

**THE EFFECTS OF PLANTING DATE AND DENSITY ON GROWTH, DEVELOPMENT
AND YIELD OF TWO CANOLA (*BRASSICA NAPUS L.*) CULTIVARS GROWN UNDER
IRRIGATED CONDITIONS**

By

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Submitted in fulfillment of the requirements for the award of degree of

**MASTER OF SCIENCE IN AGRICULTURE,
In the Department of Crop Science,
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Date Submitted

January 2010

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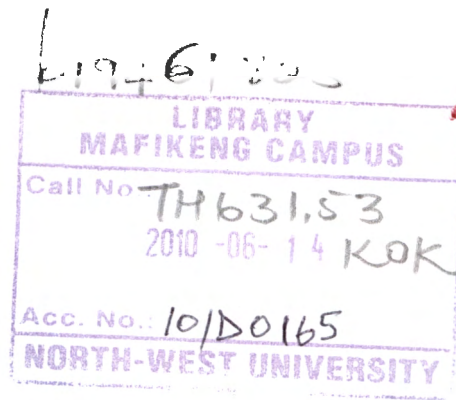
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ABSTRACT

The effects of planting date and density on growth, development and yield of two canola (*Brassica napus* L.) cultivars (Hyola 60 and Rainbow) grown at two planting dates was studied during the 2005 and 2006 growing seasons at the Agricultural Research Council- Grain Crops Institute in Potchefstroom in the North-West Province. A field study was conducted during the two growing seasons. The treatments included the two planting dates (Early and Late), two canola cultivars (Hyola 60 and Rainbow) and four planting densities (in-row spacing of 10, 20, 30, and 45 cm) for 2005 growing season, and for 2006 growing season, a hybrid cultivar was used (Hyola 61 and Rainbow) and planting densities (10, 20, 35, and 60 cm) respectively. The objective of this study was to assess the effect of planting date and density on growth, development and yield of two canola cultivars. The experiment was laid out according to Randomised Complete Block Design (RCBD) with a split-split plot arrangement having three replicates. Each plot was 9m long and 3m wide. There were eight rows per plot spaced 38 cm apart. A single super phosphate (10.5% P) fertilizer was broadcast at a rate of 25 kg/ha just before planting and incorporated into the soil. LAN (28% N) at a rate of 200 kg N/ha (1.93 kg N/plot in 3 slots) was applied at different growth stages. The crop was harvested when seeds had about 35% moisture. Data collected included days to 90% germination, number of days to 50% flowering, dry matter accumulation, number of plants/m², number of pods/plant, number of seeds/pod, protein and oil content, grain yield, plant height, and 1000-seed weight. The data were subjected to Analysis of Variance procedures of GenStat. The results of this study showed that early planting of canola produced high yield of seed and oil. Increasing planting density in general resulted in a significant increased in vegetative yield, grain yield and plant height but a decrease in number of days to 50% flowering and number of pods/plant. Planting density had no effect on protein and oil contents. Cultivars used in this study responded to treatments the same way except for variables such as dry matter yield, plant height, number of days to 50% flowering, protein and oil contents. Cultivar Rainbow produced significantly the highest amount of protein and oil contents and was the earliest cultivar to flower, whereas, cultivars Hyola 60 had the highest dry matter yield and was the tallest cultivar. In conclusion, sowing canola in May and at the highest plant density (10cm in-row spacing) is recommended for maximizing seed and oil yields under environmental conditions of this study.

ACKNOWLEDGEMENTS

This study was conducted with the permission from the ARC- Grain Crops Institute. I would like to acknowledge and extend my heartfelt gratitude to the following people who made the completion of this study possible. Firstly, I would like to thank my mentor Dr. A.A Nel for his vital encouragement and support throughout this study. My supervisor, Professor S.M Funnah for his supervision, suggestions and constant reminders and much needed motivation in preparing this manuscript. Sincere thanks to the National Research Foundation (NRF) for funding the study. I would also like to extend very special thanks to my husband, sisters for their unfailing love, encouragement and comfort, and my two daughters for putting up with the pain of doing without me during the course of my studies. Thanks to the technical staff at ARC-GCI for helping me in the field work and for helping me during critical times. Finally I would like to thank God, for providing me his salvation, love, wisdom, knowledge, courage and comfort to complete this degree.

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LIST OF ABBREVIATIONS AND SYMBOLS

ARC	Agricultural Research Council
CV	Coefficient of variance
cm	Centimeter
g	Gram
ha	Hectare
ha ⁻¹	per Hectare
K	Potassium
Kg	Kilogram
m	Metre
m ²	Square metre
N	Nitrogen
Ns	Not significant
P	Phosphorus
%	Percentage
mm	Millimeter
⁰ C	Degree Celsius
LAN	Lime ammonium nitrate
ml	Millilitre
h	hour
H ₂ O	Water
LSD	Least significant difference
WAP	Weeks after planting
NIR	Near infrared spectroscopy

CHAPTER 1

1. INTRODUCTION

Canola (*Brassica napus* L.) is now the second most important source of vegetable oil in the world, after soybean (Raymer, 2002). It has passed peanut, cottonseed and most recently, sunflower, in the worldwide production. This is due to the erucic acid in the oil and glucosinolates in the meal, making it a high value oil and protein crop (Raymer, 2002). Its seeds are used to produce edible oil that is fit for human consumption because it has the lower levels of erucic acid than traditional rapeseed oils, and to produce livestock feed because it has reduced levels of the toxin glucosinolates. It differs from standard or industrial rape because it has less than 2% erucic acid in the oil and less than 30 micromoles of glucosinolates per gram of meal in the oil-free meal (Thacker, 1990). These two quality standards allow canola to be used as a healthy cooking oil and the remaining meal as a high quality protein supplement for livestock. It is also appealing to health conscious consumers because it has the lowest saturated fat content of all major edible vegetable oils (Boyles, Peeper and Stamm, 2006).

Canola is relatively a new crop in South Africa. It was first introduced in South Africa in 1994 and its production is increasing rapidly in the Western Cape Province of South Africa (Mosiane, 2002). It is mainly planted in the South-Western Cape for its oil, on small scale, for seed production in the Free State and Northern Cape. It competes with other plant oils, mainly sunflower oil and soya oil, on the local market. South Africa is a net importer of plant oils. Approximately 300 000 to 350 000 tons of plant oils are produced in South Africa and the balance is imported primarily as sunflower oil and soya oil. According to the Animal Feed Manufacturers Association (AFMA), over 700 000 tons of oilcake of soybean is imported annually. An increase in local canola production can alleviate the dependence on imported protein and oil. The market for bottled canola oil also has a room for growth because it is not well known among consumers and the industrial deep-frying market. Therefore, the production of canola in South Africa is expected to grow in future because the local demand for canola exceeds the local supply and good prices are therefore expected.

Since canola is a relatively new crop in South Africa, the correct planting date and planting density of this crop have to be studied in detail. Ensuring the highest probability for profitable production of canola requires making effective planting decisions. Among those decisions are selecting proper date, method of planting and seeding rate to obtain optimum plant population. Information is

required to determine the optimum sowing time and seeding rate conducive to the production of high seed and oil yields, so that if canola is to become an important crop locally, there is a need to disseminate information on this aspect to our local farmers. Canola production, like the production of other oilseeds, will have to grow in the coming years to meet increasing demand in the world. Planting density and time of planting for canola can influence crop productivity, winter survival potential, competitiveness to weeds, maturity date and potential insect damage (Guy and Moore, 1995). The successful establishment of a desired plant population at the appropriate time in the growing season is the first step in determining crop productivity.

Planting date is an important factor that determines the length of the growing season and hence the yield. The correct date of planting is the next important factor to consider after the site for planting canola is selected (Ellsworth et al., 1995). Most farmers and agronomists recognize the advantage of the earliest feasible planting dates for increased crop yield potential. Increased yield potential is due to uniform seed development, less competition from weeds, less lodging, fewer green seeds at harvest and reduced risk of frost injury (Robertson and Holland, 2001). Typically, there is a gradual yield decline followed by a more rapid decline when seeding is further delayed, depending on crop type and variety. The main reasons for the decline are the shortened vegetation and grain filling periods, as well as lower water use efficiencies.

Numerous research projects have examined the effect of the planting date on canola production (Robertson et al., 2004; Gusta et al., 2003; Wright et al., 1988; Taylor and Smith, 1992; Hocking, 1993; and Hocking and Stapper, 2001). Although there are yearly variations in climatic conditions, research over several years and locations indicates that early seeded canola outperforms later seeded canola. In some locations and years, late seeding in early spring may be the only option due to rainfall. However, a wide variability has been found in the rate of yield decline as a response to sowing date. The goal of early planting is for the crop to get through its first two weeks of flowering and initial seed production without significant heat or moisture stress. This will result in higher seed yields (Robertson et al., 2004).

Planting density is another important factor controlling yield. Seed yield of canola is a function of population density, number of pods per plant, number of seeds per pod, and seed weight. However, yield structure is very plastic and adjustable across a wide range of plant populations (Diepenbrock, 2000). Plant density can also influence quality, lodging, winter survival, and weed competitiveness. Previous studies have shown that plant density is an important factor affecting canola yield.

Therefore, plant population should be based on variety, agronomic characteristics and the soil types (Leach, Stevenson, Rainbow and Mullen, 1999). Achieving the right plant density at sowing is seen as a major challenge for canola growers in South Africa. However, canola can grow well and flower as long as conditions are right and plants will develop larger canopies to compensate for lower than ideal plant populations provided there is sufficient moisture available. Canola has the ability to compensate for low plant populations and therefore, achieving the correct population is not as critical as crops like maize, beans and sugar beets. However, the process of compensation delays development, allowing space for weeds and consequently, reduces yield potential compared to a uniform, densely populated crop stand.

Cultivars presently grown in South Africa originate from Australia and currently, there is limited information on the performance of cultivars under South African conditions. New varieties are introduced annually, and continue to hit the market as breeders push the boundaries for yield, agronomic and nutritional benefits. In Southern Australia, they found a varietal response to time of sowing, with early sowing tending to reduce the yields of varieties with a high level of early vigour but increase the yield of less vigorous varieties; apparently because the vigorous varieties use most of the available moisture during the vegetative stage, leaving little for use during flowering and pod set. The choice of most suitable canola cultivars for any situation will often follow a consideration of maturity, herbicide tolerance, blackleg resistance and early vigour together with relative yield and oil content (Potter, 2009).

Other factors that need to be considered when selecting a variety include pod shattering resistance and lodging tolerance. More attention is paid to hybrid cultivars, which on average yield 10 to 15% more than conventional types, while conventional types on the other hand produce higher yields than Triazine Tolerant (TT types) and Imidazolinone Tolerant (IT or clearfield types) if no herbicide resistant weeds are present. However, a new variety must only be considered after it demonstrates its adaptability over multiple locations and multiple years. New cultivars have much higher yield potential than conventional canola cultivars and changes in production practices may be needed to achieve optimum yield from these cultivars. At present data are not available with regard to the response of canola cultivars grown in the North-West province of South Africa to planting date and density (Potter, 2009), and the investigation was aimed to study the effect of different planting densities on growth and yield of canola cultivars for early and late planting dates

1.1 Objectives

- To evaluate the effects of planting dates and density on growth, development and yield of two canola cultivars under irrigated conditions.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Canola

Canola (*Brassica napus* L.), belongs to the Cruciferae family, also known as the mustard family. It is closely related to other *Brassica* species such as cabbage, cauliflower, broccoli, brussels sprouts, turnip, kale as well as brown and oriental mustard (Thomas, 2001). The name crucifer comes from the shape of flowers, with four diagonally opposite petals in the form of a cross. The stems are well branched, although the degree of branching depends on the variety and environmental conditions, branches originate from the axils of the highest leaves on the stem, and each terminates in an inflorescence. Canola varieties have been developed into two types, the oil-yielding oleiferous rape, often referred to in Canada as Argentine rape, of which canola is a type having specific characteristics, and the tuber-bearing swede or rutabaga. The oleiferous type can also be subdivided into spring and winter forms (Canadian Food Inspection Agency, 1994).

Canola is a herbaceous plant which produces small, black, brown or yellow coloured seeds. Although the crop is described as related to cabbage, it is mainly grown for seed for the production of oil, oilcake or consumption of whole seed in animal feed blends. It is distinguished from other forms of rapeseeds by its low levels of erucic acid (a long chain fatty acid found in edible vegetable oil that can cause adverse health effects if consumed in large amounts) and glucosides (toxic sulfur compounds contained in oil meal that if consumed in large amounts, could be injurious to livestock) (Bandell, Mulford, Ritter, Kantzes and Hellman, 1991). Each canola plant grows to a height of 1 to 2m, and produces yellow flowers that, in turn, produces pods that are about 5cm in length. Each pod contains 20 to 30 round seeds. The seeds when crushed contains about 40% oil and approximately 36% protein (Kimber and Mc Gregor, 1995).

2.1.1 Uses of canola

Canola is a popular crop throughout the world because of its variety of uses and the nutritional value compared to competing crops. It has many uses both edible and inedible. It is a special type of oilseed rape and its oil is used as a salad, cooking oil and is useful in confectionery companies. The meal after oil extraction is used as a protein supplement in dairy, beef, swine and poultry rations and is recognized for its consistent quality and value. In addition, it is traditionally used for birdseed or as a potential feedstock for bio-diesel production. High oleic, low linolenic (HOLL)

varieties are grown for use in the fast-food industry, while so called industrial types, mostly Indian mustard (*Brassica juncea*), are tested for use in applications such as bio-diesel, plastics, lubricants, lacquers and detergents. These varieties have high levels of toxic glucosinolates and erucic acid, which renders the processed meal unsuitable for human or livestock consumption (Johnson and Croissant, 2004).

2.1.2 History

Many *Brassica* species have been under cultivation since prehistoric times for their edible roots, stems, leaves, buds, flowers and seeds. Canola was developed through hybridization of rapeseed (Bandell et al., 1991). Rapeseed crops have been grown for thousands of years from 2000 BC until in the 1940's when it was grown for lamp fuel, cooking oil and as a forage. It is believed that canola must have originated in Southern Europe from where it was introduced into Asia in the early 18th century (Downey and Robbelen, 1989). The crop is now widely grown in Canada, North, Central and South America, Asia, former USSR, Oceania and Africa (FAO, 1994 and Verheijen, 1995). Increasing world population and improving standards of living tend to promote its production and use. It is a major edible oil in China, India, Japan, Canada and many European countries.

2.1.3 Importance

The production of canola is expanding faster than any other oilseed crop. It is rapidly becoming one of the most important sources of vegetable oil and protein in the world. It also plays an important role as a break-crop in a sustainable production system with small grain crops in the Western Cape Province of South Africa (Mosiane, 2002). It is an excellent crop for rotation to minimize the build-up of noxious weeds, pests and diseases. Canola has the deep tap root that loosens the soil, thus improving air, water and nutrient movement. This leads to better use of water by follow-up crops, as well as better nitrogen uptake, in turn reducing the risk of soil acidification and water-logging. Research has shown that anytime canola is added to rotation, the companion crop will generally yield better, and pest pressures will be reduced (Mendham and Salisbury, 1995). The winter annual type of canola provides an excellent rotation crop with wheat, and can be used as the first crop in double crop systems, such as canola-bean and canola-sorghum.

Canola is a broad-leaf plant which protects the soil from erosion better than wheat. It grows better in areas that receive more than 300mm of rainfall, well-drained soil that also has a good potential for growing wheat. Canola seed yield and percentage oil content increase with the amount of water

or rainfall it receives. Water stress during the flowering stage has a severe impact both on seed yield and percentage oil content. Therefore, in seasons with low or no rainfall at all, the crop needs to be supported by irrigation (Steyn, 1997). If the crop is to be irrigated, an appropriate change in seeding rate and row spacing is necessary (Aiken and Lamm, 2006).

2.1.4 Adaptation

Canola is a cool season crop, not as drought tolerant as the cereals. It is widely adapted, and performs well in a range of soil conditions, provided that moisture and fertility levels are adequate. The size of the area of adaptation and the development of varieties with improved quality have permitted canola to become the major edible oilseed crop around the world. Air and soil temperature influence canola plant growth and productivity (Canadian Food Inspection Agency, 1994). Because canola is a relatively cool season crop, it grows best within the range of 12°C and 30°C with an optimal temperature of 20°C (Thomas, 2001). The threshold temperature (or base temperature) for canola below which little significant plant growth occurs is 5°C. After emergence, seedlings prefer relatively cool temperatures up to flowering, high temperatures at flowering will hasten the plant's development, reducing the time from flowering to maturity. A canola plant takes about 3.5 months to grow depending on temperature, moisture, sunlight and soil fertility. Its flowers are bright yellow and in full bloom the field is colorful. The plant produces more flowers than its capacity for setting pods. Thus, there is usually a high incidence of floral abscission. Seed size varies with variety and environmental conditions (Murdock et al., 1992).

Like many small grains, canola comes in two types, winter and spring canola. Both spring and winter types are developed under ideal conditions. Winter types have greater yield potential than spring types, and are harvested only two weeks later because of summer heat. The areas that are suitable for winter barley are also suitable for winter canola (Ernst, 2003). Winter type, *Brassica napus* is the main oilseed rape crop in most parts of Europe and China (FAO, 1994; Verheijen, 1995). In Australia and Southeastern United States, where winters are mild, spring type can be grown as a fall-planted crop. Yield of canola is highest when grown in areas where there is no extreme heat and moisture limitations. In general, best results are guaranteed when the proper balance of inputs is tailored to the particular soil and climatic conditions involved (Shahidi, 1990). For example, maximum returns from good quality seed and fertilizer are reached only when integrated with other management practices such as effective pest control measures. The growth rate of the crop is also closely related to the amount of solar radiation captured by the leaves. Depending on the variety and sowing date, between 9 and 30 leaves are produced on each main

stem. Leaves senesce and are shed rapidly from late flowering onwards (Hocking and Mason, 1993).

2.1.5 Production

Oilseeds and their production are the most valuable agricultural crops in the world trade. The global production of oilseeds has grown approximately 30% over a decade. Since canola oil is a potential feedstock for bio-diesel its production areas are increasing rapidly to meet this growing demand. Canola is a management-responsive crop. Weather certainly plays a role in canola yields, but management makes the difference between average and above average yields (Clayton, Turkington, Harker, O'Donovan and Johnson, 2000). Effective canola production requires hands-on involvement with the crop. While weather conditions vary considerably from year to year, many of the management practices that support high yielding canola are also important and within the control of the grower. According to the National Department of Agriculture (2000), the production of canola is more profitable compared to wheat as the price of canola is almost double that of the wheat, although yield obtained with canola are generally not more than 50 to 55% of that obtained with wheat.

2.1.6 Seedbed preparation

A proper seedbed preparation is essential to establish a solid, uniform stand of canola. Since the seed is quite small, a clean and level seedbed that is granular, with good moisture is necessary to provide good-seed-to-soil contact for rapid emergence (Berglund and McKay, 2002). Canola can be grown on most soil types. It is best suited to clay-loam soils that do not crust. A medium textured, well-drained soil with moderate to high water holding capacity is considered best for canola. It can either be broadcast or drilled. Drilling is the most reliable and preferred method of planting (Murdock et al., 1992). Canola is sometimes grown in rows with spacing wide enough to allow for mechanical cultivation.

A proper long-term crop rotation will ensure the soil is being adequately prepared for specific crops. Canola seed is very small and young seedlings require assistance to advance from germination through to the three and four leaf stage. This period is critical in determining final yield potential (Mendham and Salisbury, 1995). Canola requires a uniform, vigorous young stand for optimum yield. Seedling losses and uniformity of establishment are influenced by seedbed conditions at the time of sowing (Daniels et al., 1986). Crop rotation, trash management, seedbed preparation, seeding date, seeding rate, fertility and weed control are crucial for uniform crop establishment (Downey, 1983).

