The Effect of Field Pea (*Pisum sativum* L.) Basal Branching on Optimal Plant Density and Crop Competitiveness

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By
Joshua Michael Spies

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Abstract

Field pea is an important crop in western Canada. The current recommended seeding rate in field pea is 88 plants m^{-2}. As certain pea genotypes have the ability for increased branching, it may be possible for a producer to seed at a lower plant population without reduced yield or to choose a highly branched cultivar to have reduced risk of yield loss under conditions of poor emergence. The objective of this research was to determine how differences in branching among seven representative pea cultivars affected crop yield at different seeding rates, and to determine if branching affected the competitive ability of pea cultivars. In the plant population experiment, seven pea cultivars were seeded at five target plant populations (10, 30, 90, 120, and 150 plant m^{-2}) during 2005 and 2006 at Rosthern and Saskatoon, Saskatchewan. The competition experiment involved eight cultivars being seeded at 50 plants m^{-2} to measure competitiveness with weeds. Plant emergence, number of branches, light interception, harvest index and grain yield were measured. Growth, seasonal temperature and rainfall were near normal in 2005. Severe terminal drought occurred in 2006 which may have lead to decreased yields. Branching was greatest at low plant densities and decreased as plant density increased. Grain yield increased as plant density increased until it plateaued at 80 – 100 plants m^{-2}. The response of yield to plant density differed to some extent among cultivars, with *CDC Acer* and *CDC Bronco* achieving more of their potential yield at lower densities, while *Carrera* and *Courier* required higher densities to reach the same proportion of potential yield. Weed biomass was lowest in plots sown to longer vined cultivars with normal leaf type. Branching habit did not affect the competitiveness of pea cultivars. Potential exists to plant highly branched cultivars to reduce risk of yield loss in situations where low plant emergence might occur.

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List of Abbreviations

AF	Afila
Bmax	Maximum Biomass Potential
CDC	Crop Development Center
HI	Harvest Index
Lmax	Maximum Light Interception
MM	Michaelis-Menten
NLIN	Non-Linear
PD	Plant Density
R:FR	Red : Far Red
SAS	Statistical Analysis Software
SMS	Shoot Multiplication Signal
TDM	Total Dry Matter
Ymax	Maximum Yield Potential

1.0 Introduction

Field pea *(Pisum sativum* L.), a native of southwest Asia, was among the first crops cultivated by man (Zohary and Hopf 2002). When it was first introduced into Canada, the main production came from Ontario and Manitoba. Since the mid 1980's, Saskatchewan has produced the majority of the Canadian pea crop, with significant area also in Alberta and Manitoba (Saskatchewan Pulse Growers 2006). Field pea has a benefit over many other crops in that it has the ability to fix its own nitrogen. This makes it useful not only as an alternative crop but also adds rotational benefits.

Field pea is an annual, cool season pulse grain and can be of the indeterminate (climbing) type or determinate (bush or dwarf) type (Zohary and Hopf 2002). The majority of pea plants exhibit an indeterminate growth habit (Cousin 1997). Most cultivars of pea produce white or reddish-purple flowers, which are self pollinated. Each flower produces a pod containing four to nine seeds (Zohary and Hopf 2002). Indeterminate cultivars mature in 90 – 100 days while determinate types have a shorter maturity time, usually 80 – 90 days in western Canada and northern USA. The average yield of field pea is Saskatchewan is 2000 kg ha^{-1} (Saskatchewan Pulse Growers 2006), however, pea seed yield is subject to wide variation (Clayton et al. 1998).

The production of field pea on the Canadian prairies in 2005 was 3.2 million tonnes (Statistics Canada 2005), accounting for approximately 6% of all grain production and 40% of legume production in Canada. In recent years, pea production has decreased in Manitoba (by 64%) and also in Alberta (by 9%). At the same time, Saskatchewan reached record seeded area (1.1 million hectares) and production (3.4 million tonnes) (Statistics Canada 2005). Most Canadian production is exported to Europe, South America and Asia (Saskatchewan Pulse Growers 2006). Peas are sold in the following markets: (i) field pea providing forage for animal feed, (ii) market pea from which pods are harvested for human consumption as a fresh vegetable, (iii) vining pea for canning or freezing and (iv) dried pea for human or animal consumption (Cousin 1997). The majority of peas produced in Canada are exported to Europe and used for livestock feed.

The current recommended seeding rate for pea is 88 plants m^{-2} (Saskatchewan Pulse Growers 2006). Since seed is one of the major costs involved in growing field pea ($40 to $60 ha^{-1}) (Saskatchewan Agriculture and Food 2006), reduced seeding rates reduce production costs (Wall and Townley-Smith 1996). Lowering seeding rates may, however, reduce crop competitiveness and subsequently reduce field pea yields under weedy conditions (Blackshaw and O'Donovan 1993). In addition, if seeding rates are reduced too much, inadequate stands are achieved and yield losses could be dramatic due to insufficient plant biomass (Heath et al. 1991). Knowledge of pea cultivar yield potential and competitiveness can aid in making pea production more profitable.

The main focus of this thesis was to evaluate whether reduced seeding rates could be used in field pea without having significant reductions in economic yield. Basal branching in field pea is known to compensate for reduced stands (Hedley and Ambrose 1981). Based on this, it was hypothesized that cultivars with greater branching ability will prevent yield loss at reduced plant densities. In addition, it was determined whether increased basal branching could enhance the competitive ability of field pea. Nelson and Nyland (1962) stated that light was one of the primary resources that crops compete for with weeds. Cultivars that produce more branches could intercept more light and therefore be more competitive with weeds. It was hypothesized that field pea cultivars with greater basal branching will be more competitive with weeds and also have no significant yield losses at lower than recommended seeding rates.

Objectives that were addressed by this research were:
(1) Determination of the genetic variability for the production of fertile basal branches?
(2) Evaluation of branching ability of field pea cultivars in yield formation at lower than recommended seeding rates and in weed competition?

The knowledge derived from this research will aid producers in their ability to grow field pea more economically. The findings will also aid decisions with weed management and cultivar selection. This may be especially important for organic producers who rely mainly on crop competitiveness due to their limited options for weed control. These results may lead to genotype specific re-evaluation of the current seeding rate recommendation used for field pea.

2.0 Literature Review

2.1 Branching in field pea

2.1.1 Mechanism of field pea branching

Branching in field pea varies among different genotypes and plant densities. The number of branches per plant was strongly influenced by population density and species (Ayaz et al. 2004 c). Branching in plants is generally not essential for their life cycle, but rather serves to enhance vegetative proliferation and to generate multiple sites for seed production (Dun et al. 2006). Excessive branching may be costly with regards to use of resources, hence branching is carefully modulated in response to environmental factors, such as light quality, nitrogen and carbon availability, and growth and development of other plant parts (Dun et al. 2006).

Branching is thought to be related to apical dominance and is thus influenced by various environmental and genetic factors (Falloon and White 1978). These factors may determine responses to branching signals (Dun et al. 2006). The term apical dominance refers to the mechanism whereby a plant maintains the growth of a main shoot at the expense of lateral branches (Beveridge et al. 1996; Cline 1997). The first node of the pea plant, which may give rise to branches are vegetative, while subsequent nodes are reproductive (Cousin 1997). Shorter plants often have a higher number of basal branches than taller plants with the taller plants showing evidence of apical dominance (Walton 1990).

There are three hypotheses about how apical dominance controls and releases branching in plants. The first theory is called the “Classical Theory”. The classical theory states that auxin acts to regulate shoot branching in conjunction with secondary messengers, such as cytokinin (Sachs and Thimann 1967; Bangerth 1994; Li et al. 1995) by influencing the levels, transport, and/or action of other signals required to inhibit bud outgrowth (Snow 1937; Hall and Hillman 1975; Morris 1977; Bangerth 1989). The quantity of auxin present controls branching. If auxin is present in high concentrations, it inhibits cytokinin and promotes the shoot multiplication signal (SMS). Under low concentrations of auxin, cytokinin activity is promoted and SMS is inhibited. Cytokinin is a hormone that promotes branching while SMS inhibits branching.

The second hypothesis, the "Auxin Transport Theory", proposes that regulatory control is exerted by auxin movement in the auxin transport stream, as opposed to the actual level of auxin (Morris 1977; Bangerth 1989; Li and Bangerth 1999). In plants where axillary bud outgrowth is inhibited entirely, this transport stream of the main stem is suggested to be full, thus limiting the flow of auxin from the axillary bud (Dun et al. 2006). As a result, the axillary bud is unable to establish its own auxin transport stream into the main stem and is consequently prevented from growing out.

The third proposed hypothesis is "The Bud Transition Theory". This theory postulates that the bud enters different developmental stages that have varying degrees of sensitivity or responses to long-distance signals, including auxin (Stafstrom and Sussex 1992; Shimizu-Sato and Mori 2001; Morris et al. 2005). There are at least three stages at which a bud may reside: a stage of dormancy, a stage of transition and a stage of sustained growth (Stafstrom and Sussex 1992; Devitt and Stafstrom 1995; Cline 1997; Napoli et al. 1999; Shimizu-Sato and Mori 2001; Morris et al. 2005; Beveridge 2006). The dormancy stage is used to describe the extremely low or negligible growth rate of the axillary bud despite the fact that these buds are metabolically active (Dun et al. 2006). Transition stages occur when axillary buds are more receptive than dormant buds to signals that stimulate outgrowth, yet remain able to revert to a dormant state (Madoka and Mori 2000). The final stage is where the branches are growing and growth is sustained without the capability of reverting back to any previous stage.

The growth of a plant and its branches can be classified into four main stages (Fig. 2.1): lateral bud formation (Stage I), imposition of inhibition (Stage II), initiation of lateral bud outgrowth (Stage III), and subsequent elongation and development of the lateral bud into a branch (Stage IV) (Dun et al. 2006). As an apical shoot meristem of a herbaceous plant develops, axillary buds arise exogenously from superficial cell layers in the axils of leaf primordia (Fahn 1990). These embryonic lateral buds may have inhibition imposed upon them shortly after their formation or after a brief period of growth (Cline 1997). Although the elongation of the buds may be essentially inhibited, they remain metabolically active (Stafstrom 1995). Soon after apical dominance has been released and lateral bud elongation is underway (Stage IV), this developing lateral shoot or branch may begin to produce its own auxin, which may enhance elongation (Thimann and Skoog 1934). Many scientists believe that the "Classical Theory" of apical dominance is the mechanism by which pea controls the timing and amount of branching that will occur during the growth of the plant.

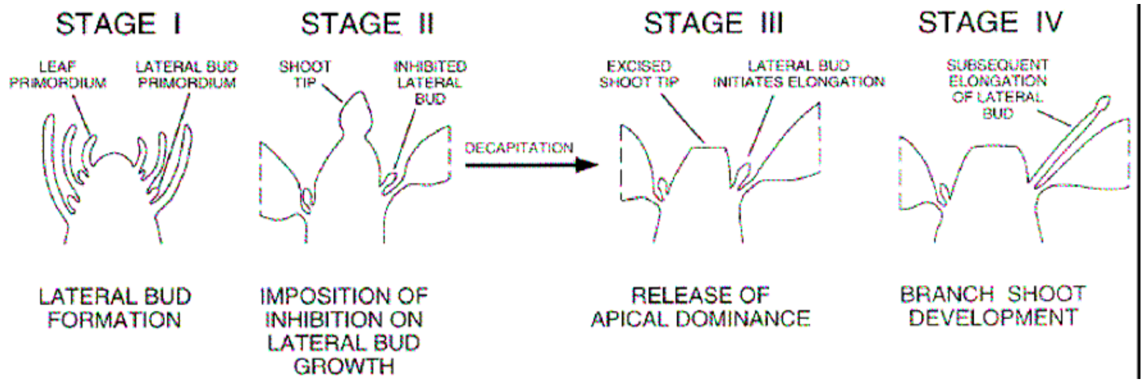


FIGURE 2.1 Development stages of apical dominance before and after release by decapitation of the shoot apex. **Source Cline 1997.**

2.1.2 Plant density and its effect on branching

Branching has an important effect on pea yield because greater branching contributes to higher yields at lower population densities (Moot and McNeil 1995). Branching in pea, which is known to compensate for low plant density (Hedley and Ambrose 1981), is not always sufficient to produce the maximum yield on commercial farms. Branching may compensate for low plant density but only to some extent (Dore et al. 1998). Lowering seeding rates may also reduce crop competitiveness and subsequently reduce field pea yield under weedy conditions (Blackshaw and O'Donovan 1993).

Several studies have been conducted on the effect of plant density on branching in pea plants. The results from these studies agree that the number of branches per plant increased with decrease in plant population (Reynolds 1950; Kruger 1977; Heath et al. 1991; Knott and Belcher 1998). Lower plant populations produced the highest number of branches per plant and the higher plant populations resulted in branching being suppressed. Hernandez (1986) stated that inter-plant competition is intense at higher plant populations with severe limitations in environmental resources available to individual plants. Competition for light at high plant densities may also reduce branching. Plant spacing also affects branching ability. As plant spacing increases, the number of branches also increase (Falloon and White 1978; Singh et al. 1979; Shaukat et al. 1999).

When planted at low population densities, pea branches are characterized by a tendency to grow laterally prior to assuming a vertical growth habit (Pullan and Hebblethwaite 1992). This aids in light capture and higher biomass production. Increased branching and biomass accumulation ultimately contribute to higher yield at lower population densities (Moot and McNeil 1995). The ability of some cultivars to produce pod-bearing branches from basal positions may enable them to be seeded at lower rates without significantly depressing yield (Falloon and White 1978).

2.1.3 The role of light in the determination of branches

Branching in pea plants is carefully modulated in response to environmental factors, such as light quality and nitrogen availability (Dun et al. 2006). Low amounts of nitrogen in the soil inhibit the branching ability of the pea plant. Light intensity plays an important role in determining whether to stimulate the formation of branches. With continued canopy growth shading becomes more intense. Shading reduces the amount of red/far-red (R:FR) light that reaches the basal part of the plants (Ballare and Casal 2000). The ratio of R:FR may be as low as 0.1 at the base of very dense stands (Ballare and Casal 2000). With less light reaching the basal axillary buds, the buds stay dormant and do not become vegetative.

The most characteristic effect of reduced R:FR ratio is a reduction in branching (Ballare and Casal 2000). The leaves at lower strata of the canopy are exposed to low levels of photosynthetically active radiation and to low R:FR ratios. Shading of the axillary buds signals that there is insufficient light to produce a branch. This ensures that the plant does not produce branches and use up resources when there is insufficient light available for the branches to photosynthesize. Singh et al. (1979) agreed that the reduced capacity for branching in high density stands could be attributed to their mutual shading, adversely affecting the photosynthesizing organs. Ayaz et al. (2004 c) stated that the high number of branches per plant at low population density was probably due to the low density allowing more radiation to penetrate the crop canopy.

Changes in the light environment also trigger morphological responses such as increased stem elongation (Ballare et al. 1991). When shading occurs at the base of the pea plant, it increases its height in order to compete with neighboring plants. This enhanced axis elongation along with reduced branching is the most characteristic effect of the reduced R:FR ratio (Ballare and Casal 2000).

2.2 Plant density and yield relationship of field pea

2.2.1 Optimal plant density

2.2.1.1 Determination of optimal economic plant density

Optimal economic plant density is the density that produces maximum economic return over seed costs. In many situations, the optimal economic density is not the density that will return the highest yield potential. Pea yield increases sharply as crop density is increased to about 54 plants m^{-2} (Lawson 1982). Knott and Belcher (1998) found that as the population density increased from 75 to 90 plants m^{-2}, the increase in yield was slight. At extremely high densities, the final yield is actually depressed (Heath and Hebblethwaite 1987a). Based on this research, optimal economic plant density s the point on the yield curve where increases in yield are not sufficient to cover the cost of the seed required to increase the yield.

Once an optimal plant density is determined, there are three main factors that are involved in achieving a targeted plant density: seed size, seed vigor and seedling mortality. Seed size refers to the weight of the individual seed, seed vigor refers to the seed's capability of germinating and seedling mortality is the death of a germinated seed. Seedling mortality is more difficult to estimate than the previous two factors and requires knowledge of the type and state of the soil into which the seed was planted. In theory, it is straightforward to achieve specific plant densities, but in practice it can be more difficult.

