969, Shiga et al. 1970). Seeding rate and the degree of heterosis for yield may affect the level of parental contamination tolerated in hybrid populations (Shiga et al. 1970).

Agronomic practices such as seeding rate and nitrogen fertilizer requirements must be determined to optimally exploit the yield advantage of rape hybrid cultivars. Currently in Canada, recommended seeding rates are in the order of 6-8 kg ha^{-1} for summer rape (Kondra 1975, 1977, Manitoba Department of Agriculture 1988). In Saskatchewan, recent work showed that 3 kg ha^{-1} yielded significantly higher than 6 and 9 kg ha^{-1} seeding rates.[3] In France, Lefort-Buson and Datee (1986) reported that the 4 kg ha^{-1} seeding rate yielded highest for both winter rape inbred lines and hybrid

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3. Canola Council of Canada. Canola Digest - Vol. 22 No. 8 1988

cultivars. The evidence suggests that a lowering in seeding rate for western Canadian planted rape may be in order.

Crops with high protein such as winter and summer rape require high amounts of nitrogen fertilizer for protein synthesis (Ridley 1972). Generally, nitrogen fertilizer response in rape has been greater on soils low in NO_3 nitrogen (Christensen et al. 1985). Yield tests showed an optimum nitrogen fertilizer rate of 150 to 200 kg ha^{-1} on soils low in NO_3 nitrogen in Canada (Soper 1971, Ridley 1972, 1973). On soils with high NO_3 nitrogen, 60 kg ha^{-1} nitrogen fertilizer maximized seed yield in summer rape in Canada (Racz et al. 1975). It has been shown by the above that rape may require a large amount of nitrogen fertilizer, especially on soils low in NO_3 nitrogen. Although there has been extensive research done on open pollinated rape, there is nothing in the literature on the fertilizer requirements of summer rape hybrid cultivars.

The objectives of this research were, therefore, to determine the seed purity requirements, the optimum seeding rate and nitrogen fertilizer requirements of summer rape hybrid cultivars to maximize seed yield and quality.

2. LITERATURE REVIEW

2.1 F1 Hybrid Cultivars

2.1.1 Heterosis

Heterosis may be defined as the developmental stimulation resulting from the union of different gametes (Schull 1948). Shiga (1976) reported that 98 out of 131 Japanese rape hybrid cultivars outyielded their pollen parents by as much as 269%. Canadian researchers found heterosis of 43% over the cultivar Regent for the hybrid of the cultivars Karat and Regent (Sernyk and Stefansson 1983). Other Canadian researchers reported that the intercultivar hybrid cultivars of Westar and Hanna produced a yield advantage of 50% over the high parent (Grant and Beversdorf 1985). In winter and summer rape, inbred line derived hybrid cultivars yielded 23% (Buson 1980) and up to 120% (Brandle 1989) more than their parents, respectively. These reports show that sufficient heterosis is available to warrant hybrid seed production in rape.

2.1.2 Pollination Control Mechanisms

The three pollen control mechanisms available for hybrid rape production are genic male sterility (GMS), self incompatibility (SI) and cytoplasmic male sterility (CMS). In rape, Heyn (1973) reported a genic male sterility system governed by two nuclear recessive genes. Self incompatible cultivars were used to produce rape hybrid cultivars with 10-30% heterosis in China (Fu 1981b). In the United Kingdom, Thompson (1983) proposed a scheme for the production of self compatible winter rape hybrid

cultivars using recessive self incompatibility. The commercial production of selfed seed in the self incompatible lines is the limiting factor in this system.

Of the three pollination control mechanisms, CMS has been worked on the most extensively. A CMS system consists of an A-line with male sterile cytoplasm and no dominant nuclear restorer genes, which is always used as the female parent in crosses. The B-line with male fertile cytoplasm and no dominant restorer genes is crossed as the male parent to the A-line to maintain male sterile seed stocks. The R-line, with dominant nuclear restorer gene(s), is crossed as the male parent to the A-line to produce male fertile hybrid cultivars.

The mur cytoplasm was first introduced into turnip rape by Hinata and Konno (1979). Shiga (1980) obtained male sterility using similar procedures in rape. The author doubled hybrid plants of Diplotaxis muralis and rape with colchicine and backcrossed them to rape. The results were plants with the rape genome and the mur male sterility inducing cytoplasm. Restorer accessions are not available in winter or summer rape, therefore they would have to be introduced from D. muralis.

The ogu cytoplasm, derived from radish (Ogura 1968), was successfully transferred to summer rape (Bannerot et al. 1977). All rape cultivars appear to be maintainers in this cytoplasm (Rousselle 1980, Fan et al. 1986), therefore restorers would have to be introduced from radish for hybrid rape production.

The nap cytoplasm was identified both in the rape cultivar Bronowski (Thompson 1972) and in crosses between the rape cultivars Chisaya natane and Hokuriku 23 (Shiga and Baba 1971, 1973). Fan et al. (1986) tested 32 strains of rape from seven countries. Only the cultivars Bronowski and Lergo were male sterile in this cytoplasm. All other strains were restorers governed by one dominant gene.

A fourth source of CMS, the pol cytoplasm, was first reported in the rape cultivar Polima from Poland (Fu 1981a). Studies have shown this cytoplasm to have few restorers (Fan et al. 1986). Male sterility restoration was first dependent on an aneuploid

line derived from the mustard cultivar Zem (Brassica juncea) (Tai and McVetty 1987). Canadian researchers used a winter rape strain as the source of pol CMS restoration to develop a summer rape restorer controlled by a single dominant gene (Fang and McVetty 1987). The nap and pol CMS systems show the most promise for hybrid rape production (Sernyk 1982, Sernyk and Stefansson 1983).

A common problem with these CMS systems in rape is incomplete male sterility. Thompson (1972) recommended against the use of the nap cytoplasm for hybrid rape production on the basis of incomplete male sterility and environmental instability. Temperatures of 26°C and 30°C induced pollen production in the nap and pol CMS systems respectively (Fan and Stefansson 1986). Male sterile plants with underdeveloped anthers devoid of pollen, short stamens and narrow petals reverted to partially sterile plants with longer stamens and some pollen production (Shiga et al. 1978, Fu 1981a, Sernyk 1982, Fan and Stefansson 1986). Pollen production of CMS lines results in selfing, thus to the production of non hybrid seed. The presence of insects increases these contaminants by disseminating the pollen produced to neighboring flowers and plants (Pinnisch 1988). This may have significant effects on the yield and quality of the hybrid cultivar.

2.1.3 Hybrid Seed Production

An insect pollinator is essential in hybrid rape production to assure transfer of pollen. Wind pollination accounted for only 3-12% of the pollination on ogu rape male sterile lines (Renard and Mesquida 1979). Bee activity was highly correlated (r=.97**) to the pod set of ogu rape hybrid cultivars. Insect pollination was responsible for 70% of the yield of these hybrid cultivars (Renard and Mesquida 1979). In field trials of the male sterile summer rape cultivar Marnoo in the pol cytoplasm, Pinnisch (1988) suggested that entomophilic pollination was largely responsible for yields. Honeybees

(Apis mellifera) have been identified as efficient pollinators of rape, visiting flowers at all developmental stages, touching all anthers, thus leading to pollination at every visit (Williams 1978, Eisikowitch 1981). The use of honeybees along with a functional CMS system would ensure hybridization of parental lines, thus a high percentage of hybrid seed being produced.

Since only the A-line is harvested in hybrid production blocks a high ratio of A-line to R-line is preferred to reduce seed costs. In France, studies on row ratios of rape hybrid cultivars in the ogu cytoplasm were conducted. A 14:2 row ratio with 35 cm row spacings was recommended for the commercial production of hybrid rape. Frequency of bee visitation decreased as distance from the pollen source was increased (Renard and Mesquida 1979). Pinnisch (1988) seeded 30 rows with 30 cm spacings of the pol cytoplasm male sterile summer rape cultivar Marnoo adjacent to 3 rows of a restorer cultivar, Regent. As row distance increased from the pollen source, seed set, seed yield and percent hybridity of the hybrid cultivar decreased. The decrease in seed yield of 17.5 kg ha^{-1} per row away from the pollen source was due mainly to a decrease in seed weight. The largest percent hybridity though, was approximately 60% because the A-line was only partially male sterile and pollen produced by it was disseminated by insects resulting in selfing.

Despite these difficulties, hybrid seed production may be feasible on a commercial scale. Additional studies on row ratios may be required for the pol CMS system once completely male sterile lines are produced.

2.2 Hybridity in Rape

In summer rape, hybridity is the proportion of the population derived from cross pollination. As mentioned previously, incomplete male sterility is common to the CMS systems in oilseed rape. Thompson (1972) grew a partially male sterile line of summer

rape in the field under open pollinated conditions. The open-pollination-derived hybrid population had 30% male sterility i.e. there was 30% selfing of the male sterile line . If male sterility can be tolerated in the hybrid population, 100% pollination control may not be needed. Stoskopf and Law (1972) suggested that in wheat, retardation of pollen release with ethrel may be satisfactory if selfed seed can be tolerated in the hybrid population. This is analogous to shortening of the stamens and reduced pollen production of the anthers in partially male sterile lines in rape.

2.2.1 Factors Affecting Hybridity

Pinnisch (1988) observed that as row distance of the pol cytoplasm male sterile cultivar Marnoo decreased away from the pollinator, hybridity increased due to higher levels of cross pollination. Since there is a lack of information on this topic in rape, perhaps the model in wheat maybe used.

In wheat, Hughes and Bodden (1978) obtained 62-97% hybrid seed using ethepon to induce male sterility. The authors suggested that high levels of cross pollination were essential to maintain high levels of hybridity because the relative proportion of hybrid wheat seed dropped off rapidly as seed set by crossing decreased. The level of hybrid seed also declined as selfing increased. It was suggested that cross pollination may be increased by: increasing pollen loads with better pollinators, increasing the area sown to pollinators, synchronization of flowering of pollinators and females, and prolonging pollen production by seeding the pollinators at several dates. Perhaps these agronomic practices may be used in hybrid rape seed production blocks to increase hybridity.

2.2.2 Factors Affecting Yield

In winter rape, differences in seed yield were larger at high seeding rates than at lower ones. In winter rape seeded at 400 plants m^{-2}, the hybrid cultivar made up a greater proportion of the stand and yield in a hybrid/parent mixture than at 200 plants m^{-2} (Murakami et al. 1969). Shiga et al. (1970) found that average heterosis for yield is reduced from 228 to 127% when plant density is increased from 100 to 400 plants m^{-2}, in 0/100, 25/75, 50/50 and 100/0 percent hybrid/parent mixtures of winter rape. With parental contamination, yield was therefore reduced more at higher plant densities. The authors also observed that at low levels of heterosis (90%), yield did not change with 50% parental contamination in hybrid/parent mixtures. With these same mixtures and higher levels of heterosis (290%), 50% parental contamination reduced yields. Yield in winter rape hybrid/parent mixtures was therefore affected by seeding rate and relative heterosis of the hybrid cultivar.

2.2.3 Hybrid/Parent Mixtures

In France, Renard and Mesquida (1987) produced three male sterile summer rape hybrid cultivars using protoplast fusion and grew them with 5, 10, 20, and 30 percent male fertile parent in isolation. The hybrid cultivars excelled over the parents in seeds pod^{-1}, seed weight and seed yield. This is opposite to the usual situation with incomplete male sterility where the hybrid cultivars are male fertile and the female parents are male sterile. Pod set was equal to the male fertile parents (control) when 20% or greater of the population was made up of pollen parents, therefore, high yielding rape hybrid cultivars can be produced with minimal parental contamination as the source of pollen.

Murakami et al. (1969) blended winter rape in 0/100, 25/75, 50/50, 75/25 and 100/0 percent hybrid/parent mixtures at 200 and 400 plants m^{-2}. As the proportion of the

hybrid cultivar increased, the height of the hybrid cultivar was more stable and lower. The final number of plants at harvest did not change at low densities but increased as hybrid cultivar contribution was raised at the higher planting density.

A similar study was undertaken in Japan with the hybrids of the winter rape cultivars, Norin 16 and Chisaya natane, sown at 400 plants m^{-2} and blended at 0/100, 25/75, 50/50 and 100/0 percent hybrid/parent ratios. In this case, the height of the hybrid cultivar was reduced with increasing parental contamination, even though the heights of the hybrid cultivars and parents were similar in pure stands (Shiga et al. 1970). This reduction in height is likely caused by better competitive ability of the parent than the hybrid cultivar. Superior competitiveness of the parent has also been observed in barley for plant weight, weight of ears and number of culms (Sakai 1955). In the same experiment, Shiga et al. (1970) observed that the hybrid cultivar made up a greater proportion of the leaf area index and final dry weight of the population than was seeded. This is expected since summer rape hybrid cultivars generally produce greater dry matter, thus larger leaf areas than open pollinated cultivars (Sernyk and Stefansson 1983).

With 90% heterosis for yield, winter rape hybrid cultivars tolerated greater than 50% parental contamination regardless of seeding rate i.e. yields did not change. At higher heterosis levels (290%), 50% parental contamination reduced yields of the hybrid cultivars, especially at higher plant densities (Shiga et al. 1970).

Although actual male sterile/hybrid mixtures have not been studied in summer rape, work in male fertile winter rape shows that more differences can be observed in mixtures at high plant densities and also as heterosis for yield is increased. Mixtures with male sterile plants may react similarly to the hybrid/parent mixtures since the A-line contaminants have a source of pollen from the hybrid cultivars for seed production.

2.3 Seeding Rate of Hybrid Rape Cultivars

2.3.1 The Effect of Seeding Rate on Phenology

Days to crop maturity in summer rape is an important factor in countries such as Canada where the growing period may be limited to less than 100 frost free days. Physiological maturity, stage 5.3 (Harper and Berkenkamp 1975), is essential to maximize yield. Early maturity and flowering, as well as increased duration of the flowering period have been associated with high yields and high growth rates (Thurling 1974, Campbell and Kondra 1978, Clarke and Simpson 1978a). Earliness to first flower, stage 4.1 (Harper and Berkenkamp 1975), also contributes to earliness of later stages (Campbell and Kondra 1977). Since summer rape has an indeterminate flowering habit, uniformity of maturity is essential to maximize yield. Scarisbrick et al. (1982) noted that as seeding rate increased from 4.5 to 13.5 kg ha^{-1} in both summer and winter rape, the range of flowering and maturity decreased, therefore, promoting uniformity. This was also observed for the summer rape cultivar Tower seeded at 2.5 to 20 kg ha^{-1} (Clarke and Simpson 1978a).

A slight decrease in days to first flower (stage 4.1, Harper and Berkenkamp 1975) and days to maturity (stage 5.3, Harper and Berkenkamp 1975) was found for the summer rape cultivar Westar by increasing seeding rate from 1.5 to 12 kg ha^{-1} (Morrison 1987). Increasing seeding rate from 3 to 12 kg ha^{-1} of five summer rape genotypes resulted in no differences in earliness of flowering but a decrease of approximately 1.7 days in maturity of the first pod (Degenhardt and Kondra 1981a). At lower plant densities (3 to 86 plants m^{-2}), earliness of flowering in summer rape was not affected but maturity was delayed by 16 days (McGregor 1987). This may be due to increased plant competition at higher seeding rates.

Length of the flowering period, measured as [days to last flower - days to first flower], slightly decreased with increasing seeding rates but it was not related to seed

yield in summer rape. The seed formation period, defined as [days to maturity - days to first flower], also decreased with increasing seeding rate in same experiments (Degenhardt and Kondra 1981a, Scarisbrick et al. 1982)

Seeding rate does not affect earliness adversely with the exception of impractical, low seeding rates therefore, as suggested by Morrison (1987), seeding rate should not be adjusted to change these characters. A higher seeding rate may be preferred, though, to maintain uniformity in open pollinated varieties since summer rape seed costs are minimal, but this may not be practical for more expensive rape hybrid seed.

2.3.2 The Effect of Seeding Rate on Height, Lodging and Stand

Lefort-Buson and Datee (1986) concluded that inbred lines and hand crossed hybrid cultivars of winter rape responded similarly to seeding rate with regards to height. An increase in seeding rate from 3 to 12 kg ha^{-1} in summer rape resulted in a decrease in height in the United Kingdom (Scarisbrick et al. 1982) and in Canada (Degenhardt and Kondra 1981a, McGregor 1987). This was due to increased interplant competition. This would be expected since increased competition would limit assimilates for elongation. Morrison (1987) found that increasing plant densities in the same range resulted in etiolation of the summer rape cultivar Westar, thus plants were taller .

Lodging may become an important factor in summer rape with regards to uniformity of ripening and ease of harvest. Again winter rape homozygotes were found to respond similarly as heterozygotes to seeding rates in the range of 0.08 to 8 kg ha^{-1} (Lefort-Buson and Datee 1986). The summer rape cultivar Westar was found to be more susceptible to lodging at higher seeding rates than at lower rates. This was due to thinner stems and greater susceptibility to stem diseases. Lodging was not related to final seed yield (Morrison 1987). Kondra (1975) observed that lodging in summer rape was more

severe at 12 kg ha^{-1} than at 3 or 6 kg ha^{-1}. Thinner stems at high plant densities were also reported in winter rape (Scarisbrick et al. 1982).

Final plant stand was directly correlated to seed yield in the summer rape cultivar Tower (Clarke and Simpson 1978a), suggesting that percent survival of the seeded stand may become an important factor in determining optimum seeding rate. In the United Kingdom, plant stands of the summer rape cultivar Willi were reduced from 67% of the seeded stand to 59% at the seeding rates of 4.5 and 13.5 kg ha^{-1}, respectively (Scarisbrick et al. 1982). A greater reduction in stand was observed for the summer rape cultivar Tower with less than 50% of the seeded stand surviving to maturity at seeding rates over 10 kg ha^{-1} (Clarke and Simpson 1978b). In summer rape, an 85% increase in plant density was found with each 2 fold increase in seeding rate from 3 to 12 kg ha^{-1} (Degenhardt and Kondra 1981a, Christensen and Drabble 1984).

2.3.3 The Effect of Seeding Rate on Total Dry Matter and Seed Yield

Total dry matter has been directly related to seed yield, thus an increase in plant size results in an increase in seed yield (Thurling 1974, Campbell and Kondra 1978). In turn, total dry matter is affected most by the time to 50% anthesis. On a per area basis, total dry matter in summer rape did not change with an increase in seeding rate from 3 to 20 kg ha^{-1} (Clarke and Simpson 1978b, Degenhardt and Kondra 1981a). On a per plant basis, dry matter decreased with increasing plant density from 3.6 to 86 plants m^{-2} (McGregor 1987). This was due to a reduction in assimilate availability because of reduced photosynthetic surface area per plant (Clarke and Simpson 1978b)

In Canada, the currently recommended seeding rate for summer rape is 6-8 kg ha^{-1} (Kondra 1975, 1977, Manitoba Department of Agriculture 1988). Other authors found no significant differences in yield with seeding rates ranging from 3 to 14 kg ha^{-1}, but the highest numerical yields were produced at seeding rates of 6-7 kg ha^{-1} in five

summer rape cultivars (Degenhardt and Kondra 1981a, b, Christensen and Drabble 1984). In the United Kingdom and Scandanavia, 6-8 kg ha^{-1} also maximizes seed yield but there is little effect of seeding rate between 4-12 kg ha^{-1} (Loof 1960, Bunting 1969). In both summer and winter rape, yield was significantly higher at 9 kg ha^{-1} than at 4.5 kg ha^{-1}. Increasing seeding rate to 13.5 kg ha^{-1} did not change yields (Scarisbrick et al. 1982). Clarke et al. (1978) seeded the summer rape cultivar Tower at 2.5, 5, 10 and 20 kg ha^{-1} in Saskatchewan. The highest seeding rate yielded the most in this case.

More recent studies show that seed yield is maximized at lower seeding rates than recommended. In Manitoba, Morrison (1987) seeded Westar at 1.5, 3, 6 and 12 kg ha^{-1}. It was established that 1.5 kg ha^{-1} yielded best on a silty clay looam soil and 3 kg ha^{-1} was superior on a clay loam soil. In Saskatchewan, summer rape yielded more when it was seeded at 3 kg ha^{-1} than 6 and 9 kg ha^{-1}.[4] Seeding rates of 4-7 kg ha^{-1} equal to 100-295 seeds m^{-2} depending on seed size. McGregor (1987) thinned plants of the summer rape cultivar Tower to densities ranging from 86 to 3 plants m^{-2}. It was concluded that densities as low as 40 plants m^{-2} may be used with less than a 20% seed yield loss.

In France, Lefort-Buson and Datee (1986) tested three winter rape hybrid cultivars and three inbred lines at seeding rates of 0.08 to 8 kg ha^{-1}. The 4 kg ha^{-1} seeding rate yielded most for both inbred lines and hybrid cultivars with a decrease in yield at higher rates for inbred lines but not hybrid cultivars. Heterozygotes and homozygotes responded similarly to seeding rate, hybrid cultivars outyielding inbred lines in all cases. Conventional summer rape cultivars would fall in between these two types since summer rape is 22% outcrossing (Rakow and Woods 1987). The stable yield above 4 kg ha^{-1} for hybrid cultivars and not inbred lines suggests that F_1 hybrid cultivars have a greater competitive ability under severe competition.

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4. Canola Council of Canada. Canola Digest - Vol. 22 No. 8 1988

Rape yield is a function of the number of plants per unit area, number of pods plant^{-1}, seeds pod^{-1} and seed weight. The last three characters are genetically regulated at critical sites and modified by the environment, in this case, plant density (McGregor 1987). The plants have developmental plasticity resulting from the use of alternate pathways to attain yield (Adams 1967, Adams and Grafius 1971). At low seeding rates, increased and prolonged dry matter production of the leaves, stems and pods, as well as increased branching results in larger yields plant^{-1} (McGregor 1987). A greater number of flowers are aborted on axillary branches than on the main raceme, therefore, assimilates are wasted at low seeding rates (Morgan 1982). At high seeding rates, pods are carried mostly on the main raceme. This exposes them to light, thus increasing photosynthesis for larger seeds and greater number of seeds pod^{-1} (Clarke and Simpson 1978a, Clarke 1979, Morgan 1982). This suggests that reduced branching at high seeding rates may be beneficial.

The high seed yields obtained at low seeding rates in recent research are likely due to better field conditions obtained with improved crop husbandry. This theory is supported by the findings of Morrison (1987). On the other hand, the high yields attained by Clarke et al. (1978) at 20 kg ha^{-1} may be a result of poor field conditions. Final plant densities were not determined in this case to study any effects of stand reduction.

2.3.4 The Effect of Seeding Rate on Harvest Index

Harvest index is the ratio of seed yield to biological yield. For practical purposes, only the mature plant biological yield is measured. The term apparent harvest index is used in cases where senescent leaves are not collected or counted as part of the plant biological yield. It is directly related to harvest index (Schapaugh and Wilcox 1980). Apparent harvest index, hereafter referred to simply as harvest index, reflects the capacity of a crop to translocate photosynthesis to economically important organs

(Thurling 1974). It is usually overestimated since the decrease in shoot weight due to leaf senescence is not accounted for (Rood and Major 1984).

For seeding rates in the range of 4.5 to 13.5 kg ha^{-1}, the highest seeding rate had the lowest harvest index for both spring and winter rape, with little difference at lower rates (Scarisbrick et al. 1982) In Canada, similar results were obtained in the 1.5 to 12 kg ha^{-1} range for the summer rape cultivar Westar (Morrison 1987) and in the 3 to 12 kg ha^{-1} range for five other summer rape genotypes. This trait responded consistently to seeding rate over genotypes therefore, it may be selected for at a constant planting density (Degenhardt and Kondra 1981a). Seeding rate therefore, only affects harvest index under competition at high seeding rates. Low harvest indices are associated with low drying rates but this disadvantage may be overcome by reduced branching and uniform maturity at high plant densities (Scarisbrick et al. 1982).

2.3.5 The Effect of Seeding Rate on Seed Protein and Oil Concentration and Seed Oil Yield

Since rape is an oilseed crop, the seed oil yield is the economically important factor. Oil yield is the product of seed yield and oil concentration, therefore maximizing these traits would maximize returns. Canola summer rape is made up of 43% oil and 26% protein on a whole seed, zero moisture basis.[5] The oil is used largely for cooking and edible oil products, whereas the protein is important in the meal used as an animal supplement. Since rape contains very little carbohydrate, there is a high negative correlation between the oil and protein concentrations (Loof 1960). Oil is synthesized as storage fatty acids, as protein content declines in the seed. The main raceme produces slightly more oil, with less linolenic acid than the branches, thus high seeding rates may

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be preferred (Diepenbrock and Geisler 1979). Olsson (1960) suggested that oil concentration increased with the degree of ripening.

Kondra (1975) showed that seeding rate had no effect on the quality of the summer rape cultivar Zephyr in the 3 to 12 kg ha^{-1} range. In 1977, similar experiments with the same cultivar and seeding rates resulted in no differences or trends in oil or protein concentration (Kondra 1977). Seeding the summer rape cultivar Westar at 1.5 to 12 kg ha^{-1} did not change oil or protein concentration at two locations in Manitoba (Morrison 1987). Identical results were obtained in the United Kingdom for the summer rape cultivar, Willi, and the winter rape cultivar, Rafal, seeded at 4.5, 9 and 13.5 kg ha^{-1} (Scarisbrick et al. 1982).