2.1.7 Crop growth and development

The growth and development of canola plant is characterized by six main growth stages. Much of the management of this crop is related to the length of time and plant characteristics within each of these stages (Oplinger, Hardman, Gritton, Doll and Kelling; 1989). The length of each growth stage is influenced by temperature, moisture, light, nutrition, variety and the environment. Stage 1 is the pre-emergence stage where the seed has been planted but prior to plant emergence. The seed absorbs water and the root emerges growing downward. The stem (hypocotyl) begins growing, pushing two leaf-like cotyledons (seed leaves) up through the soil. Stage 2 is the seedling stage where the very young plant has just emerged from the soil. The seedling may take four to ten days to emerge. Stage 3 is the rosette stage characterized by an increasing leaf area index. The plant grows rapidly forming a dense canopy of leaves. It quickly establishes a rosette with first and second true leaves at the base increasing in size, and younger leaves developing in the center. Stem length remains the same but its thickness increases. A rosette in at least six to eight leaf stage is preferred. Increasing day length and temperatures initiates the bolting and the beginning of stage 4, the bud stage. The plants reach their maximum leaf area index at this time along with 30 to 60 % of its total dry matter (Oplinger et. al, 1989). The main stem reaches its maximum length just prior to flowering. Rapid development and growth of a large leaf area strongly influences pod set and early seed growth on the main stem and first few secondary branches.

Flowering begins at stage 5 and continues for 14 to 21 days. The first flower begins with the opening of the lowest buds on the main stem. During flowering the plant continues to grow and develop new buds. Full plant height is reached at peak flowering. The length of the flowering stage varies according to the weather conditions. After pollination and fertilization, the flower petals wilt, and drop two to three days later. A young pod becomes visible in the center of the flower a day after petals drop. By mid-flowering, pods located at lower part of the stem have started to elongate. When flowering is complete, the pods start to fill with the seed enlarging. When the lower pods have started elongating, the stem now becomes the major source of food for plant growth with a decline in leaves and small amount from the developing pods (Murdock et al, 1992). Ripening or stage 6 begins when the petals fall from the last formed flower on the upper main stem. Pod fill is complete 35 to 45 days after flower initiation and the seeds contain about 40 % moisture at this point. At full size, the seed initially is somewhat translucent (resembles a water-filled balloon). At this time, the seed's embryo begins rapid development within the seedcoat, filling the space occupied by fluid. This results in a firm, green seed and an increase in seed weight. Seed filling is followed by a maturity or ripening stage characterized by plant colour changes. At

physiological maturity (complete filling) seeds change colour from green to brown to black. When all the seeds in all pods have changed colour, the plant dies.

2.2 Effects of planting date

2.2.1 General background

Planting date is more important for canola than for wheat and the greatest challenge is completing the task by appropriate date (Boyles, Peeper and Medlin, 1990). Seeding date is critical to establishing a crop possessing sufficient growth for good winter survival. It should be done as early as soil conditions permit. Canola is slightly less tolerant to frost and slower to establish than cereal crops. When seedlings emerge, the growing point is between the cotyledon leaves. The seedlings can recover from frost that damages the leaves, provided the growing point remains undamaged (OMAFRA staff, 2002). Early plantings may yield as much as 45% oil, but negative correlations between yield and protein content, are generally found; and late planting does not allow for sufficient root reserves to maximize winter survival (Boyles and Peeper, 1990). It is recommended that canola be planted with the last summer rain from January to March in the Eastern Cape, Kwazulu Natal and the Free State if it to be planted as a dual purpose crop. In The Western Cape it can be planted at the end of February with the first autumn rain (Fouchè, 2009).

2.2.2 Grain yield and yield components

Sowing date is one of the important determinants of yield in canola. The importance of sowing date is for maximizing canola yields especially in those areas where temperature, day length, rainfall and humidity vary throughout the year. However, the magnitude of the decline in yield with delayed sowing has been poorly defined for different environments. In dryland environments there is a trade off between sowing early to avoid end-of-season high temperatures and water deficit, which depresses seed yield and oil concentration. Knowledge of the consequences of delayed sowing for yield, oil concentration and frost risk can be used to define the optimum sowing dates for different varieties, climates and farming systems (Robertson, Holland, Bambach, and Cawthray, 1995). According to Gross (1963), delayed seeding resulted in later maturity, reduction in plant height and reduction in time required for vegetative and reproductive development especially in *Brassica napus*. This indicates that optimum seeding rate may vary with planting date.

The yield response to sowing date is a function of two factors; crop growth period and water stress (Thurling, 1974; Mendham et al. 1981; Hocking and Stapper, 2001). Planting date is the most critical factor in winter canola (Martin, Underman, Stegmeier, and Heer; 2006). Since planting date

is critical, if canola is to be planted too early or late, the crop will be sensitive to frost. Seed yield per hectare is of major importance to the production of any seed crop (Degenhard and Kondra, 1981b).

Seed yield decreases significantly with delayed sowing and this is primarily associated with a reduction in total dry weight of the plant at maturity. Planting too early results in excessive growth and may result in elevation of the growing point above the soil surface. Gross (1963) indicated that delayed sowing limits the size to which the crop grows before the change from vegetative to reproductive development, which in turn controls yield potential (Taylor and Smith, 1992). For example, Robertson et al. (1999) reported a yield decline of 5% per week delay in sowing as an average of several Australian studies. In contrast, planting early in the Western Australia low rainfall locations showed yield reductions from 11 to 7% per week delay in sowing (Richards and Thurling, 1978). These higher reductions were due to a rapid increase in temperatures and water deficit in spring (Fischer, 1979). So, the main area where scientists need to focus their attention is to find out the optimum sowing date for canola cultivation, which results in higher yield of the crop and maximum benefit to the farmers.

2.2.3 Oil content

Canola is highly susceptible to heat and dry weather (Endres and Berglund, 1999). It is a temperate crop. High temperatures have been shown to lower oil content and alter composition of fatty acids in canola. Carvin (1965) reported the effect of temperature on oil content in a growth chamber study with constant temperatures of 10, 16, 21, and 26.5°C imposed from pollination to physiological maturity. Corresponding oil content varied from 32.2 to 51.8%. This represented a 1.2 percentage point reduction in oil content per rise in temperature of 1° C in field studies in dry-land environments. It is difficult to separate the effects of temperature and drought on oil content, particularly as each is often correlated with delayed sowing. High temperatures and /or water deficit during grain filling, associated with late sowing, depress oil content (Walton, 1999; Hocking and Stapper, 2001), causing a decline in the profitability of canola crops. Early sowing is thus particularly important for growing profitable canola in terminal drought environments.

Taylor and Smith (1992) indicated that May was the optimum sowing month for canola and that May sowings were shown to give consistently high yields of seed and oil. Endres and Berglund (1999) also indicated in their studies that oil content declined as planting was delayed

2.2.4 Flowering

The timing of flowering in canola is an important determinant of adaptation to its environment (Farre' et al., 2002). In environments where yield is limited by terminal drought, it is important to identify an optimum flowering date that would allow maximum vegetative development and seeds maturity before the onset of drought stress or high temperatures, which are detrimental to yield and oil content (Thurling, 1974).

2.3 Effects of planting density

2.3.1 General background

In canola, plant densities vary considerably worldwide, depending on the environment, production system and cultivar. Canola can perform very well with high or low populations, depending on the variety, field conditions, soil moisture and fertility (Ozoer, 2003). The actual plant population that become established is extremely variable due to strong influence of seedbed firmness, moisture, temperature, soil texture, depth of seeding, seed vigour, amount of fertilizer with the seed, seed treatment, insects, diseases and other climatic factors (Canola Council of Canada, 2005). The seeding rate chosen depends somewhat upon conditions at the time of seeding. The most common recommendation for canola is a range that normally will provide adequate plant numbers to achieve high yield with minimal risk. Seeding rate outside this range may still produce high yields in some cases but there is also a higher risk of poor yield. Canola is often called a highly flexible or plastic crop because individual plants can change the number and size of branches and pods in response to available moisture, light and nutrients. Therefore, canola normally compensates for variations in plant population over relatively wide ranges with very little effect on final yield (Canola Council of Canada, 2005).

Development, water use and yield formation of canola crops are inter-related. Higher yields are expected with well-established canopy, a plant population sufficient to support a large number of seed set and favourable weather conditions for an extended seed fill period (Aiken and Lamm, 2006). The plasticity of a plant to compensate for suboptimal plant populations depends on the availability of resources such as light, water and nutrients (Sultan, 2000). In particular, the greater the availability of resources, the greater will be the expression of plasticity. Results reported by Stoy (1983) and Sierts et al. (1987) demonstrated that when plants are evenly distributed there are fewer losses as a result of environmental stress. In consequence, yield is most suitable when plants are evenly distributed (Diepenbrock, 2000).

2.3.2 Grain yield and yield components

Plant density in canola governs the components of yield, and thus the yield of individual plants. A uniform distribution of plants per unit area is a prerequisite for yield stability (Diepenbrock, 2000). Seed yield in canola is a function of plant population density, number of pods per plant, number of seeds per pod and seed weight (Angadi et al., 2003). However, yield structure is very plastic and adjustable across a wide range of populations. The number of pods per plant is the most responsive of all the yield components in canola and is determined by the survival of branches, buds, flowers and young pods rather than the potential number of flowers and pods (McGregor, 1981 and Diepenbrock, 2000).

Canola is a rather unique crop in that variation in seeding rate or plant population over relatively wide ranges, have very little effect on yields under favourable conditions. As far as the seed rate is concerned, trials conducted on irrigated canola in Canada, showed that 3 to 6 kg/ha seeding rates are sufficient for high yields. Yield was influenced by row spacing ranging from 16 to 48 cm. Trials conducted by Leach et al. (1999) showed the effect of high plant density in reducing the number of pods per plant as well as dry matter. Moreover, they observed that at very high densities, 1000-seed mass was increased.

Morrison et al. (1990), using seeding rates instead of actual populations, focused on above-optimum plant population range. Thus, under good growing season with adequate moisture in Southern Manitoba, lowest seeding rates of 1.5 to 3.0 kg/ha (35 to 70 plants/m²) were enough to produce maximum grain yield. McGregor (1987) used actual plant populations however, the main objective was to compare yield formation of very low populations (<22 plants/ m²) with the highest population during the season (144 to 200 plants m²). Canola yield plasticity in that study varied widely indicating the importance of weather conditions in the determination of the optimum population. Because of this wide range of plasticity, plant canola population of 80 to 180 plants/m² has been recommended for canola dry-land production in the Canadian prairie (Thomas, 1984).

Seeding rates of 4.5 - 6.5 kg/ha are currently recommended for canola in Canada (Downey et al. 1974). Kondra (1977) found that seeding rates of 6 kg/ha in 5 cm row spacing gave the highest yield. In Switzerland, seeding rates of 6-8 kg/ha were found to be best for canola (Clarke and Simpson, 1978). A seeding rate of 20 kg/ha for summer *B. napus* produced the highest yield in Sweden (Ohlsson, 1960). Number of pods per plant was found to be strongly affected by plant density (Huhn and Schuster, 1975) in winter *B. napus*. The recommended seeding rate for

Argentine canola cultivar is 6.7 kg/ha or 80-150 plants/m². Canola council of Canada's research has shown no significant yield differences between seeding rates of 6.7 kg/ha and 3.4 kg/ha, although decreasing the seeding rates may increase late maturity as the plants develop more side branches with reduced lodging and increased airflow through the canopy, which may decrease the incidence of sclerotinia.

Research studies on the Canadian Prairies have shown that established plant densities ranging from 40 to 200 plants/m² often result in similar yields for both species. In a small number of cases, even lower or higher densities have resulted in unstable yield depending on conditions (Canola Council of Canada, 2005).

2.3.3 Effects of high population density

High plant population has been recommended and adopted to reduce weeds in the early growth stages (Morrison et al. 1990). With high plant population, particularly under drought conditions, competition between plants often results in fewer and smaller pods per plant which are concentrated on the upper part of the plant (Leach, Stevenson, Rainbow and Mullen, 1999). Plants grown at high densities are often more susceptible to lodging and increased disease incidence without the benefit of any yield increase, but the presence of fewer pod-bearing branches should produce more synchronous pod and seed development and result in more uniform seed maturation, improved harvestability and possibly lower seed glucosinolate and higher oil contents (Leach et al., 1999). High seeding rates sometimes produce lower yields and are sometimes used to reduce the amount of straw and improve maturity under high levels of nitrogen.

Bunting (1969) reported that 60 plants/m² was the minimum density required to eliminate a yield response, whereas others (Hodgson, 1979; Bowerman and Rogers-Lewis, 1980) considered 50 plants per square meter to be near the minimum density. Many crops are now sown at higher seeding rates, around 100 plants per square metre being recommended by the Agricultural Development and Advisory Service (1978). This seems to be unnecessarily high, as other published work has also shown little difference between crops sown between 2 and 10 kg seed/ha, or 30-200 established plants per square meter (e. g. Helps, 1971 in England, and Nordestgaard, 1965 in Denmark); plants grown at high density were more prone to winter kill in Sweden (Loof, 1963), as crowding forced growing points above ground level. Lodging during pod development and mildew infection may also be worse on tall crops with weak stems at high density (Mendham and Scott, 1975).

2.3.4 Effects of low population density

Adequate yields can be achieved over a wide range of plant densities (e.g. 8-9 plants/m²; Mendham et al., 1981). Because of low density, crops compensate by producing a greater leaf area, more branches and greater pod number per plant. When population density is low, the individual plants tend to produce more branches that carry fertile pods, thus prolonging the seed development phase. This results in a range of seed maturity at harvest, which may affect seed quality and increase the risk of seed loss through pod shatter and poor harvestability (Leach et al., 1999).

Canopy closure in low plant densities takes longer, and reduces the crop competitiveness with weeds. With the delayed closure, flea beetles, spring frosts, and any other factors that can further reduce plant population can become a great concern. A thin stand can also affect crop performance later in the season. A crop that compensates for a thin stand with increased branching and pod formation also matures later. And since more of the yield is in the branches, it may be necessary to delay swathing beyond the normal recommendation in order to allow the seed in the branches to become firm (Farm Business Communication, 2002).

It has been shown that plant populations of 20-30 plants/m² produce yields comparable to crops with only 9-10 plants/m² if the plants are healthy and evenly distributed (Mendham et al., 1981). This means that canola is able to produce similar grain yields across a range of plant densities in weed-free situations (McGregor, 1987, Morrison et al., 1990 and O'Donovan, 1994). Examinations of yield components has shown that canola can compensate to a considerable degree for reduced plant density by increasing the number of pods per plant (Huhn and Schuster, 1975 and Clarke and Simpson, 1978). However, this ability is reduced in the presence of weeds (O'Donovan, 1994). Mendham et al. (1981) also observed in studies of winter canola that good yields were achievable with as few as 8 plants/m². They noted that at lower density, plants produced a far greater leaf area and number of pods per plant and suggested that it was likely that both primary and secondary leaves were less shaded and therefore able to expand to a greater than normal extent and remain active longer.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Site description

Field experiments were conducted under irrigation during the 2005 and 2006 growing seasons at the Agricultural Research Council- (ARC-GCI) Grain Crops Institute, Potchefstroom, in the Northwest Province. The climatic zone of the North-West province is semi-arid and has an average annual rainfall of 575 mm, with summer temperatures that range between 22 and 34°C and winter temperatures between 6 and 12° C. The soil at the experimental site used was of a Hutton form. The properties of the soil used appear in Table 3.1. Soil samples were collected and analyzed for pH and fertility status and the results are shown in Table 3.1

3.2 Experimental Design and treatments

Two field experiments were conducted during 2005 and 2006 growing seasons. A split-split plot design with three replications was used. Two planting dates (Early and late) served as the main-plot treatments, two canola cultivars (Hyola 60 and Rainbow) served as the sub-plot treatment and four in-row spacings (10, 20, 30 and 45 cm) as the sub-sub -plot treatments. The inter-row spacing of 37.5 cm was used. The seeds were planted by using a vegetable planter. At the beginning of the vegetative stage when the first and second true leaves were evident, plants were thinned to 10, 20, 30, and 45 cm between the plants in a row (Figures 3.1 to 3.4). However, in 2006 the spacings within plants were 10, 20, 35, and 60 cm (i.e. D1, D2, D3 and D4, respectively). Each plot was 9m long and 3m wide, there were two strips of cultivars. Each of the three replicates were 36m long and 7.5m wide with a 1.5m space between adjacent replicates. Seeding rates were 6.8 kg/ha, 2.2 kg/ha, 1.7 kg/ha and 1.1 kg/ha. Layout of the experiment is given in Appendix A&B. There were eight rows per plot.

3.3 Management practices

The early planting date was the 26th of May and the late planting date was the 21st of June in 2005 whereas in 2006 early planting was on the 08th of June and late planting on the 04th of July (Table 3.2). Two detailed field lay-outs for the early and late planting together with cultivars names and planting densities are shown in Appendix A and B. The plots were irrigated throughout the growing period. The number of irrigations applied are given in Table 3.2. Irrigation water was applied through a sprinkler irrigation system and the rain gauge was used to measure the amount of water.

Plots were watered for a minimum of 3 hours. Single Super phosphate (10.5% P) at a rate of 25 kg SSP/ha was broadcast just before planting and incorporated into the soil. LAN (28% N), at a rate of 200kg N/ha (1.93/3 kg/plot), was applied at different growth stages in equal parts, beginning when the crop had reached the mid-rosette stage of development. No herbicides were applied to the plots. Weeds were controlled when necessary by using hand hoes. All the sowings were sprayed with insecticide, chlorypifos (100ml/100l H₂O) before flowering to control aphids. Variables such as minimum and maximum daily temperatures; rainfall, radiation and relative humidity were recorded daily by a nearby automatic weather station and means of their readings are shown in Tables 3.3 and 3.4 respectively.

3.4 Data collection

During the 2005 and 2006 growing seasons two plants were marked in each plot to monitor the start of emergence, rosette stage, start and end of flowering. Flowering date was taken at the time when 50% of plants had one or more flowers visible to the naked eye. Days to emergence were recorded from the date of planting to the completion of 90% emergence. Canola plant density was determined by counting seedlings in four 2 m row lengths in each plot two weeks after emergence to calculate the number of plants/m². Seedlings were counted after thinning out to the desired densities in a 2m x 3m area selected at random in each plot to determine number of plants/m². Number of days to 50% flowering were calculated from the planting date to the time when 50% of the flowers were attained. Plant height was measured at maturity of the crop by taking an average of two randomly selected plants per plot from ground level to the top of the plant.

At fortnightly intervals, from July to October, plant samples were cut at ground level from 30 x 30 cm areas per plot for growth analysis. The total dry weight of plants in each sample was recorded and a representative sub sample of two plants was taken and separated for more detailed measurements of the dry weights of the stems, leaves, and pods plus flowers on different levels of branches. The various parts of the plants were dried separately, weighed and recorded. Plant samples were oven-dried at 60°C for 48 hours and weighed. At harvest a final sample was taken from each plot from which a random sub sample of two plants was taken to measure the components of yield (pod number per plant, number of seeds per pod, 1000-seed weight) and harvest index. The protein and oil content of the seeds were predicted from Near Infrared Spectroscopy (NIR) calibrated against the Fosslet distillation method.

3.5 Harvesting and threshing

The plots were harvested immediately when 50-70% of seeds changed their colour from green to brown. Canola harvesting was timely because of the potential for reduced seed yields due to shattering/loss if pods become too dry. Plants were examined from different parts of the field in each plot. The seeds were tested by rolling them between the thumb and forefinger to determine the firmness which is average maturity. Seed yields were taken at plant maturity by harvesting six middle rows of each plot in a 3m x 2m area for seed yield determination. The plants were cut using pruning shears at ground level and put inside bags and they were air dried before threshing. After threshing, the seeds were cleaned and weighed.