2.2.1.2 Emergence rates and seedling mortality

Seedling mortality occurs in almost all plant populations. In studies with different legume species, seed size was positively correlated with seedling vigor (Acikgozand and Rumbaugh 1979; Murray and Auld 1987; Evers 1999). Uzun and Acikgoz (1998) reported semi-leafless cultivars established well while normal leaf cultivars established poorly, especially under unsuitable germination conditions. This result was mainly attributed to size of the seed with larger seed size cultivars having better germination rates and fewer seedling mortalities.

Johnston et al. (2002) documented that the proportion of seedlings that emerged at lower seeding rates was greater when compared with higher seeding rates for all pea cultivars. The emergence rates relative to the corresponding target seeding rates progressively decreased as seeding rate increased (Johnston et al. 2002). At higher seeding rates, the number of surviving plants was also reduced as the growth of the plants progressed (Kruger 1977). Seedling mortality in pea increased dramatically with planting rates above 50 seeds m^{-2} (Johnston et al. 2002). Increased mortality occurs at the higher plant densities because of increased inter-specific plant competition. Allowance must also be made for germination losses due to soil types and the time of sowing (Meadley and Milbourn 1970). Soil moisture content plays an important role in seed germination, which is related to soil type, and soil temperature can also dramatically affect germination, which is related to time of sowing. This means that targeted seeding rates do not always correspond with actual plant densities.

2.2.1.3 Recommended seeding rate of field pea

The current recommended plant density for field pea in Saskatchewan is 88 plants m^{-2} (Saskatchewan Pulse Growers 2006). This rate was determined by agronomists and researchers and is an estimate of the plant density that will give producers the best return. This is only a guideline because optimum planting densities in pea range depending on genotypes, growing purposes and climatic conditions (Davies et al. 1985).

Plant density recommendations in the past have been higher than the current recommendation. In New Zealand, Bussel et al. (1983) recommended 90-120 seeds m^{-2} and Grevato (1985) suggested 80-140 plants m^{-2} was suitable for high seed yield of horticultural pea. Townley-Smith and Wright (1994) suggested that in Saskatchewan, field pea should be seeded at the rate of 100 seeds m^{-2}. More recently, the estimated optimum seeding rate for seed yield was 108 (range 82-112 among individual sites) plants m^{-2}, although yield increases were minimal at targeted seeding rates above 50 plants m^{-2} (Johnston et al. 2002).

Optimal seeding rates lower than the current recommended 88 plants m^{-2} have been investigated but positive results have not been reported. Benefits with seeding rates of 100 seeds m^{-2} were frequently realized, especially when semi-leafless upright pea cultivars were grown and optimal weed control was not possible (Johnston et al. 2002). At densities below 70 plants m^{-2}, at most sites and in most seasons, individual plants were not generally able to compensate sufficiently by increasing yield components in order to maximize yield unit per area (Heath et al. 1991). Seed yield decreased by about one half when the seeding rate of pea was reduced below 50 to 60 seeds m^{-2} (Townley-Smith and Wright 1994). Also, the potential for yield loss resulting from weeds and thin stands also suggest that reducing the rate may increase risk and weed control costs (Townley-Smith and Wright 1994).

2.2.2 Crop canopy growth

2.2.2.1 Biomass

Crop canopies changes dramatically with changes in plant density. The research on this aspect of pea growth has lead to a well supported conclusion: higher populations accumulated more dry matter as canopy closure occurred earlier at the high plant densities, resulting in greater interception from incoming solar radiation (Meadley and Milbourn 1970; Kruger 1977; McKenzie and Hill 1991; Uzun and Acikgoz 1998). On no occasion were significant decreases in plant dry weight recorded as a result of increasing plant densities (Kruger 1977). Heath and Hebblethwaite (1987 a) also found that dry matter production was greater at higher densities for both normal leaf and semi-leafless cultivars, so leaf type did not change how dry matter responded to plant density.

Biomass dry weight of pea varies depending on the density of the stand. Dry weight per plant was greater in a thin stand than a dense stand, despite the fact that the reverse was true for the dry weight of the plants per unit area (Bakry et al. 1984). The total weight per plant decreased with increasing crop density (Lawson 1982) and the plant mass decreased as crop density increased (Townley-Smith and Wright 1994). Reductions in number and weight of branches, leaves and pods per plant all contribute to this effect (Lawson 1982).

The conditions which result in optimum biomass accumulation do not necessarily promote optimum reproductive yield (Kruger 1977). The currently recommended population density for pea in New Zealand does not generally give maximum dry matter and seed yield (Ayaz et al. 2004 b). When biomass production becomes too high, interplant competition reaches a high level and the seed yield decreases (Cousin 1997). Reduction in leaf area and plant height to produce smaller, more profusely branched plants and increasing seed weight favor yield (Cousin 1997)).

2.2.2.2 Light interception

The quantity of solar radiation available to a plant determines its potential production within the constraints imposed by other limiting factors such as water supply and nutrient availability (Ayaz et al. 2004 a). In a plant community where water and nutrients are not limiting, the biological yield is largely determined by the utilization of available solar radiation (Kruger 1977). Plant populations substantially influenced the proportion of intercepted radiation and this follows a consistent pattern not only in pea but also in other legume species (Anwar 2001).

After seedling emergence, competition for light becomes intense when the canopy begins to close (Ballare and Casal 2000). Plant population has a significant positive effect on leaf area index, which had a sigmoidal response over time (Ayaz et al. 2004 a). Kruger (1977) reported that the swards with the higher plant densities recorded the greatest leaf area development. In higher density stands, leaf area development was concentrated towards the top of the plant while in lower densities, there was more even leaf distribution over the entire height of the plant (Kruger 1977). The number of leaves per plant was reduced by increasing plant density even though the overall leaf area index was increased (Kruger 1977).

Radiation interception increased throughout the vegetative growth of the plant (Heath and Hebblethwaite 1987 b) and with continued canopy growth, mutual shading was more intense. The quantity of light intercepted by a crop can be increased by rapid attainment of complete ground cover and by increasing the amount of canopy cover at any time, up to a definable threshold (Ayaz et al. 2004 a). Light interception during the early period of crop growth was increased by establishing a higher plant density (Heath and Hebblethwaite 1987a). Dense plant populations close their canopies quickly and hence intercept more sunlight per unit area than do thin populations (McKenzie and Hill 1991). Dense populations reach their maximum interception earlier than the thin plant population (Ayaz et al. 2004 a).

The relationship of dry matter and seed yield at final harvest were strongly correlated with total seasonal intercepted PAR (Ayaz et al. 2004 a). The ability of the crop canopy to utilize radiation appeared to influence the supply of photosynthate to pods and ultimately yield (Heath and Hebblethwaite 1987 b). This means that the productivity of a plant as a rule is directly related to its photosynthetic ability (Georgieva et al. 2000).

2.2.3 Lodging and disease in the reduction of yield

2.2.3.1 Disease

Variation in pea yield is often associated with disease. Diseases in pea plants are caused by either fungi, bacteria or viruses. The major fungal diseases of pea include Ascochyta blight, powdery mildew, downy mildew, Fusarium wilt and root rot. Viruses that affect pea are pea common mosaic, pea enation mosaic, pea seed-borne mosaic and top yellow while the main bacterial disease of pea is *Pseudomonas* (Cousin 1997).

Ascochyta blight caused by *Mycosphaerella pinodes* is one of the most serious aerial diseases of pea (*Pisum sativum* L.) (Garry et al. 1998). The disease can be responsible for yield losses of up to 30% (Allard et al. 1993). *M. pinodes* can infect all above-ground portions of the pea plant resulting in numerous lesions and extended necrosis (Garry et al. 1998). This disease appears around flowering time (Tivoli et al. 1996).

Mycosphaerella blight reduces seeds per stem and seed size (Tivoli et al. 1996). Disease severity can be assessed by estimating the percent of aerial biomass that is infected. The disease reduced plant growth whatever the stage of infection (Garry et al. 1998). Disease scores were usually higher on the lower parts of the plants and lower on the uppermost parts (Tivoli et al. 1996). Abundant moisture and higher humidity in the pea canopy at the base of the plants may explain the high disease scores in the lower parts of the plants (Tivoli et al. 1996). A prostrate growth habit and humid canopy conditions were also more conducive to disease development especially in dense canopies (Johnston et al. 2002). *Mycosphaerella* blight reduced pea seed yield because the higher the disease intensity on aerial organs, the lower was the seed number (Garry et al. 1998).

2.2.3.2 Lodging

Prior to the mid 1980’s, pea crops were known for their lack of ability to resist lodging. The poor standing ability of pea was associated with excessive vegetative growth of the plants (Stelling 1989). Lodging occurs when the vegetative growth causes the pea plant to be unable to hold its orientation in an upright position. This results in the stem being bent or broken. Low population treatments began to lodge approximately 20 days later then high population treatments (Pullan and Hebblethwaite 1992). Pea cultivars with weak stems grown in monoculture often exhibit severe lodging after flowering (Heath and Hebblethwaite 1985 c; Stelling 1994), resulting in reductions in forage and seed yield.

Semi-leafless pea lines had significantly better standing ability than normal leaf lines (Heath and Hebblethwaite 1984; Stelling 1989; Biarnes-Dumoulin et al. 1996; Uzun and Acikgoz 1998; Banniza et al. 2005). The semi-leafless phenotype is caused by a recessive mutation that replaces leaflets by tendrils, making semi-leafless cultivars less susceptible to lodging than normal leaf cultivars because plants cling to neighboring plants (Davies et al. 1985; Stelling 1989; Biarnes-Dumoulin et al. 1996; Uzun and Acikgoz 1998; Banniza et al. 2005). Lodging is more evident in normal leaf cultivars which results in larger yield reductions (Stelling 1994) because these cultivars are more difficult to harvest (Uzun and Acikgoz 1998). Lodged pea plants lying on top of one another are likely to be less effective at utilizing radiation for dry matter production (Heath and Hebblethwaite 1987b). Losses of dry matter from rotting during the post-flowering period are likely to be greater within a lodged compared to a standing crop (Heath and Hebblethwaite 1987b). Lodging may not be a serious problem in semi-leafless lines until full flowering stage but all genotypes lodged in later stages. (Uzun et al. 2005) This has prompted the development of semi-leafless plant types with improvements in standing ability (Snoad 1974).

Pea lodging increases with increased plant population (Heath and Hebblethwaite 1985 a). At higher plant densities, there was a tendency for increased and earlier lodging as well as more difficulty in harvesting (Heath and Hebblethwaite 1985 c). In low densities, the number of branches per unit area was reduced and therefore each branch carried an increased weight of seed in comparison to branches in high population treatments (Pullan and Hebblethwaite 1992). The weight on each branch is minimized if the number of branches per unit area is high (Pullan and Hebblethwaite 1992). Increasing plant height and pod filling also increases the risk of lodging. Although semi-leafless lines had reduced lodging than normal leaf lines, all the lines severely lodged at the seed harvesting stage. (Uzun et al. 2005) Regardless of leaf type, yields were maximized by selecting plants populations which minimized lodging (Pullan and Hebblethwaite 1990).

Greatest stability will be achieved if the plant is extended into three dimensions and a large number of radially arranged branches arise from each root system (Pullan and Hebblethwaite 1992). Branching at low plant populations were characterized by a tendency to grow laterally prior to assuming a vertical growth habit (Pullan and Hebblethwaite 1992). Intertwining of branches would improve the standing ability of pea especially in thinner populations (Snoad 1984). A high degree of branching at low plant populations is therefore seen to be beneficial for the maintenance of canopy stability (Pullan and Hebblethwaite 1992).

2.2.4 Yield response to seeding rate

2.2.4.1 Yield components

Seed yield of field pea crops has been described as the product of four components (Meadley and Milbourn 1970); the number of plants per unit area, pods per plant, seeds per pod and mean individual seed weight. Plant densities affect all these yield components. The number of pods per plant is one of the most important components in determining the yield of several legume crops including pea (Pandey and Gritton 1975). The response of pods per plant at differing densities has been well documented (Meadley and Milbourn 1970). Most grain legumes are reasonably plastic in their response to changing plant density, the main effect of variation in plant population being pods per plant, which tends to be inversely related to plant population density (McKenzie et al. 1986; Shaukat et al. 1999). A reduction in flowers and pods per plant with increased density has been frequently reported in grain legumes (Salter and Williams 1967; Meadley and Milbourn 1970; Stoker 1975; Kruger 1977; Dominguez and Hume 1978; Bakry et al. 1984; Knott and Belcher 1998). This results in a net loss of total yield per individual plant with increases in plant density.

The number of seeds per pod depends partially on the cultivar and on the environmental conditions (Cousin 1997) but has also been documented to be affected by plant density. The average number of seeds per pod was inversely related to plant population (Ayaz et al. 2004 c). A progressive and consistent reduction in the number of seeds per pod occurred with increased plant population (Bakry et al. 1984). Shaukat et al. (1999) also found that maximum seeds per pod (5.8) were recorded at low populations (10 plants m^{-2}) and declined with increase in planting density. Walton (1990) reported a positive correlation between plant height and seeds per pod. The seed number per pod associated with longer internodes with dwarf plants having significantly fewer seeds per pod than tall and medium plants.

Mean seed weight was inversely correlated with seed yield (Ayaz et al. 2004 c). Shaukat and et al (1999) reported a decline in the mean seed weight of pea genotypes with increased plant population. This agrees with Moot (1993) who reported a decline in the mean seed weight of pea genotypes with increasing plant population. Seed size is genetically pre-set. Different environmental conditions allow the seed to be filled to its genetic potential. With increased plants per area, each plant has fewer resources available which could translate into smaller seeds. In some situations, plants can abort flower sites so that all fertile seeds can fill to larger sizes. The reduction in the number of pods per plant, seeds per pod and seed weight at the higher densities might be due to increased interplant competition (Shaukat et al. 1999).

Despite the fact that these yield components in field pea mainly decrease with increasing plant density, the overall yield of an area consistently increases with plant density. The rate of change in individual components is not linear with density and in most cases not the same as other components. With regards to total yield, it appears that the large number of plants m^{-2} present at higher densities more than compensate for the lower production of pods per plant, number of seeds per pod and total pea dry weight per plant (Falloon and White 1978). Increases in crop density reduce the numbers of pods per plant but additional plants compensate by producing pods and thereby increasing overall yield (Lawson 1972; Kruger 1977).

2.2.4.2 Yield

In several crops, seed yield is closely related to total dry matter (TDM) production (Loss et al. 1998). Lower seeding rates resulted in reduced yields (Townley-Smith and Wright 1994) and higher seeding rates resulted in higher yield determinants (Uzun and Acikgoz 1998). For many crops, this is also proportional to the amount of intercepted radiation in the season (Thomson and Siddique 1997). Even though there is an increase in yield with increases in plant density, the increases are not linear and consistent. Yield response in relation to plant density showed a parabolic relationship (Kruger 1977). Matrin et al. (1994) indicated that pea yield did not increase consistently with seeding rate because pea plants were able to compensate for low rates with increased branching. Also plant density had a much greater influence on seed yield than spatial arrangement in pea (Heath and Hebblethwaite 1987a).

Yield increases due to increased plant stand eventually reach a point at which increasing the seeding rate did not increase the overall yield (Tiviolo et al. 1996). Heath et al. (1991) reported little if any yield benefit from plant densities in excess of 140 plants m^{-2}. Townley-Smith and Wright (1994) found that seeding rates greater than 50 plants m^{-2} had minimal effect on pea seed yield. Johnston et al. (2002) recommended a plant population between 50-75 plants m^{-2} for Saskatchewan while Gan et al. (2002) reported that a population density of 60-70 plants m^{-2} to maximize seed yield. An important note is that optimal plant populations do not always correlate with maximum seed return and in many cases, optimal economic return occurs at a plant population less than maximum seed yield.

2.3 Field Pea leaf type

2.3.1 Conventional and semi-leafless leaf type

There are two main leaf types in field pea. One has normal leaves and vine lengths of three to six feet; the second type is the semi-leafless type that has modified leaflets reduced to tendrils with vine lengths of two to four feet (Zohary and Hopf 2002). The first commercial cultivars of semi-leafless pea were released in the early 1980’s (Martin et al. 1994). The main reason for the semi-leafless pea becoming popular was because of their improved standing ability (Heath and Hebblethwaite 1985 b).