Seeding rate, thus, has little effect on the actual oil or protein concentrations of rape but as mentioned before, higher seeding rates may be preferred to decrease linolenic acid levels. Since the oil and protein concentrations are not affected, the actual seed yield is a good measure for the oil and protein yields at different planting densities.

2.3.6 The Effect of Seeding Rate on Seed Chlorophyll

Immaturity or greenness of the seed is a degrading factor in rape (Daun 1976). The color is from a photosynthetic pigment called chlorophyll, that is almost entirely extracted with the oil. The pigment made up of chlorophyll a and b, as well as pheophytins, is a prooxidant in the formation of oxidative rancidity of the oil, thus lowers the shelf life of the end products (Daun 1982). Currently in Canada, summer rape crops average 13 ppm chlorophyll in the seed. In Canada, the number of green seeds and crop maturity has been used to estimate chlorophyll levels in rape, but studies have determined that this factor has a poor correlation with the level of chlorophyll. It has been suggested that Canada adopt chlorophyll level as a grading factor in canola rapeseed, but quick

testing methods such as Near Infrared Reflectance analysis are not yet readily available.[6] Canadian standards for top grade oil have put 24 ppm as the upper limit for seed. This corresponds to 30 ppm in processed oil (Daun 1989).

Since maturity effects the level of chlorophyll in the seed, evenness of ripening would be important in controlling chlorophyll levels. Maturity is more uniform at higher seeding rates in rape (Clarke and Simpson 1978a, Scarisbrick et al. 1982).

Morrison (1987) seeded the summer rape cultivar Westar at 1.5, 3, 6 and 12 kg ha^{-1}. Seed chlorophyll determinations were done for both branches and main racemes. The 1.5 kg ha^{-1} seeding rate produced highest branch seed chlorophyll (24 ppm) in two out three locations while there were no differences in the main raceme chlorophyll. Overall, the total seed chlorophyll was greatest at the low seeding rate. These results confer with the uniformity information above. Low seeding rates should therefore be avoided to maintain low chlorophyll levels

2.4 Nitrogen Fertilizer Requirements of Hybrid Rape Cultivars

2.4.1 The Effect of Nitrogen Fertilizer on Phenology

Phenological characters such as days to budding, days to first flower and days to maturity are inherited quantitatively (Ringdahl et al. 1979), therefore may be influenced to large extent by environmental factors such as nitrogen fertilizer. In summer rape, ripening was delayed 6-7 days with 170 kg ha^{-1} nitrogen fertilizer (Bunting 1969). In the United Kingdom, flowering of the winter rape cultivar Victor was delayed up to 5 days with the addition of 100, 200 and 300 kg ha^{-1} nitrogen fertilizer. In the same experiment, 300 kg ha^{-1} nitrogen fertilizer delayed maturity by approximately one week (Scott et al. 1973). In Alberta, Christensen et al. (1985) added enough nitrogen fertilizer

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for a 1680 kg ha^{-1} crop of summer rape on summerfallow and fescue sod. Maturity was delayed less than 1 day with the application of nitrogen fertilizer. Low responses of rape crops to nitrogen fertilizer on soils with high NO3 nitrogen may be the cause of the small differences in maturity. On soils high in NO3 nitrogen or with high nitrogen rates, maturity or flowering may be delayed considerably in rape. Soils should be tested for NO3 nitrogen to avoid over application of nitrogen fertilizer in summer rape, thus preventing a delay in maturity.

2.4.2 The Effect of Nitrogen Fertilizer on Height, Lodging and Stand

In rape, greater than one half of the height is due to elongation of the main raceme (Tayo and Morgan 1975). Good plant nutrition during elongation should increase plant height. The addition of 105.5 and 211 kg ha^{-1} nitrogen fertilizer increased height of the summer rape cultivars Zollerngold and Cresus by approximately 30 and 40 cm, respectively, over the 0 kg ha^{-1} treatment in the United Kingdom (Allen and Morgan 1972). Stems were lengthened and plants were more vigorous.

When crops are heavy during filling, lodging in summer rape may be a problem. In the United Kingdom, poor yields were observed on a lodged crop of the summer rape cultivar Zollerngold at 100 and 200 kg ha^{-1} nitrogen fertilizer. The decrease in yield was attributed to lodging since neighboring cultivars which maintained good standability performed well (Scott et al. 1973). Lodged crops favor disease infection under moist conditions. Nitrogen fertilizer should, therefore, be applied with knowledge of the soil NO3 nitrogen status to avoid the application of more nitrogen than the summer rape plant will assimilate and thus avoid lodging.

Plant stand has been directly correlated to seed yield in summer rape (Clarke and Simpson 1978a). Allen and Morgan (1972) reported that final plant stands were reduced as nitrogen fertilizer rate increased from 0 to 211 kg ha^{-1} when applied prior to seeding.

In Alberta, emergence was 1 day later on summerfallow than on fescue sod for two summer rape cultivars (Christensen et al. 1985). Very high rates of nitrogen fertilizer applied prior to seeding may decrease stands possibly by decreasing germination or by increasing interplant competition.

2.4.3 The Effect of Nitrogen Fertilizer on Total Dry Matter and Seed Yield

Nitrogen fertilizer requirements in rape are largely dependent on the soil status and target yields. In Canada, yield responses to nitrogen fertilizer in summer rape were observed only when NO_3 nitrogen sampled at a 61 cm depth prior to seeding was less than 100 kg ha^{-1}. This figure is rarely exceeded on non fallow soils except after breaking up a perennial legume forage. Seed yield was maximized with 200 kg ha^{-1} nitrogen fertilizer on soils with 17 kg ha^{-1} NO_3 nitrogen for summer rape crops yielding 1700 kg ha^{-1} (Soper 1971). Responses to 240 kg ha^{-1} nitrogen were observed in Manitoba when split applications were used (Ridley 1972). Yield responses to 150-200 kg ha^{-1} are also common in both summer and winter rape in the United Kingdom (Bunting 1969, Helps 1971, Scott et al. 1973), Spain (Muñoz 1979) and Scandanavia (Loof 1960).

Both total dry matter and seed yield were increased at all increments, 0, 105.5 and 211 kg ha^{-1} of nitrogen fertilizer on soils derived from old river gravel in the United Kingdom (Allen and Morgan 1972, 1975). Yield was increased in 23 out of 26 experiments by the addition of 70, 140 and 210 kg ha^{-1} nitrogen fertilizer applied twice during the season. With split fertilizer applications, yield was increased as a result of increased total dry mattter production. Total dry matter is correlated with seed yield in summer rape (Thurling 1974). With a single fertilizer application, nitrogen is leached when applied at high rates. Holmes and Ainsley (1977) found that when the yield potential of the summer rape crop was greater than 1.5 t ha^{-1}, seed yield was maximized

at 203 kg ha^{-1} nitrogen fertilizer, whereas when yield potential was less than 1.5 t ha^{-1}, it was maximized at 187 kg ha^{-1}. The authors also noted that when the preceding crop was a cereal, optimum nitrogen fertilizer rate for see yield was 196 kg ha^{-1} compared to 158 kg ha^{-1} when a non cereal crop preceded rape. Racz et al. (1965) established that on soils with high NO_3 nitrogen, 60 kg ha^{-1} produced the highest seed yields for summer rape in Canada.

Nitrogen fertilizer increased the seed yield and total dry matter of summer rape when phosphate was added to soils low in NO_3 nitrogen (Racz et al. 1965, Anderson and Kusch 1968). On clover stubble, summer rape yields were depressed, especially without the addition of phosphate (Osborne and Batten 1978).

One can see from the above that rape may require high amounts of nitrogen fertilizer. The level of nitrogen available in the soil, time of application, yield potential of the crop and level of other nutrients may affect the yield response to nitrogen. Typical yield responses to nitrogen fertilizer follow quadratic curves. Soils low in NO_3 nitrogen would follow the increasing linear portion of the curve whereas soils high in NO_3 nitrogen would follow the plateau or decreasing end of the response curve.

2.4.4 The Effect of Nitrogen Fertilizer on Yield Components

In rape, yield can be divided into pods per unit area, seeds pod^{-1} and weight $seed^{-1}$ (Clarke and Simpson 1978a). Each of these components are positively correlated with seed yield but are in turn negatively correlated with each other resulting in yield component compensation (Olsson 1960, Adams and Grafius 1971). The number of pods has the greatest effect on yield but is most influenced by the environment (Olsson 1960, Tayo and Morgan 1975, Diepenbrock and Geisler 1979). The size of the component depends on available assimilates at the critical stage for each component. Some authors concluded that pod growth is solely dependent on their own photosynthesis (Allen et al.

1971, Campbell and Kondra 1978) but more extensive studies with CO_2 and leaf area proved that leaves also contributed to the number of pods (Freyman et al. 1973, Clarke 1979, Morgan 1982). Photosynthesis from the pods produces assimilates to determine the number of seeds pod^{-1} and seed size (Allen et al. 1971, Clarke and Simpson 1978a)

Experiments in the United Kingdom with the summer rape cultivars, Zollerngold and Cresus at 0-211 kg ha^{-1} nitrogen fertilizer rates resulted in increased yields due to higher pods plant^{-1} and seeds pod^{-1}. Seed weight remained constant (Allen et al. 1971, Allen and Morgan 1972, 1975). On clover stubble, yields were decreased due to reduced pods plant^{-1} for the summer rape cultivar Zephyr with the application of 60 kg ha^{-1} nitrogen (Osborne and Batten 1978).

In Canada, Finlayson et al. (1970) established that 45 kg ha^{-1} nitrogen had no effect on seed weight of the summer rape cultivar Nugget with or without the addition of phosphate or sulphur. In contrast, Scott et al. (1973) found a decrease in yield at 300 kg ha^{-1} due to an export of assimilates from the seed to the husks.

Depending on soil status, rape responses to nitrogen fertilizer are greatest for pods plant^{-1} followed by seeds pod^{-1}. Seed weight remains more stable under different fertilizer regimes.

2.4.5 The Effect of Nitrogen Fertilizer on Seed Protein and Oil Concentration and Seed Oil Yield

Crops with high protein concentration such as rape require high nitrogen levels in the soil for protein synthesis. Over 90% of the seed nitrogen may be found in the meal after processing. Finlayson et al. (1970) reported that seed nitrogen content remained constant with the addition of 45 kg ha^{-1} nitrogen fertilizer to the summer rape cultivar Nugget. Further analysis showed that the amount of free amino acids in the seed was inversely proportional to the amount of nutrients available. The control sample contained

less protein and also less free amino acids than treatments because seeds were underdeveloped, even if seed weight was stable. The addition of nitrogen induced the formation of free amino acids that were not incorporated into proteins due to sulphur deficiencies. The addition of sulphur resulted in a decrease in free amino acids since the sulphur containing components were now incorporated into proteins. Protein concentration was therefore increased by 45 kg ha^{-1} nitrogen fertilizer when accompanied by phosphate and sulphur (Finlayson et al. 1970). Increases of 8% in seed protein concentration were observed in 26 experiments in the United Kingdom in the summer rape cultivar Gulle with 210 kg ha^{-1} nitrogen fertilizer (Holmes and Ainsley 1977). Rates of less than 100 kg ha^{-1} also increased protein concentration of summer rape on both summerfallow and nonfallow fields in Australia (Osborne and Batten 1978) and Canada (Bhatty 1964, Wetter 1970). In Manitoba, summer rape seed protein levels were increased from 17 to 24 %, while the total of oil and protein remained constant with addition of up to 240 kg ha^{-1} nitrogen fertilizer (Ridley 1972). Experiments on the summer rape cultivar Zephyr in the following year resulted in a 6% and 5% increase in protein and total oil and protein, respectively, with the addition of similar levels of nitrogen fertilizer. (Ridley 1973). It is obvious from the above evidence that in rape, protein levels are affected by small increments of nitrogen fertilizer.

Since the rape crop is used mainly for oil, the oil yield is of greatest importance. When growth requirements are non limiting, seed oil and protein concentrations of rape are negatively correlated (Loof 1960, Bhatty 1964, Almond et al. 1986). Since protein levels are increased with nitrogen, oil concentration should therefore decrease. In the United Kingdom, Scott et al. (1973) applied 100, 200 and 300 kg ha^{-1} nitrogen fertilizer to two summer rape and one winter rape cultivar. Oil yield was maximized at 200 kg ha^{-1} nitrogen fertilizer for the two summer rape cultivars. This was because the first component of oil yield, seed yield, was maximized at this rate and the second component, oil concentration, remained the same. Nitrogen fertilizer rates over 200 kg ha^{-1} reduced

seed oil concentration thus oil yield of the winter rape cultivar. Osborne and Batten (1978) observed that the oil yield of the summer rape cultivar Zephyr was increased when 60 kg ha^{-1} nitrogen fertilizer was added to cereal stubble but was decreased because of yield depression on clover stubble in Australia.

The addition of 211 kg ha^{-1} nitrogen fertilizer to five different summer rape cultivars reduced oil concentration but increased oil yield by maintaining high seed yields (Allen and Morgan 1972, 1975). In the United Kingdom, seed oil concentration of rape decreased an average of 1-2% with 150 kg ha^{-1} nitrogen (Bunting 1969), whereas Canadian researchers reported a change in oil concentration from 48 to 42% in one set of experiments (Ridley 1972) and a decrease from 43 to 39% in a second set of experiments (Ridley 1973).

Large nitrogen applications also change the quality of oil. As reported by Almond et al. (1986), oleic acid was decreased, and linoleic acid, linolenic acid and erucic acid was increased as nitrogen fertilizer levels was increased.

Nitrogen fertilizer generally decreases oil concentration but since seed yield is increased, the maximum oil yield does not necessarily occur at the lowest nitrogen level.

3. HYBRIDITY IN SUMMER RAPE F_1 HYBRID CULTIVARS

3.1 Abstract

A male sterile line (A-line) was blended with two summer rape F_1 hybrid cultivars in 100/0 to 50/50% hybrid/male sterile line proportions at two locations over two years to study the effect of incomplete male sterility of the A-line in hybrid seed production fields on the performance and quality of nap CMS summer rape hybrid cultivars. Admixtures of 10 and 20% restorer line were also included to determine the effect of this possible seed contaminant on summer rape hybrid cultivars. Earliness to flowering and maturity was delayed by approximately 1 day with 30% or greater A-line contamination. The level of male sterility determined at flowering in the hybrid population increased proportionally with increasing A-line contamination, thus reducing the level of hybridity. Seed yields remained stable with up to 80% A-line contamination under adequate moisture conditions, however, they were decreased by 20% A-line contamination when the crop was under stress. Harvest index was reduced with 10-30% or greater A-line contamination depending on growing conditions. Seed oil concentration was decreased with small increments in A-line contamination, but seed protein or chlorophyll concentrations were only increased at 40% or greater A-line contamination. Hybrid seed lot contamination of up to 20% restorer line did not affect the performance or quality of the hybrid cultivars.

3.2 Introduction

Canadian researchers have shown the production of F_1 hybrid summer rape to be feasible. High parent heterosis for seed yield of 40-50% and 120% was reported from intercultivar hybrid cultivars (Sernyk and Stefansson 1983, Grant and Beversdorf 1985) and from inbred crosses, respectively (Brandle 1989). The honeybee has been identified as an efficient pollinator in rape (Renard and Mesquida 1979). Production of summer rape hybrid seed may be feasible on a commercial scale using 10:1 male sterile to restorer line ratios in the pol cytoplasm (Pinnisch 1988). The nap (Thompson 1972) and pol (Fu 1981a) cytoplasmic male sterility (CMS) systems were discovered in rape for pollination control but they both possess a common problem, incomplete male sterility. Thompson (1972) recommended against the use of the nap cytoplasm for F_1 hybrid rape production due to incomplete male sterility and environmental instability. Temperatures of 26 and 30°C induce pollen production in the nap and pol cytoplasms, respectively (Fan and Stefansson 1986). Pollen production of CMS lines results in selfing, thus to the production of non hybrid seed in the F_1 population. Stoskopf and Law (1972) suggested that in hybrid wheat, retardation of pollen release with ethrel may be satisfactory if selfed seed can be tolerated in the hybrid population. This is analogous to the shortening of the stamens and reduced pollen production of the anthers in partially male sterile lines of summer rape reported by Fan and Stefansson (1986). In winter rape, up to 50% male fertile parental seed contamination may be tolerated in hybrid/parent mixtures without a loss in yield (Murakami et al. 1969, Shiga et al. 1970). A second source of seed contamination in hybrid seed production is the restorer line, which may be mixed during harvest. The objective of this study was to determine the effect of male sterile and restorer line seed contamination on the performance and quality of summer rape F_1 hybrid populations.

3.3 Materials and Methods

3.3.1 Experimental Design and Procedures

Two summer rape F_1 hybrid cultivars in the nap cytoplasm (Lergo/Dp6-6 and Lergo/Topas) were blended at 100/0, 90/10, 80/20, 70/30, 60/40, 50/50, 0/100% hybrid/male sterile line and 100/0, 90/10, 80/20% hybrid/restorer line in 1986 and 1988 at the Arboretum and Point locations in Winnipeg, Manitoba. Additional treatments of 40/60 and 20/80% hybrid/male sterile line were used in 1988. The cultivar, Karat in the pol cytoplasm was used as the male sterile line, hereafter referred to as A-line. The pure breeding addition line Regent (2n=40) was used as the restorer line, hereafter referred to as R-line. The nap cytoplasm was used in the hybrid cultivars because complete male sterility is more easily achieved in this cytoplasm. The cultivar Karat in the pol cytoplasm was used because it was the most vigorous A-line available at the time. The common parental cultivar Lergo was also included in the experiments to measure heterosis.

In 1986, the proportions were determined on a seed weight basis, and in 1988, they were determined by seed number using an electronic seed counter. Differences between methods were less than 5% for each treatment, since seed sizes among cultivars were similar in 1986. Germination for all cultivars was over 96%. Each treatment consisted of four row plots 3 m long, spaced 30 cm apart, replicated three times in a randomized complete block design. The two inner rows were used to collect data and the two outer rows were used as guard rows.

The hybrid cultivars were produced in growth rooms in the winter prior to seeding by hand-crossing the appropriate cultivars. The experiments were seeded at approximately 6 kg ha^{-1} on May 22 and May 14 in 1986, and on May 25 and May 16 in 1988, at the Arboretum and Point, respectively. They were seeded at a 3 cm depth using an eight row belt cone seeder equipped with packers. Each experiment received fertilizer

(16-20-0) broadcast and incorporated at 112 kg ha^{-1} and trifluralin at the recommended rate to control weeds. Carbofuran was applied at 1.0 kg a.i. ha^{-1} to control flee beetles (Phyllotera cruciferae). In 1988, diamond back moths (Plutella xylostella L.) and aphids (Brevicoryne brassicae L.) were controlled with malathion at 75 g a.i. ha^{-1} during the season. The Point location received 22.6 and 10.5 mm irrigation water on May 26,1986 and June 11,1988, respectively. The soil type at the Arboretum was a imperfectly drained Red River clay loam, while the soil type at the Point was a Riverdale silty clay loam.

3.3.2 Measurements

Phenological stages (days to 50% flowering and days to maturity) were measured for each plot using the growth stage key outlined by Harper and Berkenkamp (1975). Seed formation period was calculated as [days to maturity - (days to flowering + 7)]. Seven was arbitrarily chosen to represent the number of days between commencing flowering and the beginning of seed formation. The number of male sterile plants at flowering, stage 4.2 (Harper and Berkenkamp 1975), of the inner two rows and plant stands were counted at maturity, stage 5.4 (Harper and Berkenkamp 1975) to determine percent male sterility. Percent male sterility was calculated as [number of male sterile plants $plot^{-1}$/plant stand x 100]. Plant height was measured from soil level to the top of the main raceme for three plants in each plot when flowering was complete. Lodging was recorded visually on a 1-5 scale, 1 representing plots with erect stems and 5 for horizontal stems.

Plots were trimmed prior to harvest to eliminate edge effects. Each plot was hand harvested at ground level, bagged, air dried and weighed to determine the total dry matter. The plants were passed through a stationary thresher and an air sieve cleaner, then weighed to determine seed yield. Dry matter and seed yield weights were adjusted

to kg ha^{-1} for analysis. Apparent harvest index was calculated as [seed yield/total dry matter x 100].

Threshed seed was passed through a spiral cleaner and 25 and 1 g samples were used to determine oil and protein concentration, respectively. Five gram samples were used to determine chlorophyll concentration. Oil concentration was determined by Near Magnetic Resonance analysis (Robertson and Morrison 1979) and protein concentration was determined using standard Kjeldahl analysis. Seed chlorophyll concentration was determined using the spectrophotometer method outlined by Daun (1976). Seed chlorophyll concentration data was collected only in 1988.

3.3.3 Statistical Analysis

Standard analysis of variance procedures for a 2 x 8 and a 2 x 10 factorial were used in 1986 and 1988, respectively. Least Significant Difference (LSD) tests were used to compare the admixture treatments to the control (100% hybrid). Single degree of freedom contrasts were used to detect differences between the Lergo, A and R-line treatments and the hybrid cultivars. These comparisons could not be made using the LSD tests because the Lergo, A and R-line treatments were replicated three times, whereas the LSD means were based on six observations. Regression techniques were used to determine relationships between percent male sterility and the measured parameters. Shappiro-Wilk W-test and Bartletts test were implemented to determine normality of individual populations and homogeneity of variances, respectively. Height was cubed, harvest index and protein concentration were squared and the quartic root transformation of yield was used to attain homogeneity of variances for combination of experiments over years and locations. Although the data sets for each experiment were normal and variances over experiments were homogeneous, the experiments were not combined due to the presence of year and/or location by treatment interactions (Appendix

1 Tables 2 and 3). Results were, therefore, presented on a per experiment basis and general statements over all experiments made when possible.

3.4 Results and Discussion

Average seasonal temperatures were 17.5 and 20.3°C in 1986 and 1988, respectively, with many days above 30°C in 1988 (Appendix 1 Table 1). Total seasonal precipitation was 290.7 mm in 1986, with dry months of May and August. In 1988, seasonal precipitation (223.5 mm) was 73.4 mm below normal, with very little rainfall in June and August. The high temperatures and low levels of rainfall in 1988 may be the cause of differences in phenological traits, height and seed yield between years.

3.4.1 Phenology

Days to flowering, days to maturity and seed formation period were lower in 1988 than in 1986 by 4.7, 18.2 and 14 days, respectively.

Lergo/Dp6-6 was later flowering than Lergo except at the Arboretum in 1988 (Table 3.1). The hybrid cultivars were earlier flowering and maturing than the A-line (Table 3.1). Maturity may have been delayed in the A-line because of reduced seed set. The R-line was later maturing than Lergo/Topas at the Point in both years. Seed formation period results between hybrid cultivars and admixtures were inconsistent in both years (Table 3.1).

Results for days to flowering were inconsistent at the Arboretum (Tables 3.2 and 3.3). Both hybrid cultivars had equal days to flowering at the Point in 1986 and 1988. In 1986, there were no significant differences in maturity between the hybrid cultivars (Table 3.2), but in 1988, Lergo/Dp6-6 was later maturing than Lergo/Topas by an average of 1.6 days (Table 3.3). Seed formation period results were inconsistent between

locations in 1986 (Table 3.2), but in 1988, the seed formation period of Lergo/Dp6-6 was longer than that of Lergo/Topas by 2.1 days (Table 3.3).

There was a significant hybrid x treatment interaction for days to flowering at the Arboretum in 1986. The cause of the interaction is mainly due to variable responses of the hybrid cultivars to A-line contamination. The rank of the hybrid cultivars did not change due to A-line contamination and the latest flowering treatments were at the highest level of A-line contamination. At the Arboretum in 1986, differences between flowering in both hybrid cultivars were less than 1 day. Responses to R-line contamination were different for both hybrid cultivars in this experiment. Flowering was only delayed with 30% or greater A-line contamination in two other experiments (Tables 3.2 and 3.3). R-line contamination did not affect earliness to flowering except at the Point 1986.

The effects of A-line contaminants on maturity were inconsistent over all experiments, but generally an increase in A-line contamination resulted in delayed maturity (Tables 3.2 and 3.3). There was no effect of R-line contaminants on maturity of the hybrid cultivars in three out of four experiments. There was no significant effect of seed contaminants on seed formation period except at the Point in 1986 (Tables 3.2 and 3.3). A significant hybrid x treatment interaction for seed formation period at the Arboretum in 1986 was caused by variable responses of the hybrid cultivars to the treatments. Seed formation period was changed by less than 1 day by either A or R-line contaminants, with no definable trends in either hybrid cultivar in that experiment.

3.4.2 Male Sterility

At the Arboretum in 1988, average percent male sterility of the hybrid cultivars (29%) was higher than in the other experiments (15.1-20.4%). In three of the experiments, the level of male sterility was significantly higher in Lergo/Topas than in

Lergo/Dp6-6 (Tables 3.5 and 3.6). These results suggest that Lergo/Dp6-6 may have a greater competitive ability than Lergo/Topas.