A layout of four planting density treatments from the field layout after thinning out



Figure 3.1 Planting density 4 with 45 cm in-row spacing



Figure 3.2 Planting density 3 with 30 cm in-row spacing



Figure 3.3 Planting density 2 with 20 cm in-row spacing



Figure 3.4 Planting density 1 with 10 cm in-row spacing

Table 3.1. Results of the soil analysis for 2005 growing season

Planting date	M KCL	AMBIC-1					Hydrometer		
		pH	P	Ca	K	Mg	Zn	Clay	Sand
		mg/kg		mg/kg	mg/kg	mg/kg	%	%	%
26/05/05	6.12	16.52	1397.74	85.39	423.45	7.47	28	47.26	24.74
21/06/05	6.59	4.06	1457.42	40.59	453.40	2.26	32	46.26	21.47

Table 3.2 Planting dates, harvesting dates and the number of irrigations applied during 2005 and 2006 growing seasons

Sowings	Sowing Date	Harvest Date	Number of irrigations applied	Total Water (mm)
Early (2005)	26 May	17 October	16	309.5
Late (2005)	21 June	31 October	13	278.5
Early (2006)	08 June	02 November	14	585.5
Late (2006)	04 July	06 November	10	471.0

Table 3.3 Monthly mean temperatures, rainfall, relative humidity and radiation during 2005 growing season

Month	Temperature (°C)		Rainfall (mm)	Relative Humidity (%) (RH)	Radiation (Rn)
	Max	Min			
May	23.25	5.59	3.8	59.19	15.35
June	21.77	3.69	0	51.39	13.39
July	21.4	1.26	0	46.54	14.67
August	24.18	6.27	0	45.80	15.63
September	28.02	9.55	0	33.29	20.17
October	29.16	13.85	15.23	41.55	22.15
November	29.61	14.94	34.03	46.26	24.09

Table 3.4 Monthly mean monthly temperatures, rainfall, relative humidity and radiation during 2006 growing season

Month	Temperature °C		Rainfall (mm)	Relative Humidity (%) (RH)	Radiation (Rn)
	Max	Min			
May	19.42	3.28	6.1	60.29	15.03
June	19.28	1.1	0	55.99	13.78
July	21.41	3.55	0.51	47.12	14.36
August	19.9	4.39	21.58	54.26	16.69
September	25.13	7.21	9.4	41.33	21.7
October	28.17	13.27	48.13	48.13	21.7
November	27.84	14.56	78.74	58.26	23.66

3.6 Statistical Analysis

The experiment was designed as a split-split plot design replicated 3 times. The data was analysed as a combined Split-split plot design of three factors (planting dates, densities and cultivars) using the procedures of Genstat® (2003) (10th Edition). Treatment means that showed significant differences were separated using Fisher's Protected t-test and Least Significance Difference (LSD) at the 5 % level of significance (Snedecor and Cochran, 1980). Treatment means were summarized into tables and graphs.

CHAPTER 4

4. RESULTS AND DISCUSSION

The effects of planting dates and density on growth, development and yield of two canola cultivars grown during the 2005 and 2006 growing seasons.

Table 4.1. Thermal time recorded for completion of canola phenological stages (winter 2005&2006)

Growth Stage	Thermal time from planting in Degree Days			
	2005		2006	
	Early	Late	Early	Late
Emergence	84	77	64	75
Rosette	146	133	221	314
Flowering (50%)	684	773	433	490
Grain filling	1097	1023	703	840
Maturity	1467	1490	1056	932

4.1 Phenological development of canola at two planting dates

According to Daniels, et al. (1986), phenological development of winter oilseed rape is an important aspect of the yield formation process because the time of flowering depends on the combined effect of photoperiod and temperature. Other factors such as moisture, light (day length), nutrition and variety also play a role, but they generally have less influence. Temperature has a major influence on days to maturity for canola. The recorded thermal time requirement of canola in growing Degree days, using a base temperature of 5 °C from the date of planting, is shown in table 4.1.

The duration of vegetative phase was consistent across times of planting. Days to 50% flowering increased significantly with delayed sowing (Table 4.1). However, days to maturity increased as planting date is delayed in 2005 but decreased in 2006. This had the consequence of shortening the potential grain-filling period. As sowing date is delayed plants take slightly shorter duration to mature.

4.2 Growth and development

Growing conditions in the two cropping seasons were slightly different. Temperatures were cooler and rainfall higher in 2006 than in 2005 growing season. Soil moisture was favourable for good germination and seedling emergence in 2005, but in 2006 the germination was slow and uniformity of plant stand was very poor and plots had to be replanted two weeks after. Crop establishment was good for all the planting densities of the early planted trials in both seasons. Warm temperatures in late planted plots initiated earlier growth in both seasons leading to an early harvest date.

4.2.1 Days to 90% germination

Results of this study for days to 90% germination for 2005 and 2006 growing seasons are presented in Table 4.2. The warm and dry weather from August onwards in 2005 gave very rapid development. Planting date had highly significant effects ($P < 0.05$) on days to 90% germination in both seasons. The late planting date had increased number of days (10.21) to 90% germination compared to the early planting date (8.63). This difference might have been due to the effect of soil temperature. According to Gusta et al. (2003), temperatures below 10° C result in progressively poorer germination and emergence. This also agrees with Diepenbrock (2000) that the considerable variation in the emergence of seedlings depends on moisture, temperature and the structure of the soil. Also, Larsen et al. (1998) found, in their study, that the mean time to germination revealed highly significant correlations with field performance. The cultivar rankings for days to 90% germination means was the same for both 2005 and 2006 growing seasons. No significant interaction between planting dates and cultivars ($P \times C$) were observed in both seasons. Also there were no significant differences among densities for days to 90% germination. According to Gusta et al. (2003), germination on canola can be influenced by the genetics of the variety, growth conditions as seed matures, how the seed was stored and seed treatments.

Table 4.2. F-Pr values from analysis of variance and treatment means for days to 90% germination and 50% flowering as affected by planting dates, density and cultivars in 2005 and 2006 growing seasons.

F-pr values				
Treatments	Days to 90% germination		Days to 50% flowering	
	2005	2006	2005	2006
Planting date (P)	0.009	0.009	< 0.001	<0.001
Cultivars (C)	0.305	0.574	0.007	0.423
P x C	0.192	0.806	0.561	0.423
Plant Density (D)	0.119	0.269	0.072	<0.001
P x D	0.979	0.781	0.561	0.014
C x D	0.813	0.389	0.959	0.293
P x C x D	0.943	0.617	0.861	0.721
CV (%)	7.0	8.4	0.9	1.3
Mean values				
Planting date (P)				
Early	8.63	12.04	84.46	86.29
Late	10.21	13.42	76.96	82.67
LSD (5%)	0.93	0.79	0.91	0.65
Cultivars (C)				
Hyola 60	9.54	12.88	81.04	84.67
Rainbow	9.29	12.58	80.38	84.29
LSD (5%)	0.59	1.32	0.37	1.17
Plant density (D)				
D 1	9.08	12.25	80.33	82.75
D 2	9.50	13.08	81.08	83.33
D 3	9.33	12.92	80.92	84.83
D 4	9.75	12.67	80.50	87.00
LSD (5%)	0.56	0.90	0.63	0.96
Interaction (LSD 5%)				
P x C	0.94	1.33	0.90	1.17
P x D	1.01	1.24	1.05	1.26
C x D	0.81	1.51	0.81	1.47
P x C x D	1.26	1.92	1.30	1.91

LSD is the t-test least significant difference

CV % is the percentage coefficient of variation

4.2.2 Days to 50% flowering

Days to 50% flowering increased significantly ($P < 0.001$) when sowing early than late (Table 4.2). The plants of the early sowing needed a higher number of days to flowering in 2005 (84.46) and 2006 (86.29) than late planting. Delaying in planting date enhanced flowering. This was contrary to Mendham and Scott (1975) who reported that delaying planting date delayed flowering. It could be stated that planting canola early was more suitable because late sowing may reduce the growth period and reducing number of days to 50% flowering. These results are similar to those obtained by Thomas et al. (1990), Leto et al. (1995), Starmer et al. (1996) and Saini and Sidhu (1997).

Cultivars also differed in the response to 50% flowering to delayed sowing date but their differences were only observed in 2005. Cultivar Rainbow was the earliest (80.38) in terms of days to 50% flowering and cultivar Hyola 60 flowered later (81.04). Differences among cultivars shows that there is genetical variation between cultivars. This data indicated that the later flowering cultivar adjusted its flowering date least in response to delayed sowing. Cultivar x planting date interaction showed that days to 50% flowering were not significant. Early planting date lengthened the period of days to flowering by 3.62 to 7.4 days. The effect of planting density was not significant in 2005, but in 2006 it was highly significant (Table 4.2). The number of days to 50% flowering were shorter in the high density plants (D1 and D2) than in the lowest density plants (D3 and D4). Increasing the spacing within rows considerably delayed the flowering of cultivars. Essentially such a situation could be expected. These findings agrees with that of Van Deynze et al. (1992).

Table 4.3. F-Pr values from analysis of variance and treatment means for plant height (m) in 2005 and 2006 growing seasons.

F-pr values			
Treatments	Plant height (m)		
	2005	2006	
Planting date (P)	0.003	0.003	
Cultivars (C)	0.032	0.074	
P x C	0.085	0.031	
Plant Density (D)	0.004	< 0.001	
P x D	0.357	0.437	
C x D	0.478	0.107	
P x C x D	0.653	0.158	
CV (%)	6.5	4.2	
Mean values			
Planting date (P)			
Early	1.76	1.51	
Late	1.52	1.30	
LSD (5%)	0.10	0.09	
Cultivars (C)			
Hyola 60	1.70	1.38	
Rainbow	1.58	1.42	
LSD (5%)	0.10	0.04	
Plant density (D)			
D 1	1.73	1.50	
D 2	1.67	1.41	
D 3	1.60	1.34	
D 4	1.56	1.35	
LSD (5%)	0.09	0.05	
Interaction (LSD 5%)			
P x C	0.12	0.09	
P x D	0.13	0.10	
C x D	0.13	0.07	
P x C x D	0.18	0.11	

LSD is the t-test least significant difference
CV % is the percentage coefficient of variation

4.2.3 Plant height

Plant height recorded from the early sown plots in 2005 (1.76) and 2006 (1.51) growing seasons were significantly higher than those from the late sown plots in 2005 (1.52) and 2006 (1.30) growing seasons. Mondal and Islam (1993) showed that sowing canola early in November gave the highest plant height than sowing late in October and December. Shorter plant height in late planting date would reduce the potential for lodging, which is a common problem with canola. Cultivar differences were not quite large. Cultivar Hyola 60 in 2005 was significantly taller than cultivar Rainbow, whereas in 2006 no significant differences among cultivars were observed. The interaction of planting date x cultivar was also significant ($P < 0.05$) with cultivar Hyola 60 being taller when planted early in 2005, but in 2006 their interaction was non-significant. In 2006 cultivar differences for plant height were not significant.

Increasing the spacing within rows resulted in significantly shorter plants in both seasons (Table 4.3). Since increased spacing resulted in shorter plants, one may conclude that more competition in higher plant densities results in taller plants. Among the different planting spaces the tallest plant height of 1.73 and 1.50m in 2005 and 2006 respectively, were in D1. Interaction effects between cultivars x density and planting date x cultivars were not significant in both seasons. Yousaf et al. (2002) suggested that the maximum plant height would be attained in maximum plant density. The increases in plant height due to increase in planting density may be attributed to more competition between plants for light, water and nutrients.

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4.3 Dry matter yield, total top, leaf, stem, and pod dry matter

4.3.1 Dry matter yield (g/m²)

An increase in dry matter over time was observed in all treatments for both experiments conducted in 2005 and 2006 growing seasons as shown in Appendix C (1) and (2). Planting date affected dry matter yield in both seasons. However, highly significant differences were observed at 15 WAP in 2005 and at 17 WAP in 2006 growing seasons. Late sown plots had a greater plant dry matter than early sown plots in both seasons. In 2005 there were three periods (7, 13 and 17 WAP) in the experiment when the dry matter was not significantly different (Fig 4.1 (a)). But, at week 9, 11 and 15 the late planting date started to have more dry matter yield than the early planting date. However, in 2006 there was a considerable variation in dry matter yield of the plants between planting dates from 9 WAP to the late last stage (17 WAP) (Fig 4.1 (b)). The accumulation of dry matter was slow at 9 WAP showing significant response to planting date. Differences in the duration of the early phase of growth, between the early and late sowings, were presumably related to the direction of changes in temperature and solar radiation over the period immediately after sowing. In general, dry matter accumulation takes place at a slower rate until the crop reaches full ground coverage and then increases at a much faster rate (Diepenbrock, 2000). Generally, the differences in growth found in these two planting dates may be due to differential temperature prevailing during the growth period. The lower temperatures reduced the growth activity in early sown plots. Development after 13 WAP was characterized by a continued increase in dry matter in spite of rapidly declining leaf weight. Stems, pods, and to a lesser degree leaves all contributed to the increase in total dry matter, but thereafter pods were the only organs to become heavier.

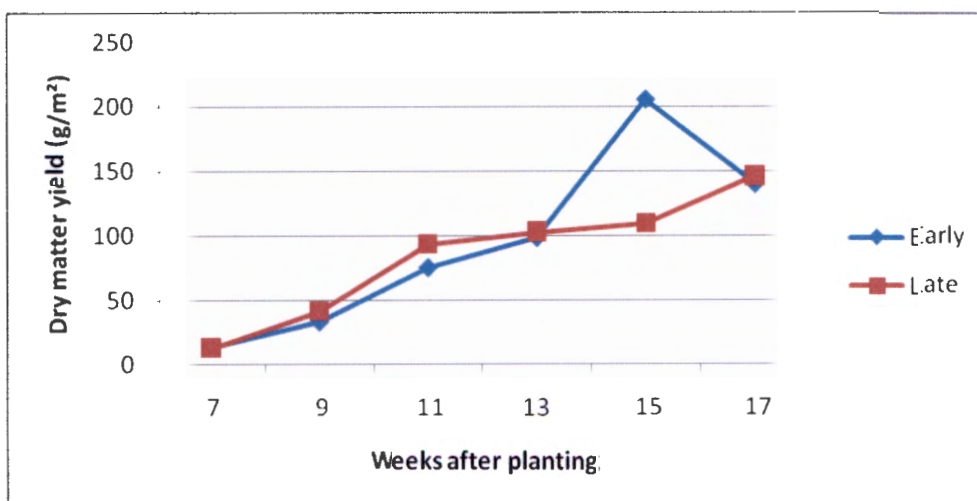


Figure 4.1 (a) The effect of planting date on dry matter yield in 2005 growing season.

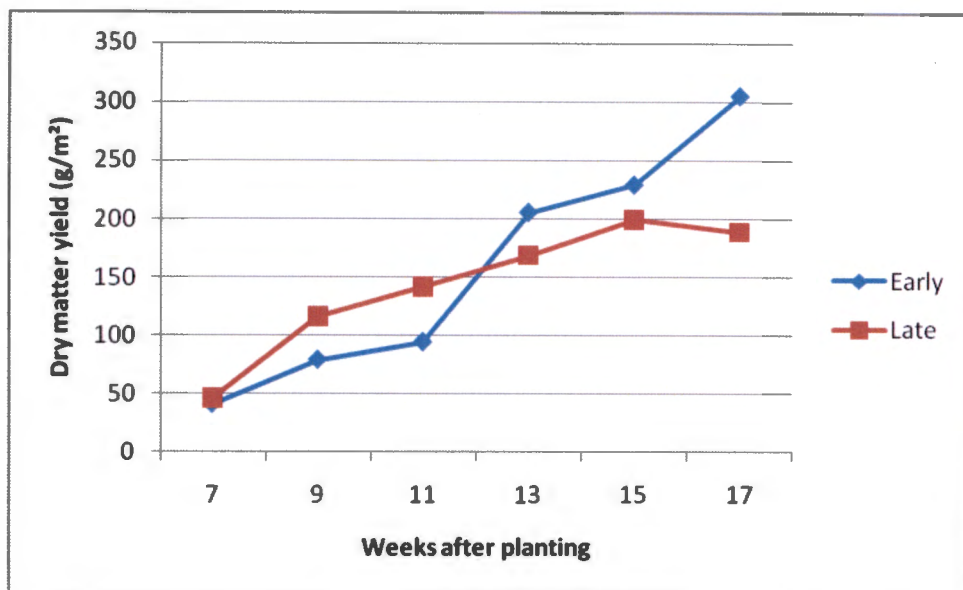


Figure 4.1 (b) The effect of planting date on dry matter yield in 2006 growing season.

There were no significant differences between cultivars for dry matter yield obtained in 2006. However, in 2005 cultivars showed a significant increase in dry matter yield with sampling dates (Figure 4.1(b)). The dry matter production of Hyola 60 was higher at certain stages of development (9 and 11 WAP) than that of cultivar Rainbow. The dry matter yield of Hyola was 39.2 g/m² at 9 WAP and 93.8 g/m² at 11 WAP compared to Rainbow which had 35.7 g/m² at 9 WAP and 74.7 g/m² at 11 WAP. The interaction between planting date and cultivars (P x C) was also significant (P < 0.05). Cultivar Hyola 60 produced significantly higher dry matter yield when planted late in 2005 (Figure 4.1 (d)).

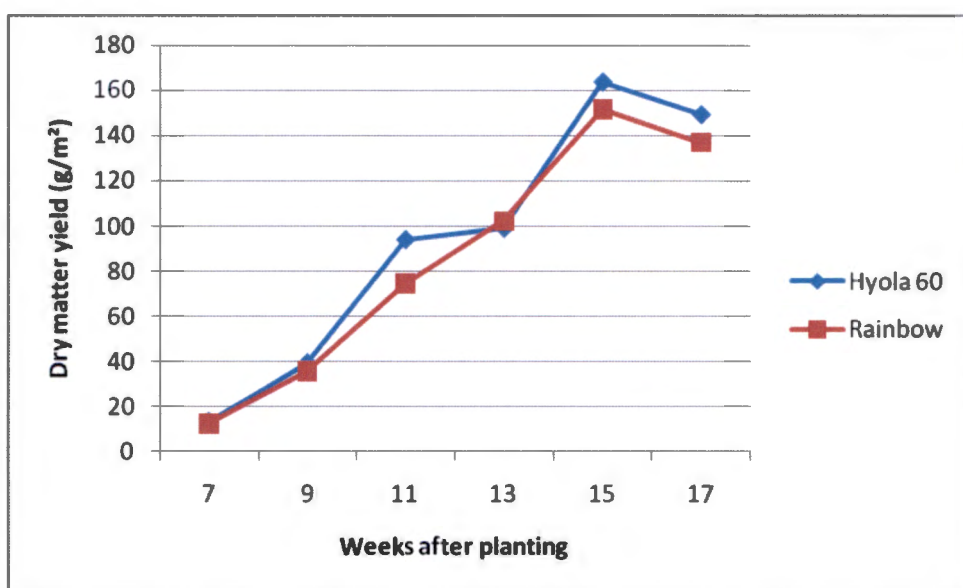


Figure 4.1 (c) Effects of cultivars on dry matter yield during the 2005 growing season

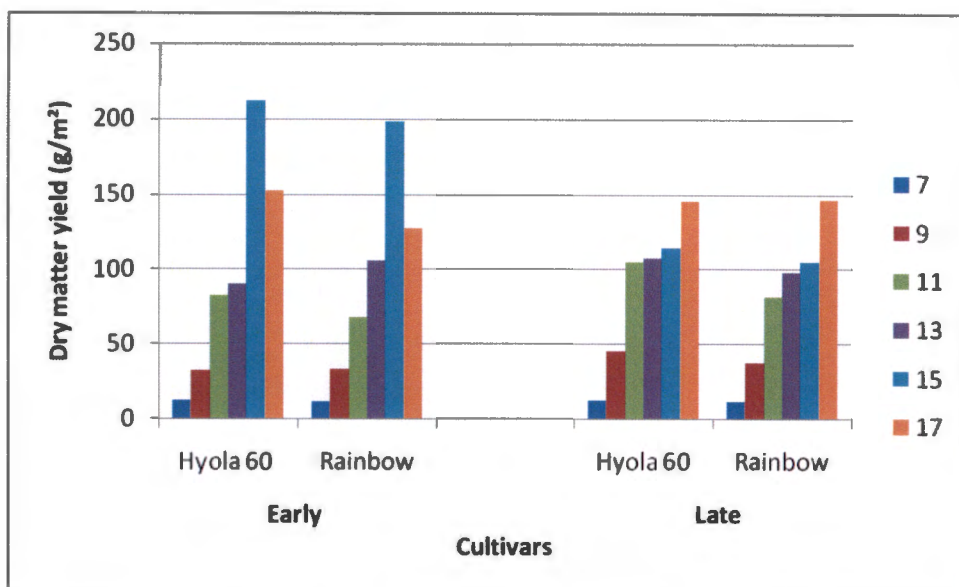


Figure 4.1 (d) The interaction effect between planting dates and cultivars (P x C) on dry matter yield in 2005

The response of dry matter yield per unit area to planting density varied throughout the seasons (Figure 4.1 (e) and (f)). Significant differences existed in the dry matter yield in the planting densities tested during both seasons. In both 2005 and 2006 seasons, crops sown at low density produced significantly less dry matter yield than at high densities. Significant differences in dry matter yield were detected among planting densities at different sampling times (WAP) during both seasons, but mostly before the 15th week after planting. However, the tendency was for dry matter to decrease as planting density decreases. Morrison et al. (1990) suggested that the leaf area index of canola at lower population takes longer to cover the ground surface than that for higher plant populations.