In semi-leafless cultivars, the leaflets are replaced with tendrils, the end result being less leaf area but better resistance to lodging (May et al. 2003). Reduced lodging aids in mechanical harvesting (Martin et al. 1994). Previous work in Australia showed that semi-leafless pea genotypes with reduced plant height had better light interception and canopy aeration than normal leaf types (Zain et al. 1983; Cawood 1987). It also showed increased dry matter partitioning to fruits, improved water use efficiency and decreased susceptibility to fungal diseases (Berry 1985; Snoad 1985; Armstrong 1989). The ability of semi-leafless cultivars to withstand lodging and disease, and the fact that their morphology allows better aeration within the canopy, have all contributed to their commercial importance (Cote et al. 1992).

2.3.2 Morphological and genetic basis for semi-leafless trait in field pea.

Semi-leafless and leafless pea differ morphologically from normal leafed pea. The conventional compound leaf type of the pea consists of stipules, leaflets, petiole and tendrils (Heath and Hebblethwaite 1985b). Semi-leafless pea cultivars have the leaflets transformed into tendrils (Martin et al. 1994). Leafless pea cultivars have leaflets transformed into tendrils and they also have a reduction in the stipules (Martin et al. 1994).

Two genes in pea control leaf type. The afila (AF) gene controls the presence of tendrils and the stipule (ST) gene controls the presence of stipules. Normal leafed pea cultivars have normal leaflet and stipule sizes, being represented by the genetic constitution AFAF STST (Baigorri et al. 1999). Semi-leafless pea, *afaf* STST, have leaflets transformed into tendrils by the gene *af* and but still have conventional stipules ST. The stipules counterbalance the disadvantages from the presence of fewer leaflets by the presence of developed stipules (Baigorri et al. 1999).

Another type of pea is leafless (afaf stst), which has reduced stipule size due to the gene st (Baigorri et al. 1999). The st gene in pea gives reduced stipules, and combined with the af gene results in leafless pea (Cousin 1997). When the ST gene is dominant, the stipules are present in normal size and when the st gene is recessive, the stipules are reduced in their size. In both semi-leafless and leafless pea, the end result is that there is less leaf area but better resistance to lodging (May et al. 2003). These two plant types have the improvements in lodging resistance due to the reduction of leaflet biomass (Snoad 1974) and increased plant inter-twining occurring, mainly from the tendrils. This also contributes to better light penetration through the canopy (Cousin 1997). This means that resistance to lodging is improved but at the expense of the amount of light being intercepted.

2.3.3 Light interception in semi-leafless field pea

Plant biomass production is closely related to the amount of radiation intercepted. Total dry matter, seed yield and harvest index (HI) are also strongly correlated with total seasonal intercepted radiation (Ayaz et al. 2004). The af gene induced a 40% decrease in leaf area, with the leaf area better distributed along the stem, chiefly at the level of the fertile nodes (Cousin 1997). Canopies composed largely of tendrils and petioles appear to function in a similar manner to canopies composed largely of leaves, with leafless or semi-leafless cultivars at no photosynthetic disadvantage (Heath and Hebblethwaite 1985 b). Comparisons of individual leaf components of the same leaf have demonstrated that tendrils are photosynthetically as efficient as leaflets and stipules on a chlorophyll basis (Cote 1991; Hobbs 1986). There is no evidence therefore to suggest that the yield of semi-leafless cultivars is limited by the altered photosynthetic area of the plant (Hedley and Ambrose 1979).

Normal leafed and semi-leafless cultivars exhibit different yield-density relationships (Heath and Hebblethwaite 1987a). Semi-leafless and leafless pea cultivars with reduced ability to intercept radiation may optimize yield at higher plant densities then normal leafed cultivars (Heath and Hebblethwaite 1984). Seed yield of normal leafed cultivars decreased with densities higher than 25 plants m^{-2} whereas yield of semi-leafless cultivars tended to increase with increasing plant density (Uzun and Acikgoz 1998). Similarly, biomass yield of normal leafed cultivars were higher than semi-leafless cultivars at lower density, while the reverse occurred at high density (Jannink et al. 1996). Heath and Hebblethwaite (1987 a) showed that yield of a normal leafed field pea cultivar was reduced at density above 75 plants m^2, while yield of a leafless cultivar increased up to 140 plants m^2. A semi-leafless cultivar was intermediate in response, with a maximum yield at approximately 100 plants m^{-2}.

2.4 Crop and weed competition

2.4.1 Plant density and competitiveness

The intensity with which neighbouring plants compete for limited supplies of water, light or mineral nutrients is influenced strongly by plant population density (Falloon and White 1980). Higher plant densities in field pea are more likely to suppress weed growth (Anderson and White 1974) and the high-density stands effectively suppressed weeds (Townley-Smith and Wright 1994). Weed biomass is reduced as the planting density of pea is increased (Marx and Hagedorn 196; Lawson and Topham 1982; Townley-Smith and Wright 1994).

By planting at recommended seeding rates, fewer weed plants established than seeding at lower rates (Wall et al. 1991). Townley-Smith and Wright (1994) reported increasing the pea seeding rate to obtain between 50 and 100 seeds m^2 reduced both weed numbers and weed dry matter production and grass weed numbers decreased with increased seed rate up to 78 plants m^2. This could signify that crop density had a larger influence on the ability of field pea to compete with weed populations than growth habits (Townley-Smith and Wright 1994).

2.4.2 Field pea leaf type

Many studies have shown that crop cultivars differ in their competitiveness with weeds (Townley-Smith and Wright 1994; Fofana et al. 1995). Normal leafed cultivars are generally highly competitive and exhibit vigorous growth (Wilson 1987). While semi-leafless and leafless genotypes are less competitive early in the season, this did not affect percent yield loss (Rauber et al. 2001; McDonald 2003). Cultivar selection greatly affected weed population density and weed shoot biomass production, however leaf characteristics alone did not affect weed density or dry weight (Wall and Townley-Smith 1996).

2.4.3 Field pea vine length

Several studies have shown that plant height is an important factor in conferring competitiveness to crop cultivars (Wicks et al. 1986). Wall and Townley-Smith (1996) found that leaf type had little effect on field pea competitiveness while plant height (vine length) was an important determinant. Increased plant density increases the height of pea plants, mainly due to the competition among plants for light (Bakry et al. 1984). This may not necessarily be true for all situations as higher plant densities result in fewer resources for individual plants and as a result, the productivity of each plant could be reduced.

Vine length has an effect on the amount of light intercepted by the plant. The traditional tall genotypes developed a denser canopy which reduced light transmission to the base of the canopy compared with the short genotypes (McDonald 2003). With less light reaching the base of the canopy, weeds have less radiation to collect which results in reduced weed biomass. Tall pea genotypes generally suppressed weeds more effectively than short genotypes (Wall and Townley-Smith 1996). Similarly in other plant species, plant height was the most important characteristic in crop competition (Reeves & Brooke 1977; Lemerled et al. 1996; Jannink et al. 2000; Coleman et al. 2001; McDonald 2003). Tall pea genotypes produced a significantly higher yield and had lower yield losses than the medium and short genotypes when under competition from weeds (McDonald 2003). The downfall is that it takes longer for taller genotypes to produce their biomass (Singh et al. 1993). A tall, normal leafed pea cultivar suppresses weed growth more than either a tall, semi-leafless cultivar or a dwarf cultivar (McCue and Minotti 1979). Thus, competitive cultivars are those that have long vines and produce dense canopies (Wall and Townley-Smith 1996). In summary, plant height is a major factor in the competitive ability of pea but it is not the sole genetically controlled factor conferring competitiveness (Wall and Townley-Smith 1996).

2.4.4 Crop yield loss and weed presence

Adequate weed control is important to attaining high yield in pea (Townley-Smith and Wright 1994). An assessment of yield losses due to weeds in central Alberta revealed that 67% of the field pea crops surveyed experienced yield losses due to weeds versus 40% for canola and 27% for barley (Harker 2001). Weed interference can reduce the seed yield of field pea (Wall et al. 1991). The number of pea pods per plant were significantly reduced by weed competition (Nelson and Nylund 1962; Lawson 1982) and pods at harvest were a major contributor to reduced yield on weedy as compared with weed-free plots in crops sown at the same densities (Proctor 1972). Reductions in mean weight pea seed contributed little to yield losses due to weed competition (Proctor 1972; Wall et al. 1991).

Weed competition can reduce pea productivity in many aspects. When weeds were allowed to compete with pea for the entire growing season, yield losses of 70% were observed (Harker et al. 2001). In Minnesota, 33 wild mustard (*Sinapis arvensis* L.) plants m^{-2} reduced pea stand density by 25%, fresh weight of pea vines by $\leq$ 71% and seed yield by $\leq$ 64% (Nelson and Nylund 1962). Yield losses due to wild mustard competition range from 2 to 35% in a Manitoba study (Wall et al. 1991). Thus, yield loss in pea caused by the presence of weeds can be significant and plant density, leaf type and vine length can be manipulated in order to reduce these losses.

3.0 Influence of field pea branching on optimal plant density

3.1 Introduction

Manipulation of plant populations, through varied seeding rates and seed placement is a critical management tool that can be used to modify crop productivity (Johnston et al. 2002). Seeding rate and plant density are important factors affecting yield of grain legumes (Uzun and Acikgoz 1998). Population density is also economically important, owing to high seed costs (Martin et al. 1994). With seed being one of the major costs involved with producing field pea (\$40 to \$60 ha^{-1}), seeding rate affects the profitability of this crop to producers. Pea seed cost accounts for approximately 20% of the variable costs while wheat seed is only accounts for 10% and canola is 18% (Saskatchewan Agriculture and Food 2006).

The current recommended seeding rate in field pea is 88 plants m^{-2} (Saskatchewan Pulse Growers 2006). Although yield increases were detected at plant densities higher than 88 plants m^{-2}, Moot and McNeil (1995) found that any yield advantage above 100 plants m^{-2} is unlikely to be economic, due to the additional seed costs. Because of the high cost of pea seed, the optimum density for maximizing financial returns is lower than the density required for maximizing yield (Heath et al. 1991).

When targeting a certain plant population, allowances must be made for germination rate and emergence losses, which vary according to soil quality and many abiotic and biotic factors (Meadley and Milbourn 1970). Targeted plant stands are not always achieved due to seedling mortality, which can be attributed to seeds being sown too deep, inadequate moisture for germination or non-viable seeds. Because of this, field pea growers adjust their seeding rate to balance the impact of environmental conditions on seedling emergence (Johnston et al. 2002).

In recent years, research studies have considered lowering the recommended seeding rate below the current recommended population of 88 plants m^{-2} in order to decrease input costs. Gan et al. (2002) recommended that in south-western Saskatchewan, a plant population density of 60-70 plants/m^{-2} will maximize seed yield. Johnston et al. (2002) recommended a plant population between 50-75 plants m^{-2}, and Townley-Smith and Wright (1994) found that seeding rates greater than 50 plants m^{-2} had minimal benefit on pea seed yield. Studies in other parts of the world showed similar evidence. Under dry conditions in Idaho, optimum populations of field pea were 55-65 plants m^{-2} (Murray and Slinkard 1969). In Spain, Martin et al. (1994) stated that is was not advisable to use population densities higher then 50 plants m^{-2}, and in England, Knott and Belcher (1998) stated that the optimum target plant population density was between 75-80 plants m^{-2}. This research all suggests that field pea grown in Saskatchewan have the potential to have an optimal plant population below the current recommendation.

The ability of some cultivars to produce pod-bearing branches from basal positions may enable them to be sown at lower rates without depressing yield (Falloon and White 1978). This could translate into more profit for the producer. Fewer plants would be required per area but the branching would compensate and the yield per area would be the same.

Finding an optimal seeding rate in field pea that is both economically and agronomically feasible requires the knowledge of how various physiological traits of pea are affected by plant density. Seed costs are important to producers because pea seeds are large in size which results in more seed weight being needed as compared with other grains. In addition to high direct seed costs, time costs are also greater due to associated handling costs with the seeding operation and the need to operate the air drill at reduced speed to prevent plugging of the pneumatic seed delivery system. This research concentrated on how field pea yield responds to different seeding rates based on basal branching and provides knowledge on how field pea can be a more profitable crop. The first objective of this study was to assess whether field pea cultivars differ in their branching ability. The second objective was to examine how field pea cultivar yields respond to differing plant populations and how their branching ability affects this response.

3.2 Materials and methods

3.2.1 Experimental design and location

The field experiments were conducted in 2005 and 2006 at the Kernen Crop Research Farm near Saskatoon, SK (52º10'12" N, 106º31'10" W) and at a field located near Rosthern, SK (52º42'38" N, 106º16'12" W). The Kernen Farm is located in central Saskatchewan in the Dark Brown soil zone while Rosthern is also situated in central Saskatchewan in the Black soil zone (Saskatchewan Agriculture and Food 2006). The soil at the Kernen farm is classified as a clay soil with a pH of 7.3 while the soil at Rosthern is a loam with a pH of 6.2. On average, Saskatoon receives about 350 mm of precipitation per year with 265 mm of that occurring as annual rainfall (Environment Canada 2007). On average, Rosthern receives slightly more precipitation than Saskatoon with 384 mm a year, 292 mm occurring as annual rainfall (Environment Canada 2007). In the year prior to the initiation of the experiments, the fields were farmed under minimal tillage practices with wheat being sown and harvested at both locations in 2005 and 2006.

The experiment was conducted as a randomized 2 way factorial (pea cultivar x plant population) with 4 replicates. The experiment included seven pea cultivars representing four market classes (Table 3.1). Each cultivar was sown at five densities (10, 30, 90, 120, and 150 targeted plants m^{-2}). This resulted in 140 plots per location in each of 2005 and 2006 with each plot being 2 x 6 m. An automated weather station was placed at the Rosthern field location to measure daily air temperature and rainfall amount. A weather station located 1.5 km southwest of the plots at Kernen Crop Research Farm was used to obtain weather data for the Saskatoon location.

3.2.2 Experimental procedure

Seed for each pea cultivar was obtained independently from pedigreed seed growers in Saskatchewan in the spring of 2005. Germination tests were conducted prior to seeding

TABLE 3.1 Field pea cultivars evaluated for the effect of basal branching on yield response.

Cultivar	Cotyledon Color	Seed Coat Color	Market Class	Primary Market	Leaf Type
Alfetta	yellow	white	yellow	food	semi-leafless
CDC Bronco	yellow	white	yellow	food	semi-leafless
Carrera	yellow	white	yellow	food	semi-leafless
CDC Striker	green	white	green	food	semi-leafless
CDC Acer	yellow	maple	maple	bird seed	semi-leafless
Courier	yellow	maple	maple	bird seed	semi-leafless
CDC Sonata	yellow	white	silage	silage	normal

Both locations at Kernen and Rosthern were included in 2005 and 2006.

so that the targeted plants m^{-2} could be achieved. The fields received an application of 440 g ha^{-1} of glyphosate prior to seeding to reduce emerged weed populations. The trials were seeded with a cone seeder using disk openers with an inter-row spacing of 23 cm. Seeding was completed on May 9th in 2005 and on May 19th in 2006. A fertilizer blend of 11-52-0 was mid row banded at a rate of 84 kg ha^{-1}. Grassy and broadleaf weeds were controlled with an application of Odyssey (35% imazamox and 35% imazethapyr) at a rate of 42 g ha^{-1} at the 5 node stage of the crop. In 2006, the Rosthern location received Poast Ultra (sethoxydiom) at a rate of 494 g ha^{-1} to control the grassy weeds and Pursuit (imazethapyr) at a rate of 49 g ha^{-1} to control the broadleaf weeds at the seven node stage. Weeds that survived herbicide application were removed by hand.