Percent male sterility increased in both hybrid cultivars with each increment in A-line contamination in all the experiments (Tables 3.5 and 3.6). The percent hybridity of the hybrid cultivars was, thus, reduced accordingly. Even though the A-line plants must be pollinated to set seed, they were not substantially outcompeted by the hybrid cultivars. Deviations of the treatments from the control in the traits measured may be caused by differences between the A-line and the hybrid cultivars. High levels of male sterility may be avoided by decreasing the A:R-line ratio in hybrid seed production blocks (Pinnisch 1988). Hughes and Bodden (1978) suggested other methods of decreasing male sterility in hybrid wheat that may be applicable to summer rape.

3.4.3 Height

The average population height was lower in 1988 (100.4 cm) than in 1986 (127.2 cm). The A-line was 9 to 26 cm taller than both hybrid cultivars except for Lergo/Dp6-6 at the Arboretum in 1988 (Table 3.4). The tall stature of the A-line may be a result of elongation of the main raceme due to the lack of pollination. Lergo/Dp6-6 was significantly taller than Lergo at the Point in 1986. The height of the hybrid cultivars and Lergo was similar in the other three experiments. The R-line was significantly shorter than the hybrid cultivars in two experiments. Lergo/Dp6-6 was significantly taller than Lergo/Topas.

There was a significant hybrid x treatment interaction for height at the Point in 1988. The cause of the interaction was a variable increase in height of both hybrid cultivars with increasing A-line contamination. The rank of the hybrid cultivars was not changed, therefore, it was concluded that A-line contamination had similar effects on the height of the hybrid cultivars. A-line contamination had inconsistent effects on height

over all experiments, but generally, the height of the hybrid cultivars increased with small increments in A-line contamination (Tables 3.5 and 3.6) due to increased number of tall A-line plants. There was no significant effect of R-line contamination on the height of the hybrid cultivars except at the Point in 1986 (Tables 3.5 and 3.6), where the height of the hybrid cultivars increased as R-line contamination increased for unknown reasons. Differences in height due to contaminants were also reported in winter rape (Murakami et al. 1969, Shiga et al. 1970).

3.4.4 Lodging

Lodging at both sites in 1986 was greater than in 1988. Both hybrid cultivars were more susceptible to lodging than the A-line in 1986 and Lergo/Dp6-6 lodged significantly more than the A-line in 1988 (Table 3.4). Reduced lodging of the A-line is probably due to decreased seed set, thus lighter crops. The R-line lodged significantly more than both hybrid cultivars in 1988. There were no significant differences in lodging among hybrid cultivars (Tables 3.5 and 3.6).

There was a significant hybrid x treatment interaction for lodging at the Point in 1986 due to a greater reduction in lodging with increased A-line contamination in Lergo/Dp6-6 than in Lergo/Topas. Although the interaction was significant, lodging differed by only one point on the scale from 1 to 5 for both hybrid cultivars. There was no effect of seed contaminants on lodging in the other experiments. Considering the small differences in lodging at the Point in 1986, it was concluded that A or R-line contamination did not affect lodging of the hybrid cultivars tested.

3.4.5 Yield and Yield Related Measurements

Total dry matter yields at the Arboretum in 1988 (4835 kg ha^{-1}) were lower than the other experiments (8115-8585 kg ha^{-1}) due to insect damage by diamond back moths (Plutella xylostella L.). The A-line produced significantly higher total dry matter yields than Lergo/Topas except at the Arboretum in 1986 where there were no differences between the A-line and the hybrid cultivars (Table 3.7). The hybrid cultivars produced more total dry matter than the parental cultivar, Lergo. Sernyk (1982) also reported hybrid vigor for total dry matter in summer rape. Averaged over treatments, the total dry matter yield of Lergo/Dp6-6 was significantly greater than that of Lergo/Topas except at the Arboretum in 1986 (Tables 3.8 and 3.9). There was no difference in total dry matter yield between hybrid cultivars in that experiment.

Total dry matter yields were not reduced by any of the treatments (Tables 3.8 and 3.9). In 1986, A-line contamination actually increased total dry matter yields because of its high biological yield. Shiga et al. (1970) reported that up to 75% parental contamination did not change total dry matter yield in winter rape hybrid cultivars. These data suggest that total dry matter yield is not reduced by either male fertile or male sterile parental contamination.

Seed yields were lower in 1988 (1974 kg ha^{-1}) than in 1986 (2128 kg ha^{-1}), especially at the Arboretum in 1988. The A-line had lower seed yield than the hybrid cultivars (Table 3.7) due to the lack of pollen, thus reduced seed set. This agrees with Stoskopf and Law (1972), who reported reduced yields in male sterile wheat lines as a result of reduced seed set. In 1986, the R-line yielded significantly lower than both hybrid cultivars, and in 1988 it yielded significantly lower than Lergo/Dp6-6 only. Lergo/Dp6-6 outyielded its parent, Lergo, in two out of four experiments. Hybrid vigor for seed yield is common in summer rape (Sernyk and Stefansson 1983, Grant and

Beversdorf 1985). Lergo/Dp6-6 produced significantly higher seed yields than Lergo/Topas except at the Arboretum in 1986 (Tables 3.8 and 3.9).

Fifty percent A-line contamination was tolerated without a significant loss in seed yield under the favorable growing conditions of 1986, promoting ample pollen production, thus ensuring high seed yield of the A-line. Seed yield was significantly reduced by A and R-line contamination only at the Arboretum in 1988 (Tables 3.8 and 3.9). As indicated by the level of male sterility at flowering, the A-line contributed to seed yield. The delay in flowering caused by male sterility encouraged feeding of diamond back moths (Plutella xylostella L.) on the A-line, thus decreasing seed yields in that experiment. The heat stress in 1988 amplified the problem by decreasing pollen production and pollen viability, thus reducing pollination of the A-line. At the Point in 1988, 80% A-line contamination did not reduce seed yields. Shiga et al. (1970) reported that when high-parent heterosis for seed yield of winter rape hybrid cultivars was high (290%), 50% male fertile parental contamination decreased yield in hybrid/parent mixtures. When high-parent heterosis for yield was lower (90%), 50% male fertile parental contamination did not change yields. These data suggests that the yield of hybrid/parent mixtures in rape is determined by the relative yield of the components and their proportions. Differences between the results of this study and those of Shiga et al. (1970) may be due to the large differences in relative yield between the mixture components and differences in the nature of the contaminant, i.e. male sterility. The results of the present study suggest that A-line contamination, thus male sterility, may reduce seed yields when the crop is under stress.

Average harvest index was lower at the Arboretum in 1988 (12.7%) than in 1986 (25.2%) and at the Point in 1988 (16.8%). This may be due to reduced seed set caused by diamond back moth (Plutella xylostella L.) infestations and higher levels of male sterility at that location.

The A-line had a significantly lower harvest index than the hybrid cultivars in all the experiments and the R-line had a lower harvest index than the hybrid cultivars at the Arboretum in 1986 and at the Point in 1988 (Table 3.7). There were no significant differences in harvest index between hybrid cultivars at the Arboretum in 1986 and at the Point in 1988 (Tables 3.8 and 3.9). In the other two experiments, Lergo/Dp6-6 had a significantly higher harvest index than Lergo/Topas due to higher seed yields and lower levels of male sterility.

A significant hybrid x treatment interaction occurred for harvest index at the Point in 1986. In that experiment, A-line contamination did not affect the harvest index of Lergo/Dp6-6 but reduced it in Lergo/Topas. There was no effect of R-line contamination in that experiment. Thirty percent A-line contamination reduced harvest index at the Arboretum in 1986 and at the Point in 1988 (Tables 3.8 and 3.9). In the most highly stressed experiment, at the Arboretum in 1988, 10% A-line contamination reduced harvest index. The above results suggest that harvest index is decreased more by A-line contamination under stressed growing conditions than under adequate moisture growing conditions. Admixtures with the R-line did not change harvest index in three out of four experiments (Tables 3.8 and 3.9), suggesting that R-line contaminations of up to 20% do not affect the harvest index of summer rape hybrid cultivars.

3.4.6 Quality

3.4.6.1 Oil and protein concentration. Oil (44.5%), protein (26.1%) and their total concentrations (70.6%) were similar in 1986 and at the Point in 1988. Lower oil, higher protein, and higher total oil and protein concentrations at the Arboretum in 1988 than in the other experiments were a result of high male sterility levels. The higher number of A-line plants containing low oil concentration decreased the quality of the hybrid cultivars.

The A-line had significantly lower oil concentration in all the experiments and significantly higher protein concentration than the hybrid cultivars except at the Point in 1986 (Table 3.10). Inverse relationships between oil and protein concentration are common in summer rape (Loof 1960). At the Arboretum in 1986, the protein concentration of the A-line was 2 percent higher than that of Lergo/Topas. Differences in total oil and protein between the A-line and the hybrid cultivars were inconsistent, therefore, no conclusions could be made. The R-line had significantly lower oil concentration and similar protein concentration as the hybrid cultivars. Consequently, it had lower total oil and protein concentration than the hybrid cultivars. Lergo/Topas produced higher total oil and protein concentration than Lergo at the Point in both years. Lergo and the hybrid cultivars had similar oil, protein and total oil and protein concentrations in the other experiments.

In 1986, results for oil concentration among hybrid cultivars were inconsistent (Table 3.11). Lergo/Dp6-6 produced significantly higher seed oil concentrations than Lergo/Topas in 1988 (Table 3.12). There were no significant differences in protein concentration between hybrid cultivars in 1986, and results were inconsistent in 1988 (Tables 3.11 and 3.12). The two hybrid cultivars produced similar total oil and protein concentrations (Tables 3.11 and 3.12).

A significant hybrid x treatment interaction for oil concentration at the Point in 1986 occurred because oil concentration was reduced in Lergo/Topas and not Lergo/Dp6-6 with 20% A-line contamination. Oil concentration was reduced with 20% A-line contamination at the Arboretum in both years and with 30% contamination at the Point in 1988 as a result of the lower oil concentration of the A-line (Tables 3.11 and 3.12). Protein concentration was not affected by A-line contamination in 1986, but it was increased 0.8 to 1 percent with 40% A-line contamination in 1988 (Tables 3.11 and 3.12). R-line contamination did not affect oil concentration in three experiments and it did not affect protein concentration in all the experiments (Tables 3.11 and 3.12). Total oil and

protein concentration was only affected by A-line contamination at the Arboretum in 1988 (Tables 3.11 and 3.12) due to the high levels of male sterility. These results suggest that oil concentration is reduced by A-line and not R-line contamination. Protein concentration is increased only by A-line contamination under stress. There is no effect of either A or R-line contamination on total oil and protein concentration of hybrid cultivars except under extreme stress.

3.4.6.2 Chlorophyll. As a result of reduced seed set and delayed maturity, chlorophyll levels of the A-line were significantly higher than both hybrid cultivars at the Arboretum in 1988 (Table 3.10). There were no significant differences in chlorophyll concentration between hybrid cultivars in both locations, but at the Point, the chlorophyll levels exceeded the Canadian standard limit (24 ppm) in both hybrid cultivars (Table 3.12). Decreased branching as a result of stress at the Arboretum resulted in more uniform maturity, thus lower chlorophyll levels. Increased chlorophyll levels due to branching were observed at low seeding rates in the summer rape cultivar Westar (Morrison 1987).

Fifty percent A-line contamination or greater increased chlorophyll concentration at the Arboretum (Table 3.12). Chlorophyll concentration was not affected by the treatments at the Point. There was no effect of R-line contamination on the chlorophyll concentration of the hybrid cultivars in both locations. These results suggest that high levels of A-line contamination increase chlorophyll concentration of hybrid cultivars only under stress and that R-line contamination up to 20% does not affect the seed chlorophyll concentration of summer rape hybrid cultivars.

3.4.7 Relationships Between Agronomic Traits and Percent Male Sterility

Regression coefficients between all the measured traits and percent male sterility of the hybrid cultivars assessed at flowering are presented in Table 3.13. The regressions

of total dry matter and chlorophyll concentration on percent male sterility were non significant (P=0.05), therefore, they were not presented.

Earliness to flowering and maturity showed significant positive linear responses to increases in percent male sterility. Approximately 13 percent male sterility delayed maturity of the hybrid cultivars one day. These results suggest that the maturity of summer rape hybrid cultivars with high percent hybridity should not be significantly affected by male sterility. The relationship between seed formation period and percent male sterility was best described by a positive linear regression in 1986 and a quadratic regression at the Arboretum in 1988. Phenological parameters were delayed by male sterility because of reduced pollination caused by the lack of pollen in male sterile plants.

There was no response in lodging to percent male sterility at the Arboretum in 1986. A significant negative quadratic response to increasing percent male sterility was observed in the other three experiments due to the better standability of the A-line as a result of poor seed set.

A quadratic regression best described the relationship between height and male percent sterility in 1988. Height was increased to a maximum, then remained stable with further increases in percent male sterility.

Seed yield was not affected by variation in percent male sterility in 1986 due to favorable growing conditions, thus ample pollen production and high seed yields. Seed yield decreased 11.3 and 6.5 kg ha^{-1} with each percent increase in male sterility at the Arboretum and Point in 1988, respectively. Poor seed set and high total dry matter yields reduced harvest index as percent male sterility increased in all experiments except at the Point in 1986.

The low oil and high protein concentration of the A-line relative to the hybrid cultivars caused significant negative and positive linear regressions of oil and protein concentration on percent male sterility, respectively, in 1988. A significant quadratic regression of protein concentration on percent male sterility was present at the Point in

1986. A significant quadratic regression of total oil and protein concentration on percent male sterility occurred at the Point in 1988. The total oil and protein concentration decreased initially due to decreasing oil concentration, then stabilized as protein concentration increased with increasing percent male sterility.

3.5 Summary and Conclusions

The effect of A-line and R-line contamination on two nap CMS summer rape hybrid cultivars was studied at two locations over two years to determine if incomplete male sterility of the A-line in hybrid seed production fields or the possible mixing of restorer lines during harvest affects the performance and quality of CMS summer rape hybrid cultivars.

Earliness to flowering and maturity were delayed by approximately 1 day with 30% A-line contamination or greater. The seed formation period was prolonged marginally with increasing A-line contamination. Phenological traits were delayed with increasing A-line contamination due to the lack of pollen production in the A-line. The R-line did not affect phenology of the hybrid cultivars.

Lower levels of male sterility in the hybrid cultivar Lergo/Dp6-6 than in the Lergo/Topas treatments suggests that the former is more competitive. The percent hybridity (100 - percent male sterility) of the hybrid cultivars was reduced with small increments in A-line contamination as indicated by the percent male sterility.

The A-line was taller than both hybrid cultivars as a result of prolonged flowering due to reduced pollination. Lergo/Dp6-6 was 3.8 to 5.9 cm taller than Lergo/Topas. A-line contamination resulted in increased height of the hybrid cultivars. The R-line had no effect on the height of the hybrid cultivars. Due to reduced seed set and low harvest index, the A-line lodged less than the hybrid cultivars. Consequently, increases in A-line contamination resulted in a marginal increase in standability of the hybrid cultivars.

Lergo/Dp6-6 produced higher total dry matter yield than its parent, Lergo, and also than Lergo/Topas. There was no effect of A-line contamination, thus percent male sterility, on the total dry matter yield of the hybrid cultivars because the A-line produced high total dry matter yields. Although the R-line produced lower total dry matter yield than the hybrid cultivars, it had no effect on their total dry matter yield.

The A-line had lower seed yield than both hybrid cultivars due to reduced pollination. Lergo/Dp6-6 outyielded Lergo and Lergo/Topas. The seed yield of the hybrid cultivars was reduced by 11.3 and 6.5 kg ha^{-1} per percent male sterility increase at the Arboretum and the Point, respectively, only in 1988, because of the stressed growing conditions. R-line admixtures of 10 to 20% did not affect seed yield of the hybrid cultivars.

Harvest indices of both the A and R-lines were much lower than that of the hybrid cultivars. As a result of reduced seed set in the A-line, the harvest index of the hybrid cultivars was reduced 3 to 4 percent with 10-30% A-line contamination depending on growing conditions. R-line contamination did not affect the harvest index of the hybrid cultivars.

The A-line had significantly lower oil (3%) and higher protein (2%) concentration than the hybrid cultivars. Lergo/Dp6-6 had significantly higher oil concentration than Lergo/Topas. A-line contamination of 20% or greater resulted in approximately a 1% decrease in oil concentration of the hybrid cultivars. Protein concentration was increased by approximately 1% with 40% A-line contamination due to the relative differences between the hybrid cultivars and the male sterile line. If the hybrid cultivars and their female parents were of equal quality, oil and protein concentrations should not be affected by A-line contamination. Although the R-line had significantly lower oil concentration, it did not affect the oil concentration of the hybrid cultivars when it was mixed at a 20% level. Protein or total oil and protein concentrations of the hybrid cultivars were not affected by R-line contamination.

The chlorophyll concentrations of both hybrid cultivars exceeded the Canadian standards limit of 24 ppm at the Point. Summer rape hybrid cultivars must be screened for uniform maturity and low chlorophyll concentration to maintain high quality standards. Although the A-line had significantly higher seed chlorophyll concentrations than the hybrid cultivars due to uneven maturity, it only increased the chlorophyll concentration of the hybrid cultivars when mixed in 50% or greater proportions.

By convention, a summer rape hybrid cultivar would require high levels of hybridity (85-90%) i.e. low levels of male sterility. In this range, phenological traits and yield were not affected. Incomplete male sterility of the A-line in the hybrid seed production block leads to low percent hybridity of the hybrid lot because male sterility is not reduced by competition in the hybrid population. Harvest index may be reduced with 10% or greater A-line contamination under stressed conditions. If the hybrid cultivars and their female parents differ in oil or protein concentration, these quality factors may be limiting with incomplete male sterility of the A-line. Chlorophyll concentration was not changed by A-line contamination in the 10-20% range. Seed contamination of 10-20% R-line did not significantly affect the performance or quality of hybrid cultivars suggesting that the R-line was less competitive than the hybrid cultivars.

3.6 Acknowledgments

The author wishes to express his sincere thanks to Agriculture Canada and the Natural Sciences and Engineering Research Council of Canada for their financial support.

TABLE 3.1. Means for phenological traits of components used in the hybridity experiments

	Days to flowering	Days to maturity	Seed formation period (days)
	Arboretum 1986		
Cultivars			
Lergo/Dp6-6	50.0	97.3	40.3
Lergo/Topas	48.7	97.7	42.0
A-line	53.0 dt	103.7 dt	43.7 d
Lergo	47.3 d	96.0 t	41.7
R-line	49.0	96.3	40.3
	Point 1986		
Lergo/Dp6-6	48.0	99.0	44.0
Lergo/Topas	48.0	98.0	43.0
A-line	51.7 dt	105.3 dt	46.7 dt
Lergo	46.0 dt	97.7	44.7
R-line	48.3	102.3 dt	47.0 dt
	Arboretum 1988		
Lergo/Dp6-6	42.3	79.7	30.3
Lergo/Topas	43.0	78.7	28.7
A-line	47.0 dt	82.7 dt	28.7
Lergo	43.0	78.0	28.0 d
R-line	42.7	78.7	29.0
	Point 1988		
Lergo/Dp6-6	44.0	81.7	30.7
Lergo/Topas	43.0	78.0	27.7
A-line	47.0 dt	84.0 dt	30.0 dt
Lergo	42.7 d	78.0 d	28.3 d
R-line	44.0	80.7 t	29.7

d, t Means are significantly different from Lergo/Dp6-6 and Lergo/Topas, respectively at P=0.05 (single degree of freedom contrasts).

TABLE 3.2. Differences between F_1 hybrid and treatment means for phenological traits in the hybridity experiments in 1986

	Days to flowering	Days to maturity	Seed formation period (days)
	Arboretum 1986		
Hybrids(1)			
Lergo/Dp6-6	49.9 #	98.0 a	41.1 #
Lergo/Topas	49.3	98.3 a	42.0
Treatments(2)			
0	49.3	97.5	41.2
10A	49.7	97.8	41.2
20A	49.8	98.3 *	41.5
30A	49.5	98.2	41.7
40A	49.5	98.5 *	42.0
50A	50.3	99.2 *	41.8
10R	49.5	97.7	41.2
20R	49.2	97.8	41.7
	Point 1986		
Hybrids			
Lergo/Dp6-6	48.5 a	101.2 a	45.7 a
Lergo/Topas	48.8 a	100.7 a	45.0 a
Treatments			
0	48.0	98.5	43.5
10A	48.0	100.5 *	45.5 *
20A	48.3	101.0 *	45.7 *
30A	48.7 *	101.2 *	45.5 *
40A	49.0 *	102.0 *	46.0 *
50A	49.5 *	102.5 *	46.0 *
10R	49.0 *	100.3 *	44.3
20R	48.5	101.5 *	46.0 *

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).
# Inferences on means were not conducted due to a significant (P=0.05) hybrid x treatment interaction.

TABLE 3.3. Differences between F_1 hybrid and treatment means for phenological traits in the hybridity experiments in 1988

	Days to flowering	Days to maturity	Seed formation period (days)
	Arboretum 1988		
Hybrids(1)			
Lergo/Dp6-6	43.2 b	80.6 a	30.4 a
Lergo/Topas	45.0 a	79.8 b	27.9 b
Treatments(2)			
0	42.7	79.2	29.5
10A	43.0	79.5	29.5
20A	43.3	80.0	29.7
30A	44.0 *	80.0	29.0
40A	44.2 *	80.0	28.8
50A	45.0 *	81.2 *	29.2
60A	46.2 *	81.0 *	27.8
80A	46.7 *	81.5 *	27.8
10R	43.0	80.2	30.2
20R	43.0	79.7	29.7
	Point 1988		
Hybrids			
Lergo/Dp6-6	44.9 a	82.7 a	30.8 a
Lergo/Topas	44.6 a	80.3 b	28.7 b
Treatments			
0	43.7	79.8	29.2
10A	43.8	80.7	29.8
20A	44.5 *	80.8	29.3
30A	44.5 *	81.3 *	29.8
40A	45.3 *	82.3 *	30.0
50A	45.5 *	83.0 *	30.5
60A	46.0 *	83.3 *	30.3
80A	46.5 *	83.5 *	30.0
10R	43.8	80.2	29.3
20R	44.0	80.0	29.0

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).

TABLE 3.4. Means for agronomic traits of components used in the hybridity experiments

	Height (cm)	Lodging (1-5)
	Arboretum 1986	
Cultivars		
Lergo/Dp6-6	126.0	3.00
Lergo/Topas	124.0	3.00
A-line	135.0 dt	2.30 dt
Lergo	122.0	3.00
R-line	117.7 dt	3.00
	Point 1986	
Lergo/Dp6-6	129.3	3.00
Lergo/Topas	125.7	3.00
A-line	151.7 dt	2.00 dt
Lergo	123.0 d	3.00
R-line	126.0	3.00
	Arboretum 1988	
Lergo/Dp6-6	94.0	1.30
Lergo/Topas	89.7	1.00
A-line	99.0 t	1.00 d
Lergo	92.0	1.00 d
R-line	97.0	2.00 dt
	Point 1988	
Lergo/Dp6-6	96.0	1.30
Lergo/Topas	89.7	1.00
A-line	116.0 dt	1.00 d
Lergo	97.0	1.00 d
R-line	107.3 dt	2.00 dt

d, t Means are significantly different from Lergo/Dp6-6 and Lergo/Topas, respectively at P=0.05 (single degree of freedom contrasts).

TABLE 3.5. Differences between F_1 hybrid and treatment means for agronomic traits in the hybridity experiments in 1986

	Sterile (%)	Height (cm)	Lodging (1-5)
	Arboretum 1986		
Hybrids(1)			
Lergo/Dp6-6	14.9 b	126.0 a	3.00 a
Lergo/Topas	15.3 a	123.8 b	3.00 a
Treatments(2)			
0	0.0	125.0	3.00
10A	6.2 *	123.8	3.00
20A	12.8 *	125.0	3.00
30A	17.2 *	124.0	3.00
40A	25.9 *	124.2	3.00
50A	28.3 *	126.0	3.00
10R	-	125.2	3.00
20R	-	126.0	3.00
	Point 1986		
Hybrids			
Lergo/Dp6-6	14.2 b	132.0 a	2.50 #
Lergo/Topas	18.1 a	127.0 b	2.71
Treatments			
0	0.0	127.5	3.00
10A	6.5 *	126.8	2.83
20A	13.1 *	129.2	2.67
30A	18.6 *	129.2	2.33
40A	25.9 *	131.3 *	2.33
50A	32.7 *	130.3 *	2.33
10R	-	130.8 *	2.83
20R	-	130.8 *	2.50

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).
- Data is not relevant for these treatments.
Inferences on means were not conducted due to a significant (P=0.05) hybrid x treatment interaction.