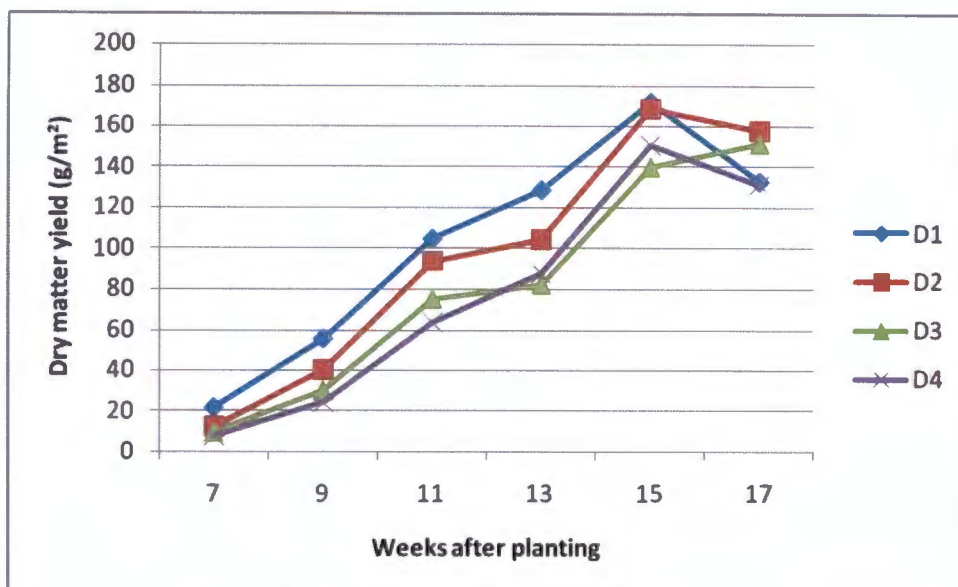


Figure 4.1 (e) Effects of planting densities on dry matter yield during the 2005 growing season

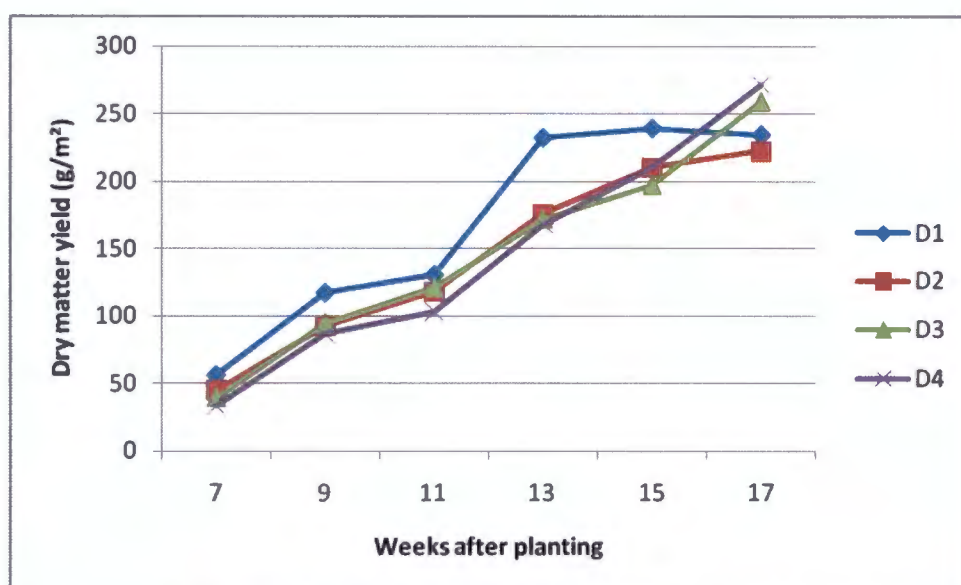


Figure 4.1 (f) Effects of planting densities on dry matter yield during the 2006 growing season

The interaction between planting dates and density ($P \times D$) was also found to be significant ($P < 0.05$) in 2005 and 2006 growing seasons (Figure 4.1(g) and (h)). In 2005, the highest planting density (D1) with early planting date produced significantly the maximum dry matter yield of 44.3 g/m² at 9 WAP. However, in 2006, the interaction between planting date and density was found to be highly significant ($P < 0.001$) at 7 WAP, and thereafter at 11 and 13 WAP ($P < 0.05$). At 7 WAP, D1 was the highest in dry matter production when planted early and at 11 and 13 WAP, D1 also produced the highest dry matter yield but when planted late figure 4.1 (h).

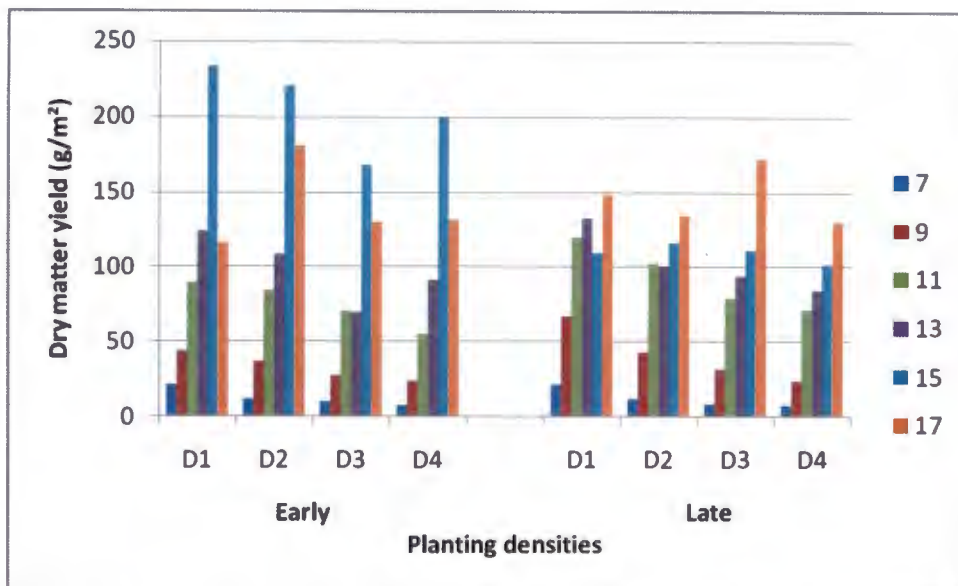


Figure 4.1 (g) The interaction effect between planting dates and densities (P x D) on dry matter yield in 2005.

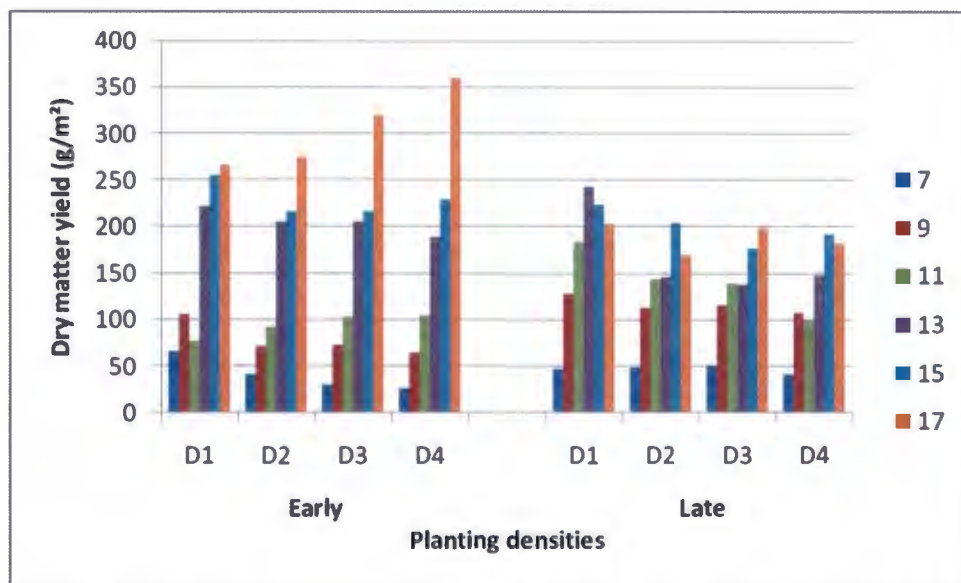


Figure 4.1 (h) The interaction effect between planting dates and densities (P x D) on drymatter yield in 2006.

4.3.2 Total top dry matter

Some indication of the differences between planting dates, densities and cultivars of total top dry matter of the plants is presented in Appendix D (1) and (2). There was a substantial variation in the total top dry matter of the plants over planting dates. In 2005, there was a slight increase in the total top dry matter at early planting date at 13 WAP, but at 17 WAP the late planting date was much greater than the early sowing date (Figure 2 (a)). In 2006, also the response to late sowing date was much greater at 17 WAP than the early sowing date (Figure 2 (b)). These results show that differences between planting dates in the total top dry matter of the plants were primarily related to differences in growth prior to anthesis (13 WAP). In the post anthesis period up to maturity, the total dry matter of the plants increased largely because of pod growth. Poorer efficiency of partitioning of dry matter for early sowings was also noted by Taylor and Smith (1992) for canola cultivars under irrigation. The effect of cultivars was non-significant for total top dry matter production in both seasons. Generally, the dry weight of the whole plant and its various organs increased to a peak just before anthesis and thereafter declined. In the post anthesis period up to maturity, the dry weight of the plant increased largely because of pod growth and the increase took place in spite of a rapid decline in leaves weight, a result which had been taken to indicate that the pods are important photosynthetic organs which produce carbon assimilates for their own growth and that of the seeds they contain (Allen, Morgan and Ridgman, 1971).

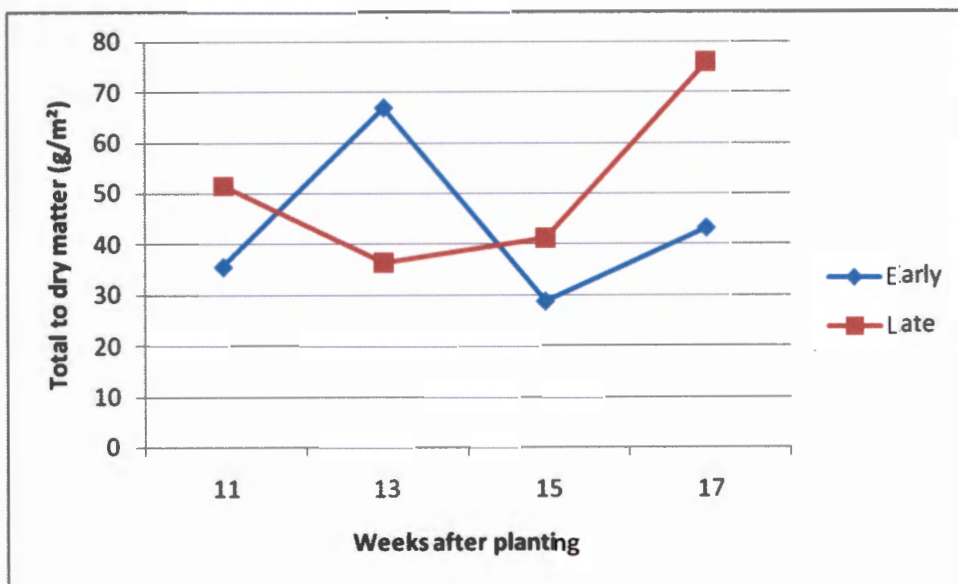


Figure 4.2 (a) Effects of planting date on total top dry matter yield in 2005.

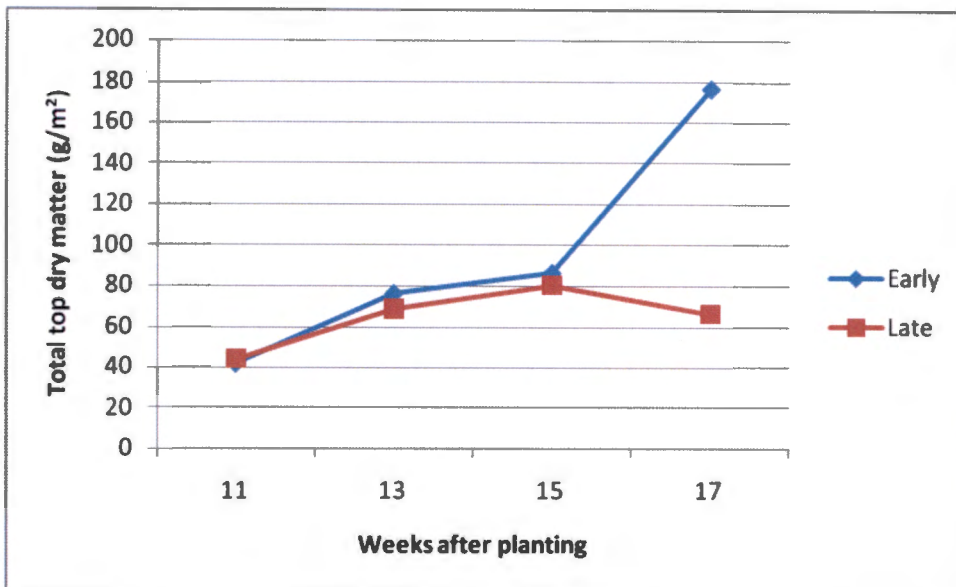


Figure 4.2 (b) Effects of planting date on total top dry matter yield in 2006.

The most significant differences were observed within the planting densities at ($P < 0.01$) at 11 and 13 WAP and $P < 0.05$ at 17 WAP in 2005 (Appendix D (1)). In 2006 significant differences between planting density were observed at 13 WAP ($P < 0.001$), 15 WAP ($P < 0.05$) and 17 WAP ($P < 0.01$) (Appendix D (2)). Total top dry matter in 2005 growing season ranged from 30.1 g/m² to 59.4 g/m² among densities at 11 WAP, 38.2 g/m² to 68.5 g/m² at 13 WAP and from 55.5 g/m² to 69.8 g/m² (Figure 2 (a)), while in 2006 growing season, the total top dry matter was highly significant and ranged from 45.9 g/m² to 88.8 g/m² among densities at 13 WAP, from 58.0 g/m² to 100.8 g/m² at 15 WAP and from 77.5 g/m² to 145.5 g/m² at 17 WAP (Figure 2 (b)). The lowest plant densities produced significantly higher total top dry matter in both seasons. The tendency was for total top dry matter to increase as plant density is decreased. Clarke and Simpson (1978) also observed that at plant densities achieved with commercial seeding rates, plant size was limited, while at lower densities dry matter accumulation was greater particularly after flowering. The interaction between planting dates and density ($P \times D$) was found to be significantly different ($P < 0.05$) in both seasons. In both seasons, the highest total top dry matter was obtained in early planted trials with the lowest plant density (Figure 2 (e) and (f)). According to Szceygielski and Owczarek (1987), early sowings in winter encourages establishment of strong, vigorous seedlings and plant population has little effect. Consequently, planting density is of less significance in relation to the total dry matter accumulated or seed yield in canola. However, it may have a negative effect on winter hardiness, which decreases after initiation of stem elongation. From the results obtained on planting density, it can be concluded that low plant populations produced more branches per plant compared to high plant populations.

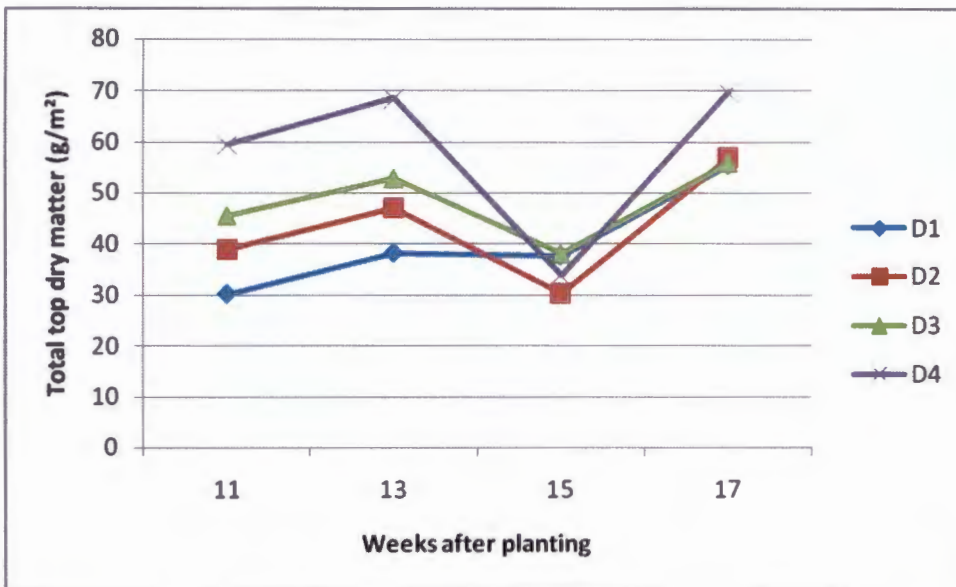


Figure 4.2 (c) Effects of planting density on total top dry matter yield in 2005.

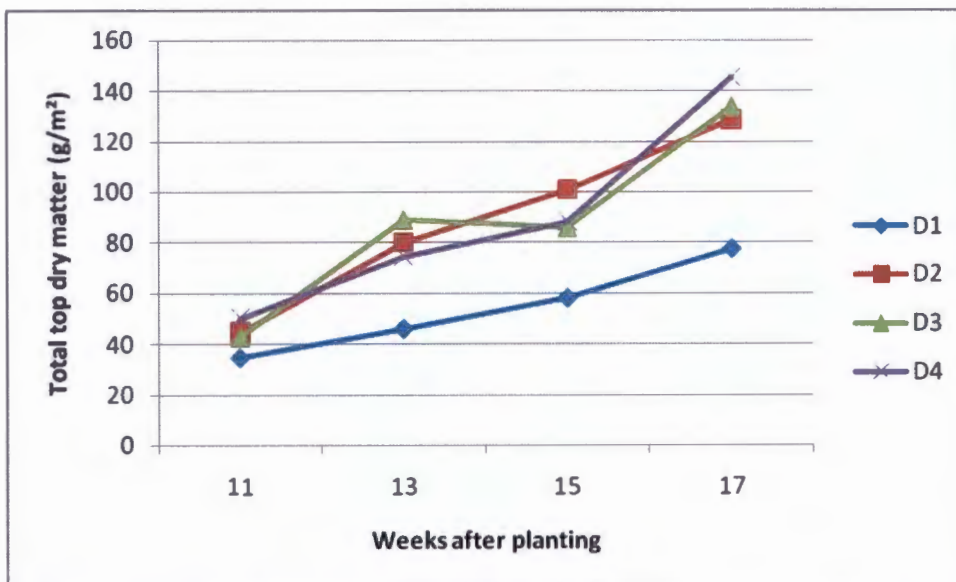


Figure 4.2 (d) Effects of planting density on total top dry matter yield in 2006.