Emergence counts were conducted at the four-node stage. Counts were taken with a 0.5 x 0.5 m quadrat and included three rows of pea. Two measurements were taken per plot, one at either end of the plot. For the plots targeted at 10 plants m^{-2}, a larger 1 x 1 m quadrat was used to sample a larger area. Branching data were collected at the six-node stage and were obtained by sampling ten adjacent plants from a single row. Canopy light interception was assessed at early vegetative season (10-node stage) and at mid vegetative season (flowering stage) to assess changes in light interception throughout the season. The light measurements were conducted with a LI-COR Quantum light bar (LI-COR Biosciences Lincoln, NE). A light measurement reading was taken in direct sunlight and then the light measurements at the base of the canopy were taken. Two light measurements were taken per plot, one across the rows and one with the rows and an average was taken between the two measurements. Vine length measurements were taken of a lengthened vine from the soil surface to the top of the apical meristem on the main stem during the flowering stage with ten adjacent plants being measured from the same row.

Biomass sampling was conducted just prior to plant senescence. All above ground biomass was collected from a 0.5 x 0.5 m area. Two samples per plot were collected, one from either end of the plot. The biomass samples were then dried at 80°C for 72 hours and then weighed. Lodging ratings on the plots were taken just prior to harvest.

Lodging was rated on a percent basis, with 0% having no lodging occurring, 50% having the pea stems bent at 45^{O} and 100% having the pea stems horizontal to the ground.

The number of pods per plant was taken during pod filling. Ten branches in total were chosen at random and the number of pods per branch was counted. The number of seeds per pod was measured prior to harvest by randomly selecting ten pods per plot and counting seed. The plots were harvested at full senescence with a plot harvester on September 14th in 2005 and September 20th in 2006. The seed was then cleaned with a Carter Day Dockage Tester (Seedburo Equipment Company Chicago, IL) using a 4 x 19 mm slotted sieve and then weighed. Thousand seed weights were based on weighing out three sub-samples of 200 seeds.

3.2.3 Statistical analysis

Analysis of Variance and Analysis of Covariance

Analysis of variance (ANOVA) using Statistical Analysis Software (SAS) generalized linear model procedures (SAS Institute 1999) along with SAS mixed model analysis (SAS Institute 1999) was initially conducted to test the significance of a linear regression analysis of targeted plant density on all of the measured variables. The random effects of site and year were combined into one random variable, site-year, resulting in four site-years of data with replicate nested in year. Levene's test was conducted initially to determine among site-years homogeneity of variance. The fixed and random variables along with their interactions were then inspected to determine if the site-years could be combined. In situations where there was a significant interaction affect, individual site-years were examined and compared with one another to determine if combining the site-years would alter in the interpretation of the data.

The data points for the variables were fitted to the equation:

$$y = b + mx \qquad [3.1]$$

where y is the responsible variable, m is the slope of the regression line, b is the intercept of the regression and x is the plant density at the outputted value. The linear regressions were declared to be significant at $P < 0.05$. The variables that showed significant linear regressions were analyzed with an analysis of covariance using mixed model analysis (SAS Institute 1999). In the analysis of covariance, the actual plant densities were used instead of the targeted plant densities to accurately represent plant stands. The different slopes of the linear regressions were tested against one another and a common slope was declared at $P > 0.05$. An ANOVA was used to compare the common sloped linear regressions and cultivars were declared significantly different at $P < 0.05$.

Non-Linear Regression Analysis

The variables that did not show significant linear regressions were analyzed with an ANOVA using SAS non-linear model procedures (SAS Institute 1999). The data points were fitted to the following hyperbolic equation which is an alteration of the Michaelis-Menten equation (Britannica 2007): (yield data used in the example)

$$Y = Ymax * d / (D_{50} + d) \qquad [3.2]$$

where Y is the yield achieved at a certain density, d is the actual plant density that the yield was achieved at and Ymax and D_{50} are fitted parameters, Ymax being the theoretical maximum yield potential of the cultivar as the density approaches infinity and D_{50} being the plant density at which 50% of the theoretical maximum yield is achieved.

Goodness of Fit F Test

The NLIN yield curves were analyzed with a goodness of fit F test (Snedecor and Cochran 1989). A common Ymax was fitted to the individual cultivars when comparing the D_{50} values and a common D_{50} value was fitted to the curves when comparing the Ymax values. Significance was declared at ($P < 0.05$).

Optimal Economic Plant Density

The optimal economic plant density was calculated at plant density which economic return was maximized. This was determined assuming the cost of pea seed to be twice that of the market return with only the seed cost being used to assess variable cost. The net return was plotted against increasing plant densities and fitted with a polynomial curve to determine what plant density gave maximum economic return. Each individual site-year was analyzed separately with the four sit-years being averaged to achieve cultivar optimal plant density.

3.3 Results and discussion

3.3.1 Environment

The total rainfall that occurred at the four site-years was above the 20-yr average (Table 3.2) and differed from the 20 yr monthly pattern. Above average rainfall occurred during the months of June and September for both 2005 and 2006. During the months of July and August, rainfall occurred less frequently resulting in terminal summer drought for both years. This led to the pea plants senescing earlier in the year than normal. Above average rainfall in September had minimal affect on pea growth and yield since the crop was already senescing at the Kernen and Rosthern sites. . The average temperatures near the 20-yr average for the majority of the months. The months with temperatures above the 20-yr average were April, July and August in 2006 which magnified terminal drought that was experienced in 2006.

3.3.2 Emergence

The ANOVA for plant emergence of pea cultivars across the targeted plant densities did not differ among site-years (Table 3.3). The only significant effects were plant density ($P < 0.01$) and site-year by plant density ($P < 0.05$). This indicates a significant difference in emergence at the differing target plant densities and actual emergence rates were similar to targeted rates. Cultivars at lower plant densities had a higher percent emergence than cultivars at higher plant densities due to intra-specific competition. The

TABLE 3.2: Monthly rainfall (mm) and mean daily temperature (^{o}C) for the Kernen and Rosthern sites from May until September in 2005 and 2006 and the long term (20-yr) average.

		Rainfall			Temperature		
Location	Month	**2005**	**2006**	**20-yr average†**	**2005**	**2006**	**20-yr average†**
		------------------	**mm**	------------------	------------------	**^{o}C**	------------------
Kernen	April	16	38	24	6.4	8.0	4.5
	May	28	40	44	10.2	11.7	11.3
	June	161	108	53	14.4	16.2	15.9
	July	54	32	64	17.5	20.0	18.2
	August	54	30	44	15.4	18.0	17.4
	September	74	118	28	11.3	12.2	11.5
	Total	387	366	257	-	-	-
Rosthern	April	12	3	27	5.7	7.1	3.8
	May	49	89	43	9.9	11.4	11.0
	June	111	98	72	14.3	16.1	15.8
	July	43	73	80	16.7	19.2	17.6
	August	82	60	63	14.7	16.5	17.0
	September	118	148	33	11.1	11.2	11.6
	Total	415	471	318	-	-	-

† 1988 – 2007 data obtained from Environment Canada (2007).

TABLE 3.3 ANOVA for field pea emergence, branching, yield and early and mid vegetative canopy light interception as affected by cultivar and plant density (PD) assessed at Kernen and Rosthern in 2005 and 2006.

Source	df	Emergence	Branching	Seed Yield	Early Vegetative Light	Late Vegetative Light
		%	no. per plant	kg ha^{-1}	% intercepted	% intercepted
Site-year	3	NS	NS	NS	NS	NS
Plant Density (PD)	4	**	*	***	***	***
Cultivar	6	NS	***	***	NS	*
Site-year x PD	12	*	*	***	NS	*
Site-year x Cultivar	18	NS	**	**	NS	NS
Cultivar x PD	24	NS	NS	NS	NS	NS
Site-year x Cultivar x PD	72	NS	*	**	NS	NS

*, **, *** denote significance at the 0.05, 0.01 and 0.001 probability levels, respectively.

TABLE 3.4 ANOVA for field pea biomass, seeds per pod, podding, seed weight, vine length and lodging as affected by cultivar and plant density (PD) assessed at Kernen and Rosthern in 2005 and 2006.

Source	df	Biomass	Seeds per pod	Podding	Seed Weight	Vine Length	Lodging
		kg ha^{-1}	no.	pods per branch	mg per seed	cm	%
Site-year	3	NS	NS	NS	NS	NS	NS
Plant Density (PD)	4	***	***	***	NS	***	***
Cultivar	6	NS	**	NS	***	***	***
Site-year x PD	12	*	NS	NS	NS	NS	*
Site-year x Cultivar	18	NS	NS	NS	**	*	*
Cultivar x PD	24	***	NS	NS	*	NS	NS
Site-year x Cultivar x PD	72	NS	NS	*	**	***	***

*, **, *** denote significance at the 0.05, 0.01 and 0.001 probability levels, respectively.

emergence rates averaged for the densities at each site-year are displayed in Appendix I. The was some differences in the emergence rates at the different site-years so the site-years were combined and actual plant densities were used resulting in data interpretation that is related to the biological response of the cultivars and allowing for more accurate modeling of the data.

3.3.3 Branching

The ANOVA for branching indicated there was a significant effects in site-year by cultivar ($P < 0.05$), site-year by cultivar by plant density ($P < 0.05$) and site-year by plant density ($P < 0.01$) (Table 3.3). These significant interactions indicate that the cultivars did not respond similarly at the four site-years and therefore should not be combined for analysis. However, after examining the branching for each of the site-years (Appendix A), the interpretation of the site-years did not differ. All of the sites indicated that *CDC Acer* and *CDC Bronco* had profuse branching while *Carrera* and *Courier* had sparse branching. The main difference was that at Rosthern in 2005, *Alfetta* had greater branching. Based on this I determined that combining the site-years would not significantly alter the interpretation of the data. Furthermore, since I considered site-year a random effect, a combined site-year analysis will result in a greater ability to infer what would happen in an average environment as well as make the interpretation become more conservative.

The analysis of covariance was able to determine an equation with a common slope for all cultivars ($P = 0.24$, Equation 3.3). This signified that all cultivars showed significant linear regressions between branching and plant density and that all of the cultivars had similar reductions in branching with increasing plant density. The b value of the equation is the intercept of the regression for each cultivar with a common slope of -0.0075. This common slope indicates that all cultivars had a loss of 0.0075 branches for every increase in one plant m^{-2}. The d value is the plant density and the y value is the branching achieved at that plant density, which varied for each cultivar.

$$y = -0.0075*d + b \qquad [3.3]$$

TABLE 3.5 The intercepts of field pea cultivar branching linear regressions at the six node stage from an analysis of covariance assessed at Kernen and Rosthern in 2005 and 2006, where branching = $-0.0075*d + b$.

Cultivar	**Branch Intercept (*b*) (branches per plant)**	**Standard Error**	**Group†**
CDC Acer	1.82	0.082	a
CDC Bronco	1.72	0.081	ab
CDC Sonata	1.62	0.081	b
CDC Striker	1.62	0.080	b
Alfetta	1.43	0.081	c
Carrera	1.33	0.081	c
Courier	0.80	0.088	d

† Means with the same letters are not significantly different ($P < 0.05$).

There were significant differences in branching among the cultivars across the different plant densities ($P < 0.001$, Table 3.5). Since the slopes for all of the cultivars were similar, comparisons made among cultivars at any point along the regression would be the same and thus, branching regression intercepts were used for comparison for simplicity purposes. The intercepts of the branching regression indicates the number of branches per plant as the density approaches zero plants m^{-2}. The cultivars CDC Acer and CDC Bronco had the most branches (1.82 and 1.72 branching intercepts, respectively), with *CDC Acer* being significantly higher than every cultivar expect *CDC Bronco*. *Courier* had the fewest branches (0.80 branches per plant intercept), significantly fewer than all of the other cultivars. *Alfetta* and *Carrera* also had few branches, significantly more than *Courier* but significantly fewer than the other cultivars. This range in cultivar branching allowed for examination of different yield-density components.

Figure 3.1 shows that the common slope model adequately fits all of the cultivars. Interestingly, *Courier* was estimated to have no branching occur beyond the density of 106 plants m^{-2}. The figure also indicates that *CDC Striker* and *CDC Sonata* are nearly identical in branching suggesting that they have the potential to respond similar to one another with regards to yield, biomass and light interception.

Previous studies (Fallon and White 1978; Singh at al. 1979; Bakry et al. 1984; Knott and Belcher 1998; Ayaz et al. 2004 c) support these results in that branching decreases with increasing plant density. In addition, the number of branches per plant in field pea previously reported ranged from 0 – 2.4 (Heath et al. 1991), 0 – 2.0 (Kruger 1977) and 0.9 – 1.4 (Uzun and Acikgoz 1998). These branching numbers are similar those in this study.

3.3.4 Seed yield

The ANOVA for yield indicated that the only significant effects were site-year by cultivar ($P < 0.01$) and site-year by plant density ($P < 0.001$, Table 3.3). Although this may indicate that the site-years should be analyzed separately, inspection of these effects indicated that there were no major differences that would affect the interpretation of the

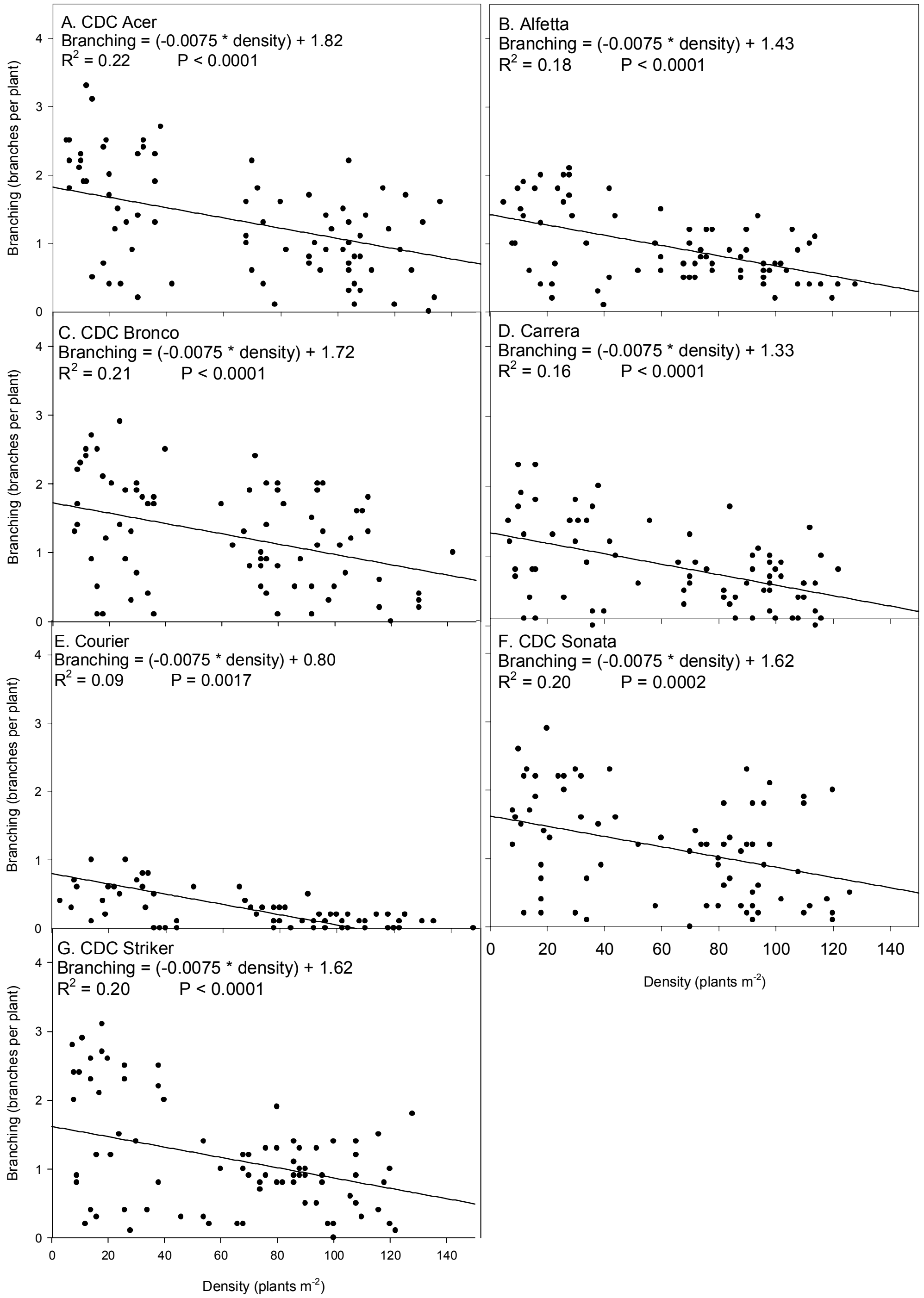


FIGURE 3.1 Effect of plant density on number of branches per plant at the six node stage for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2006 and 2006. Curves are based on the equation branches = (slope * density) + y-intercept where slope is the rate of branching loss with increased plant density and the y-intercept is the maximum potential branches for a cultivar.