TABLE 3.6. Differences between F_1 hybrid and treatment means for agronomic traits in the hybridity experiments in 1988

	Sterile (%)	Height (cm)	Lodging (1-5)
	Arboretum 1988		
Hybrids(1)			
Lergo/Dp6-6	26.4 b	98.6 a	1.03 a
Lergo/Topas	31.6 a	92.5 b	1.00 a
Treatments(2)			
0	0.0	91.8	1.17
10A	9.0 *	91.2	1.00
20A	19.9 *	98.2 *	1.00
30A	28.5 *	98.5 *	1.00
40A	35.3 *	98.7 *	1.00
50A	37.6 *	99.2 *	1.00
60A	49.7 *	101.3 *	1.00
80A	52.0 *	98.5 *	1.00
10R	-	89.5	1.00
20R	-	89.0	1.00
	Point 1988		
Hybrids			
Lergo/Dp6-6	20.4 a	108.1 #	1.03 a
Lergo/Topas	20.4 a	102.2	1.00 a
Treatments			
0	0.0	92.8	1.17
10A	6.2 *	102.7	1.00
20A	11.4 *	103.3	1.00
30A	18.1 *	107.5	1.00
40A	24.3 *	111.7	1.00
50A	27.1 *	113.7	1.00
60A	34.5 *	115.2	1.00
80A	41.6 *	114.3	1.00
10R	-	95.5	1.00
20R	-	95.2	1.00

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).
- Data is not relevant for these treatments.
Inferences on means were not conducted due to a significant (P=0.05) hybrid x treatment interaction.

TABLE 3.7. Means for yield and yield related traits of components used in the hybridity experiments

	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
	Arboretum 1986		
Cultivars			
Lergo/Dp6-6	7360	1979	26.9
Lergo/Topas	7760	2098	27.1
A-line	7710	1168 dt	15.8 dt
Lergo	6720	2022	30.1
R-line	4780 t	1029 dt	22.0 dt
	Point 1986		
Lergo/Dp6-6	8390	2273	26.9
Lergo/Topas	7420	2050	27.7
A-line	10120 dt	1497 dt	14.8 dt
Lergo	6590 d	1698 d	25.7
R-line	6190 dt	1539 dt	24.9
	Arboretum 1988		
Lergo/Dp6-6	6050	1198	19.8
Lergo/Topas	3650	664	19.5
A-line	5140 t	342 dt	6.7 dt
Lergo	4650	814 d	16.7
R-line	2990 d	462 d	16.6
	Point 1988		
Lergo/Dp6-6	8240	1604	19.5
Lergo/Topas	7140	1355	18.9
A-line	8910 t	1341	14.6 dt
Lergo	7220	1517	21.1
R-line	7400	1010 d	13.5 dt

d, t Means are significantly different from Lergo/Dp6-6 and Lergo/Topas, respectively at P=0.05 (single degree of freedom contrasts).

TABLE 3.8. Differences between F_1 hybrid and treatment means for yield and yield related traits in the hybridity experiments in 1986

	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
	Arboretum 1986		
Hybrids(1)			
Lergo/Dp6-6	8170 a	2055 a	25.4 a
Lergo/Topas	8100 a	2001 a	24.7 a
Treatments(2)			
0	7560	2039	27.0
10A	7890	2098	26.6
20A	8620 *	2187	25.2
30A	8580 *	2038	23.9 *
40A	8850 *	2023	23.2 *
50A	9460 *	2188	23.1 *
10R	6480	1666	25.3
20R	7620	1988	26.0
	Point 1986		
Hybrids			
Lergo/Dp6-6	8830 a	2388 a	27.1 #
Lergo/Topas	8340 b	1967 b	23.7
Treatments			
0	7900	2162	27.3
10A	8510	2170	25.5
20A	8510	2120	24.7
30A	8770 *	2224	25.4
40A	9170 *	2343	25.5
50A	9110 *	2104	23.1
10R	8160	1921	23.6
20R	8520	2377	27.9

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).
# Inferences on means were not conducted due to a significant (P=0.05) hybrid x treatment interaction.

TABLE 3.9. Differences between F_1 hybrid and treatment means for yield and yield related traits in the hybridity experiments in 1988

	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
	Arboretum 1988		
Hybrids(1)			
Lergo/Dp6-6	5550 a	782 a	14.1 a
Lergo/Topas	4120 b	445 b	11.2 b
Treatments(2)			
0	4850	931	19.6
10A	4990	801	15.7 *
20A	5020	727 *	14.2 *
30A	5290	592 *	11.0 *
40A	4900	530 *	10.7 *
50A	4880	478 *	9.6 *
60A	4780	392 *	7.9 *
80A	4950	319 *	6.3 *
10R	4220	738 *	16.6
20R	4460	628 *	14.6 *
	Point 1988		
Hybrids			
Lergo/Dp6-6	8750 a	1512 a	17.4 a
Lergo/Topas	7480 b	1209 b	16.1 a
Treatments			
0	7690	1480	19.2
10A	7800	1387	17.7
20A	8280	1489	18.1
30A	8170	1293	15.8 *
40A	8360	1244	14.7 *
50A	8130	1262	15.4 *
60A	8850	1265	14.0 *
80A	8380	1225	14.4 *
10R	7950	1514	18.9
20R	7560	1446	19.4

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).

TABLE 3.10. Means for quality traits of components used in the hybridity experiments

	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll (ppm)
		Arboretum 1986		
Cultivars				
Lergo/Dp6-6	44.8	26.9	71.6	-
Lergo/Topas	45.6	25.7	71.3	-
A-line	42.1 dt	27.7 t	69.8 d	-
Lergo	44.9	26.1	70.9	-
R-line	42.3 dt	27.2	69.5 dt	-
		Point 1986		
Lergo/Dp6-6	43.6	26.3	69.9	-
Lergo/Topas	45.2	25.6	70.8	-
A-line	42.0 dt	28.5 dt	70.4	-
Lergo	43.1 t	25.9	69.1 t	-
R-line	42.1 dt	25.9	68.0	-
		Arboretum 1988		
Lergo/Dp6-6	41.9	30.4	72.3	16.2
Lergo/Topas	41.4	31.3	72.7	19.3
A-line	38.2 dt	32.6 dt	70.8 dt	56.0 dt
Lergo	40.4 d	31.2	71.6	11.8
R-line	39.3 dt	31.1	70.4 dt	12.4
		Point 1988		
Lergo/Dp6-6	45.1	25.1	70.1	25.5
Lergo/Topas	46.2	24.9	71.1	36.5
A-line	42.4 dt	27.1 dt	69.5 t	28.6
Lergo	46.5 d	23.6	70.1 t	16.4 t
R-line	44.3 t	23.9	68.2 dt	14.5 t

d, t Means are significantly different from Lergo/Dp6-6 and Lergo/Topas, respectively at P=0.05 (single degree of freedom contrasts).
- Data was not collected for this variable in this experiment.

TABLE 3.11. Differences between F_1 hybrid and treatment means for quality traits in the hybridity experiments in 1986

	Oil (%)	Protein (%)	Protein + oil (%)
	Arboretum 1986		
Hybrids(1)			
Lergo/Dp6-6	44.4 b	26.7 a	71.1 a
Lergo/Topas	44.9 a	26.6 a	71.4 a
Treatments(2)			
0	45.2	26.3	74.4
10A	45.5	26.0	71.5
20A	44.1 *	26.7	70.8
30A	44.2 *	27.1	71.3
40A	44.1 *	26.9	70.9
50A	44.1 *	27.2	71.4
10R	44.4 *	26.9	71.2
20R	45.2	26.2	71.4
	Point 1986		
Hybrids			
Lergo/Dp6-6	44.4 #	25.8 a	70.2 a
Lergo/Topas	43.9	25.8 a	69.7 a
Treatments			
0	44.4	25.9	70.4
10A	44.9	25.8	70.7
20A	44.5	25.2	69.7
30A	44.0	25.6	69.6
40A	44.6	25.6	70.2
50A	43.6	26.4	70.0
10R	43.2	26.0	69.2
20R	44.1	25.8	69.9

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
- Data was not collected for this variable in this experiment.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
Inferences on means were not conducted due to a significant (P=0.05) hybrid x treatment interaction.

TABLE 3.12. Differences between F_1 hybrid and treatment means for quality traits in the hybridity experiments in 1988

	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll (ppm)
		Arboretum 1988		
Hybrids(1)				
Lergo/Dp6-6	41.0 a	31.0 b	71.9 a	22.7 a
Lergo/Topas	40.0 b	31.8 a	71.8 a	26.8 a
Treatments(2)				
0	41.6	30.8	72.5	18.1
10A	41.2	30.8	72.0	17.3
20A	40.6 *	31.4	72.0	19.4
30A	40.6 *	31.3	72.0	25.2
40A	40.3 *	31.6 *	72.0	24.4
50A	40.0 *	31.5	71.5 *	35.4 *
60A	38.8 *	32.1 *	70.9 *	34.4
80A	39.0 *	31.9 *	70.9 *	45.2 *
10R	41.0	31.2	72.2	10.1
20R	41.5	31.0	72.5	17.3
		Point 1988		
Hybrids				
Lergo/Dp6-6	44.2 a	26.1 a	70.2 a	25.8 b
Lergo/Topas	45.1 b	25.3 b	70.4 a	34.5 a
Treatments				
0	45.6	25.0	70.6	31.0
10A	45.7	24.9	70.6	29.1
20A	45.0	25.4	70.4	31.0
30A	44.6 *	25.7	70.2	30.6
40A	43.9 *	26.0 *	69.9	36.3
50A	43.7 *	26.5 *	70.2	34.0
60A	42.9 *	27.1 *	69.9	26.2
80A	43.5 *	26.5	70.0	29.5
10R	45.7	24.9	70.6	27.7
20R	45.9	25.0	70.9	26.0

(1)Means are averaged over treatments.
(2)Means are averaged over hybrids.
a-b Means followed by the same letter are not significantly different at P=0.05 (LSD).
* Significantly different from the '0' treatment at P=0.05 (LSD).

TABLE 3.13. Regression coefficients and r-square values for percent male sterility and other traits

	(1)L	Q	R^2		L	Q	R^2	
	Days to flowering				Days to maturity			
Arboretum 1986(2)	+				0.05	-	0.86	**
Point 1986	0.05	-	0.95	**	0.11	-	0.89	**
Arboretum 1988	0.08	-	0.91	**	0.04	-	0.85	**
Point 1988	0.07	-	0.98	**	0.10	-	0.96	**
	Seed formation period (days)					Height (cm)		
Arboretum 1986	+				-	-	-	
Point 1986	0.061	-	0.62	**	-	-	-	
Arboretum 1988	0.023	-0.001	0.93	**	0.373	0.004	0.84	**
Point 1988	-	-	-		+			
	Lodging (1-5)					Yield (kg ha^{-1})		
Arboretum 1986	-	-	-		-	-	-	
Point 1986	+				-	-	-	
Arboretum 1988	-0.0080	0.0001	0.73	**	-11.4	-	0.99	**
Point 1988	-0.0100	0.0002	0.66	**	-6.5	-	0.74	**
	Harvest index (%)					Oil (%)		
Arboretum 1986	-1.51	-	0.95	**	-	-	-	
Point 1986	+				+			
Arboretum 1988	-0.23	-	0.97	**	-0.051	-	0.92	**
Point 1988	-0.13	-	0.87	**	-0.069	-	0.88	**
	Protein (%)					Protein + oil (%)		
Arboretum 1986	-	-	-		-	-	-	
Point 1986	-0.083	-	0.83	**	-	-	-	
Arboretum 1988	0.023	-	0.93	**	-	-	-	
Point 1988	0.051	-	0.86	**	-0.0300	0.0003	0.87	**

(1)L and Q refer to the linear and quadratic regression coefficients,respectively.
(2)Regression coefficients are based on 6 and 8 observations in 1986 and 1988, respectively.
- Regression coefficients are nonsignificant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
+ Not calculated due to a significant (P=0.05) hybrid x treatment interaction.

4. SEEDING RATES OF SUMMER RAPE F_1 HYBRID CULTIVARS

4.1 Abstract

The effect of seeding rates between 1.5 and 9.0 kg ha^{-1} was studied on four F_1 hybrid and two open pollinated summer rape cultivars at two locations for two years to determine if current seeding rate recommendations for open pollinated cultivars may be applied to F_1 hybrid cultivars. Hybrid cultivars were later flowering and later maturing than the currently recommended cultivar Westar by 1-3 and 1-4 days, respectively. They produced more total dry matter in all experiments and higher seed yields in one year than the open pollinated cultivars. Hybrid cultivars had lower harvest indices than open pollinated cultivars. Hybrid cultivars also had lower oil concentrations and higher protein concentrations. Except for lodging, there were no significant cultivar x seeding rate interactions suggesting that hybrid and open pollinated summer rape cultivars respond similarly to seeding rate. Increasing seeding rate resulted in increased mature plant stand and lodging. Earliness and height were reduced at high seeding rates. The 3.0 kg ha^{-1} seeding rate produced the highest seed yields, but 1.5 kg ha^{-1} may be used under irrigated field conditions. Seeding rate had no effect on seed quality of either hybrid or open pollinated summer rape cultivars.

4.2 Introduction

Canadian researchers have shown the production of F_1 hybrid summer rape to be feasible. High parent heterosis for seed yield of 40-50% and 120% has been reported from intercultivar hybrid cultivars (Sernyk and Stefansson 1983, Grant and Beversdorf 1985) and from inbred crosses, respectively (Brandle 1989). The nap and pol cytoplasmic male sterility (CMS) systems show promise for effective pollination control (Thompson 1972, Fang and McVetty 1987). Production of hybrid seed with a high level of hybridity may be feasible on a commercial scale using 6:1 A to R-line ratios in the pol cytoplasm (Pinnisch 1988).

The next step in F_1 hybrid summer rape production is determining the optimum seeding rate to maximize yield and quality. Currently recommended seeding rates for summer rape in Canada are 6-8 kg ha^{-1} (Kondra 1975, 1977, Christensen and Drabble 1984). In Saskatchewan, summer rape seeded at 3 kg ha^{-1} yielded significantly higher than 6 and 9 kg ha^{-1}.[7] Morrison (1987) seeded the summer rape cultivar Westar at 1.5 to 12 kg ha^{-1}. Seed yield was maximized at the 1.5 kg ha^{-1} seeding rate on a Riverdale silty clay loam soil and at 3.0 kg ha^{-1} on a Red River clay soil. Seeding rates of 4-7 kg ha^{-1} represent 100-295 seeds m^{-2}. In Saskatchewan, McGregor (1987) tested the summer rape cultivar Tower at 3 to 86 plants m^{-2}. It was concluded that plant density may be reduced to 40 plants m^{-2} with less than a 20% yield loss. Lefort-Buson and Datee (1986) seeded three winter rape inbred lines and three F_1 hybrid cultivars at 0.08 to 8 kg ha^{-1}. The hybrid cultivars and inbred lines responded similarly to seeding rate up to 4 kg ha^{-1}. Seed yield was maximized at the 4 kg ha^{-1} seeding rate for both inbred lines and hybrid cultivars. The current trends suggest that a lowering in seeding rate for summer rape may be in order.

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The optimum seeding rate to maximize seed yield for summer rape F_1 hybrid cultivars has not yet been determined in Canada. The objective of this study was to determine the optimum seeding rate to maximize yield and quality of summer rape F_1 hybrid cultivars.

4.3 Materials and Methods

4.3.1 Experimental Design and Procedures

In 1986 and 1987, four intercultivar summer rape F_1 hybrid cultivars, two in the pol cytoplasm (Marnoo/Regent and Karat/Regent), two in the nap cytoplasm (Lergo/Dp3505 and Lergo/R83-14) and two open pollinated cultivars (Westar and Regent) were seeded at the rates of 3.0, 4.5, 6.0 and 9.0 kg ha^{-1} at the Arboretum and Point locations in Winnipeg. An additional 1.5 kg ha^{-1} treatment was used in 1987. Each treatment consisted of four row plots 3 m long, spaced 30 cm apart, replicated three times in a randomized complete block design. The 30 cm row spacing was used to ease data collection. Although interrow spacing is wider than conventional row spacings (15 cm), intrarow spacing is narrower at a given seeding rate. The two inner rows were used to collect data and the two outer rows were used as guard rows.

The nap hybrid cultivars were produced in growth rooms in the winter prior to seeding by hand-crossing the appropriate cultivars. The pol based hybrid cultivars were produced in the field using 1:1 A to R-line row ratios in 1985. The Arboretum and the Point trials were seeded on May 21 and May 13 in 1986 and on May 5 and May 15 in 1987, respectively. They were seeded at a 3 cm depth using an eight row belt cone seeder equipped with packers. Each experiment received fertilizer (16-20-0) broadcast at 112 kg ha^{-1} and trifluralin at the recommended rate to control weeds. Carbofuran was applied at 1.0 kg a.i. ha^{-1} to control flee beetles (Phyllotera cruciferae). The Point location received 22.6 and 7.6 mm irrigation water on May 26,1986 and May 14,1987,

respectively. The soil type at the Arboretum was a imperfectly drained Red River clay loam, while the soil type at the Point was a Riverdale silty clay loam.

4.3.2 Measurements

The phenological stages (days to 50% flowering and days to maturity) were measured for each plot using the growth stage key outlined by Harper and Berkenkamp (1975). Seed formation period was calculated as [days to maturity - (days to flowering + 7)]. Seven was arbitrarily chosen to represent the number of days from the commencement of flowering to the beginning of the seed formation period. Plant stands of the inner two rows were counted at the seedling stage 2.2 (Harper and Berkenkamp 1975) and at maturity, stage 5.4 (Harper and Berkenkamp 1975) to determine plants m^{-2} and percent survival. Plants m^{-2} was calculated as [mature plant stand/plot area] and percent survival as [mature plant stand/seedling stand x 100]. Plant stand and percent survival were only measured in 1987. Plant height was measured from soil level to the top of the main raceme for three plants in each plot when flowering was complete. Lodging was recorded visually on a 1-5 scale, 1 representing plots with erect stems and 5 for horizontal stems.

Plots were trimmed prior to harvest to eliminate edge effects. Each plot was hand harvested at ground level, bagged, air dried and weighed to determine the total dry matter. The plants were passed through a stationary thresher and an air sieve cleaner, then weighed to determine seed yield. Dry matter and seed yield weights were adjusted to kg ha^{-1} for analysis. Apparent harvest index was calculated as [seed yield/total dry matter x 100].

Quality characteristics were only measured in 1987. Threshed seed was passed through a spiral cleaner and 25 g and 1 g samples were used to determine oil and protein concentration, respectively. Five gram samples were used to determine chlorophyll

concentration. Oil concentration was determined by Near Magnetic Resonance analysis (Robertson and Morrison 1979) and protein concentration was determined using standard Kjeldahl analysis. Seed chlorophyll concentration was determined using the spectrophotometer method outlined by Daun (1976).

4.3.3 Statistical Analysis

Analysis of variance combined with orthogonal polynomial procedures were used to analyze the data. The regression of seed yield on mature plant stand was calculated to determine the effect of stand on seed yield. The Shappiro-Wilk W-test and Bartletts test were used to determine the normality of the individual experimental populations and homogeneity of variances among populations, respectively. Waller-Duncan k-ratio tests were used to detect mean differences among cultivars. Although the populations were normal, the error variances between populations were non homogeneous, therefore, individual experiments were not combined. The results were, therefore, presented on a per experiment basis with general statements made over all experiments when possible.

4.4 Results and Discussion

Average seasonal temperatures were 17.5 and 17.8 °C in 1986 and 1987, respectively (Appendix 1 Table 1). In 1986, total precipitation for the season was 290.7 mm with low levels in May and August. In 1987, total seasonal precipitation was 314 mm with high levels of rainfall in June. Average yield was high at 1.5 t ha^{-1} for all experiments even though maturity was hastened by 7 days in 1987. Except for lodging, there were no significant cultivar x seeding rate interactions (Tables 4.1-4.7), suggesting that hybrid and open pollinated cultivars respond similarly to seeding rate in the 1.5 to 9.0 kg ha^{-1} range.

4.4.1 Phenology

In 1986, days to flowering and maturity and seed formation period were 47, 98 and 44 days, respectively. These values were 2, 7 and 6 days, lower in 1987, respectively. Generally, the hybrid cultivars were later flowering and later maturing than Westar by 1-3 and 1-4 day(s), respectively (Tables 4.1 and 4.2). This agrees with Sernyk (1982), who reported that the hand-crossed hybrid cultivars Marnoo/Regent and Karat/Regent were later maturing than Regent by 1 day. The nap hybrid cultivar Lergo/R83-14 was the latest flowering cultivar in 1986 and the pol hybrid cultivar Karat/Regent was the latest flowering in 1987. Results were inconsistent over locations and years. Differences among hybrid cultivars were less than 1 day for both characters in three out of four experiments.

Seed formation period varied significantly among cultivars but these differences were less than 1.5 days for all experiments (Tables 4.1 and 4.2). In 1986, Lergo/R83-14 had the shortest seed formation period as a result of the higher number of days to flowering. The cultivar Westar had the shortest seed formation period in all experiments except at the Point in 1986.

As seeding rate increased, days to flowering decreased linearly in all experiments (Tables 4.1 and 4.2). Flowering was hastened by an average of 0.95 days between 3.0 to 9.0 kg ha^{-1} in 1986 and by 1.3 days between 1.5 to 9.0 kg ha^{-1} seeding rates in 1987. Days to maturity decreased linearly as seeding rate increased (Tables 4.1 and 4.2). These responses were significant in only one location per year. Maturity was hastened by less than 1 day in the 3.0 to 9.0 kg ha^{-1} range in all experiments. Morrison (1987) reported that days to flowering and maturity was decreased only marginally when the seeding rate of the summer rape cultivar Westar was increased from 1.5 to 12 kg ha^{-1}. Degenhardt and Kondra (1981a) found no differences in earliness to flowering, but maturity was hastened by 1.7 days when the seeding rate of five summer rape cultivars was increased

from 3 to 12 kg ha^{-1}. The decrease in earliness of summer rape with increasing seeding rate may be due to stress caused by increased interplant competition. These small differences in phenological stages do not justify changes in seeding rate.

There were no significant responses in seed formation period to seeding rate as a result of similar effects of seeding rate on flowering and maturity (Tables 4.1 and 4.2). Contradictory to these results, seed formation period was decreased in summer rape with increasing seeding rate from 3 to 12 kg ha^{-1} (Scarisbrick et al. 1982, Degenhardt and Kondra 1981b).

4.4.2 Plant Stand

The number of plants m^{-2} at maturity was higher at the Point (45.1) than at the Arboretum (40.7). This is probably because the Point location was irrigated at the time of seeding, thus providing optimum moisture conditions for germination and stand establishment, whereas the Arboretum was not. Percent survival was lower at the Point than at the Arboretum. This may be because of greater reduction of high stand values due to competition for space later in the growing season. Low percent survival at high seeding rates was observed by other Canadian researchers (Clarke and Simpson 1978b).

At both the Arboretum and Point the small seeded nap hybrid cultivars (Lergo/Dp3505 and Lergo/R83-14) had significantly greater plant m^{-2} at maturity than the pol hybrid cultivars (Marnoo/Regent and Karat/Regent) (Table 4.4). There were no significant differences in percent survival between cultivars at the Arboretum (Table 4.4). The percent survival of the hybrid cultivars (60.3-63.7%) was not significantly different to that of Westar (53.1%) at the Point.

Plants m^{-2} increased with increasing seeding rate at both locations (Table 4.4). The analysis of variance showed that both linear and quadratic components were significant at P=0.05 (Table 4.4). Mature plant stands ranged from 16.9 plants m^{-2} at 1.5

kg ha^{-1} to 62.1 plants m^{-2} at the 9.0 kg ha^{-1} seeding rate at the Arboretum. Similar stands were found at the Point. The regression of seed yield on plants m^{-2} was significant at the Point but not at the Arboretum. The regression equation (R^2=.99) that best decribed the relationship between the two traits at the Point is [Seed yield (kg ha^{-1}) = 1089 + 17.9(Plants m^{-2}) - 0.2(Plants m^{-2})2]. No conclusions could be made on the regression of seed yield on mature plant stand since the results between locations were inconsistent.

An increase in mature plant stand of 85% occurred when seeding rate was increased from 7 to 14 kg ha^{-1} in summer rape (Christensen and Drabble 1984). Increasing seeding rate also resulted in a linear decrease in percent survival at both locations (Table 4.4). At the Arboretum, 72.9% of the stand survived to maturity at 1.5 kg ha^{-1} whereas 56.5% survived at 9.0 kg ha^{-1}. Similar reductions in percent survival were observed at the Point. Clarke and Simpson (1978b) reported that less than 50% of the seeded stand survived to maturity when the seeding rate was over 10 kg ha^{-1} for the summer rape cultivar Tower. The decrease in percent survival with increasing plant density can be explained by an increase in competition for space and nutrients at high seeding rates. Results from the current and the above mentioned study suggest that percent survival is decreased with increasing seeding rate.

4.4.3 Height

Summer rape was taller in 1986 (133.3 cm) than in 1987 (121.8 cm). This may be explained by the shorter life cycle observed in 1987. The shorter vegetative and reproductive periods would decrease the time and assimilates available for stem elongation.

Hybrid cultivars were 1 to 25 cm taller than open pollinated cultivars in all experiments (Tables 4.3 and 4.4). The Karat/Regent pol hybrid cultivar was tallest in

three out of four experiments. Semyk (1982) also reported that summer rape hybrid cultivars were taller than the cultivar Regent.