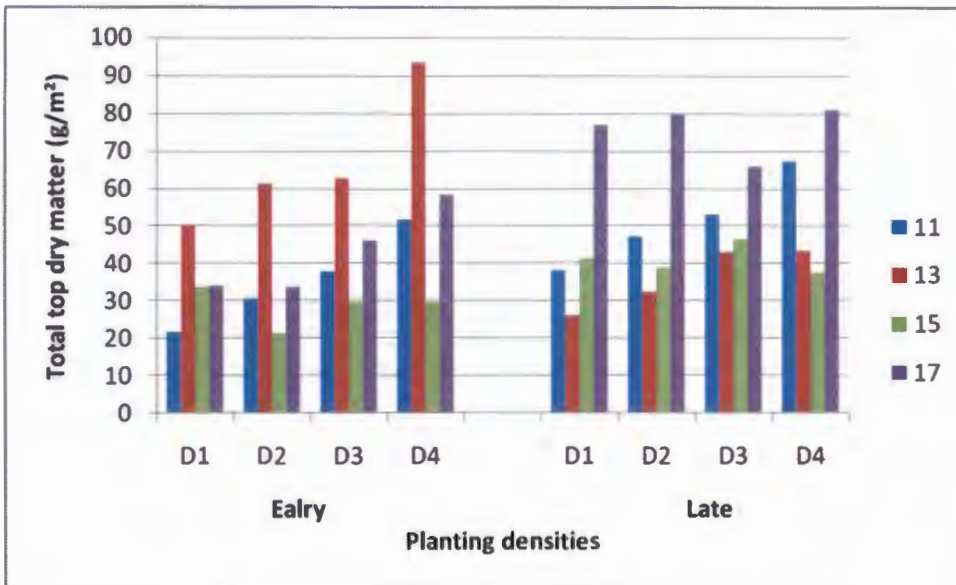


Figure 4.2 (e) The interaction effect between planting dates and densities (P x D) on total top dry matter in 2005.

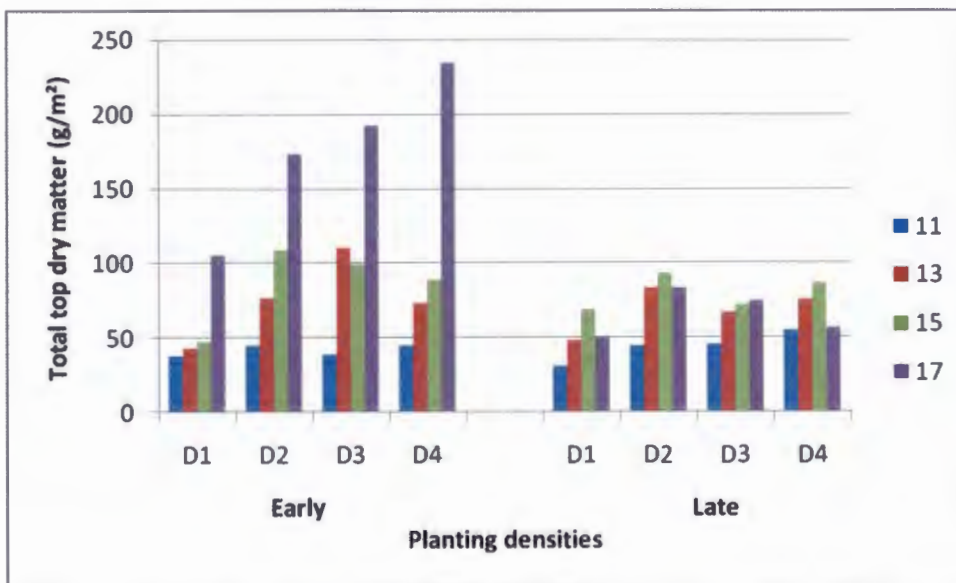


Figure 4.2 (f) The interaction effect between planting dates and densities (P x D) on total top dry matter in 2006.

4.3.3 Leaf dry matter

Planting dates and planting densities significantly affected the leaf dry matter of canola in both seasons. In 2005 and 2006, the proportion of dry matter represented by the leaves reached a maximum in early planting date (Figure 3 (a) and (b)). In 2005 the maximum leaf dry matter production was recorded at 13 WAP in early sown plots. Whereas in 2006, the maximum leaf dry matter was recorded from 13 to 17 WAP also in early sown plots. The leaf dry matter declined steadily with successively later sowings. Effects of cultivars on leaf dry matter of canola was non significant. The dry weights, however, varied from 0.63 to 10.62 for cultivar Hyola 60 and from 0.68 to 11.74 for cultivars Rainbow in 2005. In 2006, the dry weights varied from 2.20 to 15.50 for cultivars Hyola 60 and from 2.27 to 13.58 for cultivar Rainbow. The interaction between planting dates and cultivars was also significant. Significant differences were only observed at 11 WAP. Cultivar Rainbow produced significantly the highest leaf dry matter in early planting date (Figure 3 (c)).

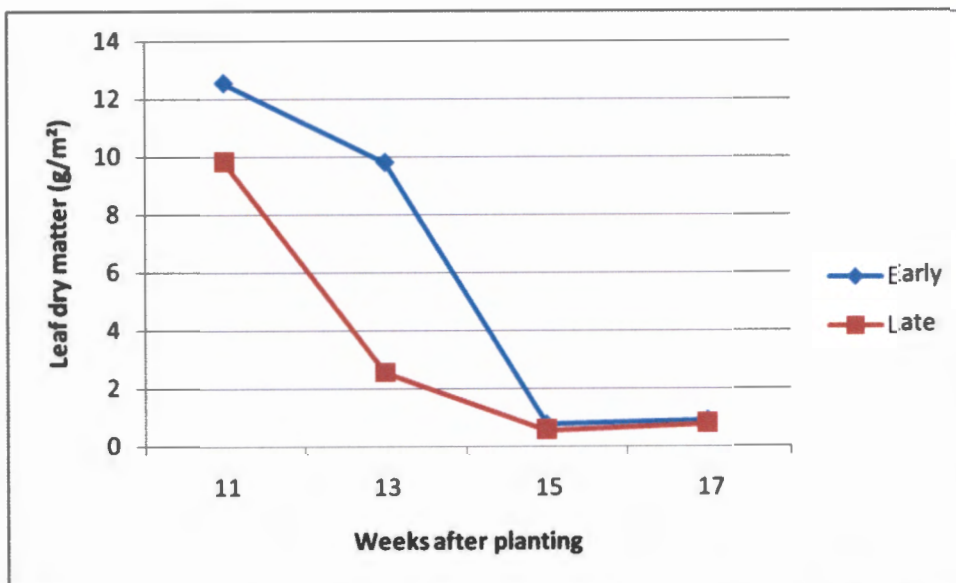


Figure 4.3 (a) Effects of planting date on leaf dry matter in 2005.

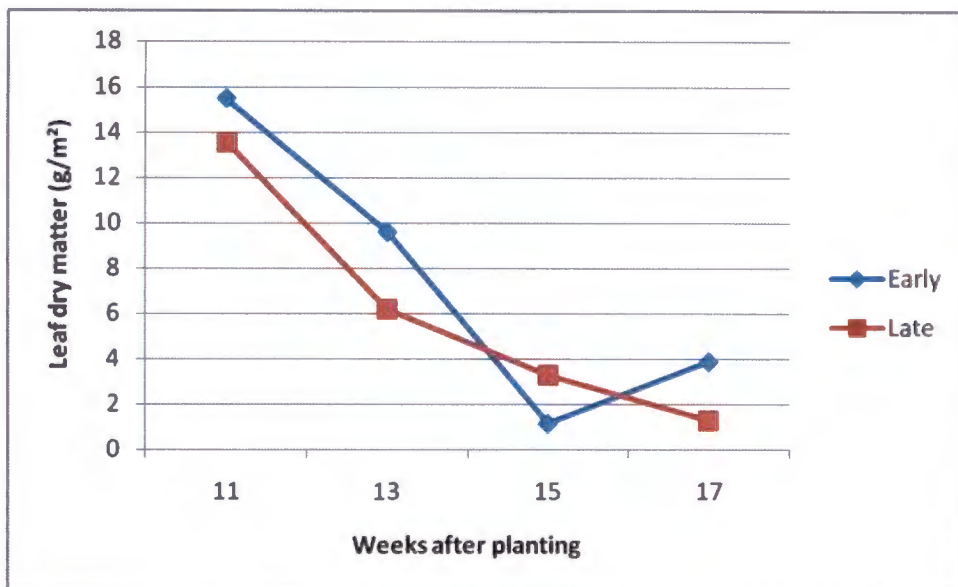


Figure 4.3 (b) Effects of planting date on leaf dry matter in 2006.

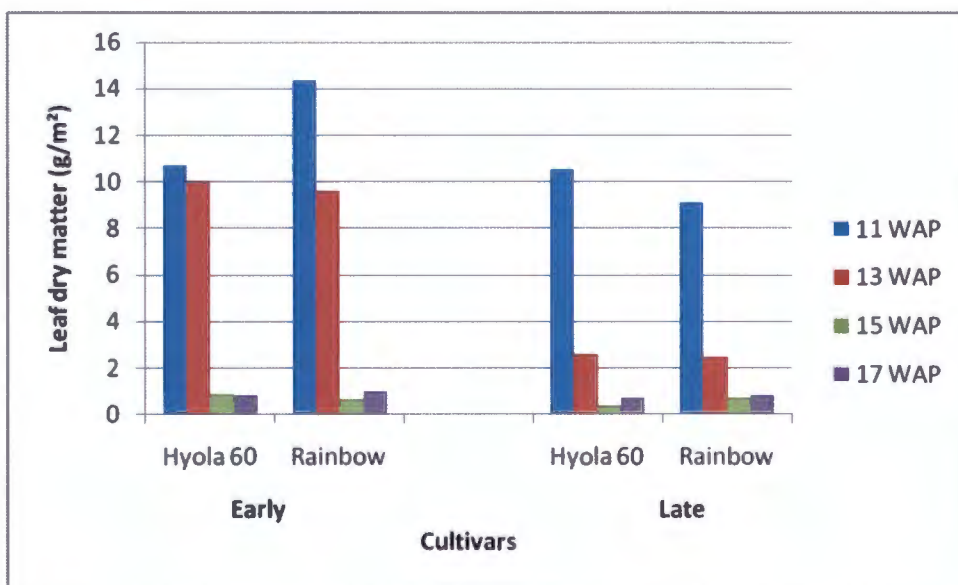


Figure 4.3 (c) The interaction effect between planting dates and cultivars (P x C) on leaf dry matter in 2005.

Differences in leaf dry matter between different planting densities were also observed. Crops grown at low densities produced significantly high leaf dry matter compared to crops grown at high densities. The leaf dry matter increased with increasing the spacing within the plants. The highest leaf dry matter was recorded in plants with the lowest density at 11 and 13 WAP in 2005 (Figure 3(d)). Whereas in 2006, the highest leaf dry matter was recorded only at 13 WAP and also in lowest density plots (Figure 3 (e)). This shows that the plants which remained after thinning were

able to compensate for plants removed. This compensation appeared to be the result of increased and prolonged dry matter accumulation in leaves, largely at 11 and 13 WAP, which was associated with increased branching. This is in agreement with Boyles et al. (2006), that at lower plant populations, between plants competition is reduced and individual plants are able to grow larger, have bigger stems, branch more profusely and produce more pods. The interaction effect between planting dates and planting density were observed at 13 WAP in 2005 and are shown in Figure 4.3 (f). The lowest plant density produced significantly the highest leaf dry matter with early planting date.

Canola leaves are an important source of photosynthesis even though they senesce rapidly during pod development (Major, Bole, and Charnetski, 1978). Leaves establish the sink potential in terms of structures such as number of pods per plant or number of seeds per pod and as a source of translocated photosynthates during their senescence, but eventually stems and pods become more important sources of photosynthates (Major et al., 1978; Chapman, Daniels and Scarisbrick, 1984). Maximum dry weight is usually reached near the beginning of flowering and then begins to decline with the loss of lower leaves. The leaves, especially the upper ones at this stage, are the major source of food for growth of stems and buds. Leaves senesce and are shed rapidly from late flowering onwards.

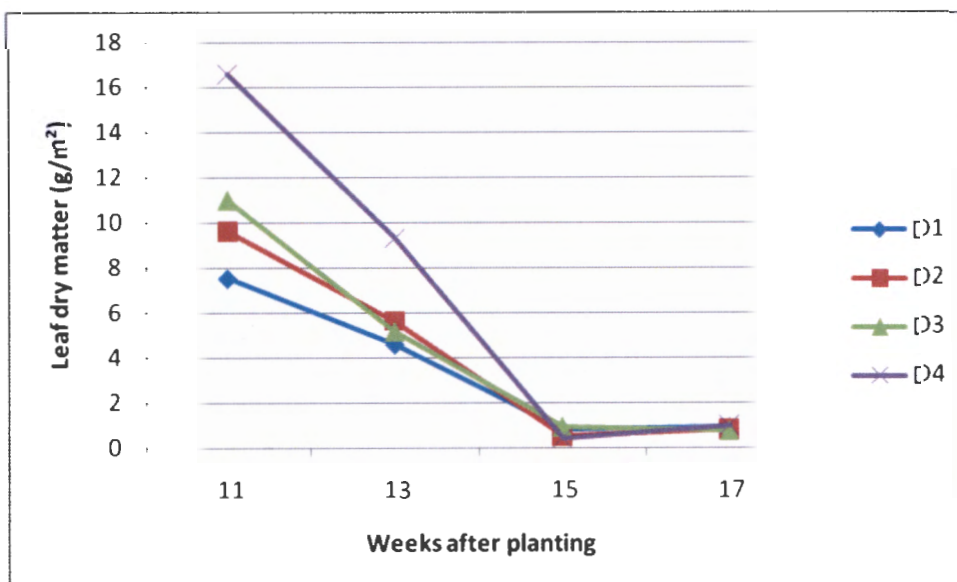


Figure 4.3 (d) Effects of planting density on leaf dry matter in 2005.

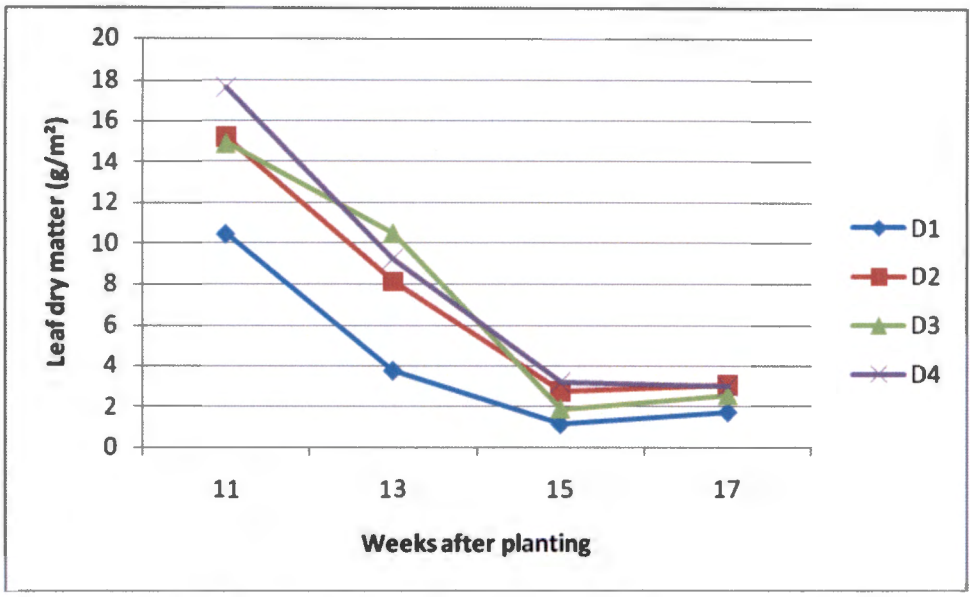


Figure 4.3 (e) Effects of planting density on leaf dry matter in 2006.

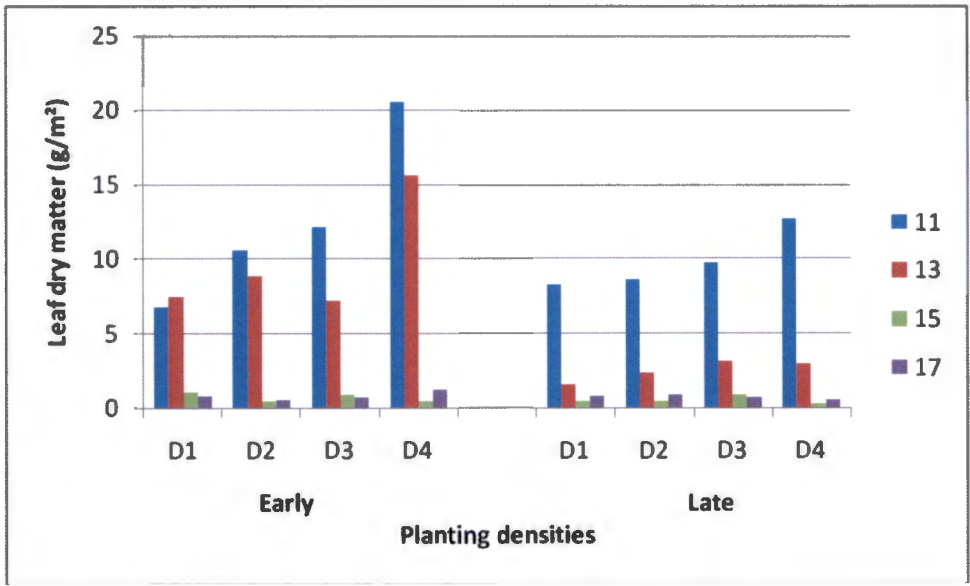


Figure 4.3 (f) Interaction effect between planting date and density (P x D) on leaf dry matter in 2005.

4.3.4 Stem dry matter

The results obtained regarding stem dry matter as affected by planting dates are reported in Figure 4 (a) and (b). The data reveals that the early planting date resulted in a significant increase in stem dry matter. However, significant differences were only found at 13 WAP in 2005 and in 13 and 17 WAP in 2006. A study of the distribution of dry weight between different organs shows that the differences in stem dry matter closely follow those of total top dry matter and those of leaf dry matter. There were no significant differences among cultivars for stem dry matter.

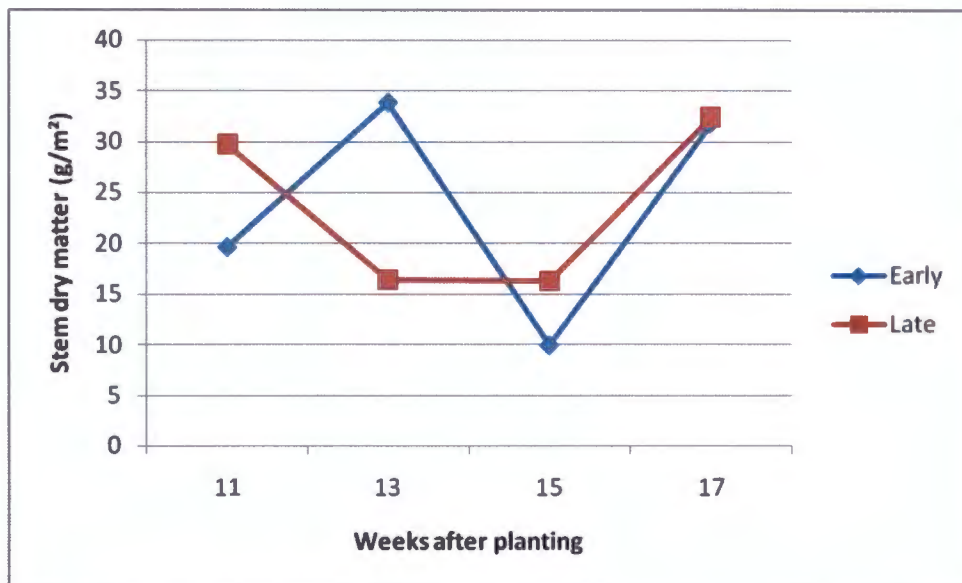


Figure 4.4 (a) Effects of planting date on stem dry matter in 2005.