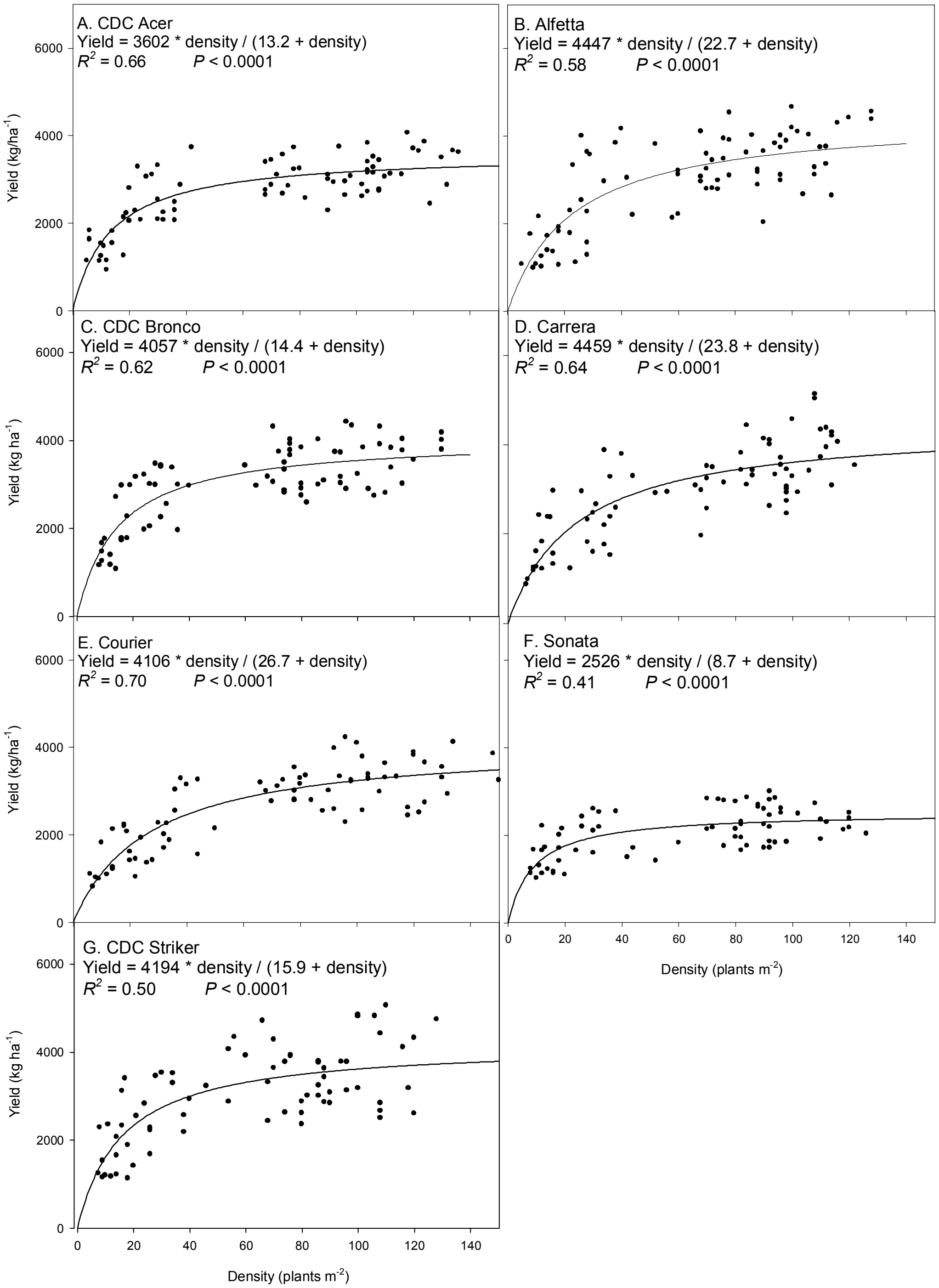


FIGURE 3.2 Effect of plant density on seed yield for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera, (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation yield = Ymax * density / (D_{50} + density) where Ymax is the theoretical maximum yield as density approaches infinity and D_{50} is the density at which 50% of the max yield is achieved.

TABLE 3.6 Field pea cultivar D_{50} seed yield-density values and branching intercepts at the six node stage of seven pea cultivars assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	D_{50}	Standard Error	Group†	Branching Intercepts (branches per plant)
	plants m^{-2}			
CDC Sonata	8.7	5.20	a	1.62
CDC Acer	13.2	2.36	ab	1.82
CDC Bronco	14.4	1.71	abc	1.72
CDC Striker	15.9	1.68	bcd	1.62
Alfetta	22.7	1.87	cd	1.43
Carrera	23.8	1.95	cd	1.33
Courier	26.7	2.70	d	0.80

† Means with the same letters are not significantly different ($P < 0.05$).
D_{50} is the plant density where 50% of the theoretical maximum yield is achieved.

TABLE 3.7: Field pea cultivar seed yield Ymax values and branching intercepts at the six node stage of seven pea cultivars assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	Ymax	Standard Error	Group†	Branching Intercepts (branches per plant)
	kg ha^{-1}			
CDC Sonata	2530	101	a	1.62
CDC Acer	3600	105	b	1.82
CDC Bronco	4060	104	bc	1.72
Courier	4110	112	bc	0.80
CDC Striker	4190	115	c	1.62
Alfetta	4450	112	c	1.43
Carrera	4460	112	c	1.33

† Means with the same letters are not significantly different ($P < 0.05$).
Ymax is the theoretical maximum yield as plant density approaches infinity.

results (Appendix B). At all site-years, the cultivars CDC Bronco and Alfetta had the highest, yields whereas *CDC Acer* and *Courier* had the lowest yields. Furthermore, since site-year was considered a random effect, a combined site-year analysis results in a greater ability to infer what would happen in an average environment.

All cultivars displayed an asymptotic yield response to density that was well characterized by the Michaelis-Menten (MM) equation with R^2 values ranging from 0.41 to 0.71 (Figure 3.2). Other researchers also found that asymptotic relationships described yield density relationship in pea (Holliday 1960; Moot and McNeil 1995). There were differences in the yield density response among pea cultivars (Figure 3.2, Table 3.6, Table 3.7). The D_{50} parameter characterizes the shape of the yield density response by estimating the plant density required to achieve 50% of the maximum estimated yield. *CDC Sonata* had the lowest D_{50} value (8.7 plants m^{-2}) which was significantly lower than all of the cultivars except for *CDC Acer* (13.2 plants m^{-2}) and *CDC Bronco* (14.4 plants m^{-2}, Table 3.6). This indicated that the yield of *CDC Sonata* is less affected by plant density than the other cultivars. For example, increasing the plant population of *CDC Sonata* from 20 to 80 plants m^{-2} resulted in only a 21% increase in yield whereas with Courier the same change in density resulted in a 31% increase in yield.

The cultivars CDC Acer, CDC Bronco and CDC Striker had similar D_{50} values (range 13.2 – 15.9 plants m^{-2}) indicating similar relative yield density responses (Table 3.6). *Alfetta, Carrera* and *Courier* had higher D_{50} values (range 22.7 – 26.7 plants m^{-2}) indicating that they require higher plant densities in order to achieve maximum yield and are more sensitive to changes in plant density. This suggests that lower plant densities in *CDC Acer*, *CDC Bronco* and *CDC Striker* will not reduce their yields to the proportion that lower plant densities will reduce yields in *Alfetta*, *Carrera* and *Courier.*

The Ymax parameter estimated the maximum yield of the pea cultivars. The silage cultivar CDC Sonata had a lower Ymax (2530 kg ha^{-1}) than any of the other pea cultivars indicating that it had the lowest yield potential (Figure 3.2, Table 3.7). *CDC Acer* had the second lowest yield potential (3600 kg ha^{-1}) and was lower than *CDC*

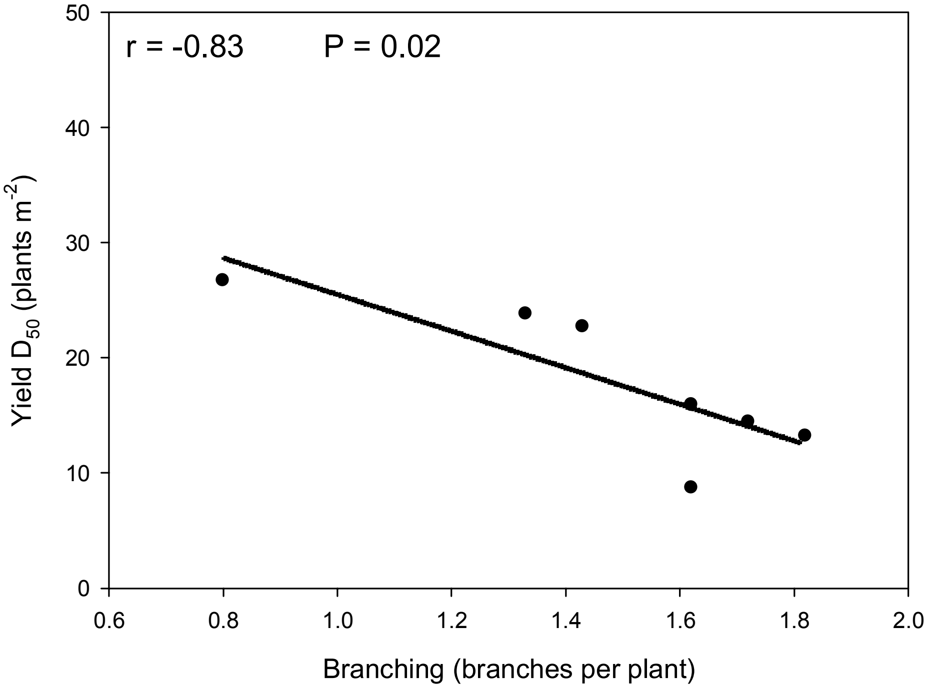


FIGURE 3.3 Correlation association between field pea cultivar branching at the six node stage and seed yield-density D_{50} values averaged at Kernen and Rosthern in 2005 and 2006.

Striker, Alfetta and *Carrera*. The remaining six cultivars did not differ from one another suggesting they have similar yield potentials. The maximum yields observed in this experiment were similar to what others have observed in the northern Great Plains (Johnston and Stevenson 2001; Townley-Smith and Wright 1993; Gan et al. 2002).

There was a strong negative correlation between branching potential and D_{50} values ($r = -0.83$; $P = 0.02$, Figure 3.3). Cultivars such as Carrera and Courier had low branching ability and high D_{50} parameters. This indicates that cultivars with less branching potential are more sensitive to reduced plant densities than cultivars with high branching potential. Because of this, optimum seeding rates for pea cultivars that have a high potential to branch will be lower than those that have less potential to branch.

3.3.5 Early vegetative season canopy light interception

The ANOVA for early vegetative canopy light interception indicated no site-year interactions ($P < 0.05$, Table 3.3) and therefore the site-years were combined. However, the early vegetative canopy light measurements were only taken at the 2006 sites, thus resulting in only two site-years. All of the cultivars exhibited significant NLIN regressions using the Michaelis-Menten equation (Figure 3.4). There were no differences among the Lmax values for the cultivars ($P = 0.08$) indicating that at high plant densities, all of the cultivars had the same maximum light interception. However, there were differences among the cultivar D_{50} values ($P < 0.05$). *CDC Sonata* and *Alfetta* had the lowest D_{50} values (23.9 and 26.3 plants m^{-2} respectively) and were different ($P < 0.05$) from the highest D_{50} value cultivar, Carrera (51.6 plants m^{-2}, Table 3.8). A lower D_{50} value indicates more light interception at lower plant densities and thus *CDC Sonata* and *Alfetta* light interception was less sensitive to increases in plant density at early vegetative canopy development. *Carrera* had the least amount of light intercepted at lower plant densities. The remaining cultivars did not differ from one another.

There was no strong correlation between branching and early vegetative canopy light interception ($r = -0.35$, $P = 0.44$). A higher branching cultivar like CDC Acer did not respond differently from a lower branching cultivar like Courier (Table 3.8). This

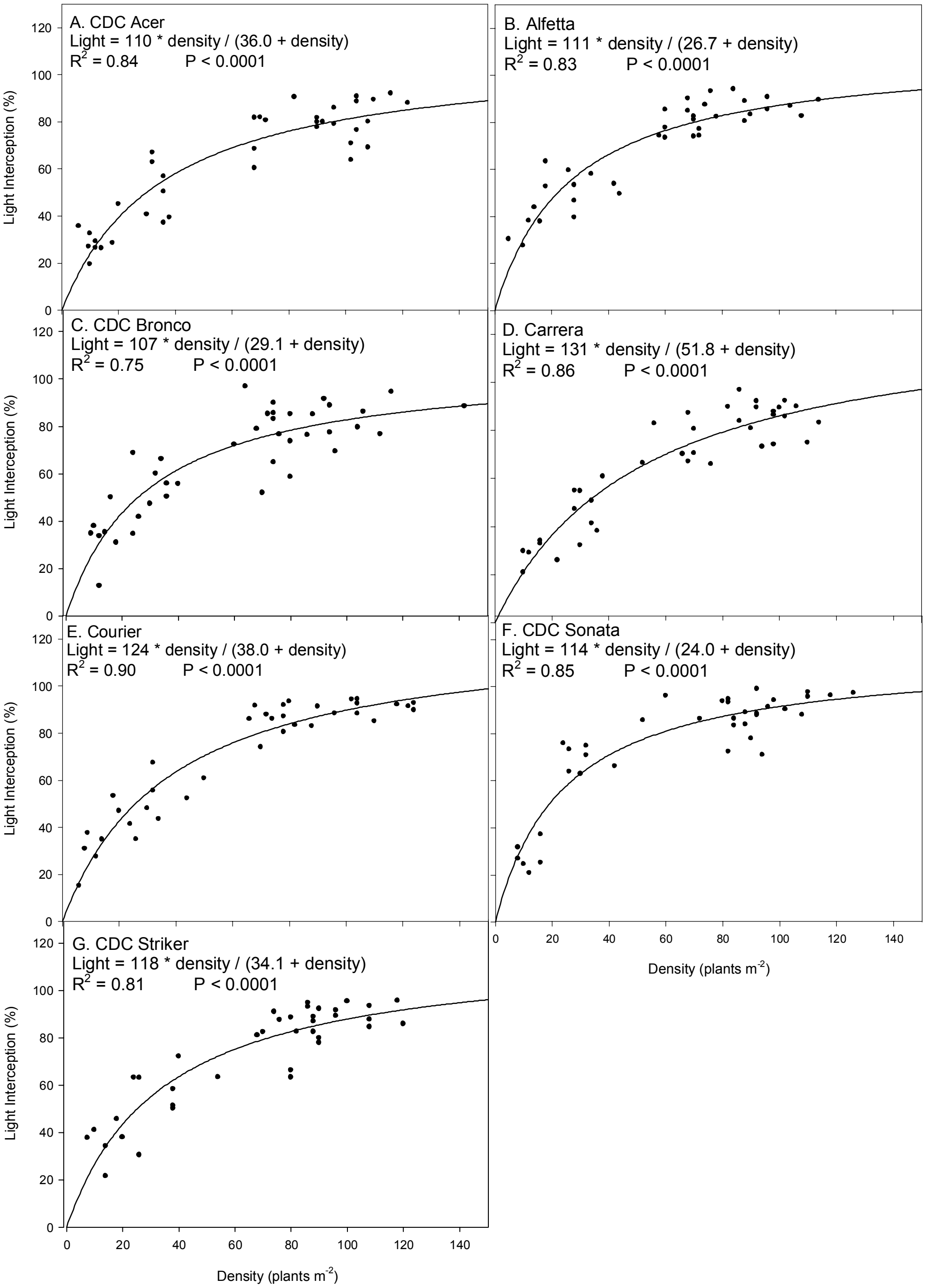


FIGURE 3.4 Effect of plant density on early vegetative canopy (10-node stage) light interception for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation Light Interception = Lmax * density / (D_{50} + density) where Lmax is the theoretical maximum light interception as density approaches infinity and D_{50} is the density at which 50% of the max light is intercepted.