There was a significant linear decrease in height with increasing seeding rate in all experiments except at the Arboretum in 1987 (Table 4.3 and 4.4). In 1986, height was decreased by an average of 5 cm from 3.0 to 9.0 kg ha^{-1} seeding rates. Height was reduced by 9.8 cm with a six fold increase in seeding rate from 1.5 kg ha^{-1} at the Point in 1987. The reduction in height with increasing seeding rate may be caused by increasing interplant competition, thus a decrease in assimilates available for stem elongation. A reduction in height with increasing seeding rate in the 3 to 12 kg ha^{-1} range was also reported in summer rape by British (Scarisbrick et al. 1982) and Canadian researchers (Degenhardt and Kondra 1981a, McGregor 1987). In contrast, Morrison (1987) observed that increasing plant densities in the same range resulted in etiolation, thus an increase in height of the summer rape cultivar Westar. Etiolation may have been a result of more dense plant canopies obtained with this cultivar, thus more competition for light.

4.4.4 Lodging

In both years, lodging was higher at the Arboretum than at the Point. The analysis of variance showed significant differences among cultivars for lodging in all experiments (Tables 4.3 and 4.4). Results were inconsistent between experiments, therefore no conclusions could be made on lodging of the cultivars.

An increase in seeding rate resulted in a linear increase in lodging in all four experiments (Tables 4.3 and 4.4). There was a significant cultivar x seeding rate interaction at the Point in 1987. This was due to a linear increase in lodging with increasing seeding rate in all cultivars but Regent. Since the interaction only made up 1.8% of the model variation, it was concluded that seeding rate increased lodging linearly at the Point in 1987 as it did for the other experiments. Thinner plant stems at high plant

densities may be the cause of increased lodging. Canadian researchers reported that lodging in summer rape was more severe at high seeding rates in the 1.5 to 12 kg ha^{-1} range due to thinner stems (Kondra 1975, Morrison 1987). The published reports and the results of this study suggest that lodging in summer rape is more severe at high seeding rates.

4.4.5 Yield and Yield Related Measurements

Total dry matter yields were higher in 1987 (8253 kg ha^{-1}) than in 1986 (5463 kg ha^{-1}). In all four experiments, hybrid cultivars produced significantly higher total dry matter yield than open pollinated cultivars (Tables 4.5 and 4.6). In 1986, the Lergo/R83-14 hybrid cultivar produced the highest total dry matter yield at both locations. Results were inconsistent in 1987 but generally there were few significant differences among hybrid cultivars and among open pollinated cultivars in all four experiments

There was no significant effect of seeding rate on total dry matter except at the Arboretum in 1987 (Tables 4.5 and 4.6). In that experiment, total dry matter yield increased with seeding rate from 1.5 to 6.0 kg ha^{-1} and then decreased at higher seeding rates (Table 4.6). This resulted in significant linear and quadratic components. Canadian researchers reported that total dry matter yields did not change with seeding rates of 3 to 20 kg ha^{-1} for five summer rape cultivars (Degenhardt and Kondra 1981a, Clarke and Simpson 1978b). The above results suggest that seeding rate does not significantly affect total dry matter yield above a critical seeding rate of 3 kg ha^{-1}.

All of the experiments produced seed yields of 1.5 t ha^{-1} except at the Point in 1986 where the seed yield was 1.2 t ha^{-1}. In 1986, hybrid cultivars significantly outyielded Regent and Westar at both locations (Table 4.5). Relative yields between cultivars in 1986 were inconsistent but the cultivar Regent was consistently the lowest

yielding. In 1987, there were no significant differences in yield between cultivars at the Point (Table 4.6). The Lergo/Dp3505 nap hybrid cultivar produced the highest seed yield in both years at the Arboretum. Different hybrid cultivars were the highest yielding at the Point in 1986 and 1987. Hybrid vigor for seed yield over the cultivar Regent in intercultivar hybrid cultivars is common in summer rape (Sernyk and Stefansson 1983, Grant and Beversdorf 1985).

There were no significant response of seed yield to seeding rate at the Arboretum in 1986 (Table 4.5). Seed yield decreased linearly with increasing seeding rate at the Point in 1986 with the highest numerical value at the 4.5 kg ha^{-1} seeding rate (Table 4.5). In 1987, there was a linear quadratic response to seeding rate at the Arboretum and no significant response of seed yield to seeding rate at the Point (Table 4.6). At the Arboretum in 1987, seed yield increased from 1.5 to 3.0 kg ha^{-1}. There were no further changes in seed yield with additional increments in seeding rate. The higher seed yield at the Arboretum of the 3.0 kg ha^{-1} seeding rate over 1.5 kg ha^{-1} may be a result of poor germination. Overall, the summer rape hybrid and open pollinated cultivars produced the highest seed yields at the 3 kg ha^{-1} seeding rate. Results from the Point in 1987 suggest that a lower seeding rate (1.5 kg ha^{-1}) may be used for both summer rape hybrid and open pollinated cultivars under irrigated field conditions. These results agree with those of Morrison (1987), who reported that 1.5 and 3.0 kg ha^{-1} seeding rates maximized the seed yield of the summer rape cultivar Westar on a silty clay loam soil and a clay loam soil, respectively. In Saskatchewan, the 3.0 kg ha^{-1} seeding rate also maximized the seed yield of summer rape.[8] Although current seeding rate recommendations for summer rape in Canada are 6-8 kg ha^{-1} (Christensen and Drabble 1984), recent research suggests that 3.0 kg ha^{-1} may be optimum to maximize yield of summer rape. The development of superior cultivars and better crop husbandry may be the reason for the high seed yields achieved at low (3 kg ha^{-1}) seeding rates. Since yield is stable in summer rape with 3-14

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kg ha^{-1} seeding rates (Degenhardt and Kondra 1981a, b) and seed costs are low for open pollinated cultivars, higher seeding rates may be used to buffer against crop failures. The lower seeding rates may be preferred for more expensive summer rape hybrid seed.

Harvest indices in 1986 (25.1%) were greater than in 1987 (18.4%). There were significant differences in harvest index among cultivars in all experiments (Tables 4.5 and 4.6). As a result of higher total dry matter yields and similar seed yields, hybrid cultivars had lower harvest indices than open pollinated cultivars in three out of four experiments (Tables 4.5 and 4.6). Some hybrid cultivars had higher harvest indices than Regent at the Point in 1986 due to the low seed yield of Regent. The open pollinated cultivar Westar had the highest harvest index in all experiments because it had the largest seed yield and lowest total dry matter yield. The Lergo/Dp3505 nap hybrid cultivar had the largest harvest index of the hybrid cultivars in all experiments. Differences among hybrid cultivars were inconsistent between experiments.

There were no significant effects of seeding rate on harvest index in all the experiments except at the Point in 1986 (Tables 4.5 and 4.6). There, the linear decrease in harvest index with increasing seeding rate was a result of reduced yields at high seeding rates (Table 4.5). The lowest harvest indices were at the highest planting densities. In winter and summer rape, Scarisbrick et al. (1982) reported that the lowest harvest index occurred at the highest seeding rate between 4.5 and 13.5 kg ha^{-1} and no differences occurred at lower seeding rates. Similar results were reported by Morrison (1987) for the summer rape cultivar Westar seeded at 1.5 to 12 kg ha^{-1} and for five other summer rape cultivars seeded at 3 to 12 kg ha^{-1} (Degenhardt and Kondra 1981a). The results of this study and of the published reports suggest that seeding rate has little effect on the harvest index of summer rape.

4.4.6 Quality

4.4.6.1 Oil and Protein Concentration. The oil, protein nad total oil and protein concentrations for both locations were 42.6%, 27.8% and 70.4%, respectively. Differences between locations for these traits were less than 1%. The two pol CMS based hybrid cultivars (Karat/Regent and Marnoo/Regent) produced the lowest seed oil concentrations at the Arboretum and the Point (Table 4.7). All the hybrid cultivars produced lower oil concentrations than the open pollinated cultivars except for the Lergo/Dp3505 nap hybrid cultivar at the Point. The hybrid cultivars had significantly higher protein concentrations (2-3%) than the open pollinated cultivars (Table 4.7). Negative relationships between oil and protein concentrations are common in rape (Loof 1960). The total of oil and protein concentration was highest in the nap hybrid cultivars and lowest in the Marnoo/Regent pol CMS hybrid cultivar at both locations (Table 4.7). The low total oil and protein of the Marnoo/Regent pol CMS hybrid cultivar is a result of low protein concentration. This hybrid cultivar in the pol cytoplasm should be removed from breeding programs.

There was no significant effect of seeding rate between 1.5 and 9.0 kg ha^{-1} on oil, protein and their total except for total oil and protein concentration at the Point (Table 4.7). In this experiment, a significant quadratic effect was present, but the total concentration differed by less than 0.4%. Kondra (1975, 1977) reported that seeding rates between 3 and 12 kg ha^{-1} did not affect oil or protein concentrations of the cultivar Zephyr. Morrison (1987) observed that oil and protein concentrations did not change in the summer rape cultivar Westar when seeded at 1.5 to 12 kg ha^{-1}. The results of this study and of the published reports suggest that seeding rate has no effect on summer rape seed oil and protein concentrations or their totals.

4.4.6.2 Chlorophyll. Chlorophyll concentration (17.0 ppm) was similar for both locations. There were significant differences in chlorophyll concentration among cultivars at both locations (Table 4.7). These results were inconsistent, therefore no conclusions could be made. Only the pol hybrid cultivar Marnoo/Regent at the Arboretum exceeded the Canadian standard limit (24ppm) for chlorophyll.

There were no significant effects of seeding rate on chlorophyll (Table 4.7). The highest seeding rates produced the highest seed chlorophyll level at the Arboretum. Chlorophyll levels for all seeding rates were below the Canadian standard limit. Morrison (1987) measured seed chlorophyll levels of the summer rape cultivar Westar seeded at 1.5 to 12 kg ha^{-1}. The author found that the lowest seeding rate produced the highest seed chlorophyll levels. It was suggested that, although seed chlorophyll levels cannot be controlled by agronomic practices alone, low seeding rates should be avoided to maintain acceptable seed chlorophyll levels in summer rape. Since no overall trends were observed in the current study, the results suggest that seeding rate has no effect on seed chlorophyll levels of summer rape. As suggested by Morrison (1987), other factors such as uniformity of maturity, lodging and diseases play a role in reducing chlorophyll levels in summer rape.

4.5 Summary and Conclusions

The effect of seeding rates between 1.5 and 9.0 kg ha^{-1} was studied on four hybrid and two open pollinated summer rape cultivars to determine if current seeding rate recommendations for summer rape open pollinated cultivars apply to hybrid cultivars. There were no significant cultivar x seeding rate interactions, except for lodging, suggesting that hybrid and open pollinated cultivars respond similarly to seeding rate.

Hybrid cultivars were later flowering and later maturing than the open pollinated cultivar Westar by 1-3 and 1-4 day(s), respectively. This may be a result of the higher

total dry matter production of the hybrid cultivars. The latest flowering hybrid cultivar, nap CMS Lergo/R83-14, had the shortest seed formation period. Increases in seeding rate from 1.5 to 9.0 kg ha^{-1} resulted in decreased days to flowering of 1.3 days but maturity was hastened by less than 1 day. As a result, seeding rate did not change the length of the seed formation period. Seeding rates of summer rape should not be changed for these minor changes in crop maturity.

Large seeded cultivars had the lowest mature plant densities. Percent survival was similar among cultivars. Increasing seeding rate resulted in an increase in mature plant stand and a decrease in percent survival due to increased interplant competition.

Hybrid cultivars were up to 25 cm taller than open pollinated cultivars. Increasing seeding rate resulted in shorter plants due to increased interplant competition and reduced time available for stem elongation as a result of a shortening in life cycle. Lodging was increased with increasing planting density due to a reduction in stem diameter.

Hybrid cultivars produced higher total dry matter yields than open pollinated cultivars. There was no effect of seeding rate on this character. In 1986, hybrid cultivars produced higher seed yields than the open pollinated cultivars. The high yielding cultivar Westar had the shortest seed formation period. High yields in this cultivar must be associated with high growth rates. Overall the 3.0 kg ha^{-1} seeding rate produced the highest seed yields. Under irrigated field conditions, 1.5 kg ha^{-1} may be used for hybrid cultivars or open pollinated cultivars. Since yield was stable at the higher seeding rates, high planting densities may be used to buffer against crop failures. This practice may be avoided to reduce costs with more expensive hybrid seed. As a result of higher dry matter yields, hybrid cultivars had the lowest harvest indices. Seeding rate did not affect this character.

Hybrid cultivars produced up to 3.5% lower oil and up to 3.5% higher protein concentrations than open pollinated cultivars. This is a disadvantage in oilseed crops

such as summer rape. Selection for high oil and protein concentrations in parental lines must be done to improve the hybrid quality. The two highest yielding hybrid cultivars (nap CMS Lergo/Dp3505 and nap CMS Lergo/R83-14) at the Arboretum in 1987 also had the highest total oil and protein concentrations. These two hybrid cultivars should be included in hybrid breeding programs. Seeding rate did not affect oil or protein concentrations in the cultivars tested.

All cultivars tested except the pol CMS Marnoo/Regent hybrid cultivar had seed chlorophyll levels below the Canadian standard limit of 24 ppm. The use of this hybrid cultivar in the pol cytoplasm should be avoided. Seeding rate had no consistent effects on seed chlorophyll level, therefore no conclusions could be made. Since agronomic practices such as seeding rate did not control seed chlorophyll levels, selection for low chlorophyll levels should be made to maintain high quality standards in summer rape.

4.6 Acknowledgements

The author wishes to express his sincere thanks to Agriculture Canada and the Natural Sciences and Engineering Research Council of Canada for their financial support.

TABLE 4.1. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of phenological traits in seeding rate experiments in 1986

	Days to flowering	Days to maturity	Seed formation period (days)
		Arboretum 1986	
Seeding rate			
3.0	47.8	97.8	43.0
4.5	46.8	96.9	43.1
6.0	46.8	96.9	43.2
9.0	46.2	96.7	43.5
Contrast*	L,Q,C	L	NS
Cultivar			
Karat/Regent	47.0 b	97.2 a	43.2 ab
Lergo/Dp3505	47.1 b	97.3 a	43.2 ab
Lergo/R83-14	48.0 a	97.8 a	42.8 b
Marnoo/Regent	47.6 a	97.9 a	43.3 ab
Regent	46.8 b	97.7 a	43.8 a
Westar	44.8 c	94.7 b	42.8 b
		Point 1986	
Seeding rate			
3.0	47.9	98.7	43.8
4.5	47.8	98.6	43.8
6.0	47.7	98.8	44.1
9.0	47.6	98.4	43.9
Contrast	L	NS	NS
Cultivar			
Karat/Regent	48.2 b	99.7 a	44.5 a
Lergo/Dp3505	47.9 b	98.6 b	43.7 bc
Lergo/R83-14	48.8 a	98.8 b	42.9 c
Marnoo/Regent	48.2 b	98.6 b	43.4 c
Regent	47.3 c	98.8 b	44.6 a
Westar	46.2 d	97.4 c	44.3 ab

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-d Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

TABLE 4.2. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of phenological traits in seeding rate experiments in 1987

	Days to flowering	Days to maturity	Seed formation period (days)
		Arboretum 1987	
Seeding rate			
1.5	47.2	94.4	40.2
3.0	46.3	94.0	40.7
4.5	46.5	94.3	40.8
6.0	46.4	94.1	40.7
9.0	46.1	93.5	40.4
Contrast*	L	NS	NS
Cultivar			
Karat/Regent	47.9 a	95.5 a	40.5 ab
Lergo/Dp3505	46.0 bc	94.1 bc	41.1 a
Lergo/R83-14	46.5 b	94.8 ab	41.3 a
Marnoo/Regent	48.0 a	94.4 bc	39.4 b
Regent	45.4 cd	93.5 c	41.1 a
Westar	45.1 d	92.0 d	39.9 b
		Point 1987	
Seeding rate			
1.5	44.1	87.2	36.1
3.0	43.8	86.2	35.4
4.5	43.3	86.2	35.9
6.0	43.1	85.7	35.6
9.0	42.6	85.3	35.8
Contrast	L	L	NS
Cultivar			
Karat/Regent	44.6 a	87.0 b	35.4 b
Lergo/Dp3505	43.3 b	85.9 c	35.5 b
Lergo/R83-14	43.1 b	85.8 c	35.7 ab
Marnoo/Regent	44.7 a	88.4 a	36.7 a
Regent	42.7 b	85.5 c	35.8 ab
Westar	41.9 c	84.3 d	35.4 b

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-d Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

TABLE 4.3. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of agronomic traits in seeding rate experiments in 1986

	Height (cm)	Lodging (1-5)
	Arboretum 1986	
Seeding rate		
3.0	132.2	2.8
4.5	130.3	2.5
6.0	131.4	3.1
9.0	127.8	3.4
Contrast*	L	L,C
Cultivar		
Karat/Regent	132.9 ab	3.0 bc
Lergo/Dp3505	134.6 a	2.5 cd
Lergo/R83-14	129.6 b	3.8 a
Marnoo/Regent	131.7 ab	3.3 b
Regent	129.6 b	2.9 bc
Westar	124.2 b	2.3 d
	Point 1986	
Seeding rate		
3.0	138.9	2.1
4.5	136.8	2.1
6.0	135.6	2.3
9.0	133.4	2.8
Contrast	L	L
Cultivar		
Karat/Regent	147.6 a	2.3 b
Lergo/Dp3505	138.3 b	1.8 b
Lergo/R83-14	134.5 b	2.2 b
Marnoo/Regent	139.1 b	2.4 b
Regent	135.3 b	3.1 a
Westar	122.2 c	2.1 b

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-c Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

TABLE 4.4. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of agronomic traits in seeding rate experiments in 1987

	Plants m^{-2}	Survival (%)	Height (cm)	Lodging (1-5)
		Arboretum 1987		
Seeding rate				
1.5	16.9	72.9	116.1	2.9
3.0	31.9	74.9	116.9	2.9
4.5	43.4	71.0	116.6	3.3
6.0	49.1	62.2	116.9	3.5
9.0	62.1	56.5	115.3	3.7
Contrast*	L,Q	L	NS	L
Cultivar				
Karat/Regent	31.1 e	67.2 a	128.7 a	3.4 ab
Lergo/Dp3505	48.9 a	68.3 a	117.5 bc	2.5 b
Lergo/R83-14	48.2 ab	63.5 a	114.7 cd	3.4 ab
Marnoo/Regent	35.8 de	68.8 a	119.5 a	3.7 a
Regent	37.0 cd	69.2 a	112.8 d	3.1 b
Westar	42.8 bc	67.9 a	105.1 e	3.5 ab
		Point 1987		
Seeding rate				
1.5	20.1	73.2	131.9	1.9 #
3.0	37.0	66.5	128.3	2.4
4.5	46.3	61.4	128.7	3.1
6.0	55.8	57.9	125.2	3.2
9.0	66.3	50.4	122.1	3.8
Contrast	L,Q	L	L	
Cultivar				
Karat/Regent	33.2 e	63.7 ab	138.1 a	1.5
Lergo/Dp3505	59.0 a	60.3 b	126.7 b	3.0
Lergo/R83-14	51.7 b	62.4 ab	126.0 b	3.6
Marnoo/Regent	38.5 d	62.1 b	135.5 a	2.3
Regent	46.8 c	69.7 a	121.7 c	3.2
Westar	41.2 d	53.1 b	115.4 d	3.7

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-e Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

Inferences on means were not done due to a significant (P=0.05) cultivar x seeding rate interaction.

TABLE 4.5. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of yield and yield related traits in seeding rate experiments in 1986

	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
	Arboretum 1986		
Seeding rate			
3.0	5540	1486	27.3
4.5	5600	1533	28.1
6.0	5770	1585	28.2
9.0	5820	1553	27.2
Contrast*	NS	NS	NS
Cultivar			
Karat/Regent	6130 a	1477 b	24.1 d
Lergo/Dp3505	6670 a	1884 a	28.3 bc
Lergo/R83-14	6800 a	1796 a	26.4 c
Marnoo/Regent	6380 a	1501 b	23.8 d
Regent	3930 b	1166 c	29.6 b
Westar	4200 b	1411 b	33.9 a
	Point 1986		
Seeding rate			
3.0	5080	1206	23.8
4.5	5540	1322	24.0
6.0	5240	1211	22.9
9.0	5120	1088	21.2
Contrast	NS	L	L
Cultivar			
Karat/Regent	5930 ab	1355 ab	22.8 abc
Lergo/Dp3505	5680 a	1351 ab	23.8 ab
Lergo/R83-14	6180 ab	1407 a	22.8 abc
Marnoo/Regent	5540 b	1234 b	22.4 bc
Regent	4040 c	877 c	21.5 c
Westar	4100 c	1016 c	24.8 a

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-d Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

TABLE 4.6. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of yield and yield related traits in seeding rate experiments in 1987

	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
	Arboretum 1987		
Seeding rate			
1.5	5570	1052	19.3
3.0	7310	1637	22.8
4.5	7650	1590	20.7
6.0	8750	1646	19.3
9.0	8480	1620	19.5
Contrast*	L,Q	L,Q	NS
Cultivar			
Karat/Regent	8330 a	1450 a	17.9 c
Lergo/Dp3505	8550 a	1724 a	20.3 bc
Lergo/R83-14	8160 a	1449 a	17.8 c
Marnoo/Regent	7800 a	1397 a	17.7 c
Regent	6360 b	1408 a	21.6 b
Westar	6100 b	1627 a	26.5 a
	Point 1987		
Seeding rate			
1.5	8240	1383	17.6
3.0	8670	1538	18.0
4.5	9200	1581	17.4
6.0	9600	1585	16.7
9.0	9060	1584	17.7
Contrast	NS	NS	NS
Cultivar			
Karat/Regent	10910 a	1852 a	17.1 b
Lergo/Dp3505	8790 b	1517 bc	17.4 b
Lergo/R83-14	9360 b	1372 bc	14.7 c
Marnoo/Regent	10680 a	1569 b	14.5 c
Regent	7090 c	1284 c	18.1 b
Westar	6900 c	1611 ab	23.3 a

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-c Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

TABLE 4.7. Effect of seeding rate (kg ha^{-1}) and differences between cultivar means of quality traits in seeding rate experiments in 1987

	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll (ppm)
		Arboretum 1987		
Seeding rate				
1.5	42.3	28.4	70.7	17.7
3.0	42.6	28.0	70.6	14.2
4.5	42.3	28.8	71.1	15.4
6.0	42.2	28.5	70.7	15.5
9.0	42.2	28.5	70.7	14.8
Contrast*	NS	NS	NS	NS
Cultivar				
Karat/Regent	40.8 c	30.0 a	70.8 b	19.1 a
Lergo/Dp3505	43.1 b	28.8 b	71.8 a	11.8 b
Lergo/R83-14	42.7 b	29.1 b	71.8 a	10.8 b
Marnoo/Regent	40.4 c	28.9 b	69.3 c	17.2 a
Regent	43.1 b	27.7 c	70.7 b	17.1 a
Westar	44.0 a	26.3 d	70.3 b	17.1 a
		Point 1987		
Seeding rate				
1.5	42.8	26.9	69.7	18.3
3.0	43.0	27.1	70.1	19.0
4.5	43.0	27.1	70.1	17.1
6.0	42.5	27.5	70.0	19.0
9.0	42.7	27.0	69.7	18.5
Contrast	NS	NS	Q	NS
Cultivar				
Karat/Regent	42.5 d	27.2 b	69.7 b	19.1 bc
Lergo/Dp3505	44.1 a	27.0 b	71.0 a	15.9 c
Lergo/R83-14	42.9 cd	28.2 a	71.1 a	12.3 d
Marnoo/Regent	40.3 e	28.0 a	68.4 d	25.9 a
Regent	43.3 bc	26.7 b	70.0 b	19.6 b
Westar	43.7 ab	25.5 c	69.2 c	17.5 bc

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-d Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

5. NITROGEN FERTILIZER REQUIREMENTS OF SUMMER RAPE F_1 HYBRID CULTIVARS

5.1 Abstract

Three summer rape hybrid cultivars and the cultivar Regent were seeded at 3 and 6 kg ha^{-1} with 0, 60, 120, 240 kg ha^{-1} nitrogen fertilizer treatments at one location in 1988 to determine the optimum nitrogen fertilizer rate to maximize yield and quality of summer rape hybrid cultivars. Generally, the hybrid cultivars were later maturing than Regent by 1 to 2 days and produced higher total dry matter yields. Although they had lower oil concentrations, their total oil and protein concentrations were similar to that of Regent. There were no cultivar x nitrogen fertilizer interactions suggesting that summer rape hybrid and open pollinated cultivars respond similarly to nitrogen fertilizer. There were three significant nitrogen fertilizer x seeding rate interactions, however, seeding rate did not change the direction of nitrogen fertilizer response for performance and quality traits of the cultivars tested. Nitrogen fertilizer did not affect plant density traits, height, harvest index and seed weight. The highest seed yields were obtained at 120 kg ha^{-1} nitrogen fertilizer due to increased pods $plant^{-1}$ and seeds pod^{-1}. Maturity was delayed by 3.3 days at this rate. Oil concentration was reduced 1 to 2% and chlorophyll concentration was increased with nitrogen fertilizer.