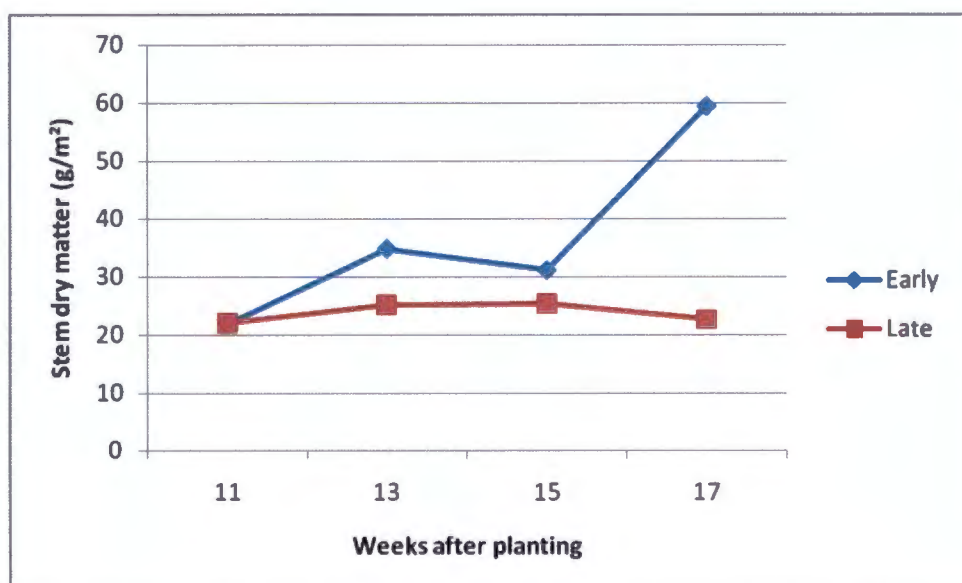


Figure 4.4 (b) Effects of planting date on stem dry matter in 2006.

The responses of stem dry matter to plant density were also similar to those of total top dry matter and leaf and are shown in Figure 4 (c) and (d). In 2005, the highest stem dry matter was obtained in the lowest plant density plots and was observed at 11, 13 and 17 WAP. In 2006 also, the increased stem dry matter was obtained in lower density plots but was observed at 13, 15 and 17 WAP. Plants in the lowest density plots produced the highest stem dry matter yield compared to plants in the highest density plots. Generally plants in the lowest density plots had developed thicker stems and more branching than the plants in the highest density plots which resulted in higher stem dry matter. According to Boyles et al. (2006), the compensating ability of canola means stem diameter is strongly influenced by plant density. After flowering plants at low densities were shorter, more robust and bore more branches. At higher densities, plants became thinner-stemmed, taller and with smaller leaves and they lodged during rapid pod growth. Overall crop growth was not as vigorous, so lodging was not that severe. In the late planting date plants merely leaned rather than lodging, and then only towards the end of the season.

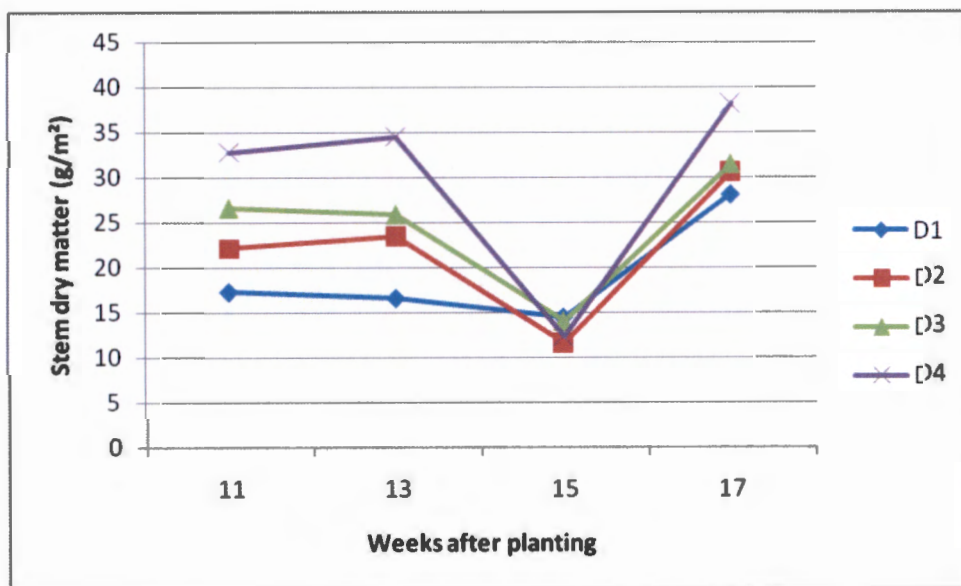


Figure 4.4 (c) Effects of planting density on stem dry matter in 2005.

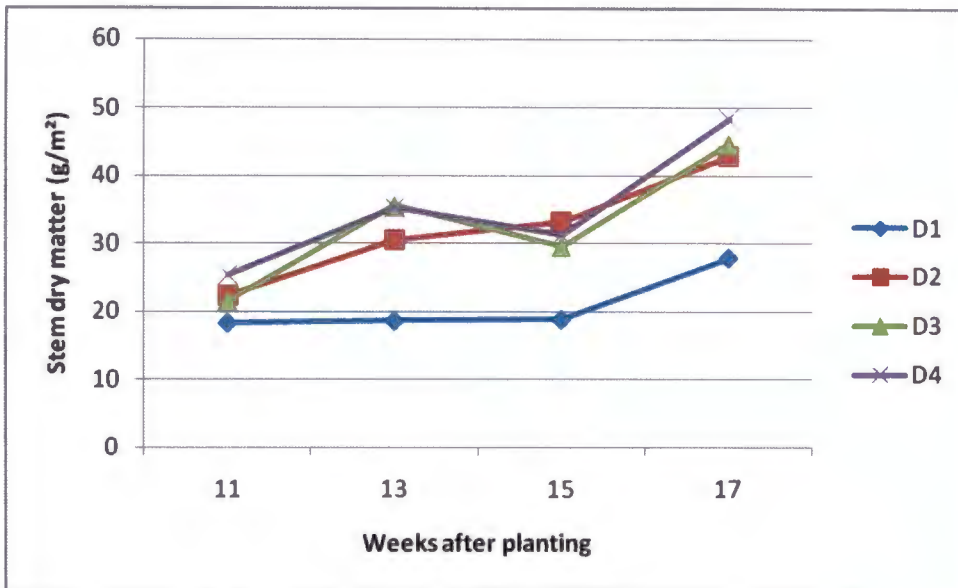


Figure 4.4 (d) Effects of planting density on stem dry matter in 2006.

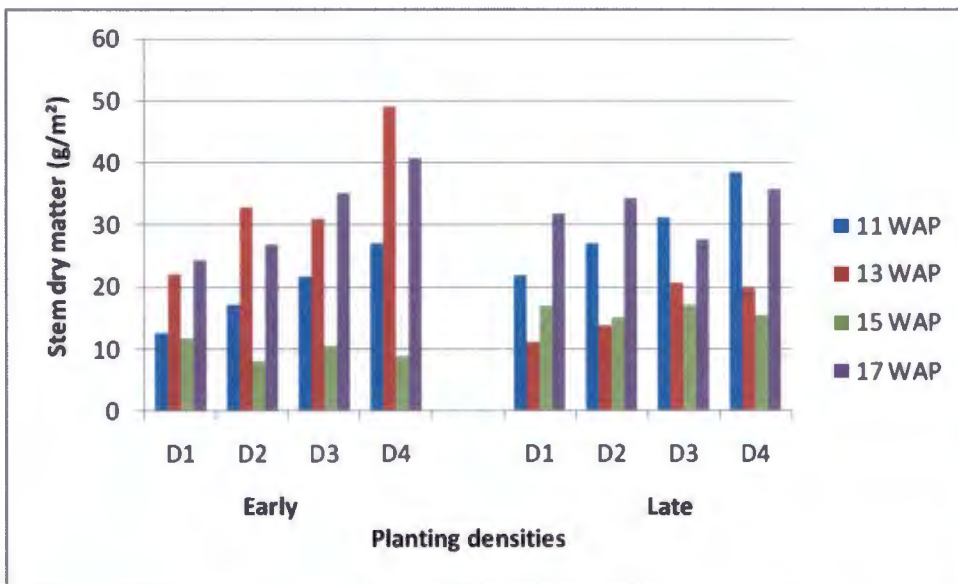


Figure 4 (e) Interaction effect between planting dates and density (P x D) on stem dry matter in 2005.

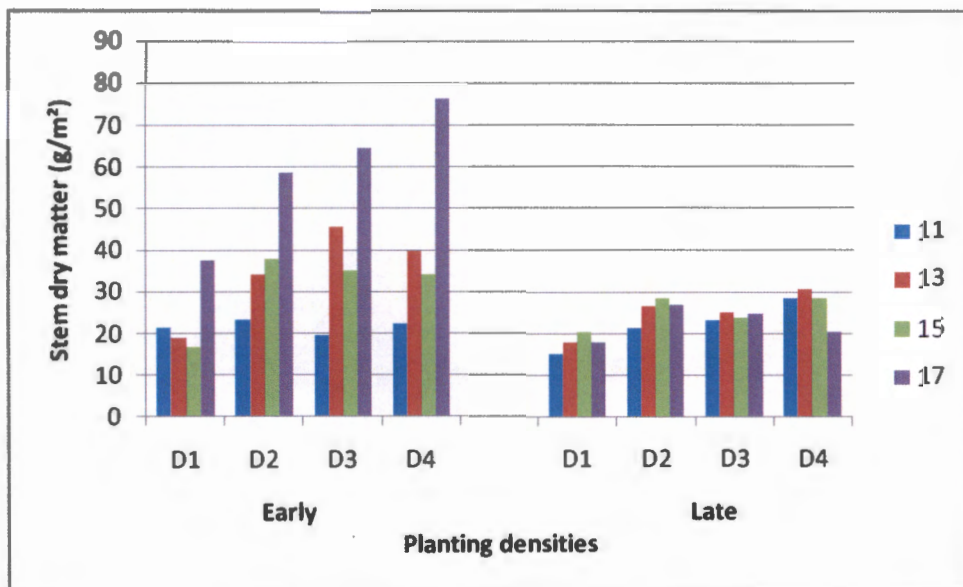


Figure 4.4 (f) Interaction effect between planting dates and density (P x D) on stem dry matter in 2006.

4.3.5 Pod dry matter

Effects of planting date on pod dry matter were found to be significant in both seasons. In 2005, it is observed that at 11 WAP, the weight of pods on the plants was greater in the late planting date, and at 13 and 17 WAP, the weight was greater in the early planting date. In 2006, at 11 WAP also the pod dry weight was greater in the late planting date, but at 17 WAP the higher pod dry weight was produced in the early planting date. Since the late planting date has a consequence of shortening the length of the reproductive period relative to the vegetative period, and consequently the potential grain-filling period; the plants in the late sown plots were growing faster due to high temperatures and produced more pods earlier than plants in the early planting date which their growth period was slow until maturity. At harvest the early sown plots were able to produce the highest dry weight of the pods than the plants in the late sown plots. From these results it is clear that increases in pod dry weight were largely responsible for the increase in total top dry matter at harvest. Thus, it is likely that the pods produce the assimilates required for their own growth and that of the seeds they contain. Mendham et al. (1995) showed that there was a relationship between the amount of crop dry matter to support each pod and the number of seeds it was likely to retain. There were no significant differences among cultivars for pod dry matter.

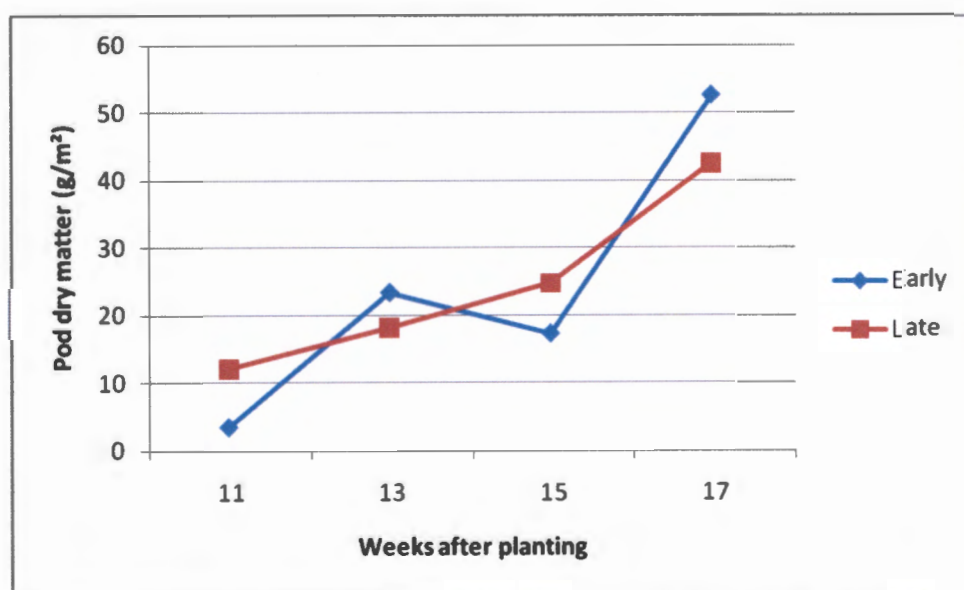


Figure 4.5 (a) Effects of planting date on pod dry matter in 2005.

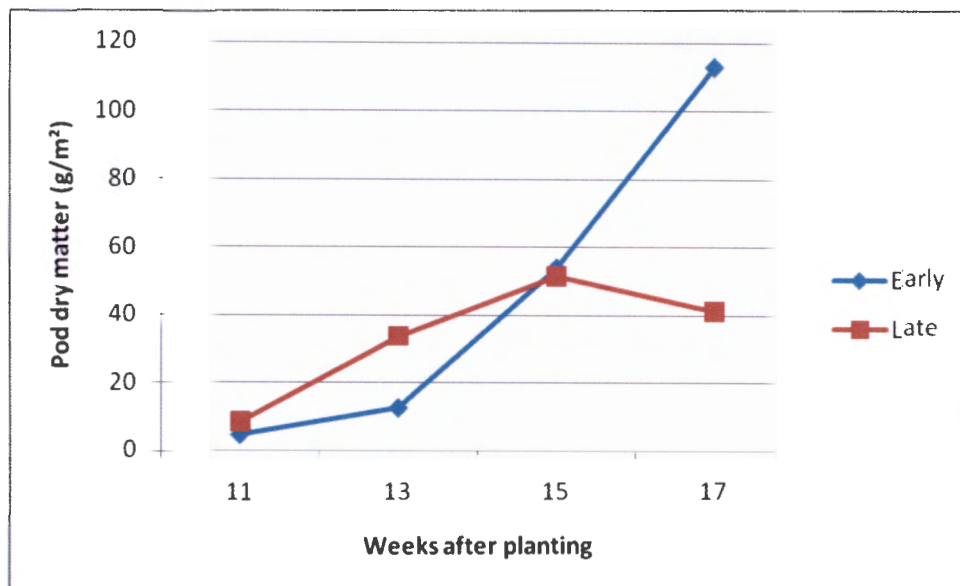


Figure 4.5 (b) Effects of planting date on pod dry matter in 2006.

Plant density had an effect on pod dry matter in both seasons. In 2005, significant differences were observed at 11 and 17 WAP (Figure 5 (c)), whereas in 2006, significant differences were obtained at 11, 15 and 17 WAP (Figure 5 (d)). Increasing the spacing between the plants significantly increased the pod dry matter of canola. The interaction between planting dates and density was also found to be significant in both seasons. Significant differences were only observed at 17 WAP for in both seasons. The pod dry matter had a tendency to reach its maximum at progressively early sowing dates with lower plant densities (Figure 5 (e) and (f)). The increase in the pod dry matter at lower densities might have been due to increased number of pods obtained at lower plant density plots. Increase in pod numbers in canola was due to greater retention of flower buds (Mc Gregor, 1981). Better light penetration into the canopy at lower plant populations favour retention of leaf area (McWilliam et al., 1995). Improved photosynthetic source in the form of these leaves stimulates better retention of pods.

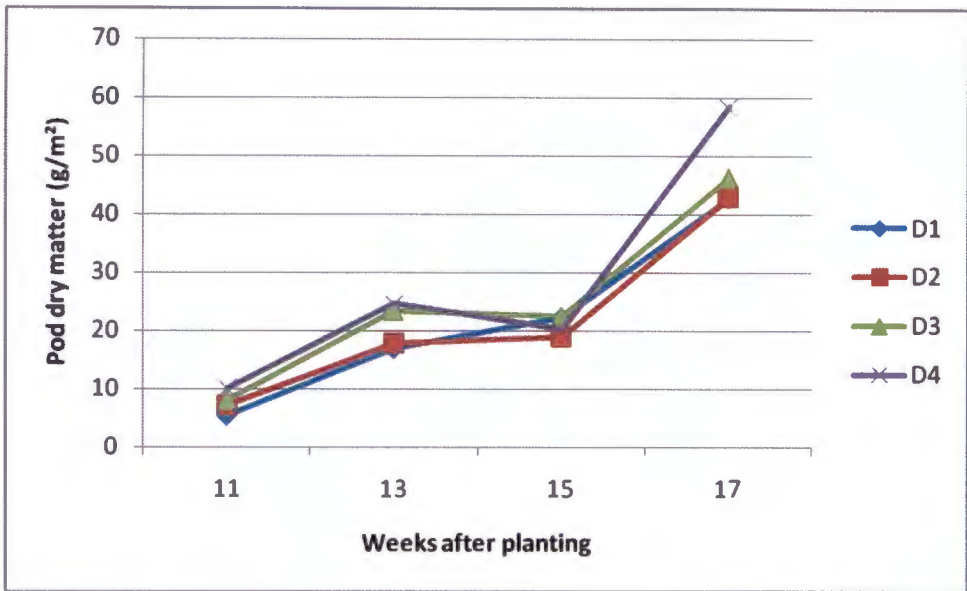


Figure 4.5 (c) Effects of planting density on pod dry matter in 2005.

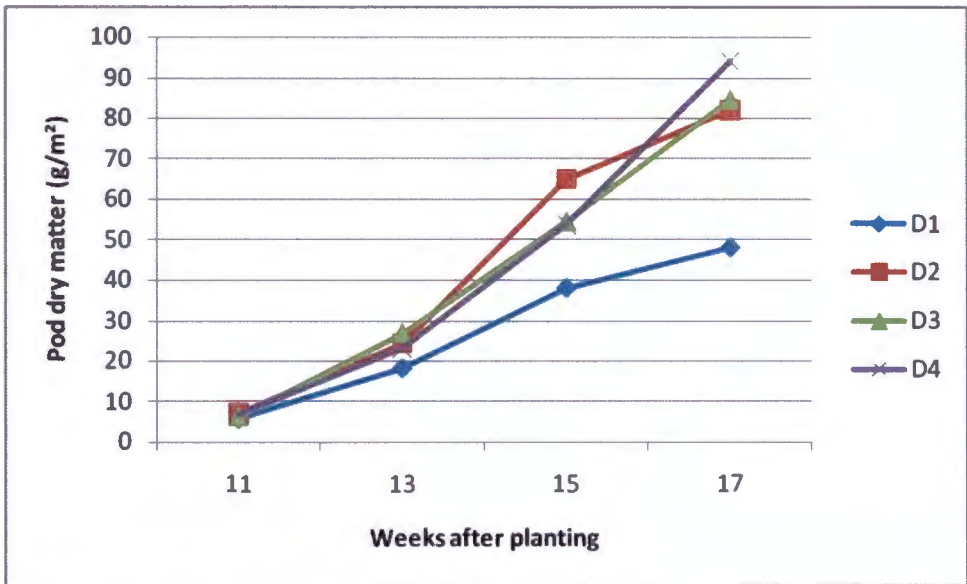


Figure 4.5 (d) Effects of planting density on pod dry matter in 2006.

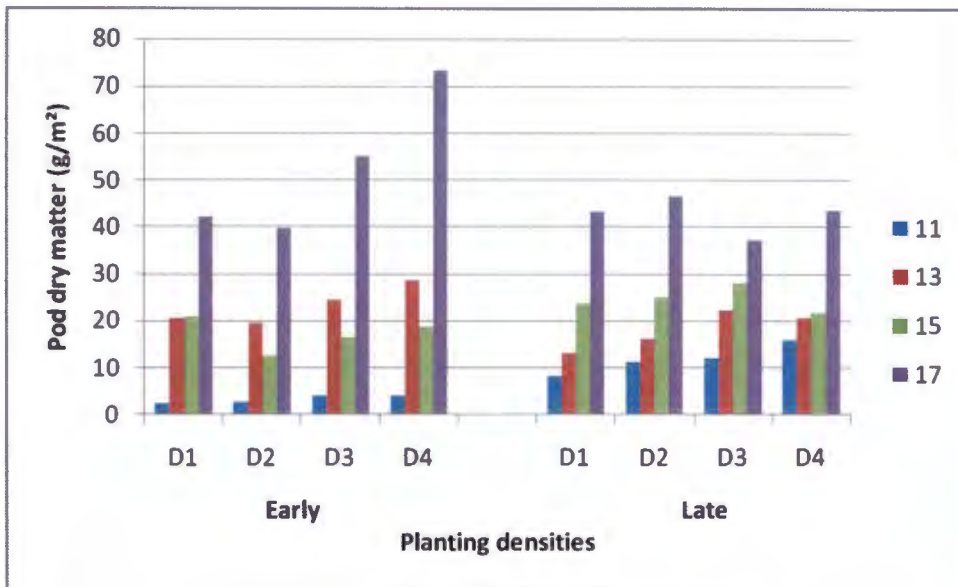


Figure 4.5 (e) Interaction effects between planting dates and density (P x D) on pod dry matter in 2005.