TABLE 3.8 Field pea cultivar D_{50} early vegetative canopy (10-node stage) light interception-density values and branching intercepts at six node stage of pea cultivars assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	**D_{50}**	**Standard Error**	**Group†**	**Branching Intercepts (branches per plant)**
	plants m^{-2}			
CDC Sonata	23.5	2.56	a	1.62
Alfetta	26.3	2.80	a	1.43
CDC Bronco	29.0	3.12	ab	1.72
CDC Striker	34.3	2.99	ab	1.62
CDC Acer	36.0	3.56	ab	1.82
Courier	38.0	2.89	ab	0.80
Carrera	51.6	3.23	b	1.33

† Means with the same letters are not significantly different ($P < 0.05$).

D_{50} is the plant density where 50% of maximum light interception is achieved.

suggests that even though some cultivars are capable of intercepting more light at lower plant densities during early vegetative canopy development, branching is not one of the main factors that indicates this. The reason could be because the plant's branches have not yet had time to fully develop and therefore are not large enough to significantly alter light interception. At the early vegetative canopy stage, plant growth rate is likely to have more of an influence on light interception than any other factor.

3.3.6 Mid-vegetative season canopy light interception

The random and fixed variables from the ANOVA for mid-vegetative season canopy light interception (Table 3.3) indicated only a slight site-year by cultivar interaction with no other significant site-year interactions. This suggests that the interpretation did not differ among site-years and could be combined for analysis. There were plant density ($P < 0.001$) and cultivar ($P < 0.05$) differences which translated into differences between NLIN curve D50 and Ymax values.

There were differences among cultivar D_{50} values ($P < 0.05$, Table 3.9) with all of the cultivars being characterized by the MM equation (Figure 3.5). The low D_{50} value cultivars, CDC Bronco (11.1 plants m^{-2}) and CDC Acer (12.1 plants m^{-2}) were significantly lower ($P < 0.05$) than the high D_{50} value cultivars Carrera, CDC Striker and Courier (Table 3.9). As with early light vegetative canopy interception, higher D_{50} values translated into less light interception which indicates *Carrera*, *CDC Striker* and *Courier* intercepted less light at lower plant densities at mid-season vegetative canopy. *CDC Bronco* and *CDC Acer's* lower D_{50} values indicated more light interception at the lower plant densities and thus are less sensitive to changes in plant density.

Unlike the early vegetative canopy light interception, at flowering there was a significant difference between cultivar maximum light interception ($P < 0.05$). *CDC Acer* and *CDC Bronco* had the lowest potential light interception (99% and 102 %, respectively) and were lower than *CDC Sonata* (112%), *Courier* (113%), and *CDC Striker* (115%), which had the highest Lmax values (Table 3.10). Even though the Lmax values are larger than 100% and indicate an impossible situation where more than 100% of available light is intercepted, it provides a comparison of the cultivars

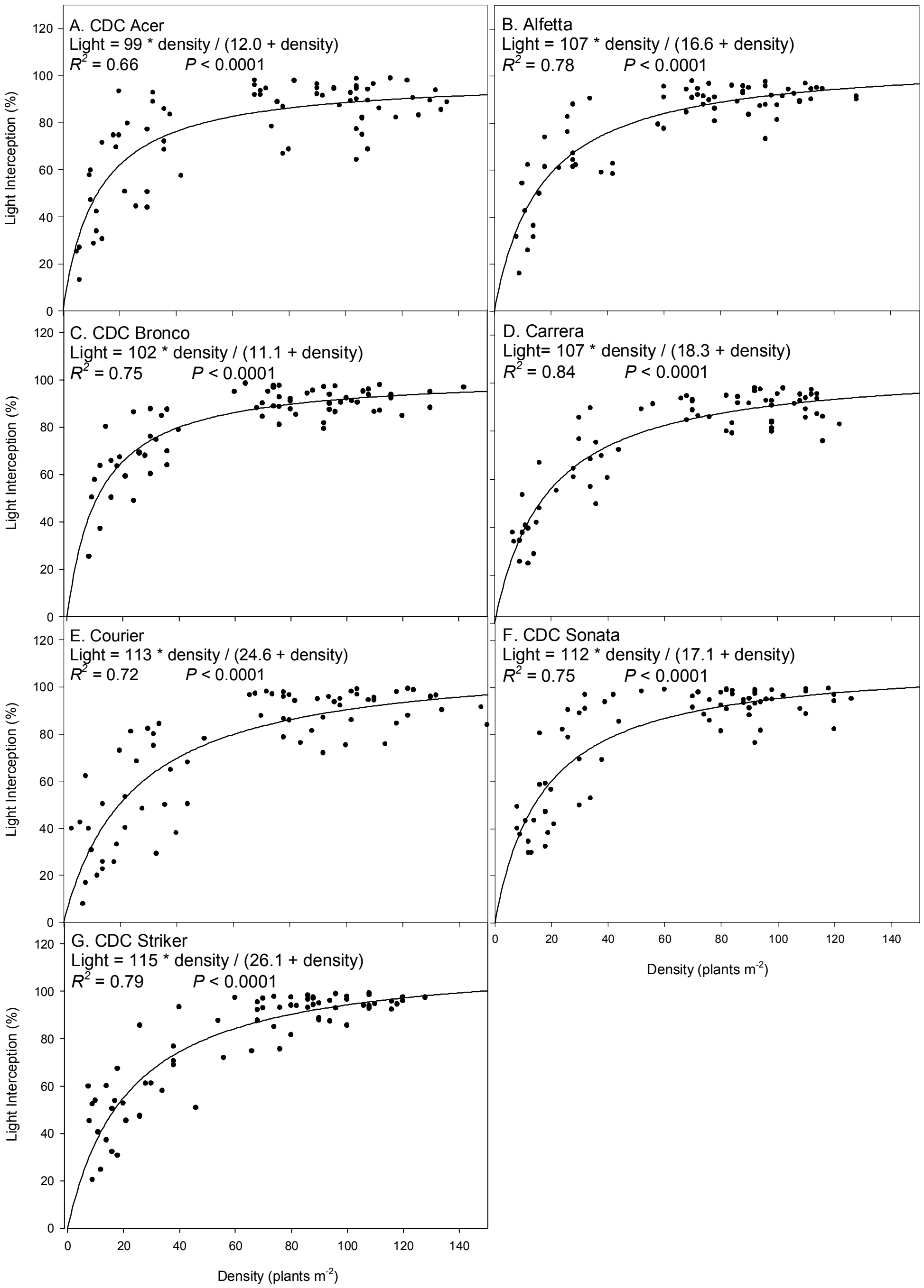


FIGURE 3.5 Effect of plant density on mid-season (flowering) canopy light interception for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera, (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation Light Interception = Lmax * density / (D_{50} + density) where Lmax is the theoretical maximum light interception as density approaches infinity and D_{50} is the density at which 50% of the max light interception is achieved.

TABLE 3.9 Field pea cultivar D_{50} mid vegetative season (flowering) light interception-density values and branching at the six node stage intercepts of pea cultivars assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	D_{50}	Standard Error	Group†	Branching Intercepts (branches per plant)
	plants m^{-2}			
CDC Bronco	11.1	1.24	a	1.72
CDC Acer	12.1	1.39	ab	1.82
Alfetta	16.6	1.37	abc	1.43
CDC Sonata	17.1	1.17	bc	1.62
Carrera	18.2	1.46	c	1.33
CDC Striker	21.6	1.34	c	1.62
Courier	24.6	1.58	c	0.80

† Means with the same letters are not significantly different ($P < 0.05$).
D_{50} is the plant density where 50% of maximum light interception is achieved

TABLE 3.10: Field pea cultivar mid vegetative season (flowering) light interception Lmax values and branching at the six node stage intercepts of pea cultivars assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	Lmax	Standard Error	Group†	Branching Intercepts (branches per plant)
	% intercepted			
CDC Acer	99	2.0	a	1.82
CDC Bronco	102	2.1	a	1.72
Carrera	107	2.1	ab	1.33
Alfetta	107	2.1	ab	1.43
CDC Sonata	112	2.1	b	1.62
Courier	113	2.0	b	0.80
CDC Striker	115	2.1	b	1.62

† Means with the same letters are not significantly different ($P < 0.05$).
Lmax is the theoretical maximum % of light intercepted as compared to available light as density approaches infinity.

estimated maximum light interception with *CDC Bronco* and *CDC Acer* intercepting less total light.

The correlation analysis on branching and D_{50} values indicated a strong negative correlation ($r = -0.79$, $P = 0.04$). The high branching cultivars CDC Acer and CDC Bronco had the lowest D_{50} values. This indicates that high branching cultivars are less influenced by plant density and thus are able to intercept more light at lower densities because of high branching potential. The branches were able to fill in the space between the plants and increase light interception. At low plant densities, there is more space between growing plants as opposed to a high plant density and, as a result, higher branching cultivars intercepted more light at low plant densities.

3.3.7 Biomass

The ANOVA for biomass averaged across the four different site-years (Table 3.4) resulted in a slight site-year by cultivar interaction ($P < 0.05$). With no other site-year interactions, it was determined that the site-years responded similarly and thus were combined. There was a plant density by plant density interaction ($P < 0.001$) as well as a difference among plant densities ($P < 0.001$) which indicates significant differences between D_{50} and Bmax values. The NLIN regressions were also significant with the MM equation (Figure 3.6). The cultivar CDC Sonata had the lowest D_{50} value (3.2 plants m^{-2}) and was lower than all other cultivars ($P < 0.05$) except for *CDC Acer* (5.9 plants m^{-2}) and *CDC Bronco* (7.7 plants m^{-2}, Table 3.11). This indicates that *CDC Sonata* can achieve more of its potential biomass at lower plant densities when compared to the other cultivars. *CDC Acer*, whose D_{50} value was second lowest, was lower than *Alfetta* (16.9 plants m^{-2}) and *Courier* (20.2 plants m^{-2}) while *CDC Bronco* was only lower ($P < 0.05$) than *Courier*. Of the non-silage cultivars, *CDC Acer* and *CDC Bronco* were less sensitive to plant density and thus obtained more of their potential biomass at low plant densities, whereas *Alfetta* and *Courier* require high densities to achieve the same proportion of potential biomass.

There were differences among the cultivar Bmax values ($P < 0.05$). *CDC Sonata* (7120 kg ha^{-1}) had the lowest estimated maximum biomass, lower ($P < 0.05$) than every

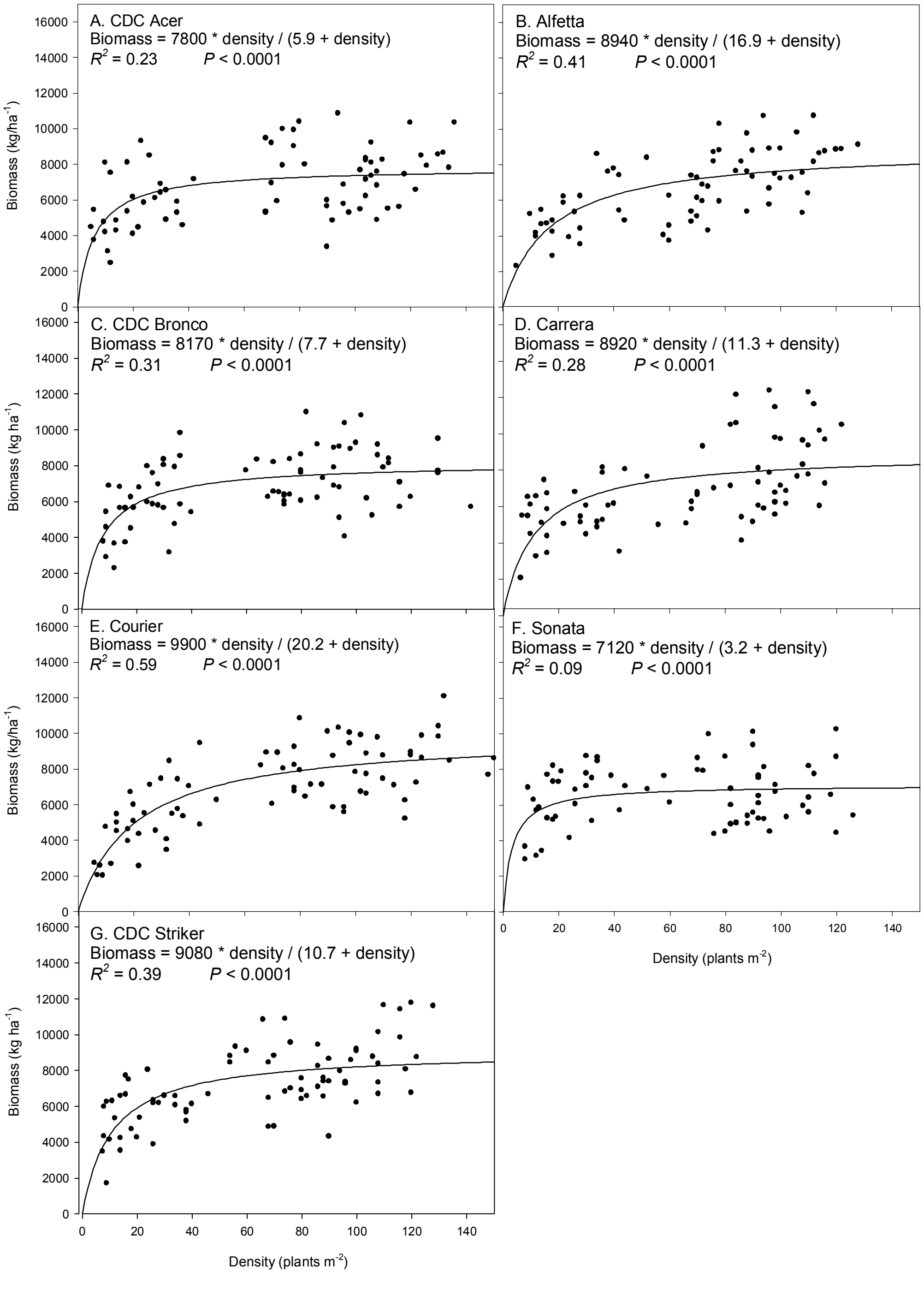


FIGURE 3.6 Effect of plant density on biomass at early senescence for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera, (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation Biomass = Bmax * density / (D_{50} + density) where Bmax is the theoretical maximum biomass as density approaches infinity and D_{50} is the density at which 50% of the max biomass is achieved.

TABLE 3.11 Field pea cultivar D_{50} biomass-density values at early senescence and branching at six node stage intercepts of the cultivars assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	D_{50}	Standard Error	Group†	Branching Intercepts (branches per plant)
	plants m^{-2}			
CDC Sonata	3.2	1.78	a	1.62
CDC Acer	5.9	1.72	ab	1.82
CDC Bronco	7.7	1.60	abc	1.72
CDC Striker	10.7	1.42	bcd	1.62
Carrera	11.3	1.65	bcd	1.33
Alfetta	16.9	2.26	cd	1.43
Courier	20.2	1.78	d	0.80

† Means with the same letters are not significantly different ($P < 0.05$).
D_{50} is the plant density where 50% of maximum biomass is achieved.

TABLE 3.12: Field pea cultivar biomass Bmax values at early senescence and branching at six node stage intercepts of the cultivars assessed at Kernen in 2005 and 2006.