5.2 Introduction

Crops with high protein such as rape require high nitrogen levels in the soil for protein synthesis. Nitrogen fertilizer requirements in rape are largely dependent on the nutrient status of the soil and target yield. In Canada, Soper (1971) demonstrated that summer rape showed seed yield responses to added nitrogen fertilizer only in soils with less than 100 kg ha^{-1} NO_3 nitrogen sampled at a 61 cm depth prior to seeding. This figure is rarely exceeded in non fallow soils except after breaking up a perennial legume. In Canada, yield tests on summer rape showed that 150-200 kg ha^{-1} nitrogen fertilizer was optimum on soils low in NO_3 nitrogen (Soper 1971, Ridley 1972, 1973). On soils high in NO_3 nitrogen, 60 kg ha^{-1} nitrogen fertilizer maximized the seed yield of summer rape in Canada (Racz et al. 1965). Factors such as time and mode of application (Holmes and Ainsley 1977), carrier of the fertilizer and other nutrient levels (Anderson and Kusch 1968, Osborne and Batten 1978) may affect the response of summer rape to nitrogen fertilizer.

Although there are many reports on the nitrogen fertilizer requirements of open pollinated summer rape, there are no published reports on this topic for F_1 hybrid summer rape cultivars. The objective of this study was to determine the nitrogen fertilizer requirements to maximize yield and quality of F_1 hybrid summer rape cultivars in Canada.

5.4 Materials and Methods

5.4.1 Experimental Design and Procedures

In 1988, three intercultivar summer rape pol CMS F_1 hybrid cultivars (Karat/Regent, Lergo/Regent and Marnoo/Regent) and an open pollinated cultivar (Regent) were seeded at 3 and 6 kg ha^{-1} under 0, 60, 120 and 240 kg ha^{-1} nitrogen

fertilizer regimes on barley stubble at the Point location, University of Manitoba campus, Winnipeg, Manitoba. The 3 and 6 kg ha^{-1} seeding rates were chosen to optimize seeding rate, thus maximize genotypic responses to nitrogen fertilizer. Soil tests were taken to a 120 cm depth prior to seeding to determine the nutrient status of the soil. Each treatment consisted of four row plots 3 m long, spaced 30 cm apart, replicated four times in a split-split plot design with nitrogen fertilizer rates as the main plots, seeding rate as the sub plots and cultivars as the sub-sub plots. The two inner rows were used to collect data and the two outer rows were used as guard rows. Four guard rows of the cultivar Regent were seeded in between the four nitrogen fertilizer treatments to compensate for lateral movement of the fertilizer.

The hybrid cultivars were produced in the field in the previous season using 1:1 A to R-line ratios. The experiment was seeded on May 24, with a four row belt cone seeder at a 3 cm depth. An overall dressing of 20 kg ha^{-1} actual phosphate (11-51-0) was applied with the seed, and 30 kg ha^{-1} actual sulphur (0-0-50-(18)) was added prior to seeding. All the nitrogen fertilizer (34-0-0) was applied by hand prior to seeding and each plot was raked to assure uniform distribution. Granular carbofuran was applied with the seed at a rate of 1.0 kg a.i. ha^{-1} to control flee beetles (Phyllotera cruciferae). Diamond back moth (Plutella xylostella L.) and aphid (Brevicoryne brassicae L.) infestations were controlled with malathion at 75 g a.i. ha^{-1} during the season. The experiment was irrigated at regular intervals to maintain good soil moisture status. The soil type at the Point was a Riverdale silty loam.

5.4.2 Measurements

Phenological stages (days to 50% flowering and days to maturity) were measured for each plot using the growth stage key outlined by Harper and Berkenkamp (1975). Seed formation period was calculated as [days to maturity - (days to flowering + 7)].

Seven was arbitrarily chosen to represent the number of days between the beginning of flowering and the beginning of the seed formation period. Plant stands of the inner two rows were counted at the seedling stage 2.2 (Harper and Berkenkamp 1975) and at maturity, stage 5.4 (Harper and Berkenkamp 1975), to determine plants m^{-2} and percent survival. Plants m^{-2} was calculated as [mature plant stand/plot area] and percent establishment as [number of seeds planted x percent germination/seedling stand x 100]. Percent survival was calculated as [mature stand/seedling stand x 100]. Plant vigor was evaluated visually at stage 2.4 (Harper and Berkenkamp 1975) on a scale of 1 to 5, 5 representing the most vigorous plants. Plant height was measured from soil level to the top of the main raceme for three plants in each plot when flowering was complete. Lodging was recorded visually on a 1-5 scale, 1 representing plots with erect stems and 5 for horizontal stems.

At maturity, stage 5.4 (Harper and Berkenkamp 1975), ten plants from the inner two rows of each plot were randomly selected for yield component analysis. The total number of pods (PD) was counted on each plant. The pods were then air dried at 30°C for two weeks, threshed using a belt thresher, cleaned with an air sieve cleaner and weighed to determine seed yield $plant^{-1}$ (YLPL). One thousand seeds from each plot, counted on an electronic seed counter were weighed to determine 1000-seed weight (MSW). Seeds pod^{-1} was calculated as [YLPL x 1000/(MSW x PD)].

Plots were trimmed prior to harvest to eliminate edge effects. Each plot was hand harvested at ground level, bagged, air dried and weighed to determine the total dry matter. The plants were passed through a stationary thresher and an air sieve cleaner, then weighed to determine seed yield. The seed yield and dry matter yield of the plants used for yield component analysis were added to the initial plot values to determine the total seed and dry matter yields of each plot. Dry matter and seed yield weights were adjusted to kg ha^{-1} for analysis. Apparent harvest index was calculated as [seed yield/total dry matter x 100]. To determine if the sample size for the yield components

was sufficient, yield plant^{-1} (YP) was also calculated as [seed yield/plants m^{-2}] and compared with YLPL.

Threshed seed was passed through a spiral cleaner and 25 g and 1 g samples were used to determine oil and protein concentration, respectively. Five gram samples were used to determine chlorophyll concentration. Oil concentration was determined by Near Magnetic Resonance analysis (Robertson and Morrison 1979) and protein concentration was determined using standard Kjeldahl analysis. Seed chlorophyll concentration was determined using the spectrophotometer method outlined by Daun (1976).

Total nitrogen uptake from the soil (kg ha^{-1}) was determined by adding the nitrogen taken up by the seed (percent protein/6.25 x seed yield) and the nitrogen taken up by the straw (total dry mattter - seed yield x nitrogen content of the straw). The values for the nitrogen content of the straw obtained by Ridley (1973) for 0 to 60 (0.43%) and 90 to 240 (0.63%) kg ha^{-1} nitrogen fertilizer were used to calculate the nitrogen taken up by the straw for the 0 to 60 and 120 to 240 kg ha-1 nitrogen fertilizer treatments in this experiment, respectively.

5.4.3 Statistical Analysis

Analysis of variance combined with orthogonal polynomials procedures were used to analyze the data. The Shappiro-Wilk W-test was used to test normality of the population and Waller-Duncan k-ratio tests were used to detect differences among cultivar means. Rank correlations between YP and YLPL were determined for nitrogen fertilizer rates, seeding rates and cultivars to determine the validity of the yield components. Correlation coefficients were also determined between seed yield and yield components.

5.4 Results and Discussion

Average seasonal temperature and total precipitation was 20.3°C and 223 mm, respectively (Appendix 1 Table 1). The month of August was dry and there were many days with temperatures above 30°C throughout the season (Appendix 1, Table 1). The soil analysis data is presented in Table 5.1. Average NO_3 nitrogen level to a 120 cm depth was 56 kg ha^{-1}. The total nitrogen taken up from the soil by summer rape was 108, 140, 169 and 175 kg ha^{-1} for the 0, 60, 120 and 240 kg ha^{-1} nitrogen fertilizer treatments, respectively. Average seed yield (2.4 t ha^{-1}) was high for summer rape in Canada. These results suggest that growing conditions were favorable for high rates of mineralization, thus promoting high seed yields. There were no fertilizer x cultivar interactions suggesting that hybrid and open pollinated cultivars responded similarly to nitrogen fertilizer. Increasing seeding rate from 3 to 6 kg ha^{-1} hastened earliness to flowering and maturity by 1 day and increased pods $plant^{-1}$ (Tables 5.2 and 5.4). Seeding rate did not affect the nitrogen fertilizer response of the cultivars except for lodging, total dry matter and pod $plant^{-1}$. For these traits, the intensity of the nitrogen fertilizer response was changed by seeding rate. Since the direction of the nitrogen fertilizer response was not changed by seeding rate, it was concluded that seeding rate in the 3 to 6 kg ha^{-1} range does not influence the nitrogen fertilizer response of summer rape.

5.4.1 Phenology

The hybrid cultivars Karat/Regent and Marnoo/Regent began flowering in 42.5 days whereas the open pollinated cultivar Regent flowered in 40.7 days Only Karat/Regent was significantly later maturing than Regent (Table 5.2). Generally, the hybrid cultivars (78.1-79.2 days) were later maturing than the open pollinated cultivar

Regent (77.1 days). Sernyk (1982) also reported that hybrid cultivars were later maturing than the cultivar Regent. A 1-2 day delay in maturity should not limit the production of summer rape hybrid cultivars in Canada.

An increase in the nitrogen fertilizer rate from 0 to 240 kg ha^{-1} resulted in a significant quadratic response in earliness to flowering and seed formation period (Table 5.2). These two traits increased by 2 days with the addition of 240 kg ha^{-1} nitrogen fertilizer. Maturity was delayed from 75.9 to 79.8 days with the addition of 240 kg ha^{-1} nitrogen fertilizer (Table 5.2). Bunting (1969) reported that the maturity of summer rape was delayed by 6 to 7 days with the addition of 170 kg ha^{-1} nitrogen fertilizer. The published reports and the results of the this study suggest that fields should be tested for NO_3 nitrogen content to avoid delays in maturity of summer rape, caused by excessive nitrogen fertilizer application.

5.4.2 Plant Stand

There were significant differences in mature plant density among cultivars (Table 5.2). The largest seeded cultivar, Lergo/Regent, had the lowest mature plant density. The hybrid cultivar Karat/Regent had significantly lower percent establishment than the other cultivars (Table 5.2). There were no significant differences among cultivars for percent survival (Table 5.2).

Nitrogen fertilizer did not affect mature plant density, percent establishment or percent survival (Table 5.2). Allen and Morgan (1972) reported decreasing plant stands with the addition of 211 kg ha^{-1} nitrogen fertilizer in the summer rape cultivars Zollerngold and Cresus, becoming significant only at maturity. This is contradictory to the results of the present study since none of the plant density traits were changed significantly by nitrogen fertilizer. Differences in response may be due to differences in cultivars used, soil moisture, nutrient status of the soil or carrier of the fertilizer. Allen

and Morgan (1972) used 'Nitro chalk' as the source of fertilizer, whereas ammonium nitrate was used in this experiment.

5.4.3 Vigor

Plant vigor was similar in the hybrid cultivars and the open pollinated cultivar Regent (Table 5.3). Increasing nitrogen fertilizer rate resulted in a linear decrease in plant vigor over all cultivars (Table 5.3). No logical explanation could be made for this response. These results contrast with those of Allen and Morgan (1972), who observed that increasing nitrogen fertilizer rate from 0 to 211 kg ha^{-1} increased vigor of the summer rape cultivars, Zollerngold and Cresus.

5.4.4 Height

The hybrid cultivar Karat/Regent (133.5 cm) was significantly taller than the other cultivars (121.7-128.7 cm) (Table 5.3). The hybrid cultivars were taller than Regent by an average of 8.2 cm. Nitrogen fertilizer did not affect height significantly (Table 5.3). Allen and Morgan (1972) observed an increase in height of 30 and 40 cm with the addition of 211 kg ha^{-1} nitrogen fertilizer in the summer rape cultivars Zollerngold and Cresus, respectively. Soil nitrogen content and/or cultivar differences may be the reason for the different responses to nitrogen fertilizer.

5.4.5 Lodging

There was a significant fertilizer x seeding rate interaction for lodging. At the 3 kg ha^{-1} seeding rate, lodging incresed from 1.8 to 2.3 when nitrogen fertilizer rate was increased from 0 kg ha^{-1} to 60 kg ha^{-1} . Further addition of nitrogen fertilizer did not

change lodging. Lodging measurements were 1.6, 2.3, 2.6 nad 3.2 with each increment in nitrogen fertilizer from 0 to 240 kg ha^{-1} at the 6 kg ha^{-1} seeding rate. Since the rank of the seeding rates did change and the responses to nitrogen fertilizer were in the same direction, it was concluded that nitrogen fertilizer promoted lodging in the cultivars tested. In the United Kingdom, Scott et al. (1973) reported that 100 and 200 kg ha^{-1} nitrogen fertilizer promoted lodging in the summer rape cultivar Zollerngold. The above results suggest that fields should be tested for NO_3 nitrogen content to reduce lodging caused by excessive nitrogen fertilizer application.

5.4.6 Yield and Yield Related Measurements

The hybrid cultivars produced significantly higher total dry matter yields than Regent (Table 5.3). Sernyk (1982) also reported hybrid vigor for total dry matter of 25 and 29% over the summer rape cultivar Regent for two summer rape hybrid cultivars.

At the 3 kg ha^{-1} seeding rate, total dry matter yield increased from 9030 to 11630 kg ha^{-1} with 60 kg ha^{-1} nitrogen fertilizer and remained stable with further additions. At the 6 kg ha^{-1} seeding rate, the total dry matter yield increased from 9050 to 11000 and 11690 kg ha^{-1} with 60 and 120 kg ha^{-1} nitrogen fertilizer, respectively, and did not change with further addition up to 240 kg ha^{-1}. These different total dry matter yield responses to nitrogen fertilizer at different seeding rates resulted in a significant fertilizer x seeding rate interaction. Since both responses to nitrogen fertilizer were positive, it was concluded that increasing nitrogen fertilizer rate resulted in higher total dry matter yields of the cultivars tested. The differences in response are probably due to increased demand for nutrients at higher seeding rates. Allen and Morgan (1972, 1975) also observed increased dry matter yields with increasing nitrogen fertilizer rate from 0 to 211 kg ha^{-1} in five summer rape cultivars. These results suggest that nitrogen fertilizer

promotes high total dry matter yields in summer rape in soils with 60 kg ha^{-1} NO_3 nitrogen or less.

The cultivar Lergo/Regent (2745 kg ha^{-1}) produced significantly higher seed yield than the other three cultivars (2322-2401 kg ha^{-1}) (Table 5.3). This may be due to its prolonged seed formation period combined with high total dry matter yield. High total dry matter yield has been associated with high seed yields in summer rape (Campbell and Kondra 1978).

The summer rape cultivars had a significant linear and quadratic response of seed yield to increasing nitrogen fertilizer rate (Table 5.3). The seed yield increased with 120 kg ha^{-1} nitrogen fertilizer and did not change with higher rates (Table 5.3). On soils low in NO_3 nitrogen, 150-200 kg ha^{-1} nitrogen fertilizer rates produced the highest seed yields in summer rape in Canada (Soper 1971, Ridley 1972, 1973). The above results suggest that both summer rape hybrid and open pollinated cultivars require the addition of high levels of nitrogen fertilizer on soils low in NO_3 nitrogen.

Lower harvest indices were observed in the hybrid cultivars Karat/Regent (21.5%) and Marnoo/Regent (21.8%) than in the Lergo/Regent (24.5%) hybrid cultivar and the Regent (23.8%) open pollinated cultivar due to high total dry matter yields (Table 5.3). The hybrid cultivar, Lergo/Regent, had the highest harvest index and consequently the highest seed yield.

There was no effect of nitrogen fertilizer on harvest index (Table 5.3). These results suggest that nitrogen fertilizer does not affect the harvest index of summer rape hybrid and open pollinated cultivars.

5.4.7 Yield Components

The cultivar Lergo/Regent (131) had significantly higher pods $plant^{-1}$ than the other cultivars (98-117) (Table 5.4). Lergo/Regent (2.98 g) also had relatively low

thousand seed weight compared to the other cultivars (2.96-3.22 g). In contrast, the cultivar Regent had the least pods plant^{-1} and largest seed weight. Negative relationships between yield components are common in summer rape (Olsson 1960). There were no differences in seeds pod^{-1} among cultivars (Table 5.4).

Minor differences in the response of pods plant^{-1} to nitrogen fertilizer at the two seeding rates caused a significant fertilizer x seeding rate interaction pods plant^{-1}. Pods plant^{-1} increased at different rates with up to 120 kg ha^{-1} nitrogen fertilizer for the two seeding rates, and more pods plant^{-1} were always produced at the 3 kg ha^{-1} seeding rate than at 6 kg ha^{-1}. There was a linear increase in seeds pod^{-1} with increasing nitrogen fertilizer rate, but seed weight was not affected (Table 5.4). British researchers reported that pods plant^{-1} and seeds pod^{-1} increased with increasing fertilizer rates from 0 to 211 kg ha^{-1} in three experiments in the cultivars Zollerngold and Cresus (Allen et al. 1971, Allen and Morgan 1972, 1975) Seed weight was not affected in these experiments. These results suggest that the number of pods plant^{-1} and seeds pod^{-1} in summer rape is increased with the addition of nitrogen fertilizer. Seed weight is not affected by nitrogen fertilizer.

Although relatively low, the correlation coefficients derived in this experiment suggest that pods plant^{-1} (r=.41**), and seeds pod^{-1} (r=.47**) are directly related to seed yield. Seed weight was not significantly correlated to seed yield in this case. The correlations among the yield components were nonsignificant. Olsson (1960) established that pods plant^{-1}, seeds pod^{-1} and seed weight were positively correlated to seed yield in summer rape. Except for seed weight the results of the present study confirm this report.

Rank correlation coefficients were determined between YLPL and YP for each treatment. The correlation coefficients were 0.8, 1.0 and 1.0 for nitrogen fertilizer rate, seeding rate and cultivars (Table 5.5). The small difference in YLPL (.09 g) between the two highest nitrogen fertilizer treatments can explain the imperfect relationship between

YLPL and YP. Based on these results, it was concluded that a ten plant sample was sufficient to measure yield components in summer rape.

5.4.8 Quality

5.4.8.1 Oil and Protein Concentration. The hybrid cultivars Lergo/Regent and Karat/Regent had intermediate seed oil concentrations (43.0-43.5%) and the highest protein concentrations (26.5%) (Table 5.6). Consequently, they produced the highest total oil and protein concentrations (69.5-70.0%). The cultivar Regent had the highest oil and lowest protein concentration. Negative relationships between oil and protein concentrations are common in summer rape (Loof 1960).

Both oil and protein concentration had linear and quadratic responses to nitrogen fertilizer, the former being negative and the latter positive (Table 5.6). Their total had a positive linear response to nitrogen fertilizer (Table 5.6). Differences in oil and protein were largest at the low nitrogen fertilizer rates and least at higher nitrogen fertilizer rates. Ridley (1973) reported a 6 and 5% increase in protein and total oil and protein concentration, respectively, when 240 kg ha^{-1} nitrogen fertilizer was applied to the summer rape cultivar Zephyr. Oil concentration was decreased by 4% in the same experiment. These results suggest that protein and total oil and protein concentration are increased at high rates of nitrogen fertilizer, but the economically important trait, oil concentration, is reduced.

5.4.8.2 Chlorophyll. Although the hybrid cultivars had significantly higher chlorophyll concentration than Regent, they were all below the Canadian standard limit of 24 ppm (Table 5.6). Heat and drought stress caused a hastening in maturity, thus promoted uniform ripening of the crop. This is probably the reason for the low chlorophyll concentrations (Morrison 1987).

Increasing nitrogen fertilizer rates increased the chlorophyll concentration linearly, but all values were below 24 ppm (Table 5.6). Heat and drought stress caused low chlorophyll concentrations in this experiment, but as suggested by the data, high nitrogen rates may increase chlorophyll concentration of summer rape cultivars above the Canadian standard limit in years when ripening is not promoted by stress.

5.5 Summary and Conclusions

Three summer rape hybrid cultivars and one open pollinated cultivar were seeded at 3 and 6 kg ha^{-1} with 0 to 240 kg ha^{-1} nitrogen fertilizer to determine the optimum nitrogen fertilizer rate to maximize the seed yield and quality of summer rape hybrid cultivars. Generally the hybrid cultivars were later maturing than the cultivar Regent by 1 to 2 days. This difference in maturity should not be a problem in Canada. The hybrid cultivars were taller and produced significantly higher total dry matter yields than Regent. Although the hybrid cultivars produced lower seed oil concentrations (1-2%), their total oil and protein concentrations were similar to Regent. Hybrid cultivars had 1.5 to 3.3 ppm higher chlorophyll concentrations than Regent, but these were well under the Canadian standard limit of 24 ppm.

Seeding rate did not change the direction of the nitrogen fertilizer response for performance and quality traits of the cultivars tested, therefore it was concluded that seeding rate did not influence the nitrogen fertilizer response of summer rape hybrid or open pollinated cultivars. As indicated by the lack of cultivar x nitrogen fertilizer interaction, summer rape hybrid and open pollinated cultivars respond to nitrogen fertilizer similarly. Nitrogen fertilizer rates of 0 to 240 kg ha^{-1} did not affect plant density characters, height, harvest index and seed weight. Earliness to flowering, maturity, and seed formation period were delayed by 2, 4 and 2 days, respectively, with the addition of 240 kg ha^{-1}. Lodging increased with increasing nitrogen fertilizer rate.

Soils should be tested for NO_3 nitrogen content to avoid delays in maturity and to reduce lodging in summer rape caused by excessive application of nitrogen fertilizer. The highest seed yield was achieved at 120 kg ha^{-1} nitrogen fertilizer due to a high number of pods $plant^{-1}$ and seeds pod^{-1}. Seed protein and total oil and protein concentrations were increased 4.9 and 1.3%, respectively with 240 kg ha^{-1} nitrogen fertilizer. Oil concentration was reduced by 3.5% with the same rate of nitrogen fertilizer. The decrease in oil concentration with the addition of nitrogen fertilizer is compensated for by an increase in seed yield. The oil yield (seed yield x oil concentration), therefore, is not necessarily reduced with the addition of nitrogen fertilizer. Although chlorophyll concentration increased with increasing nitrogen fertilizer rate, it remained well below the Canadian standard limit of 24 ppm.

In Canada, producers are paid for seed yield and not oil yield, in summer rape. Based on the results of this experiment, the optimum nitrogen fertilizer rate to maximize yield of summer rape hybrid cultivars is 120 kg ha^{-1}. At this rate maturity is delayed 3.3 days, therefore, it may be the most important factor to consider when determining optimum nitrogen fertilizer rate in summer rape where the growing season is limiting.

5.6 Acknowledgements

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TABLE 5.1. Soil data for the nitrogen fertilizer experiment at the Point in 1988.

Depth (cm)	Texture	Carbonate content	pH	Salinity (ms/cm)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Sulphur (kg ha^{-1})
0-30	Clay	Very low	7.4	0.4	18.0	38.9	703	11.3
30-60	Clay	Very low	7.4	0.3	30.2	86.1	1810	13.0
60-120	Clay	Very low	7.7	0.2	7.6	26.9	1948	11.1

TABLE 5.2. Effect of nitrogen fertilizer rate (kg ha^{-1}), seeding rate (kg ha^{-1}) and differences between cultivar means of phenological and plant stand traits in the nitrogen fertilizer experiment

	Days to flowering	Days to maturity	Seed formation period (days)	Plants m^{-2}	Establishment (%)	Survival (%)
Fertilizer rate						
0	40.4	75.9	28.6	43.1	73.9	95.6
60	41.2	78.0	29.6	41.7	72.2	94.8
120	42.2	79.2	30.0	38.9	68.6	93.4
240	42.6	79.8	30.2	39.8	68.3	95.4
Contrast*	L,Q	L,Q	L,Q	NS	NS	NS
Seeding rate						
3.0	42.1 a	78.7 a	29.5 a	30.6 b	75.5 a	95.7 a
6.0	41.0 b	77.7 b	29.7 a	51.2 a	66.0 b	93.9 a
Cultivar						
Karat/Regent	42.7 a	79.2 a	29.5 b	36.9 c	52.0 b	94.3 a
Lergo/Regent	40.4 b	78.1 b	30.7 a	35.4 c	75.9 a	95.4 a
Marnoo/Regent	42.4 a	78.4 b	28.9 b	47.0 a	78.3 a	93.7 a
Regent	40.7 b	77.1 c	29.4 b	44.2 b	76.8 a	95.9 a

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).
a-c Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

TABLE 5.3. Effect of nitrogen fertilizer rate (kg ha^{-1}), seeding rate (kg ha^{-1}) and differences between cultivar means of agronomic, yield and yield related traits in the nitrogen fertilizer experiment

	Vigor (1-5)	Height (cm)	Lodging (1-5)	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest Index (%)
Fertilizer rate						
0	4.2	124.6	1.7 #	9040 #	2062	22.8
60	3.5	128.0	2.3	11320	2513	22.2
120	3.4	129.4	2.4	11330	2648	23.4
240	2.9	129.4	2.8	11390	2635	23.3
Contrast*	L	NS			L,Q	NS
Seeding rate						
3.0	3.1 b	128.8 a	2.2	10690	2433 a	22.9 a
6.0	3.9 a	126.9 a	2.4	10840	2495 a	23.0 a
Cultivar						
Karat/Regent	3.4 a	133.5 a	2.1 b	11190 a	2401 b	21.5 b
Lergo/Regent	3.6 a	128.1 b	2.4 a	11200 a	2745 a	24.5 a
Marnoo/Regent	3.6 a	128.1 b	2.2 a	10660 ab	2322 b	21.8 b
Regent	3.4 a	121.7 c	2.5 a	10020 b	2390 b	23.8 a

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).
a-c Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).
Inferences on means were not done due to a significant (P=0.05) nitrogen fertilizer rate x seeding rate interaction.