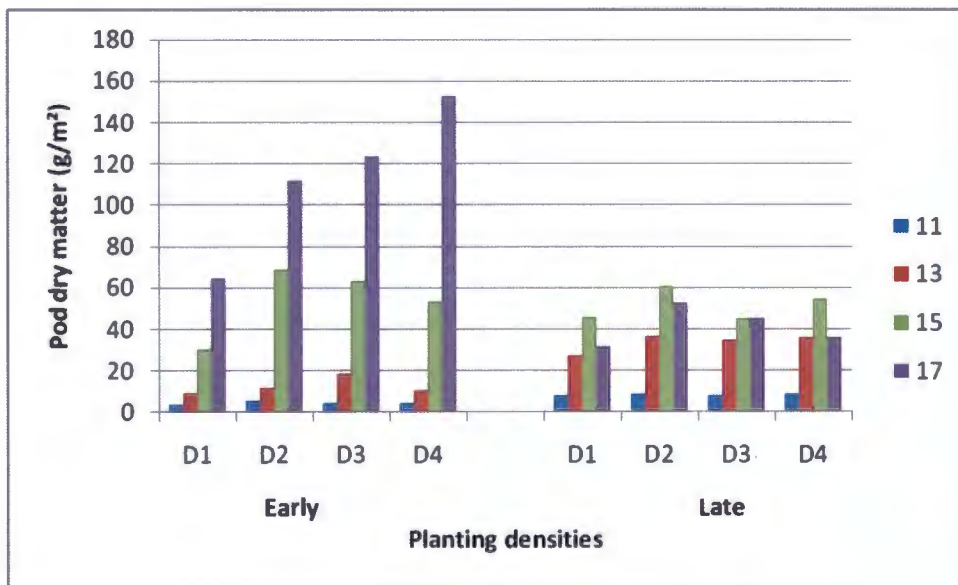


Figure 4.5 (f) Interaction effects between planting dates and density (P x D) on pod dry matter in 2005.

Table 4.4 F-Pr values from analysis of variance and treatment means for grain yield and yield components as affected by planting date, density and cultivars in 2005 and 2006 growing seasons.

F-pr values								
Treatments	Grain yield (kg/ha)		Pods/plant		Seeds/pod		1000-seed weight (g)	
	2005	2006	2005	2006	2005	2006	2005	2006
Planting date (P)	0.004	0.835	0.544	< 0.001	0.530	0.123	0.185	0.224
Cultivars (C)	0.667	0.731	0.235	0.204	0.075	0.795	0.907	0.844
P x C	0.196	0.041	0.314	0.856	0.001	0.238	0.327	0.980
Plant Density (D)	0.831	0.001	0.013	0.043	0.421	0.098	0.204	0.968
P x D	0.122	0.142	0.037	0.002	0.093	0.964	0.256	0.187
C x D	0.746	0.409	0.874	0.634	0.342	0.486	0.781	0.142
P x C x D	0.181	0.360	0.979	0.358	0.706	0.280	0.637	0.815
CV %	26.8	20.7	29.2	35.6	13.5	20.8	8.6	30.6
Mean values								
Planting date (P)								
Early	2409.0	2568.0	526.00	527.00	22.67	17.71	2.85	4.13
Late	1326.0	2618.0	495.00	234.00	21.96	19.42	2.74	3.65
LSD (5%)	508.6	622.3	132.10	59.20	2.87	2.44	0.20	0.93
Cultivars (C)								
Hyola 60	1896.0	2575.0	530.00	412.00	23.12	18.67	2.79	3.92
Rainbow	1839.0	2611.0	491.00	349.00	21.50	18.46	2.80	3.85
LSD (5%)	339.6	270.3	76.50	116.00	1.89	2.09	0.09	0.90
Plant density (D)								
D 1	1977.0	3166.0	415.00	291.00	22.00	19.83	2.92	3.91
D 2	1797.0	2601.0	464.00	376.00	22.83	17.58	2.71	3.87
D 3	1865.0	2207.0	543.00	394.00	21.25	20.17	2.79	3.77
D 4	1831.0	2399.0	621.00	460.00	23.17	16.67	2.76	4.01
LSD (5%)	421.0	453.0	125.70	114.00	2.55	3.25	0.20	1.00
Interaction (LSD 5%)								
P x C	521.2	612.6	132.50	115.00	2.93	2.67	0.12	0.09
P x D	644.7	736.2	182.70	145.40	3.79	4.35	0.13	0.10
C x D	570.3	585.8	163.00	164.00	3.40	4.25	0.13	0.07
P x C x D	849.7	926.7	242.90	217.60	5.04	6.05	0.18	0.11

LSD is the t-test least significant difference

CV % is the percentage coefficient of variation

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4.4 Yield and yield components

4.4.1 Grain yield

The effects of planting date, density and cultivars on grain yield for 2005 and 2006 growing seasons are shown in Table 4.4. Significant differences of planting dates were only observed in the 2005 growing season. The early planting date produced higher grain yield of 2409 kg/ha than the late planting date (1326 kg/ha). Yield declined as sowing date was delayed. This is likely due to lower soil temperatures which resulted in higher seedling emergence at early planting, while the later planting was most likely related to greater heat stress which led to fewer days from flowering to maturity. Taylor and Smith (1992) also reported in their study that delay in sowing of canola results in low yield. There was no difference between the yields of cultivars in both seasons. However, in 2006, there was a significant cultivars by planting date interaction. Yields of cultivar Hyola 60 were greater (2745 kg/ha) than those measured from Rainbow (2405 kg/ha) when sown early. The greater yield of Hyola 60 was due not only to the greater number of pods and seeds but also to the heavier seeds. Yield reductions with delayed sowing have been extensively reported in canola, both under irrigated conditions (Thurling, 1974; Wright et al., 1988; Taylor and Smith, 1992) and under rainfed conditions (Richards and Thurling, 1978; Taylor et al., 1992). Thurling (1974) found that under irrigated conditions the yield reduction was associated primarily with a reduction in total dry weight of the plant, which, in turn, was closely correlated with the crop duration. Under rainfed conditions, however, the yield reductions is the result of shorter crop duration and increased water deficit during grain filling (Hocking, 1993). The relative contribution of each of those factors depends on environmental conditions.

The results regarding the effect of planting density are shown at Table 4.9. Overall, maximum yield was obtained from plots with the highest planting density. The yield increased to a maximum of 3166 kg/ha where plant to plant distance was kept at 5 cm. The reason of the highest yield in case of planting density (5 cm) was due to the greater number of plants per plot, which has a prominent effect on yield per hectare. There are some reports of increased yield with increased plant density (Christensen and Drabble, 1984; Morrison et al., 1990 and O'Donovan, 1994). On the other hand, high plant populations can also contribute to the control of the growth and development of weeds in canola plants (O'Donovan, 1994). The data of the present study suggest that canola grown at high plant density would produce higher grain yield compared to the lower plant density.

4.4.2 Number of pods per plant

Both planting dates and densities influenced number of pods per plant (Table 4.9). The seed yield of individual plants is closely related to the number of pods per plant. Plant population density and planting date play a crucial role in control of pod number (Diepenbrock, 2000). Differences were not significant for pod number per plant for the two cultivars in both seasons. Results regarding planting dates were highly significant ($P < 0.001$) in 2006 and non-significant in 2005. From the table, it is clear that restricted pod production was the principal cause of yield loss with late sowing. The greatest number of pods per plant (526) was produced in the early planting date as compared to the late planting date which produced the lowest pod number per plant (495) in 2006. Delayed sowing generally reduces pod number (Hodgson, 1979; Mendham et al., 1981; Scarisbrick et al., 1981; Jenkins and Leitch, 1986). The interaction between cultivars and planting dates ($P \times C$) was found to be non-significant in pod number. Also the cultivars showed no significant differences among them for pods number per plant.

The numbers of pods per plant increased with decreasing plant density in both seasons, although the magnitude was different for each season (Table 4.9). The maximum number of pods per plant (621 and 460 in 2005 and 2006, respectively) were obtained from the plots with the lowest density. Increased pod number only partially compensated for the decreased planting density and its compensation also depended on growing conditions. Increasing competition not only reduces branching, but also the number of pods on all branches (Diepenbrock, 2000). Allen and Morgan (1972) suggested that the ability of canola plant to supply assimilates is important in determining pod number. The interaction between planting dates and density ($P \times D$) was also significant in both seasons. The lowest plant densities produced the highest number of pods per plant (738 and 713 in 2005 and 2006, respectively) in early planted plots.

4.4.3 Number of seeds per pod and 1000-seeds weight

The number of seeds per pod and 1000-seed weight were not affected by planting dates in both growing seasons (Table 4.9). However the interaction between planting dates and cultivars was significant in 2005. Cultivars Hyola 60 produced significantly higher number of pods (25.67) in the early sown plots while cultivars Rainbow produced lower (20.58). In contrast to the results obtained above, Mendham et al. (1981); Jenkins and Leitch, (1986) and Sierts et al., (1987) found in their study an increased number of seeds per pod with delayed sowing. This may be due to compensation for the lower pod number associated late sowing. Differences were also not significant for seed number per pod in cultivars and planting densities. Mc Gregor (1987) also

found that seeds per pod and seed weight were not as strongly influenced by population as were number of pods per plant. Number of seeds/pod in plants is function of resource drawing ability of ovules (Ganeshiah and Uma Shanker, 1992). This contrasts with the observation of Morrison et al. (1990), who reported significant increase in seeds per pod at lower populations. However, in that study, the highest seed yield was observed with the lowest seeding rate, suggesting higher inter-plant competition due to a better growing environment. Data collected in the average results of two study years indicate that there were no significant differences for 1000-seeds weight (Table 4.9). This agrees with literature which reported that 1000-seed weight was not significantly affected by planting densities (Kondra, 1977, Morrison et al., 1990, O'Donovan, 1994).

Table 4.5 F-Pr values from analysis of variance and treatment means for Protein and Oil contents as affected by planting date, density and cultivars in 2005 growing season.

F-pr values

Treatments	Protein content (mg/g)	Oil content (mg/g)
	2005	2005
Planting date (P)	< 0.001	0.001
Cultivars (C)	0.002	< 0.001
P x C	0.003	< 0.001
Plant Density (D)	0.998	1.000
P x D	0.998	1.000
C x D	1.000	1.000
P x C x D	1.000	1.000
CV (%)	37.2	34.5
Mean values		
Planting date (P)		
Early	254.0	405.0
Late	157.0	274.0
LSD (5%)	26.4	47.0
Cultivars (C)		
Hyola 60	164.0	265.0
Rainbow	247.0	414.0
LSD (5%)	31.3	38.8
Plant density (D)		
D 1	208.0	339.0
D 2	207.0	338.0
D 3	202.0	341.0
D 4	204.0	340.0
LSD (5%)	64.4	98.7
Interaction (LSD 5%)		
P x C	34.2	51.0
P x D	80.9	125.1
C x D	81.7	123.8
P x C x D	114.9	175.9

LSD is the t-test least significant difference

CV % is the percentage coefficient of variation

4.5 Protein and Oil content

Planting date had a significant effect on oil and protein contents in 2005. There was no data for protein and oil contents in 2006 due to seed spoilage. The data on protein and oil content reveals that higher amounts were attained in early sown plots. Early planting date significantly increased the protein and oil contents. A comparison of cultivars Hyola 60 and Rainbow used in this study showed significant differences in protein content. Cultivars Rainbow had higher protein content (247 mg/g) than cultivars Hyola 60 (164 mg/g). The protein content was not affected by changes in plant density. This result agrees with the findings of Kondra (1977) and Van Deynze et al. (1992) who reported that protein content did not change with varying plant densities. However, Shrief et al. (1990) in contrast reported that protein content was higher under higher population densities. There was a significant ($P < 0.01$) planting date and cultivars ($P \times C$) interaction. Protein content from cultivars Rainbow was greater (247 mg/g) than that of cultivars Hyola 60 (164 mg/g) for crops planted early.

The effects of planting date on oil content are shown in Table 4.10. The early planting date produced significantly higher oil content of 405 mg/g than the late planting date (274). Cultivars showed a highly significant differences in oil content. Seed oil content of cultivars Rainbow was found to be higher (414 mg/g) than that of cultivars Hyola 60 (265 mg/g). Non significant differences between plant densities on oil content were not found. A lack of any effect of plant density on oil content has also been reported by Morrison et al. (1990) and Leach et al. (1999) while Van Deynze et al. (1992) showed a small decrease in oil content as sowing rate increased to 9 kg/ha. In practical terms it seems that plant density can be varied with little effect on oil content. Sharief and Keshta (2002) found in their study that the oil percentage was positively and significantly correlated with plant height. The interaction between planting dates and cultivars was highly significant ($P < 0.001$). Cultivars Rainbow had the highest oil content in early planting date compared to cultivars Hyola 60 which had the lowest. The low oil concentration associated with the late planting date may be explained by the short period of seed fill and high temperatures of July and August to stimulate maturity during seed formation of late planting.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Time of planting greatly influenced the growth and development of canola. Planting dates significantly affected all studied parameters: dry matter yield, yield and its components except number of seeds/pod and 1000-seeds weight. The late planting date resulted in a decrease in grain yield, number of pods/plant, plant height, protein and oil content but an increase in dry matter yield and only at certain stages of development. These results suggests that crops sown early generally yield more than those sown late. Oil content in response to sowing date could be related to seed size and temperature conditions. It could be stated that planting canola early was the most suitable date because late sowings reduced the growth period and reducing number of days to 90% germination, 50% flowering and plant height.

Cultivars used in this study responded to treatments the same way except for number of days to 50% flowering, plant height, dry matter yield, protein and oil content. Rainbow was the earliest in terms of days to 50% flowering than cultivars Hyola 60, and also exceeded cultivars Hyola 60 in protein and oil contents. However, cultivars Hyola 60 had the highest plant height and obtained the maximum dry matter yield than cultivars Rainbow. The differences in cultivars in terms of growth and development may be attributed to the genetical variation among them.

Planting density in general resulted in an increased dry matter yield (including dry matter of all three components measured, leaves, stems, and pods) number of pods/plant and days to 50% flowering, but a decrease in plant height in both seasons and grain yield only in 2006 growing season. Density had variable effect on the cultivars for characteristics such as dry matter. Therefore, a constant planting density is essential for comparing single plants within populations. The wide variability in plant densities between sowing dates was the response to soil conditions experienced in the period of vegetative growth. Although high yields are possible from late sown crops, the outcome is dependent on favourable weather conditions for crop establishment, crop growth and seed ripening. Irrigation offers the best opportunity to maintain favourable growing conditions and thus minimize the impact of a late sowing date.

5.2 Recommendations

May was the optimum sowing month for canola, a strategy that should be adopted by farmers to maximize the yield of seed and oil. Delayed sowing date generally resulted in a decrease in seed yield, and the duration of growth. This study also has suggested that to obtain maximum grain yield of canola, the plant to plant distance should be maintained as 10cm. The cultivars used in this study responded to treatments in the same way, thus there was no interaction of cultivars with planting density. Further work is required with more improved cultivars over a wide range of locations and seasons and early seeding is the key to the success of the crop.

CHAPTER 6

6. REFERENCES

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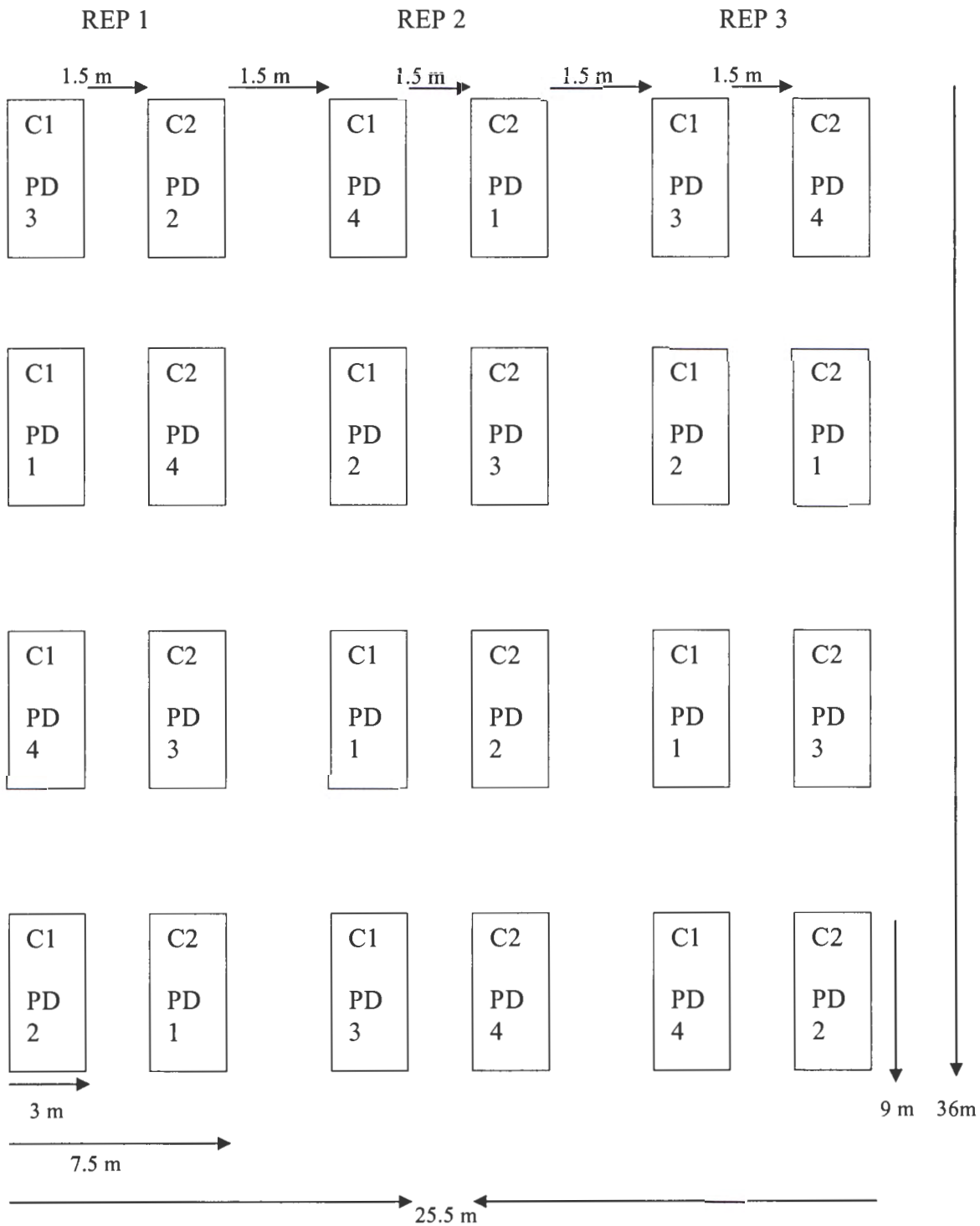
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APPENDICES

Appendix A: A field layout and treatments for the early planting date during 2005 and 2006 growing seasons