Cultivar	Bmax	Standard Error	Group†	Branching Intercepts (branches per plant)
	kg ha^{-1}			
CDC Sonata	7120	270	a	1.62
CDC Acer	7800	268	ab	1.82
CDC Bronco	8170	268	bc	1.72
Carrera	8920	274	bcd	1.33
Alfetta	8940	274	bcd	1.43
CDC Striker	9080	276	cd	1.62
Courier	9900	270	d	0.80

† Means with the same letters are not significantly different ($P < 0.05$).
Bmax is the theoretical maximum as plant density approaches infinity.

cultivar except *CDC Acer* (7800 kg ha^{-1}, Table 3.12) indicating it had the lowest biomass potential. Cultivars CDC Acer and CDC Bronco also had low Bmax values (7800 and 8170 kg ha^{-1}, respectively) and were lower ($P < 0.05$) than *Courier* which had the highest Bmax value (9900 kg ha^{-1}). Thus, *Courier* is able to produce the highest biomass potential while *CDC Acer* and *CDC Bronco* produce the least biomass potential of the non-silage cultivars. The biomass potential of these cultivars was similar to previous reports in the northern Great Plains (Townley-Smith and Wright 1993; Clayton et al. 2003).

Strong negative correlations were detected between branching and D_{50} values ($r = -0.83$, $P = 0.02$) as well as branching and Bmax values ($r = -0.78$, $P = 0.04$). High branching cultivars like CDC Acer and CDC Bronco exhibited both low D_{50} values and low maximum biomass potential maximum. This infers that cultivars with low branching potential are more sensitive to plant density and thus require higher plant densities in order to achieve similar relative biomass that high branching cultivars are able to achieve at the low plant densities. This also indicates that although low branching cultivars require high densities to achieve biomass, their maximum potential biomass is greater than high branching cultivars. This leads to a strong correlation between D_{50} and Ymax values ($r = 0.93$, $P = 0.003$) and suggests a trade off between maximum potential biomass and the ability of a cultivar to achieve near its maximum biomass at low plant densities.

3.3.8 Yield components

Three different yield components were analyzed in this experiment: seeds per pod, pods per branch and seed weight. Seeds per pod did not interact with site-year and pods per branch only had a site-year by cultivar by plant density ($P < 0.05$) interaction suggesting there were not important differences among site-years and that the data could be combined for both components (Table 3.4). Interactions were found between site-year and cultivar ($P < 0.01$) as well as site-year by cultivar by plant density ($P < 0.01$) for seed weight indicating the site-years should not be combined. However, examination of the individual site-years (Appendix C) showed that at Kernen 2006,

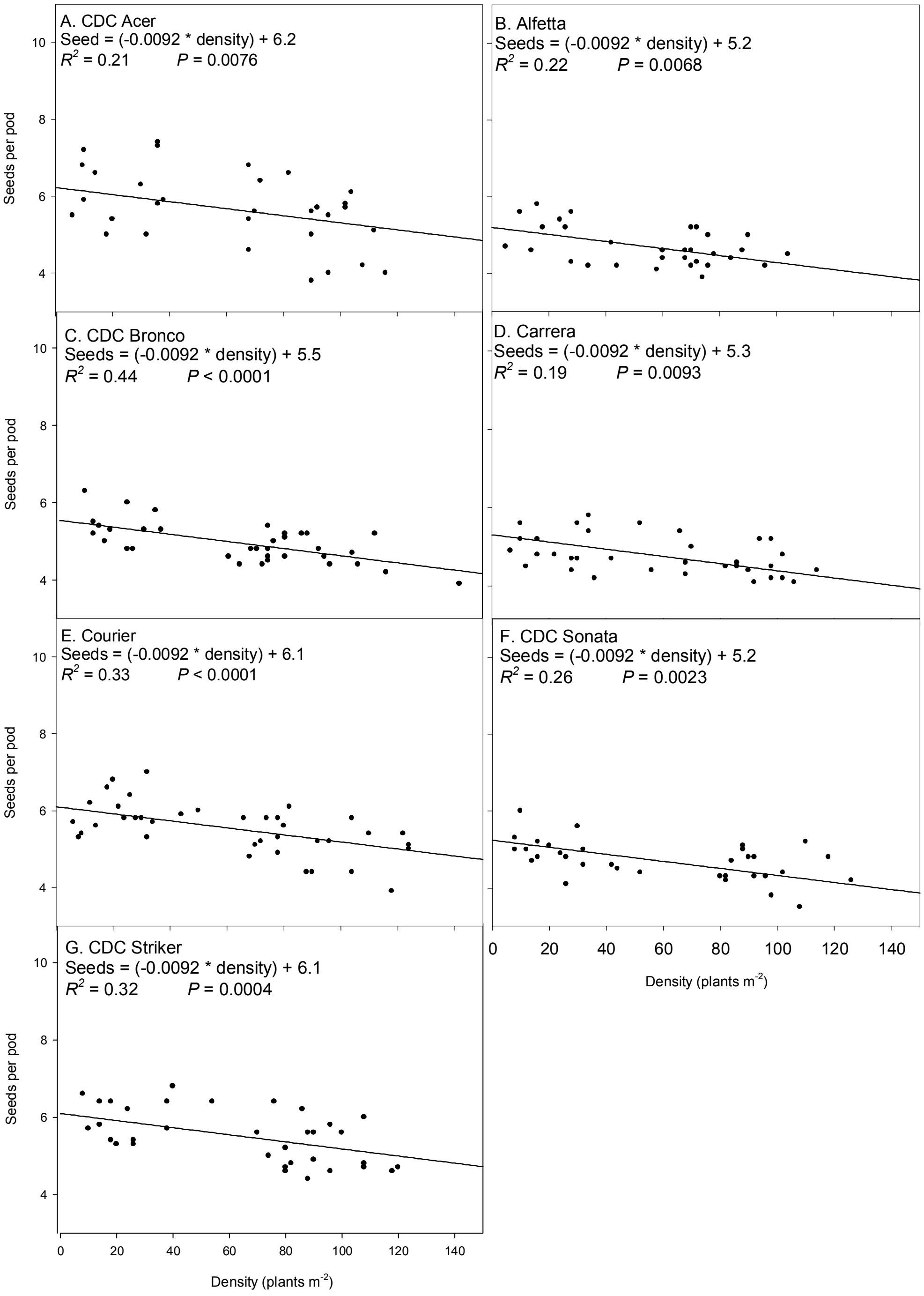


FIGURE 3.7 Effect of plant density on seeds per pod for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera, (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation seeds = (slope * density) + y-intercept where slope is the rate of seeds loss with increased plant density and the y-intercept is the maximum potential seeds for a cultivar.

TABLE 3.13 The intercepts of field pea cultivar seeds per pod linear regressions from an analysis of covariance assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	Seeds per Pod Intercept	Standard Error	Group†
CDC Acer	6.2	0.12	a
Courier	6.1	0.11	a
CDC Striker	6.1	0.12	a
CDC Bronco	5.5	0.12	b
Carrera	5.3	0.11	bc
CDC Sonata	5.2	0.12	c
Alfetta	5.2	0.11	c

† Means with the same letters are not significantly different ($P < 0.05$).

CDC Sonata was predicted as having a higher seed weight compared to the other cultivars at other sites and thus with only this difference, the site-years were combined. Important to note is that the seeds per pods and pods per branch were only assessed at two site-years, whereas seed weight was assessed at four site-years.

The analysis of covariance for seeds per pods indicated significant differences between both plant density ($P < 0.001$) and cultivar ($P < 0.001$) with Figure 3.7 showing these regressions. A common slope of -0.0092 indicates that all cultivars exhibited similar changes seeds per pod with a decease of 0.09 seeds per pod for every increase in 10 plants m^{-2}. The cultivars differed ($P < 0.001$) in the number of seeds per pod at the differing densities. *CDC Acer*, *Courier* and *CDC Striker* had the most seeds per pod and were higher ($P < 0.05$) than the other four cultivars (Table 3.13). This observation along with the observation that cultivars all responded similarly to changes in plant density indicates that *CDC Acer*, *Courier* and *CDC Striker* produced the most seeds per pod regardless of the plant density.

The pods per branch were analyzed with an analysis of covariance resulting in a common slope of -0.031 (Figure 3.8). This common slope indicated that all cultivars responded the same to changes in plant density with a loss of 0.3 pods branch with every increase in 10 plants m^{-2}. There were also differences among the cultivars ($P < 0.001$) in that *Alfetta, Carrera* and *CDC Striker* had fewer pods per branch than the other cultivars (Table 3.14).

The analysis of covariance of seed weight indicated that none of the cultivars changed their seed weights in response to increasing plant densities (Figure 3.7). However, there were differences among cultivars ($P < 0.05$) at differing plant densities with each cultivars being different ($P < 0.05$) from one another (Table 3.15). *Alfetta* and *Carrera* had the largest seed weights (278 and 256 mg, respectively) while *CDC Sonata* and *CDC Acer* had the smallest seed weights (205 and 148 mg, respectively). This indicates that seed weight is genetically inherent and not altered by plant density.

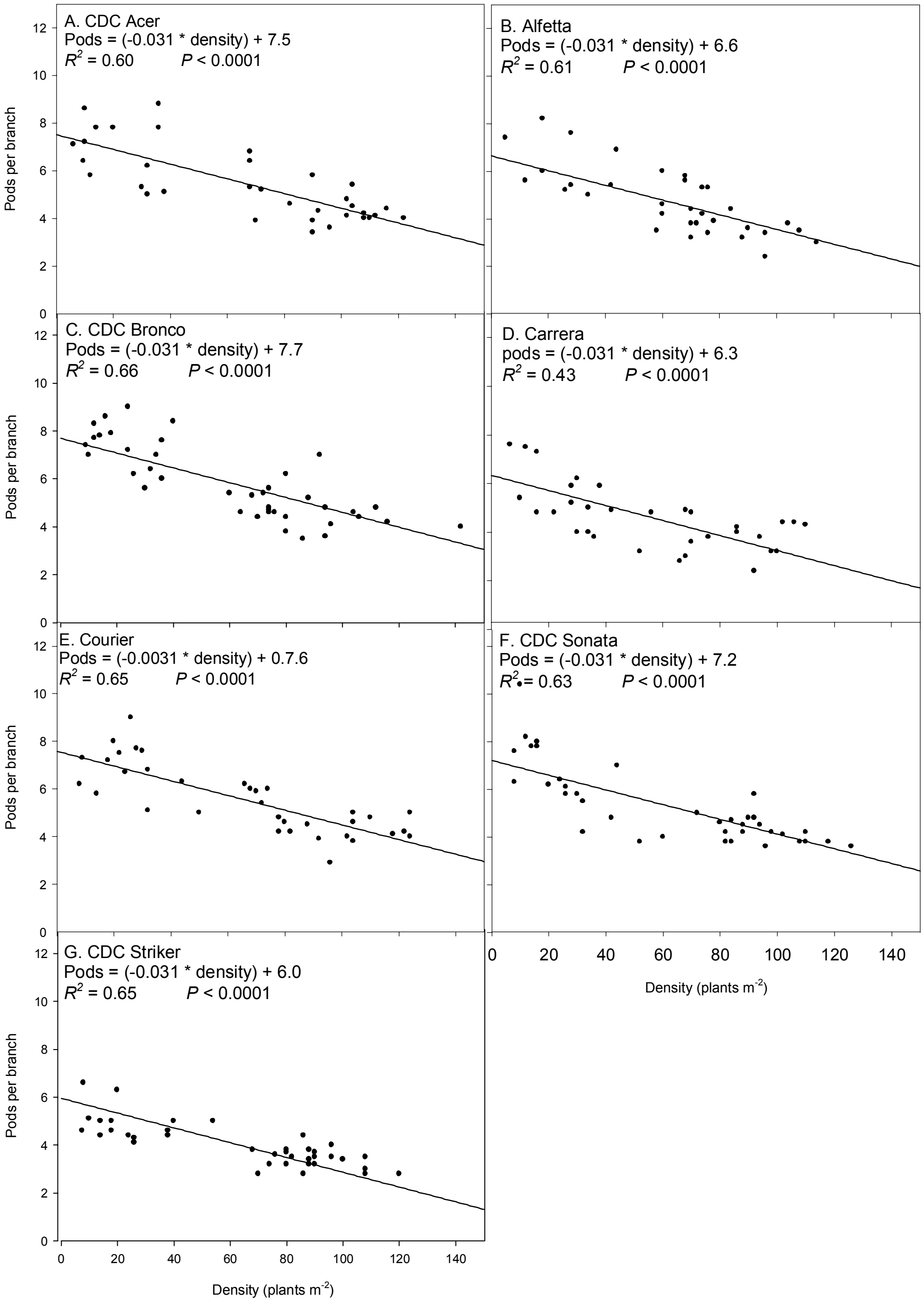


FIGURE 3.8 Effect of plant density on pods per branch at pod fill for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera, (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation pods = (slope * density) + y-intercept where slope is the rate of pod loss with increased plant density and the y-intercept is the maximum potential pods for a cultivar.

TABLE 3.14 The intercepts of field pea cultivar pods per branch linear regressions at pod fill from an analysis of covariance averaged assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	**Pods per Branch Intercept**	**Standard Error**	**Group†**
CDC Bronco	7.7	0.18	a
Courier	7.6	0.19	ab
CDC Acer	7.5	0.19	ab
CDC Sonata	7.2	0.18	b
Alfetta	6.6	0.19	c
Carrera	6.3	0.18	cd
CDC Striker	6.0	0.18	d

† Means with the same letters are not significantly different ($P < 0.05$).

TABLE 3.15 Field pea cultivar seed weight analyzed with an ANOVA assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	**Seed Weight (milligrams)**	**Standard Error**	**Group†**
Alfetta	278	1.9	a
Carrera	256	1.9	b
CDC Striker	241	1.9	c
Courier	220	1.9	d
CDC Bronco	213	1.9	e
CDC Sonata	205	1.9	f
CDC Acer	148	1.9	g

† Means with the same letters are not significantly different ($P < 0.05$) by LSD.

The correlation among branching and the three yield components (seeds per pod, pods per branch and seed weight) indicated that branching was not strongly correlated with any of them ($r = -0.07$, $P = 0.89$; $r = -0.07$, $P = 0.90$ and $r = -0.36$, $P = 0.43$, respectively). This was expected as Rao and Singh (1985) found no correlation between branching and yield components.

3.3.9 Vine length

The vine length of pea plants was classified as the length of a pea vine as opposed to the standing height of the pea plant with vine length being measured as the lengthened vine from the soil surface to the top of the apical meristem on the main stem during the flowering stage. Table 3.4 shows the random and fixed effects from the ANOVA indicating site-years by cultivar ($P < 0.05$) and site-year by cultivar by plant density ($P < 0.001$) interactions. This suggests that the site-years be analyzed separately. However, examining the site-years (Appendix D) indicated that there were no differences in the interpretation of this response among the site-years. For example, *CDC Sonata* had the longest vine length and *Alfetta* and *Carrera* the shortest at all site-years. Thus site-years were combined for analysis.

Density affected vine length of all cultivars similarly. A common slope was obtained for the cultivars (Figure 3.9) suggesting that vine length increased 1.2 cm for every increase in 10 plants m^{-2}. There were also differences among the average vine length ($P < 0.05$, Table 3.16), with CDC Sonata (69 cm) having longer vines ($P < 0.05$) than all other cultivars. Of the non-silage cultivars, *CDC Striker* and *Courier* (62 and 60 cm, respectively) had the longest vines ($P < 0.05$) while *Carrera* and *Alfetta* (52cm each) had the shortest ($P < 0.05$) vines. This indicates that although all the cultivars respond the same to changing plant density, vine length was genetically inherent. There was no correlation between branching and vine length ($r = 0.03$, $P = 0.94$).