TABLE 5.4. Effect of nitrogen fertilizer rate (kg ha^{-1}), seeding rate (kg ha^{-1}) and differences between cultivar means of yield components in the fertilizer experiment

	Pods $plant^{-1}$	Seeds pod^{-1}	1000-seed weight (g)
Fertilizer rate			
0	98.4 #	11.40	3.043
60	111.4	14.71	3.074
120	125.4	15.62	3.039
240	116.4	17.42	3.064
Contrast*		L	NS
Seeding rate			
3.0	125.5	15.00 a	3.057 a
6.0	100.4	14.57 a	3.052 a
Cultivar			
Karat/Regent	116.6 b	15.19 a	2.964 c
Lergo/Regent	131.4 a	14.52 a	2.984 c
Marnoo/Regent	105.7 c	14.21 a	3.050 b
Regent	97.9 c	15.22 a	3.223 a

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-c Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

Inferences on means were not done to a significant (P=0.05) nitrogen fertilizer rate x seeding rate interaction.

TABLE 5.5 Means and rank correlation coefficients (R) of yield $plant^{-1}$ determined on a plot basis (YP) and on a yield component basis (YLPL) for nitrogen fertilizer rate (kg ha^{-1}), seeding rate (kg ha^{-1}) and cultivars in the nitrogen fertilizer experiment

	YP	YLPL	R
Fertilizer rate			
0	5.37	3.41	
60	6.59	5.05	
120	7.62	5.97	
240	7.08	6.06	0.80
Seeding rate			
3.0	8.23	5.74	
6.0	5.10	4.50	1.00 **
Cultivar			
Karat/Regent	7.06	5.30	
Lergo/Regent	8.23	5.73	
Marnoo/Regent	5.45	4.59	
Regent	5.91	4.87	1.00 **

** Significant at the 0.01 level of probability.

TABLE 5.6. Effect of nitrogen fertilizer rate (kg ha^{-1}), seeding rate (kg ha^{-1}) and differences between cultivar means of quality traits in the nitrogen fertilizer experiment

	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll (ppm)
Fertilizer rate				
0	45.3	23.5	68.9	3.9
60	44.0	25.3	69.3	5.4
120	42.5	27.0	69.5	6.6
240	41.8	28.4	70.2	7.7
Contrast*	L,Q	L,Q	L	L
Seeding rate				
3.0	43.5 a	26.0 a	69.6 a	6.2 a
6.0	43.2 a	26.1 a	69.4 a	5.6 a
Cultivar				
Karat/Regent	43.0 c	26.5 a	69.5 b	7.8 a
Lergo/Regent	43.5 b	26.5 a	70.0 a	5.2 bc
Marnoo/Regent	42.5 d	25.9 b	68.5 c	6.0 b
Regent	44.5 a	25.4 b	69.9 ab	4.5 c

*Orthogonal contrasts are significant (P=0.05) for the main effect (L=linear, Q=quadratic, C=cubic, NS=nonsignificant).

a-d Means followed by the same letter are not significantly different at P=0.05 (Waller-Duncan k-ratio).

6. GENERAL DISCUSSION

Heterosis for yield over the better parent (Sernyk and Stefansson 1983, Grant and Beversdorf 1985), a pollination control system (Fang and McVetty 1987) and hybrid seed production on a field scale (Pinnisch 1988) show promise for the development of summer rape hybrid cultivars in Canada. The next step in the development of summer rape hybrid cultivars is to examine the hybridity, seeding rate and nitrogen fertilizer requirements of summer rape hybrid cultivars to maximize seed yield and quality. These three factors were studied in field trials at two locations over three years.

6.1 Hybridity

The effect of male sterile and restorer line seed contamination on summer rape hybrid cultivar performance was studied by blending an A-line and R-line in various proportions with two summer rape hybrid cultivars. A-line contamination delayed earliness to flowering and maturity of the hybrid cultivars approximately 1 day and prolonged seed formation period up to 2 days due to reduced pollen production. As a result of reduced seed set, A-line contamination reduced lodging of the hybrid cultivars. Percent male sterility was increased proportionally with each increment in A-line contamination, therefore, decreasing the hybridity of the hybrid cultivars. The level of male sterility in hybrid cultivars may be reduced by decreasing the A:R-line ratio in the hybrid seed production block (Pinnisch 1988).

Total dry matter yield of the hybrid cultivars was not reduced with up to 80% A-line contamination. These results agree with those of Shiga et al. (1970), who reported

that 75% male fertile parental contamination of winter rape hybrid cultivars did not reduce total dry matter yield. The summer rape hybrid cultivar Lergo/Dp6-6 outyielded Lergo in two out of four experiments. Hybrid vigor for seed yield is common in summer rape (Sernyk and Stefansson 1983). Yield was only significantly reduced with 20% A-line contamination at the Arboretum location in 1988 where growing conditions were poor. Since the male sterile plants were not outcompeted, as indicated by the level of male sterility at flowering, the low yield of the A-line reduced the hybrid population yield. On the other hand, the high pollen production and pollen viability of the hybrid cultivars achieved under adequate moisture growing conditions in the other experiments ensured high yield of the A-line. Eighty percent A-line contamination did not significantly reduce seed yields under the irrigated field conditions at the Point in 1988. Shiga et al. (1970) reported that 50% male fertile parental contamination did not change the seed yield of a winter rape hybrid population when high-parent heterosis for seed yield was 90%, however, seed yield was reduced in these same hybrid/parent mixtures with 50% male fertile parental contamination when heterosis for seed yield was 290%. Differences between these results and those of the present study may be due to differences in the level of heterosis for yield in the hybrid cultivars used and the nature of the contaminating parent. These data suggest that yield of hybrid/parent mixtures is determined by the relative yield of the components multiplied by their proportion in the mixture. The results of this study suggest that the yield of summer rape hybrid cultivars is reduced with low percent male sterile line contamination under stress, but under good growing conditions, up to 80% male sterility does not significantly reduce seed yield. Harvest index of the hybrid cultivars was decreased with 10-30% A-line contamination as a result of reduced seed set in the A-line.

The seed quality of the hybrid cultivars was changed due to the relative differences between the hybrid cultivars and the A-line. Twenty percent A-line contamination reduced the oil concentration of the hybrid cultivars by approximately 1%.

This is detrimental in an oilseed crop such as summer rape. R-line contamination (10-20%) did not affect the performance or quality of the summer rape hybrid cultivars.

6.2 Seeding Rate

To determine if the current seeding rate recommendations for summer rape open pollinated cultivars apply to hybrid cultivars, four hybrid and two open pollinated summer rape cultivars were seeded at 1.5 to 9 kg ha^{-1}. Hybrid and open pollinated cultivars responded similarly to seeding rate for phenological, agronomic, yield and quality traits.

Hybrid cultivars were later maturing than the open pollinated cultivars by approximately 1 day. This agrees with Sernyk (1982), who reported that the Karat/Regent and Marnoo/Regent hybrid cultivars were 1 day later maturing than the open pollinated cultivar Regent. The hybrid cultivars were also 1-25 cm taller and produced higher total dry matter yield than the open pollinated cultivars. The hybrid cultivars only outyielded the open pollinated cultivars in one out of two years. As a result of high total dry matter yields and similar seed yields as the open pollinated cultivars, the hybrid cultivars also had the lowest harvest indices. They also had lower oil concentration than the open pollinated cultivars, which is disadvantageous in an oilseed crop such as summer rape.

Maturity was hastened 1.3 days by increasing seeding rate from 1.5 to 9 kg ha^{-1}. Morrison 1987 observed that seeding rates of 1.5 to 12 kg ha^{-1} only changed earliness to maturity slightly in the summer rape cultivar Westar. Degenhardt and Kondra (1981a) found that increasing seeding rate from 3 to 12 kg ha^{-1} hastened maturity 1.7 days in five summer rape cultivars. These small changes in maturity do not warrant a change in seeding rate. Due to increased interplant competition, percent survival of the hybrid and open pollinated cultivars decreased 16.4 to 28.8 percent when seeding rate increased

from 1.5 to 9.0 kg ha^{-1}. This agrees with Clarke and Simpson (1978a), who reported that percent survival was less than 50% when seeding rate of summer rape was over 10 kg ha^{-1}. Lodging was increased at high seeding rates. Similar results were reported in summer rape in the 1.5 to 12 seeding rate range (Kondra 1975, Morrison 1987).

The 3 kg ha^{-1} seeding rate produced the highest seed yields, but 1.5 kg ha^{-1} may be used under irrigated growing conditions. Morrison (1987) obtained similar results for the summer rape cultivar Westar in Manitoba.

Seeding rate did not affect the oil, protein or chlorophyll concentration of either hybrid or open pollinated cultivars. Oil and protein concentration of the summer rape cultivars Zephyr (Kondra 1975, 1977) and Westar (Morrison 1987) were not affected at 3-12 kg ha^{-1} and 1.5-12 kg ha^{-1} seeding rates, respectively. Chlorophyll concentration was higher at lower seeding rates for the summer rape cultivar Westar tested in Manitoba (Morrison 1987). Except for chlorophyll concentration, the results of the present study agree with the published reports.

Although, the higher seeding rates of 6-8 kg ha^{-1} presently recommended in Canada for summer rape (Kondra 1975, Christensen and Drabble 1984) assure high seed yields by buffering against environmental stress, the above results suggest that seeding rates as low as 1.5 kg ha^{-1} may be used under irrigated growing conditions. Low seeding rates (3 kg ha^{-1}) may reduce lodging in summer rape and are advantageous when planting more expensive hybrid seed. As suggested by Morrison (1987), a lowering of seeding rate may be in order for western Canadian grown summer rape.

6.3 Nitrogen Fertilizer Requirements

The performance and quality of three summer rape hybrid cultivars and one open pollinated cultivar were examined at two seeding rates and 0 to 240 kg ha^{-1} nitrogen fertilizer rates to determine the nitrogen fertilizer requirements of summer rape hybrid

cultivars. Seeding rate did not change the nitrogen fertilizer response of the hybrid or open pollinated cultivars except for lodging, total dry matter and pods plant^{-1}. For those traits, the intensity and not the direction of the nitrogen fertilizer response was changed, therefore, seeding rate effects were not considered. There were no nitrogen fertilizer x cultivar interactions, suggesting that summer rape hybrid and open pollinated cultivars respond similarly to nitrogen fertilizer.

The hybrid cultivars were later maturing than the open pollinated cultivar Regent by 1-2 days. Similarly, Sernyk (1982) reported that the Karat/Regent and Marnoo/Regent hybrid cultivars were later maturing than Regent by 1 day. The hybrid cultivars produced higher total dry matter yield and similar seed yield to Regent. Although they had lower seed oil concentration (1-2%) than Regent, the hybrid cultivars had similar total oil and protein concentration. Similar results were reported for the summer rape cultivar Zephyr (Ridley 1972, 1973). Generally the hybrid cultivars performed equal to or better than Regent and had similar quality.

Nitrogen fertilizer rates of 240 kg ha^{-1} delayed maturity 4 days and increased lodging. This agrees with Bunting (1969), who reported that maturity of summer rape was delayed 6-7 days with 170 kg ha^{-1} nitrogen fertilizer. Scott et al. (1973) observed that the summer rape cultivar Zollerngold was more susceptible to lodging with 100 and 200 kg ha^{-1} nitrogen fertilizer. Soils should be tested for NO_3 nitrogen content to avoid excessive application of nitrogen fertilizer, thus limiting lodging and avoiding a delay in maturity in summer rape.

The highest seed yields were produced with 120 kg ha^{-1} nitrogen fertilizer due to higher pods plant^{-1} and seeds pod^{-1}. Maximum seed yields were achieved at 150-200 kg ha^{-1} nitrogen fertilizer for the summer rape cultivar Zephyr in Canada (Soper 1971, Ridley 1972, 1973). Oil concentration was decreased 3-5% with 240 kg ha^{-1}. This is detrimental in an oilseed crop such as summer rape. Ridley (1972) reported similar

decreases in oil concentration for the summer rape cultivar Zephyr with 240 kg ha^{-1} nitrogen fertilizer.

To determine the appropriate nitrogen fertilizer rate for summer rape hybrid or open pollinated cultivars, soils must be tested for NO3 nitrogen to assure crop maturity, reduce lodging and maintain high quality standards, as well as high seed yields. The results of this study suggest that the nitrogen fertilizer rates (150-200 kg ha^{-1}) presently recommended for summer rape open pollinated cultivars are satisfactory for use in summer rape hybrid cultivars.

7. CONCLUSIONS

Studies on the effect of blending a male sterile line (A-line) and a restorer line with summer rape hybrid cultivars revealed that restorer line contamination of 10-20% has no affect on the performance or quality of summer rape hybrid cultivars. A-line contamination delayed earliness to flowering and maturity approximately 1 day, and prolonged seed formation period up to 2 days due to reduced pollination. Male sterile plants were not outcompeted by the hybrid cultivars, therefore, only low levels of incomplete male sterility can be tolerated in the hybrid seed production block and still maintain acceptable levels of hybridity. Seed yield decreased 11.3 and 6.5 kg ha^{-1} per percent male sterility under heat stressed growing conditions, but 50% A-line contamination did not change yield of summer rape hybrid cultivars under good growing conditions. Adequate moisture growing conditions promoted pollen production and pollen viability to ensure high seed yield of the A-line. Harvest index of the hybrid cultivars was reduced with 10-30% A-line contamination depending on growing conditions. Due to the relative differences in quality between the A-line and hybrid cultivars, 20% A-line contamination reduced seed oil concentration of the hybrid cultivars by 1%. The results of this study indicate that A-line contamination must be 10% or less to ensure high seed yields and high percent hybridity, and to maintain high quality standards in summer rape hybrid cultivars.

Studies on the seeding rate of summer rape hybrid and open pollinated cultivars suggested that hybrid and open pollinated cultivars respond similarly to seeding rate. Hybrid cultivars were later flowering and maturing than open pollinated cultivars. They were taller and produced significantly higher total dry matter yield than open pollinated

cultivars. Hybrid cultivars only outyielded the open pollinated cultivars under good growing conditions. They had the lowest harvest indices and seed oil concentrations. Low oil concentration is undesirable in oilseed crops such as summer rape.

Increasing seeding rate from 1.5 to 9 kg ha^{-1} hastened maturity about 1 day and increased lodging. Percent survival was also reduced approximately 20%. The 3 kg ha^{-1} seeding rate produced the highest seed yield, however, 1.5 kg ha^{-1} may be used under good growing conditions. Seeding rate did not change quality characteristics in the summer rape cultivars. Overall, maximum performance and seed quality of summer rape open pollinated and hybrid cultivars were obtained at the 3 kg ha^{-1} seeding rate. This low seeding rate is preferable over currently recommended ones (6-8 kg ha^{-1}) when planting expensive hybrid seed.

Field trials on summer rape hybrid and open pollinated cultivars seeded at 3 and 6 kg ha^{-1} with 0 to 240 kg ha^{-1} nitrogen fertilizer revealed that seeding rate did not change the direction of the nitrogen fertilizer response for performance and quality traits of summer rape. Hybrid and open pollinated cultivars responded similarly to nitrogen fertilizer.

The hybrid cultivars were later maturing; produced higher total dry matter yield and similar seed yields; had lower harvest indices and oil concentration than the open pollinated cultivar Regent.

Nitrogen fertilizer rates of 240 kg ha^{-1} delayed maturity 4 days and increased lodging. The highest seed yields were produced at 120 kg ha^{-1} nitrogen fertilizer due to increased pods $plant^{-1}$ and seeds pod^{-1}. Oil concentration was reduced 3-5% with 240 kg ha-1. This is detrimental in an oilseed crop such as summer rape. The results of this study suggest that the nitrogen fertilizer rates (150-200 kg ha^{-1}) presently recommended for summer rape open pollinated cultivars may be used for summer rape hybrid cultivars.

The results of this research suggest that hybrid and open pollinated cultivars respond similarly to agronomic practices. High levels of hybridity (low percent male

sterility) must be achieved when producing hybrid cultivars to take full advantage of the heterosis for yield displayed in these cultivars.

8. CONTRIBUTIONS TO KNOWLEDGE

8.1 Hybrid Development

Experiments on winter rape (Shiga et al. 1970) and hybrid wheat (Hughes and Bodden 1978) suggest that heterosis of the hybrid cultivar may affect its response to parental contamination. Murakami et al. (1969) also suggested that the seeding rate of the F_1 population affects its response to parental contamination in winter rape. Blend studies with hybrid cultivars displaying different levels of heterosis for seed yield at different seeding rates should be conducted. The 3 kg ha^{-1} seeding rate should be considered since it maximized performance and quality for hybrid cultivars in this research.

Blend studies with an A-line of equal quality to the hybrid cultivars should also be conducted to determine if differences in quality in hybrid/parent mixtures are due to relative differences between the cultivars or caused by competition.

The ultimate solution to the problem of hybridity is to develop completely male sterile A-lines that are temperature insensitive. Research conducted by Burns (1989) suggests that stable male sterility can be selected for in pol CMS summer rape.

8.2 Agronomic Research

Although hybrid cultivars and open pollinated cultivars respond similarly to seeding rate and nitrogen fertilizer rate, planting date, weed control and irrigation studies should be conducted with summer rape hybrid cultivars. The time of application of nitrogen fertilizer and sulphur fertilizer rate should also be studied in summer rape hybrid

cultivars. Split application of nitrogen fertilizer and sulphur fertilizer increased yields in the summer rape cultivar Zephyr (Ridley 1972, 1973). Hybrid cultivars seem to be more responsive to optimum growing conditions than open pollinated cultivars.

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APPENDIX 1.

APPENDIX 1 TABLE 1. Mean monthly temperatures (TEMP °C) and total monthly precipitation (PPT mm) for the growing season in 1986, 1987 and 1988

	[1]1986		[2]1987		[3]1988		[4]NORMAL	
	TEMP	PPT	TEMP	PPT	TEMP	PPT	TEMP	PPT
May	13.9	25.2	14.8	31.6	15.3	34.8	11.3	65.7
June	17.3	109.3	19.0	55.2	22.9	44.2	16.8	80.1
July	20.2	136.8	20.0	130.1	22.2	69.3	19.6	75.9
August	18.4	19.4	17.2	97.1	20.7	16.5	18.3	75.2
Mean/Total	17.5	290.7	17.8	314.0	20.3	223.5	16.5	296.9

[1]22.6 mm irrigation water was applied to the Point experiments on May 26.
[2]7.6 mm irrigation water was applied to the Point experiments 1 day prior to seeding.
[3]10.5 mm irrigation water was applied to the Point experiments on June 11.
[4]Long-term average (1951-1980). Environment Canada Monthly Meteorological Summary 1987.

APPENDIX 1 TABLE 2. Mean squares and degrees of freedom for phenological and agronomic traits of combined analysis of hybridity experiments

Source(1)	df	df(2)	Days to flowering	Days to maturity	Seed formation period (days)	Sterile (%)	Height(3) (cm)	Lodging (1-5)
Year	1	1	1276.2 **	17404.1 **	9254.6 **	2.54 *	5492364.9 **	152.29 **
Location	1	1	0.1	180.2 **	190.0 **	3.81 **	259813.2 **	1.88 **
Y x L	1	1	41.3 *	36.8 *	155.9 *	6.82 **	347.6	1.88 **
Error a	8	8	4.3	16.5	16.5	0.25	56360.5	0.78
Hybrid	1	1	1.2	42.2 **	57.4 **	2.05 **	155523.6 **	0.05
Y x H	1	1	5.7 **	33.3 **	66.5 **	0.02	9.1	0.26 *
L x H	1	1	2.3 *	20.0 **	8.8 *	0.03	10969.3	0.13
Y x L x H	1	1	20.7 **	4.1 *	6.4 *	0.36 *	2652.0	0.13
Treatment	7	5	7.1 **	15.8 **	2.4	81.10 **	24018.9 **	0.18 **
Y x T	7	5	1.2 **	0.9	2.3	0.22 *	20930.1 **	0.07
L x T	7	5	0.4	2.6 *	2.4	0.24 *	6381.7 **	0.11 *
Y x L x T	7	5	0.5	1.3	1.2	0.36 **	3211.1	0.11 *
H x T	7	5	0.6	1.9	2.0	0.15	4987.0 *	0.13 *
Y x H x T	7	5	0.6	0.7	2.4	0.02	4881.9 *	0.10
L x H x T	7	5	0.9 *	1.1	1.2	0.16	2473.5	0.09
Y x L x H x T	7	5	1.2 *	1.5	1.5	0.31 **	1611.8	0.09
Error b	120	88	0.4	1.0	1.5	0.09	1982.1	0.05

(1)All values are transformed as indicated in materials and methods.
(2)Degrees of freedom in this column are for percent sterile only.
(3)Values for height were divided by 10^7.
*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 3. Mean squares and degrees of freedom for yield and yield related traits, and quality traits of combined analysis of hybridity experiments

Source(1)	df	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)	Oil (%)	Protein (%)	Protein + oil (%)
Year	1	182221770 **	68.92 **	6993416 **	100.2 *	713460 **	19.8 *
Location	1	156892090 **	17.02 **	144246	164.1 **	1653924 **	103.8 **
Y x L	1	88501680 **	10.38 **	62117	252.3 **	952491 **	1.5
Error a	8	5301360	0.48	50019	10.7	28536	2.4
Hybrid	1	35264870 **	6.46 **	286151 **	0.0	158	0.0
Y x H	1	15984750 **	1.34 **	26151	0.0	1948	0.1
L x H	1	323900	0.01	31266	3.4 *	25996 **	0.9
Y x L x H	1	714680	1.00 **	75829 *	27.7 **	39072 **	3.2 *
Treatment	7	4604550 **	0.21 **	120402 **	6.7 **	8027 **	1.2
Y x T	7	1414540	0.37 **	16846	2.0 **	1889	0.8
L x T	7	990700	0.09	20773	0.5	1539	0.4
Y x L x T	7	508760	0.08	9650	1.2	1783	0.4
H x T	7	486920	0.07	28855 *	1.0	1341	0.6
Y x H x T	7	548900	0.05	16869	1.0	4233 *	0.4
L x H x T	7	1006880	0.10	17147	2.7 **	2116	1.0
Y x L x H x T	7	1124810	0.07	11384	0.9	2114	0.8
Error b	120	870280	0.07	11231	0.6	1892	0.7

(1)All values are transformed as indicated in materials and methods.
*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 4. Mean squares for single degree of freedom contrasts for phenological traits of components used in the hybridity experiments

	df	Days to flowering	Days to maturity	Seed formation period (days)
		Arboretum 1986		
Lergo/Dp6-6 vs A-line	1	13.5 **	60.2 **	16.7 **
Lergo/Dp6-6 vs Lergo	1	10.7 **	2.7	2.7
Lergo/Dp6-6 vs R-line	1	1.5	1.5	0.0
Lergo/Topas vs A-line	1	28.2 **	54.0 **	4.2
Lergo/Topas vs Lergo	1	2.7	4.2 *	0.2
Lergo/Topas vs R-line	1	0.2	2.7	4.2
Error	36	0.7	0.8	1.4
		Point 1986		
Lergo/Dp6-6 vs A-line	1	20.2 **	60.2 **	10.7 *
Lergo/Dp6-6 vs Lergo	1	6.0 **	2.7	0.7
Lergo/Dp6-6 vs R-line	1	0.2	16.7 **	13.5 **
Lergo/Topas vs A-line	1	20.2 **	80.7 **	20.2 **
Lergo/Topas vs Lergo	1	6.0 **	0.2	4.2
Lergo/Topas vs R-line	1	0.2	28.2 **	24.0 **
Error	36	0.2	1.5	1.8
		Arboretum 1988		
Lergo/Dp6-6 vs A-line	1	32.7 **	13.5 **	4.2
Lergo/Dp6-6 vs Lergo	1	0.7	4.2	8.2 *
Lergo/Dp6-6 vs R-line	1	0.2	1.5	2.7
Lergo/Topas vs A-line	1	24.0 **	24.0 **	0.0
Lergo/Topas vs Lergo	1	0.0	0.7	0.7
Lergo/Topas vs R-line	1	0.2	0.0	0.2
Error	44	0.6	1.2	1.8
		Point 1988		
Lergo/Dp6-6 vs A-line	1	13.5 **	8.2 *	0.7
Lergo/Dp6-6 vs Lergo	1	2.7 **	20.2 **	8.2 *
Lergo/Dp6-6 vs R-line	1	0.0	1.5	1.5
Lergo/Topas vs A-line	1	20.2 **	54.0 *	8.2 *
Lergo/Topas vs Lergo	1	0.7	0.0	0.7
Lergo/Topas vs R-line	1	0.7	10.7 **	6.0
Error	44	0.3	1.3	1.7