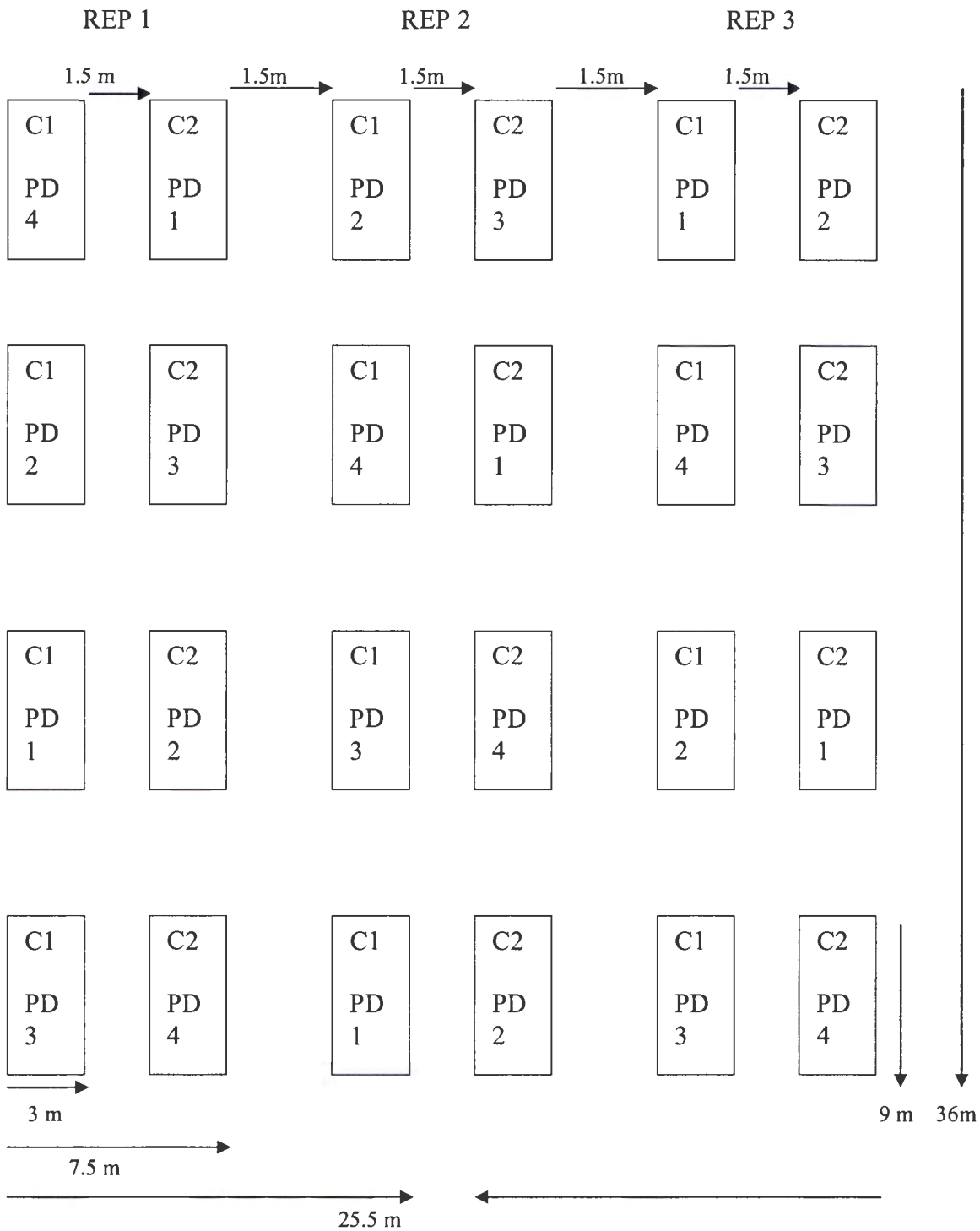


C1 = Hyola 60

C2= Rainbow

PD1-4= Planting densities

Appendix B: A field layout and treatments for the late planting date during 2005 and 2006 growing seasons



C1= Rainbow

C2= Hyola 60

PD= Planting densities

Appendix C (1): F-Pr values from analysis of variance for dry matter yield (g/m²) in 2005 growing season.

F-pr values						
Treatments	Week 7	Week 9	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.839	0.012	0.003	0.508	< 0.001	0.583
Cultivars (C)	0.598	0.012	0.011	0.614	0.306	0.329
P x C	0.864	0.007	0.344	0.108	0.855	0.291
Planting Density (D)	< 0.001	< 0.001	< 0.001	0.003	0.358	0.323
P x D	0.798	0.013	0.659	0.501	0.425	0.065
C x D	0.915	0.239	0.753	0.657	0.073	0.232
P x C x D	0.686	0.096	0.882	0.215	0.092	0.990
CV (%)	20.5	22.1	24	29.2	31.3	29.2

Appendix C (2): F-Pr values from analysis of variance for dry matter yield (g/m²) in 2006 growing season.

F-pr values						
Treatments	Week 7	Week 9	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.218	0.008	0.027	0.004	0.406	< 0.001
Cultivars (C)	0.978	0.465	0.853	0.766	0.538	0.647
P x C	0.564	0.850	0.810	0.316	0.390	0.821
Planting Density (D)	< 0.001	0.012	0.376	0.001	0.367	0.215
P x D	< 0.001	0.559	0.014	0.044	0.934	0.164
C x D	0.843	0.762	0.675	0.064	0.217	0.392
P x C x D	0.541	0.265	0.729	0.404	0.242	0.639
CV (%)	19.7	22.7	32.4	20.6	27.4	24.7

Appendix D (1): F-Pr values from analysis of variance for total top dry matter (g/m²) in 2005 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.070	0.002	0.119	< 0.001
Cultivars (C)	0.993	0.362	0.309	0.740
P x C	0.475	0.137	0.167	0.465
Planting Density (D)	0.001	0.003	0.698	0.037
P x D	0.999	0.199	0.855	0.040
C x D	0.353	0.864	0.835	0.987
P x C x D	0.625	0.980	0.647	0.872
CV (%)	37.0	34.3	53.2	21.9

Appendix D (2): F-Pr values from analysis of variance for total top dry matter (g/m²) in 2006 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.647	0.436	0.318	< 0.001
Cultivars (C)	0.102	0.564	0.631	0.957
P x C	0.958	0.988	0.468	0.992
Planting Density (D)	0.078	< 0.001	0.013	0.003
P x D	0.446	0.011	0.247	0.013
C x D	0.059	0.065	0.935	0.942
P x C x D	0.396	0.090	0.921	0.569
CV (%)	32.4	27.2	35.7	35

Appendix E (1): F-Pr values from analysis of variance for leaf dry matter (g/m²) in 2005 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.206	< 0.001	0.450	0.581
Cultivars (C)	0.055	0.749	0.845	0.181
P x C	0.004	0.878	0.330	0.748
Planting Density (D)	0.002	0.012	0.310	0.698
P x D	0.210	0.035	0.790	0.134
C x D	0.140	0.805	0.870	0.458
P x C x D	0.417	0.296	0.507	0.260
CV (%)	47.0	56.3	117.9	56.4

Appendix E (2): F-Pr values from analysis of variance for leaf dry matter (g/m²) in 2006 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.814	0.037	< 0.001	0.009
Cultivars (C)	0.529	0.206	0.900	0.659
P x C	0.359	0.904	0.473	0.520
Planting Density (D)	0.061	< 0.001	0.088	0.487
P x D	0.783	0.127	0.976	0.335
C x D	0.648	0.471	0.101	0.913
P x C x D	0.416	0.720	0.685	0.874
CV (%)	42.2	41.8	88.9	87.5

Appendix F (1): F-Pr values from analysis of variance for stem dry matter (g/m²) in 2005 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.066	0.003	0.047	0.750
Cultivars (C)	0.307	0.154	0.411	0.908
P x C	0.572	0.284	0.169	0.822
Planting Density (D)	0.006	< 0.001	0.594	0.026
P x D	0.992	0.056	0.981	0.041
C x D	0.340	0.902	0.763	0.756
P x C x D	0.683	0.935	0.387	0.773
CV (%)	40.1	35.9	45.2	24.1

Appendix F (2): F-Pr values from analysis of variance for stem dry matter (g/m²) in 2006 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.900	0.038	0.046	0.002
Cultivars (C)	0.838	0.760	0.451	0.752
P x C	0.057	0.831	0.495	0.973
Planting Density (D)	0.158	0.001	0.005	0.014
P x D	0.196	0.152	0.248	0.044
C x D	0.423	0.317	0.801	0.691
P x C x D	0.043	0.522	0.802	0.609
CV (%)	33.9	33.9	33.4	36.8

Appendix G (1): F-Pr values from analysis of variance for pod dry matter (g/m²) in 2005 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.001	0.009	0.087	0.015
Cultivars (C)	0.527	0.535	0.196	0.974
P x C	0.544	0.131	0.181	0.104
Planting Density (D)	0.018	0.085	0.886	0.016
P x D	0.190	0.811	0.687	0.005
C x D	0.931	0.517	0.874	0.965
P x C x D	0.621	0.506	0.833	0.923
CV (%)	44.0	41.3	60.8	26.3

Appendix G (2): F-Pr values from analysis of variance for pod dry matter (g/m²) in 2006 growing season.

F-pr values				
Treatments	Week 11	Week 13	Week 15	Week 17
Planting date (P)	0.016	0.001	0.525	< 0.001
Cultivars (C)	0.319	0.504	0.322	0.594
P x C	0.350	0.738	0.187	0.854
Planting Density (D)	0.842	0.023	0.025	0.002
P x D	0.983	0.203	0.234	0.008
C x D	0.297	0.014	0.752	0.921
P x C x D	0.306	0.105	0.953	0.536
CV (%)	54.0	27.4	37.6	35.6

Appendix H (1): Abbreviated Anova table of dry matter yield in 2005 growing season

Source	Df	Mean squares					
		Week 7	Week 9	Week 11	Week 13	Week 15	Week 17
P	1	0.270 ns	842.53 *	4004.1 **	240.4 ns	110333.0 ***	502.0 ns
C	1	11.213 ns	149.46 *	4396.8 *	136.6 ns	1639.0 ns	1698.0 ns
P x C	1	1.141 ns	201.31 *	258.5 ns	1940.2 ns	45.0 ns	2029.0 ns
D	3	477.627 ***	2314.99 ***	4060.9 ***	5212.3 **	2732.0 ns	2130.0 ns
P x D	3	2.317 ns	305.93 *	221.2 ns	699.1 ns	2343.0 ns	4784.0 ns
C x D	3	1.171 ns	103.12 ns	164.3 ns	470.6 ns	6393.0 ns	2668.0 ns
P x C x D	3	3.425 ns	162.02 ns	89.7 ns	1384.2 ns	5830.0 ns	65.00 ns
Residual	24	6.849	68.50	408.7	864.2	2426.0	1742.0

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix H (2): Abbreviated Anova table of dry matter yield in 2006 growing season

Source	Df	Mean squares					
		Week 7	Week 9	Week 11	Week 13	Week 15	Week 17
P	1	307.04 ns	16785.1 *	27222.0*	16358.0 **	10827.0 ns	163228.0 ***
C	1	0.07 ns	747.3 ns	39.0 ns	483.0 ns	1132.0 ns	1518.0 ns
P x C	1	30.72 ns	46.8 ns	67.0 ns	6369.0 ns	2320.0 ns	365.0 ns
D	3	1170.44 ***	2212.1 *	1584.0 ns	11074.0 **	3812.0 ns	5937.0 ns
P x D	3	920.61 ***	344.9 ns	6321.0 *	4651.0 *	492.0 ns	6880.0 ns
C x D	3	20.38 ns	190.6 ns	757.0 ns	4093.0 ns	5512.0 ns	3860.0 ns
P x C x D	3	54.61 ns	689.5 ns	640.0 ns	1499.0ns	5161.0 ns	2118.0 ns
Residual	24	74.21	490.0	1465.0	1481.0	3458.0	3709.0

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix I (1): Abbreviated Anova table of total top dry matter in 2005 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	3062.4 ns	11285.3**	1847.6 ns	12897.6***
C	1	0.0 ns	332.9 ns	792.2 ns	0.13 ns
P x C	1	83.2 ns	1083.0 ns	1668.5 ns	0.65 ns
D	3	1835.8**	1953.3**	166.2 ns	562.5*
P x D	3	1.5 ns	525.5 ns	88.9 ns	550.8*
C x D	3	295.6 ns	76.9 ns	98.5 ns	7.8 ns
P x C x D	3	153.9 ns	19.1 ns	192.8 ns	39.8 ns
Residual	24	259.2	313.5	344.6	170.4

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix I (2): Abbreviated Anova table of total top dry matter in 2006 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	64.6 ns	646.8 ns	403.1 ns	144343.0***
C	1	1400.8 ns	614.9 ns	37.3 ns	10.0 ns
P x C	1	1.0 ns	0.4 ns	88.8 ns	0.0 ns
D	3	496.5 ns	4117.7***	3916.5*	10838.0**
P x D	3	178.4 ns	1771.6*	1297.9 ns	7991.0*
C x D	3	550.6 ns	1059.2 ns	123.0 ns	499.0 ns
P x C x D	3	204.8 ns	936.1 ns	142.6 ns	1239.0 ns
Residual	24	193.7	385.9	881.7	1805.0 ns

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix J (1): Abbreviated Anova table of leaf dry matter in 2005 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	88.29 ns	628.58***	0.4800 ns	0.1430 ns
C	1	15.08 ns	0.88 ns	0.0300 ns	0.2380 ns
P x C	1	75.75**	0.20 ns	0.8533 ns	0.0108 ns
D	3	181.08**	54.61 ns	0.7594 ns	0.1102 ns
P x D	3	44.84 ns	40.83*	0.2106 ns	0.4676 ns
C x D	3	55.26 ns	3.96 ns	0.1428 ns	0.2046 ns
P x C x D	3	27.16 ns	15.75 ns	0.4806 ns	0.3260 ns
Residual	24	27.59 ns	12.08	0.6023	0.2286

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix J (2): Abbreviated Anova table of leaf dry matter in 2006 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	44.28 ns	139.40*	55.255***	80.860 ns
C	1	22.28 ns	22.69 ns	0.060 ns	3.685 ns
P x C	1	50.23 ns	0.16 ns	0.63 ns	8.085 ns
D	3	106.34 ns	102.57***	9.636 ns	4.264 ns
P x D	3	13.55 ns	22.79 ns	0.269 ns	6.045 ns
C x D	3	21.05 ns	9.43 ns	9.118 ns	0.881 ns
P x C x D	3	37.22 ns	4.87 ns	1.974 ns	1.172 ns
Residual	24	37.73	10.86	3.933	5.090

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix K (1): Abbreviated Anova table of stem dry matter in 2005 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	1212.03 ns	3640.08 **	489.60 ns	4.47 ns
C	1	62.56 ns	155.52 ns	86.14 ns	3.44 ns
P x C	1	17.28 ns	77.01 ns	288.61 ns	13.18 ns
D	3	522.18 *	651.30 ***	22.49 ns	221.97 *
P x D	3	3.03 ns	236.05 ns	2.04 ns	193.07 *
C x D	3	114.73 ns	15.51 ns	13.53 ns	23.87 ns
P x C x D	3	49.32 ns	11.37 ns	36.72 ns	22.46 ns
Residual	24	97.72	81.4	34.87	60.06

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix K (2): Abbreviated Anova table of stem dry matter in 2006 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	1.44 ns	1083.0 *	379.69 ns	16177.4 **
C	1	4.50 ns	23.2 ns	14.30 ns	60.8 ns
P x C	1	663.80 ns	11.2 ns	11.60 ns	0.7 ns
D	3	103.73 ns	754.6 **	500.96 *	991.3 *
P x D	3	92.64 ns	199.2 ns	130.56 ns	710.7 *
C x D	3	53.21 ns	128.2 ns	29.68 ns	111.6 ns
P x C x D	3	172.99 ns	79.5 ns	29.49 ns	140.7 ns
Residual	24	54.77	103.3	88.84	227.0

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix L (1): Abbreviated Anova table of pod dry matter in 2005 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	895.28 **	325.00 *	670.5 ns	1192.0 *
C	1	15.30 ns	56.55 ns	545.4 ns	0.2 ns
P x C	1	13.98 ns	441.05 ns	595.0 ns	766.4 ns
D	3	46.57 *	182.55 ns	34.7 ns	655.1 *
P x D	3	19.58 ns	23.51 ns	80.8 ns	855.8 *
C x D	3	1.67 ns	57.28 ns	37.4 ns	13.9 ns
P x C x D	3	6.83 ns	58.81 ns	46.9 ns	24.9 ns
Residual	24	11.39	73.54	162.1	156.3

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix L(2): Abbreviated Anova table of pod dry matter in 2006 growing season

Source	Df	Mean squares			
		Week 11	Week 13	Week 15	Week 17
P	1	165.39 *	5391.16 **	64.4 ns	61540.2 ***
C	1	17.89 ns	116.25 ns	102.7 ns	295.5 ns
P x C	1	15.53 ns	27.76 ns	204.2 ns	34.2 ns
D	3	3.33 ns	153.00 *	1467.2 *	4854.9 **
P x D	3	0.66 ns	66.49 ns	598.7 ns	3769.5 *
C x D	3	15.70 ns	173.94 *	158.6 ns	0.16 ns
P x C x D	3	15.35 ns	91.29 ns	43.4 ns	560.3 ns
Residual	24	12.06	40.10	393.5	753.1

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix M: Abbreviated Anova table of vegetative growth 2005 and 2006 growing seasons

Source	Df	Mean squares					
		Days to 90% germination		Days to 50% flowering		Plant height	
		2005	2006	2005	2006	2005	2006
P	1	30.0833 *	22.688 *	675.000 ***	157.688 ***	0.68402 **	0.529200 **
C	1	0.7500 ns	1.021 ns	5.3333 *	1.688 ns	0.16450 *	0.013333 ns
P x C	1	1.3333 ns	0.187 ns	0.0833 ns	1.688 ns	0.08250 ns	0.024300 *
D	3	0.9444 ns	1.576 ns	1.4722 ns	43.132 ***	0.06576 **	0.064461 ***
P x D	3	0.0278 ns	0.410 ns	0.3889 ns	5.576 *	0.01269 ns	0.003172 ns
C x D	3	0.1389 ns	1.188 ns	0.0556 ns	1.688 ns	0.00960 ns	0.007639 ns
P x C x D	3	0.0556 ns	0.688 ns	0.1389 ns	0.576 ns	0.00618 ns	0.006383 ns
Residual	24	0.4375 ns	1.132	0.5556	1.285	0.01124	0.003376

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix N: Abbreviated Anova table of yield and yield components in 2005 and 2006 growing seasons

Source	Df	Mean squares							
		Grain yield		Pods/plant		Seeds/pod		1000-seeds	
		2005	2006	2005	2006	2005	2006	2005	2006
P	1	14083550 **	29716 ns	11939 ns	1032533 ***	6.021 ns	35.02 ns	0.15187 ns	2.803 ns
C	1	38601 ns	15449 ns	17749 ns	48260 ns	31.688 ns	0.52 ns	0.00021 ns	0.053 ns
P x C	1	432326 ns	1012744 *	12065 ns	784 ns	402.521 **	13.02 ns	0.01688 ns	0.001 ns
D	3	72816 ns	2056828 **	97765 *	57734 *	8.910 ns	34.97 ns	0.09465 ns	0.120 ns
P x D	3	532416 ns	575550 ns	73726 *	126120 **	21.910 ns	1.35 ns	0.08243 ns	2.454 ns
C x D	3	102831 ns	289289 ns	5135 ns	10626 ns	10.688 ns	12.52 ns	0.02076 ns	2.815 ns
P x C x D	3	439582 ns	324224 ns	1401 ns	20626 ns	4.299 ns	20.24 ns	0.03299 ns	0.445 ns
Residual	24	249595	289030	22266	18307	9.14	14.92	0.06	1.42

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001

Appendix O: Abbreviated Anova table of protein and oil contents in 2005 growing season

Source	Df	Mean squares	
		Protein content	Oil content
P	1	112230 ***	208033 **
C	1	82088 **	267605 ***
P x C	1	65195 **	292656 ***
D	3	83 ns	18 ns
P x D	3	84 ns	4 ns
C x D	3	11 ns	10 ns
P x C x D	3	22 ns	10 ns
Residual	24	5841	13735

P = Planting dates

C = Cultivars

D = planting densities

P x C = Planting date x Cultivars interaction

C x D = Cultivars x planting density interaction

P x C x D = Planting dates x cultivars x Planting density interaction

ns = not significantly

* = P < 0.05, ** = P < 0.01, *** = P < 0.001