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 5. Mean squares and degrees of freedom for phenological traits in hybridity experiments

	df	Days to flowering	Days to maturity	Seed formation period (days)
		Arboretum 1986		
Replication	2	10.6 **	6.7 **	33.9 **
Hybrid	1	4.7 *	0.8	9.2 **
Treatment	7	0.8	1.8 **	0.6
H x T	7	2.2 **	0.3	3.3 *
Error	30	0.6	1.1	1.1
		Point 1986		
Replication	2	0.2	1.2	1.9
Hybrid	1	0.8	2.5	6.0
Treatment	7	1.7 **	9.0 **	5.0 *
H x T	7	0.4	2.5	1.3
Error	30	0.2	1.7	1.8
		Arboretum 1988		
Replication	2	7.8 **	7.8 **	31.1 **
Hybrid	1	45.1 **	8.8 *	93.8 **
Treatment	9	12.0 **	3.5 *	3.6
H x T	9	1.1	1.0	1.9
Error	38	0.7	1.3	1.9
		Point 1988		
Replication	2	1.1	21.1 **	21.7 **
Hybrid	1	1.1	81.7 **	64.1 **
Treatment	9	6.0 **	12.2 **	1.5
H x T	9	0.5	2.0	1.5
Error	38	0.3	1.2	1.7

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 6. Mean squares for single degree of freedom contrasts for agronomic traits of components used in the hybridity experiments

	df	Height (cm)	Lodging (1-5)
		Arboretum 1986	
Lergo/Dp6-6 vs A-line	1	121.5 **	0.67 **
Lergo/Dp6-6 vs Lergo	1	24.0	0.00
Lergo/Dp6-6 vs R-line	1	104.2 **	0.00
Lergo/Topas vs A-line	1	181.5 **	0.67 **
Lergo/Topas vs Lergo	1	6.0	0.00
Lergo/Topas vs R-line	1	60.2 *	0.00
Error	36	1.5	0.02
		Point 1986	
Lergo/Dp6-6 vs A-line	1	748.2 **	1.50 **
Lergo/Dp6-6 vs Lergo	1	60.2 **	0.00
Lergo/Dp6-6 vs R-line	1	16.7	0.00
Lergo/Topas vs A-line	1	1014.0 **	1.50 **
Lergo/Topas vs Lergo	1	10.7	0.00
Lergo/Topas vs R-line	1	0.2	0.00
Error	36	7.4	0.14
		Arboretum 1988	
Lergo/Dp6-6 vs A-line	1	37.5	0.17 **
Lergo/Dp6-6 vs Lergo	1	6.0	0.17 **
Lergo/Dp6-6 vs R-line	1	13.5	0.67 **
Lergo/Topas vs A-line	1	130.7 *	0.00
Lergo/Topas vs Lergo	1	8.2	0.00
Lergo/Topas vs R-line	1	80.7	1.50 **
Error	44	26.2	0.01
		Point 1988	
Lergo/Dp6-6 vs A-line	1	600.0 **	0.17 **
Lergo/Dp6-6 vs Lergo	1	1.5	0.17 **
Lergo/Dp6-6 vs R-line	1	192.7 *	0.67 **
Lergo/Topas vs A-line	1	1040.2 **	0.00
Lergo/Topas vs Lergo	1	80.7	0.00
Lergo/Topas vs R-line	1	468.2 **	1.50 **
Error	44	27.8	0.01

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 7. Mean squares and degrees of freedom for agronomic traits in hybridity experiments

	df	df(1)	Sterile (%)	Height (cm)	Lodging (1-5)
			Arboretum 1986		
Replication	2	2	5.1	177.3 *	0.00
Hybrid	1	1	1.8	63.0 *	0.00
Treatment	7	5	729.7 **	4.3	0.00
H x T	7	5	12.7	11.4	0.00
Error	30	22	6.1	11.4	0.00
			Point 1986		
Replication	2	2	10.5	98.0 **	0.27
Hybrid	1	1	142.8 **	290.1 **	0.52
Treatment	7	5	884.5 **	16.2 *	0.43 *
H x T	7	5	28.3	14.5	0.38 *
Error	30	22	12.3	6.8	0.16
			Arboretum 1988		
Replication	2	2	64.5	2822.1 **	0.02
Hybrid	1	1	330.4 **	558.1 **	0.02
Treatment	9	7	2050.3 **	128.7 **	0.02
H x T	9	7	29.8	19.2	0.02
Error	38	30	29.3	26.9	0.02
			Point 1988		
Replication	2	2	62.5 **	583.7 **	0.02
Hybrid	1	1	0.00	522.2 **	0.02
Treatment	9	7	1210.8 **	439.4 **	0.02
H x T	9	7	8.6	56.9 *	0.02
Error	38	30	4.5	25.2	0.02

(1)Degrees of freedom in this column are for percent sterile only.
*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 8. Mean squares for single degree of freedom contrasts for yield and yield related traits of components used in the hybridity experiments

	df	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
		Arboretum 1986		
Lergo/Dp6-6 vs A-line	1	186070	986987 *	185.9 **
Lergo/Dp6-6 vs Lergo	1	621270	2709	14.7
Lergo/Dp6-6 vs R-line	1	9940790	1356126 **	37.0 **
Lergo/Topas vs A-line	1	3540	1297815 **	191.5 **
Lergo/Topas vs Lergo	1	1635950	8778	13.2
Lergo/Topas vs R-line	1	13276830 *	1716815 **	39.5 **
Error	36	2512230	140795	4.5
		Point 1986		
Lergo/Dp6-6 vs A-line	1	4459990 **	903186 **	219.6 **
Lergo/Dp6-6 vs Lergo	1	4845070 **	496973 **	2.0
Lergo/Dp6-6 vs R-line	1	7246370 **	809676 **	6.2
Lergo/Topas vs A-line	1	10901280 **	457940 *	248.3 **
Lergo/Topas vs Lergo	1	1022750	186032	5.6
Lergo/Topas vs R-line	1	2256210 *	392090 *	11.8
Error	36	418880	66333	5.7
		Arboretum 1988		
Lergo/Dp6-6 vs A-line	1	1245820	1099873 **	258.2 **
Lergo/Dp6-6 vs Lergo	1	2954590	221021 **	14.4
Lergo/Dp6-6 vs R-line	1	14064840 **	812145 **	15.3
Lergo/Topas vs A-line	1	3350770 *	155417 *	247.8 **
Lergo/Topas vs Lergo	1	1507450	34000	12.0
Lergo/Topas vs R-line	1	645830	60847	12.8
Error	44	728720	23720	9.9
		Point 1988		
Lergo/Dp6-6 vs A-line	1	682210	104052	36.3 *
Lergo/Dp6-6 vs Lergo	1	1562760	11434	3.9
Lergo/Dp6-6 vs R-line	1	1054460	529279 **	54.2 **
Lergo/Topas vs A-line	1	4688780 **	303	27.4 *
Lergo/Topas vs Lergo	1	7970	39295	7.6
Lergo/Topas vs R-line	1	97670	178385	43.2 *
Error	44	562230	66244	6.7

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 9. Mean squares and degrees of freedom for yield and yield related traits in hybridity experiments

	df	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
		Arboretum 1986		
Replication	2	11067550 **	794929 **	50.4 **
Hybrid	1	69120	35051	7.0
Treatment	7	5206660 *	161640	13.5 *
H x T	7	1534400	145873	11.1
Error	30	1957640	140230	5.0
		Point 1986		
Replication	2	1169320	79426	6.9
Hybrid	1	2813730 *	2132242 **	135.7 **
Treatment	7	1131740 *	123484	16.1 *
H x T	7	505870	83603	15.0 *
Error	30	484480	77851	6.3
		Arboretum 1988		
Replication	2	1017840	182450 **	56.9 **
Hybrid	1	30708290 **	1699268 **	126.8 **
Treatment	9	542430	217665 **	105.9 **
H x T	9	460040	29794	7.0
Error	38	630400	19560	9.2
		Point 1988		
Replication	2	10452410 **	354071 **	2.6
Hybrid	1	24418130 **	1373361 **	22.7
Treatment	9	870660	78329	26.7 **
H x T	9	895440	25485	1.6
Error	38	453090	62442	7.0

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 10. Mean squares for single degree of freedom contrasts for quality traits of components used in the hybridity experiments

	df	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll[1] (ppm)
		Arboretum 1986			
Lergo/Dp6-6 vs A-line	1	10.4 **	1.0	5.0 *	-
Lergo/Dp6-6 vs Lergo	1	0.0	1.0	0.7	-
Lergo/Dp6-6 vs R-line	1	9.4 **	0.2	7.0 *	-
Lergo/Topas vs A-line	1	18.0 **	6.0 **	3.2	-
Lergo/Topas vs Lergo	1	0.8	0.2	0.2	-
Lergo/Topas vs R-line	1	16.7 **	3.5	4.9 *	-
Error	36	0.7	1.1	1.1	-
		Point 1986			
Lergo/Dp6-6 vs A-line	1	4.0 *	6.8 *	0.4	-
Lergo/Dp6-6 vs Lergo	1	0.3	0.2	1.1	-
Lergo/Dp6-6 vs R-line	1	3.5 *	0.2	5.6 *	-
Lergo/Topas vs A-line	1	16.0 **	12.6 **	0.2	-
Lergo/Topas vs Lergo	1	6.6 **	0.2	4.5 *	-
Lergo/Topas vs R-line	1	15.0 **	0.2	11.8 **	-
Error	36	0.7	0.9	0.9	-
		Arboretum 1988			
Lergo/Dp6-6 vs A-line	1	19.8 **	7.3 **	3.1 *	1791.1 **
Lergo/Dp6-6 vs Lergo	1	3.4 *	1.0	0.7	34.0
Lergo/Dp6-6 vs R-line	1	10.1 **	0.8	5.2 **	27.0
Lergo/Topas vs A-line	1	15.4 **	2.7 *	5.2 **	2051.2 **
Lergo/Topas vs Lergo	1	1.7	0.0	1.9	84.7
Lergo/Topas vs R-line	1	7.0 **	0.0	7.9 **	72.2
Error	44	0.7	0.4	0.5	220.3
		Point 1988			
Lergo/Dp6-6 vs A-line	1	10.9 **	6.4 *	0.6	15.0
Lergo/Dp6-6 vs Lergo	1	3.1 *	3.2	0.0	122.3
Lergo/Dp6-6 vs R-line	1	0.9	1.9	5.4 **	180.8
Lergo/Topas vs A-line	1	22.0 **	7.7 **	3.7 **	93.1
Lergo/Topas vs Lergo	1	0.1	2.4	1.4 *	604.4 *
Lergo/Topas vs R-line	1	5.4 *	1.3	12.0 **	727.5 *
Error	44	0.8	0.9	0.3	103.7

(1) The error degrees of freedom for chlorophyll at the Arboretum in 1988 are 40.
- Data was not collected for this variable in this experiment.
*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 1 TABLE 11. Mean squares and degrees of freedom for quality traits in hybridity experiments

	df	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll[1] (ppm)
		Arboretum 1986			
Replication	2	12.4 **	8.4 **	4.6 *	-
Hybrid	1	3.2 *	0.4	1.1	-
Treatment	7	2.1 *	1.2	0.4	-
H x T	7	1.6	1.2	0.4	-
Error	30	0.7	1.0	1.2	-
		Point 1986			
Replication	2	8.1 **	10.0 **	1.2	-
Hybrid	1	2.7	0.0	2.6	-
Treatment	7	1.8	0.7	1.3	-
H x T	7	2.3 *	1.7	1.3	-
Error	30	0.8	0.8	1.0	-
		Arboretum 1988			
Replication	2	0.7	1.2 *	2.6 *	372.3
Hybrid	1	14.7 **	9.9 **	0.5	235.7
Treatment	9	5.6 **	1.1 *	2.0 **	663.4 **
H x T	9	1.0	0.3	0.6	75.3
Error	38	0.6	0.4	0.5	182.3
		Point 1988			
Replication	2	26.1 **	25.2 **	1.4 *	290.8
Hybrid	1	12.5 **	7.8 **	0.6	1150.4 *
Treatment	9	7.2 **	3.8 **	0.7	63.0
H x T	9	0.8	1.2	0.3	20.2
Error	38	0.7	0.8	0.3	115.2

[1]The error degrees of freedom for chlorophyll at the Arboretum in 1988 are 34.
- Data was not collected for this variable in this experiment.
*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 2.

APPENDIX 2 TABLE 1. Mean squares and degrees of freedom for phenological traits in seeding rate experiments

Source	df	Days to flowering	Days to maturity	Seed formation period (days)
		Arboretum 1986		
Replication	2	0.1	5.0 *	5.1 *
Cultivar	5	14.4 **	17.9 **	1.7
Seeding rate	3	8.6 **	4.8 **	0.8
linear	1	21.4 **	9.4 **	2.4
quadratic	1	2.2 *	3.0	0.1
cubic	1	2.3 *	1.9	0.0
C x S	15	0.8	0.5	0.8
Error	46	0.4	1.1	0.8
		Point 1986		
Replication	2	0.5	1.3	2.3
Cultivar	5	10.3 **	6.3 **	5.3 **
Seeding rate	3	0.5	0.4	0.3
linear	1	1.3 *	0.6	0.2
quadratic	1	0.0	0.2	0.4
cubic	1	0.0	0.4	0.2
C x S	15	0.3	1.1	1.6
Error	46	0.2	0.8	1.0
		Arboretum 1987		
Replication	2	15.7 **	17.6 **	1.2
Cultivar	5	22.9 **	21.5 **	9.3 **
Seeding rate	4	3.5	2.3	1.3
linear	1	8.6 *	6.3	0.2
quadratic	1	1.2	0.8	4.0
cubic	1	3.1	0.7	0.9
C x S	20	0.6	1.7	1.6
Error	58	1.6	2.4	2.4
		Point 1987		
Replication	2	22.5 **	75.6 **	97.0
Cultivar	5	18.0 **	30.0 **	3.8
Seeding rate	4	6.4 **	8.5 **	1.3
linear	1	25.1 **	30.0 **	0.2
quadratic	1	0.1	1.9	1.2
cubic	1	0.0	0.6	1.0
C x S	20	1.5	1.0	1.7
Error	58	1.0	1.4	1.8

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 2 TABLE 2. Mean squares and degrees of freedom for agronomic traits in seeding rate experiments

Source	df	Plants m^{-2}	Survival (%)	Height (cm)	Lodging (1-5)
			Arboretum 1986		
Replication	2	-	-	129.1 **	0.7
Cultivar	5	-	-	157.6 **	3.5 **
Seeding rate	3	-	-	67.0 *	2.9 **
linear	1	-	-	157.5 **	5.9 **
quadratic	1	-	-	7.1	0.5
cubic	1	-	-	36.8	2.3
C x S	15	-	-	26.5	0.3
Error	46	-	-	21.6	0.5
			Point 1986		
Replication	2	-	-	129.5	4.3
Cultivar	5	-	-	823.7 **	2.2
Seeding rate	3	-	-	95.2	2.4 **
linear	1	-	-	278.0 *	6.8 **
quadratic	1	-	-	6.8	0.3
cubic	1	-	-	0.9	0.1
C x S	15	-	-	28.2	0.6
Error	46	-	-	56.3	0.6
			Arboretum 1987		
Replication	2	275.1 *	999.0 **	239.7 **	2.7 *
Cultivar	5	772.1 **	63.3	916.6 **	2.7 **
Seeding rate	4	5315.5 *	1101.1 **	8.6	2.3 *
linear	1	20293.6 **	3872.6 **	9.6	8.3 **
quadratic	1	859.4 **	104.9	21.9	0.1
cubic	1	83.8	413.9	0.0	0.5
C x S	20	106.5	175.2	18.2	0.6
Error	58	74.7	144.8	30.9	0.6
			Point 1987		
Replication	2	229.8 **	341.5 *	238.6 **	14.7 **
Cultivar	5	1319.2 **	432.7 **	1079.5 **	10.1 **
Seeding rate	4	5653.6 **	1339.3 **	251.9 **	9.1 **
linear	1	21323.9 **	5248.2 **	951.2 **	34.6 **
quadratic	1	1214.6 **	94.2	1.7	1.3 *
cubic	1	34.9	14.2	1.9	0.0
C x S	20	22.0	133.0	52.8	0.6 *
Error	58	41.8	102.1	38.0	0.3

- Data was not collected for this trait in this experiment.
*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 2 TABLE 3. Mean squares and degrees of freedom for yield and yield related traits in seeding rate experiments

Source	df	Total dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
		Arboretum 1986		
Replication	2	2349260	21550	20.0
Cultivar	5	19649580 **	831295 **	174.6 **
Seeding rate	3	309030	31343	4.8
linear	1	805800	41399	0.5
quadratic	1	59910	49043	13.8
cubic	1	61390	3586	0.1
C x S	15	606990	62610	4.5
Error	46	977110	92181	8.8
		Point 1986		
Replication	2	360620	46819	34.8 *
Cultivar	5	10471940 **	548267 **	15.7 *
Seeding rate	3	781720	164681 **	28.6 **
linear	1	95680	253154 *	78.3 **
quadratic	1	998560	140675	4.8
cubic	1	1250920	100215	2.7
C x S	15	334810	38293	2.8
Error	46	529600	38031	5.0
		Arboretum 1987		
Replication	2	5218370	342400	5.3
Cultivar	5	16744440 **	270085	177.0 **
Seeding rate	4	2827580 **	1186247 **	40.4
linear	1	81401530 **	1924243 **	18.8
quadratic	1	27360970 **	1814771 **	16.0
cubic	1	4030	725072	111.4 *
C x S	20	3208040	180874	19.4
Error	58	2194360	241886	25.2
		Point 1987		
Replication	2	29733300 **	2971812 **	109.1 **
Cultivar	5	43983890 **	591103 **	152.6 **
Seeding rate	4	4882380	135529	4.2
linear	1	8679200	300993	1.2
quadratic	1	9753570	202089	5.0
cubic	1	1096750	38255	10.6
C x S	20	1660410	138138	11.1
Error	58	2510140	119947	9.9

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 2 TABLE 4. Mean squares and degrees of freedom for quality traits in seeding rate experiments

Source	df	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll (ppm)
		Arboretum 1987			
Replication	2	9.7 **	4.4	4.5	184.4 **
Cultivar	5	30.1 **	25.1 **	14.3 **	169.5 **
Seeding rate	4	0.6	1.4	0.6	31.4
linear	1	0.7	0.7	0.0	33.0
quadratic	1	0.0	0.6	0.8	19.9
cubic	1	1.2	0.4	0.2	55.7
C x S	20	0.7	2.4	1.1	14.7
Error	58	1.3	1.7	1.6	29.5
		Point 1987			
Replication	2	66.3 **	76.4 **	1.5 *	1105.0 **
Cultivar	5	25.9 **	67.8 **	16.9 **	306.7 **
Seeding rate	4	0.9	0.9	0.6	10.3
linear	1	1.2	0.5	0.1	0.5
quadratic	1	0.0	2.0	1.8	1.0
cubic	1	2.2	0.7	0.4	0.9
C x S	20	0.7	0.4	0.2	23.7
Error	58	0.7	0.9	0.3	25.0

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 3.

APPENDIX 3 TABLE 1. Mean squares and degrees of freedom for phenological traits in the nitrogen fertilizer experiment

Source	df	Days to flowering	Days to maturity	Seed formation period (days)
Replication	3	2.0	20.0 **	10.9 **
Fertilizer rate	3	31.4 **	90.5 **	16.9 **
linear	1	83.1 **	225.9 **	35.0 **
quadratic	1	9.6 *	45.6 **	13.3 *
cubic	1	1.4	0.2	2.5
Error a	9	1.2	1.7	1.4
Seeding rate	1	38.3 **	28.1 **	0.8
F x S	3	0.4	0.3	1.5
Error b	12	1.9	2.5	1.5
Cultivar	3	43.5 **	23.9 **	17.1 **
F x C	9	1.2	0.3	1.5
S x C	3	1.8	2.3	0.6
F x S x C	9	0.5	0.8	1.3
Error c	72	1.0	1.6	1.6

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 3 TABLE 2. Mean squares and degrees of freedom for plant stand traits in the nitrogen fertilizer experiment

Source	df	Plants m^{-2}	Establishment (%)	Survival (%)
Replication	3	423.7 *	1286.9 **	35.7
Fertilizer rate	3	111.8	237.4	31.4
linear	1	192.9	575.1	0.6
quadratic	1	109.4	89.1	82.4
cubic	1	33.2	47.9	11.1
Error a	9	67.9	131.3	36.0
Seeding rate	1	13522.2 **	2879.1 **	105.2
F x S	3	33.4	112.8	122.4
Error b	12	23.4	116.0	61.8
Cultivar	3	1011.3 **	5039.2 **	32.8
F x C	9	37.1	83.7	34.4
S x C	3	115.6 *	99.2	36.0
F x S x C	9	23.0	96.0	22.6
Error c	72	32.4	131.9	31.9

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 3 TABLE 3. Mean squares and degrees of freedom for agronomic traits in the nitrogen fertilizer experiment

Source	df	Vigor (1-5)	Height (cm)	Lodging (1-5)
Replication	3	1.4	99.7	0.6
Fertilizer rate	3	8.9 *	160.9	7.3 **
linear	1	24.8 **	317.7	19.6 **
quadratic	1	0.9	161.5	1.5
cubic	1	0.9	3.6	0.8
Error a	9	1.5	78.8	0.4
Seeding rate	1	23.6 **	114.4	1.3
F x S	3	0.0	31.7	1.4 **
Error b	12	0.5	36.1	0.3
Cultivar	3	0.4	750.6 **	0.9 *
F x C	9	0.5	10.3	0.1
S x C	3	1.9 *	72.0	0.7 *
F x S x C	9	0.3	45.7	0.3
Error c	72	0.5	30.6	0.2

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 3 TABLE 4. Mean squares and degrees of freedom for yield and yield related traits in the nitrogen fertilizer experiment

Source	df	Total dry matter (kg ha^{-1})	Sedd yield (kg ha^{-1})	Harvest index (%)
Replication	3	16148540 *	2366279 **	66.9 **
Fertilizer rate	3	42626200 **	2428116 **	9.4
linear	1	63269950 **	4409143 **	10.9
quadratic	1	51015180 **	2746190 **	0.0
cubic	1	13593470 *	129014	17.3
Error a	9	2560880	80978	4.6
Seeding rate	1	708800	124630	0.1
F x S	3	2829150 *	192315	12.7
Error b	12	805920	87341	6.3
Cultivar	3	9970770 **	1158695 **	67.3 **
F x C	9	1376800	108499	10.3
S x C	3	3448220	254792	8.8
F x S x C	9	2094600	55691	1.2
Error c	72	2408100	145732	5.7

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 3 TABLE 5. Mean squares and degrees of freedom for yield components in the nitrogen fertilizer experiment

Source	df	Pods plant-1	Seeds pod-1	1000-seed weight (g)
Replication	3	95.5	88.98 *	0.024
Fertilizer rate	3	4067.9 **	203.82 **	0.009
linear	1	5163.3 *	537.32 **	0.002
quadratic	1	6576.4 **	59.29	0.000
cubic	1	463.8	14.87	0.025
Error a	9	538.7	15.31	0.060
Seeding rate	1	20156.1 **	5.72	0.001
F x S	3	533.0 *	46.70	0.032
Error b	12	142.5	18.42	0.023
Cultivar	3	6746.6 **	8.13	0.441 **
F x C	9	418.6	4.20	0.033
S x C	3	99.1	4.80	0.007
F x S x C	9	297.1	3.06	0.012
Error c	72	491.3	4.57	0.019

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

APPENDIX 3 TABLE 6. Mean squares and degrees of freedom for quality traits in the nitrogen fertilizer experiment

Source	df	Oil (%)	Protein (%)	Protein + oil (%)	Chlorophyll (ppm)
Replication	3	4.7 *	14.7 *	3.1 *	26.4
Fertilizer rate	3	80.6 **	141.2 **	9.3 **	86.5 **
linear	1	216.4 **	397.5 **	27.3 **	243.8 **
quadratic	1	23.0 **	25.1 **	0.0	15.6
cubic	1	2.5	0.8	0.4	0.0
Error a	9	1.2	1.5	0.6	8.6
Seeding rate	1	3.0	0.6	0.9	13.6
F x S	3	0.9	2.1	0.4	8.1
Error b	12	2.0	2.0	0.4	8.0
Cultivar	3	22.1 **	10.0 **	15.8 **	65.3 **
F x C	9	1.1	1.6	0.2	5.6
S x C	3	1.2	1.1	0.0	3.2
F x S x C	9	0.7	0.9	0.3	5.7
Error c	72	1.0	1.4	0.5	3.5

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.