3.3.10 Lodging

The fixed and random variables for the lodging scores are displayed in Table 3.4 indicating site-year by cultivar ($P = 0.04$), site-year by plant density ($P = 0.04$) and site-

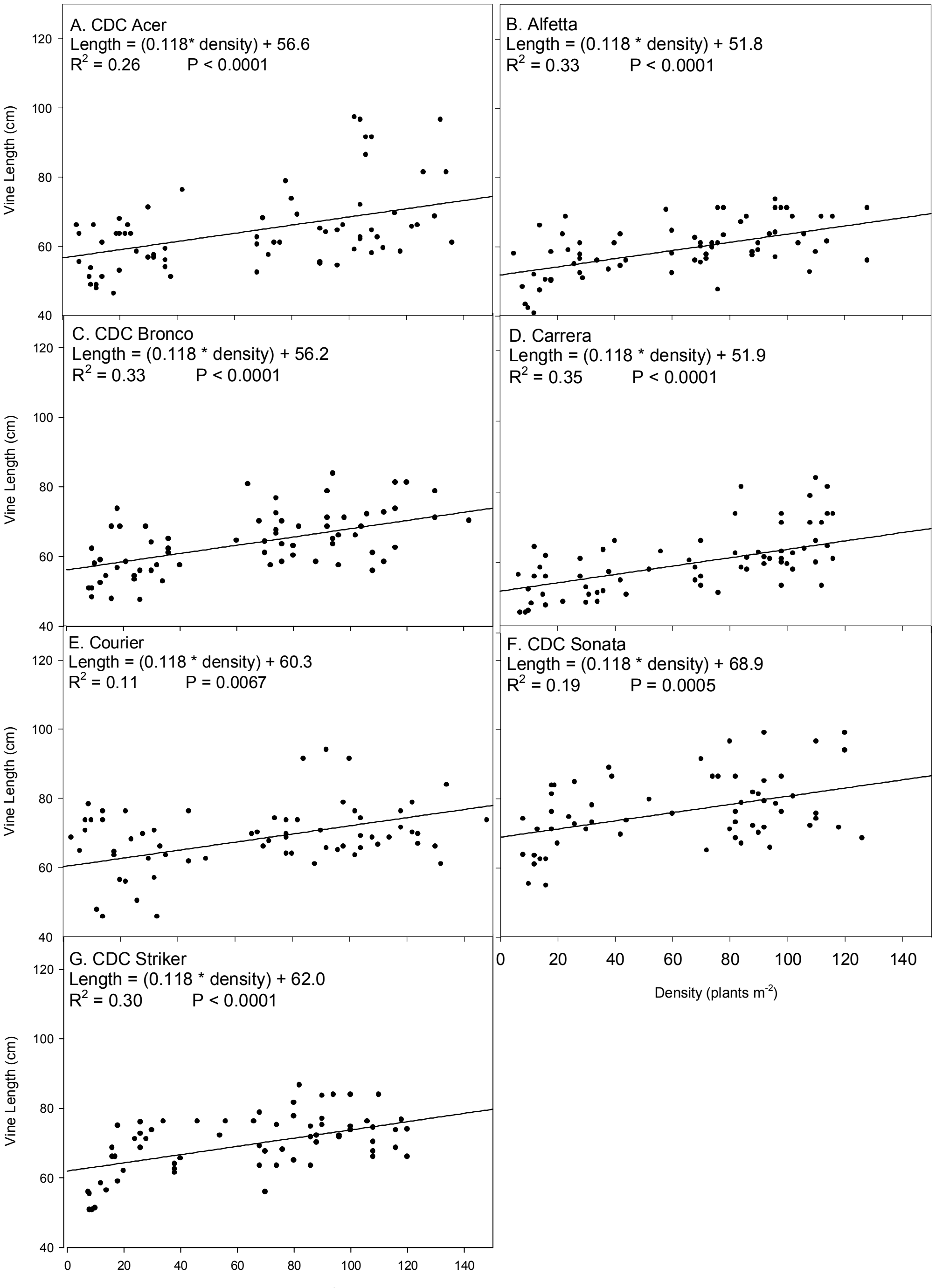
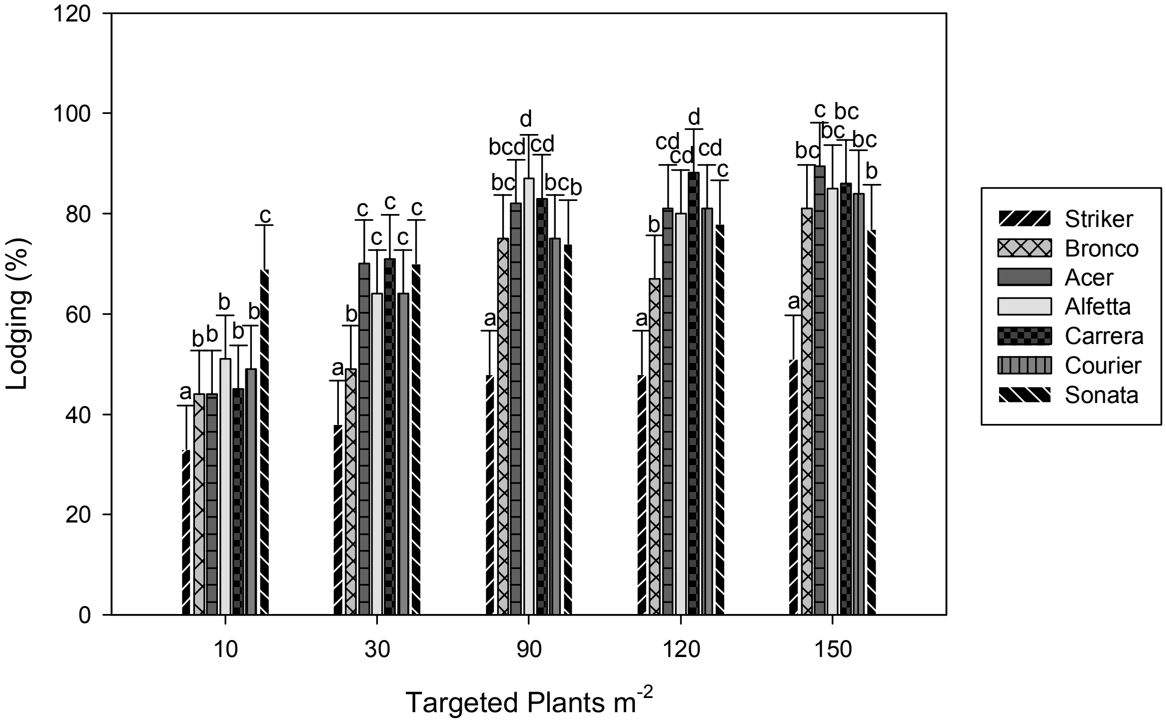


FIGURE 3.9 Effect of plant density on vine length at flowering for field pea cultivars (A) CDC Acer, (B) Alfetta, (C) CDC Bronco, (D) Carrera, (E) Courier, (F) CDC Sonata and (G) CDC Striker assessed at Kernen and Rosthern in 2005 and 2006. Curves are based on the equation length = (slope * density) + y-intercept where slope is the rate of vine length increase with increased plant density and the y-intercept is the minimum potential vine length for a cultivar.

TABLE 3.16 The intercepts of field pea cultivar vine length at flowering for linear regressions from an analysis of covariance assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	Vine Length Intercept (cm)	Standard Error	Group†
CDC Sonata	69	1.4	a
CDC Striker	62	1.4	b
Courier	60	1.4	b
CDC Acer	57	1.4	c
CDC Bronco	56	1.4	c
Carrera	52	1.4	d
Alfetta	52	1.4	d

† Means with the same letters are not significantly different ($P < 0.05$) by LSD.



*comparisons are made within the plant densities and not between densities with similar letters indicating no significant difference ($P < 0.05$) between scores.

FIGURE 3.10 Lodging scores prior to harvest for field pea cultivars at different plant densities assessed at Kernen and Rosthern in 2005 and 2006**.**

year by cultivar by plant density ($P < 0.001$) interactions occurred. This would instruct that the site-years be analyzed separately but once the individual site-years were examined (Appendix G), it was determined that interpretation did not differ among site-years of the data. At all of the site-years, the cultivars CDC Bronco and CDC Striker had the least lodging except at Rosthern in 2005, where *Courier* also had low lodging scores. Based on this observation, the site-years were combined. There were no linear or non-linear trends in the lodging data and therefore the ANOVA was used to compare the cultivars.

The ANOVA indicated that there were differences among cultivars and rates so the different plant densities were examined individually. Figure 3.10 shows the lodging scores for the cultivars at the five different plant densities. At the lowest target density (10 plants m^{-2}), *CDC Striker* (33% lodging) was significantly lower than all of the other cultivars while *CDC Sonata* (69% lodging) was significantly higher than all of the cultivars (Figure 3.10). This suggests that at low plant density, *CDC Striker* was able to maintain upright plant stands where *CDC Sonata* is unable to do so.

At the four higher target plant densities (30, 90, 120 and 150 plants m^{-2}), *CDC Striker* had less lodging than the other cultivars ($P < 0.05$). The remaining cultivars did not differ from one another at the different plant densities except at 30 and 120 plants m^{-2} where lodging of *CDC Bronco* was significantly higher than *CDC Striker* but lower than the other cultivars. This indicates that *CDC Striker* was able to resist lodging at all plant densities. This also indicates that the majority of the cultivars had similar lodging responses with the exception of *CDC Striker*, which was able to best resist lodging at all plant densities. The data also suggests that *CDC Bronco* was also able to resist lodging but only up to moderate plant densities (120 plants m^{-2}). Interestingly, *CDC Sonata* was the only cultivar that did not differ in lodging at the low (10 plants m^{-2}) and high (150 plants m^{-2}) densities. *CDC Sonata* had constant lodging at all plant densities, as expected for a silage cultivar. The lodging differences of the pea cultivars in this experiment were similar to that found by Banniza et al. (2005).

When comparing the lodging scores to branching ability, there was no correlation at any of the target plant densities. For example, a high branching cultivar like *CDC Acer* did not differ from a lower branching cultivar, Courier. This suggests that branching does not influence lodging in pea.

The branching ability of field peas differed among the cultivars. The cultivars that had a higher number of branches achieved more of their potential yield at lower plant densities than lower branching cultivars. Thus, branching potential in pea cultivars can predict the yield-density response. Branching in pea is also correlated to biomass production and mid-vegetative season light interception with higher branching cultivars accumulating more of their potential biomass and intercepting more light at low plant densities. However, branching was not correlated to yield components such as seeds per pod, pods per branch and seed weight. Branching was also not correlated to lodging or vine length of the pea.

4.0 Influence of field pea branching on weed-crop competition

4.1 Introduction

Adequate weed control is important in attaining high yield of pea (*Pisum sativum* L.) (Townley-Smith and Wright 1994). The development of competitive pea genotypes, which can reduce weed growth and seed production, is an important aspect of integrated weed management (McDonald 2003). Field pea is believed to compete poorly with annual weeds (Lutman et al. 1994). Pea is generally classified as being less competitive with weeds than barley (*Hordeum vulgare* L.) or canola (*Brassica napus* L.) and consequently, yield losses are usually more frequent and more in pea crops (Harker 2001). Increased basal branching may enhance the competitiveness of pea crops.

Ideally, a competitive genotype should be tolerate of weeds but also be suppressive (McDonald 2003). As such, in the competitive relationship between a crop and a weed there are two key attributes of the crop that need to be considered: the ability to produce high yields under weed competition (tolerance) and the ability to reduce growth and seed production in the weed (suppression) (McDonald 2003). Improving the competitive ability of field pea may allow lower rates of herbicides to be used or to be used less frequently. This can be beneficial in making pea more profitable to grow when compared with other crops.

Pea plants encounter varying levels of competition from weeds and neighbouring plants throughout its growth (Lawson 1982). Nelson and Nyland (1962) stated that competition between pea and weeds was primarily for light and moisture. Since light is an important factor, rapid canopy development is an important component of pea competitiveness (Wall and Townley-Smith 1996). Thus, plant height along with leaf type may determine pea competitiveness.

In recent years, semi-leafless pea cultivars are preferred over the normal leafed cultivars due to improved harvestability (Rauber et al. 2001). However, semi-leafless cultivars were reported to be less competitive than normal leaf type cultivars (Semere and Froud-Williams 2001). Wall and Townley-Smith (1996) further indicated that the differences among cultivars were attributed to canopy density, plant height and leaf characteristics. Weed competition also increased when pea plants lodged (Simeonouski 1972).

Determining what factors influence the competitiveness of pea crop and how to manipulate them will be beneficial to producers. This research focused on the competitiveness of pea cultivars and specific traits that determine competitiveness against weeds. Differences in the amount of branching that occurred among genetically contrasting cultivars was assessed in the plant population study. The primary objective in this experiment was to examine whether branching affects the competitiveness of pea cultivars.

4.2 Materials and methods

4.2.1 Experimental design and location

The field experiments were conducted in 2005 and 2006 at the Kernen Crop Research Farm near Saskatoon, SK (52º10’12” N, 106º31’10” W) and at a field located near Rosthern, SK (52º42’38” N, 106º16’12” W). The Kernen Farm is located in central Saskatchewan in the Dark Brown soil zone while Rosthern is also situated in central Saskatchewan in the Black soil zone (Saskatchewan Agriculture and Food 2006). The soil at the Kernen farm is classified as a clay soil with a pH of 7.3 while the soil at Rosthern is a loam with a pH of 6.2. On average, Saskatoon receives about 350 mm of precipitation per year with 265 mm of that occurring as annual rainfall (Environment Canada 2007). On average, Rosthern receives slightly more precipitation than Saskatoon with 384 mm a year, 292 mm occurring as annual rainfall (Environment Canada 2007). In the year prior to the initiation of the experiments, the fields were farmed under minimal tillage practices with wheat being sown and harvested at both locations in 2005 and 2006.

The experiment was conducted as a split-plot randomized complete block design with 4 replicates with and without weeds in the whole plots and pea cultivars in the sub-plots. Eight pea cultivars were used, representing four market classes in Canada. This resulted in 64 plots per location in both 2005 and 2006 with each plot being 2 x 6 m in size. A weather station was placed at the Rosthern field location to measure air temperature and rainfall amount. . A weather station located 1.5 km southwest of the plots at Kernen Crop Research Farm was used to obtain weather data for the Saskatoon location.

4.2.2. Experimental procedure

Seed for each pea cultivar was obtained independently from pedigreed seed growers in Saskatchewan in the spring of 2005. Germination tests were conducted prior to seeding so that the targeted plants m^{-2} could be achieved. Half of the treatments were planted with spring wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.) to simulate weed pressure. Spring wheat cultivar CDC Imagine was seeded at 25 plant m^{-2}. Canola cultivar 45H73 was also planted at a rate of 25 plants m^{-2}. These cultivars of wheat and canola were chosen because they are group 2 herbicide tolerant. This means that when the pea plants were sprayed with Odyssey for weed control, all the weeds should be eliminated with the exception of these two. The fields received an application of 440 g ha^{-1} of glyphosate prior to seeding to reduce emerged weed populations. The trials were seeded with a cone seeder using disk openers with an inter-row spacing of 23 cm. Seeding was completed on May 9th in 2005 and on May 19th in 2006. A fertilizer blend of 11-52-0 was mid row banded at a rate of 84 kg ha^{-1}. Grassy and broadleaf weeds were controlled with an application of Odyssey (35% imazamox and 35% imazethapyr) at a rate of 42 g ha^{-1} at the 5 node stage of the crop. The weeds that survived the herbicide application were removed by hand.

Emergence counts were conducted at the four-node stage. Counts were taken with a 0.5 x 0.5 m quadrat and included three rows of pea. Two measurements were taken per plot, one at either end of the plot. Branching data were collected at the six-node stage and were obtained by sampling ten adjacent plants from a single row. Vine length measurements were taken of a lengthened vine from the soil surface to the top of the

TABLE 4.1 Field pea cultivars evaluated for the effect of basal branching on competitiveness.

Cultivar	Cotyledon Color	Seed Coat Color	Market Class	Primary Market	Leaf Type
Alfetta	yellow	white	yellow	food	semi-leafless
CDC Bronco	yellow	white	yellow	food	semi-leafless
Carrera	yellow	white	yellow	food	semi-leafless
CDC Striker	green	white	green	food	semi-leafless
CDC Acer	yellow	maple	maple	bird seed	semi-leafless
Courier	yellow	maple	maple	bird seed	semi-leafless
40-10	yellow	speckled	silage	silage	normal
CDC Sonata	yellow	white	silage	silage	normal

Both locations at Saskatoon (Kernen) and Rosthern were included in 2005 and 2006.

apical meristem on the main stem during the flowering stage with ten adjacent plants being measured from the same row.

Biomass sampling was conducted just prior to plant senescence. All above ground biomass was collected from a 0.5 x 0.5 m area. Two samples per plot were collected, one from either end of the plot. The pea plants were collected into a bag with the weeds (wheat and canola) being collected in a separate bag. The biomass samples were then dried at 80°C for 72 hours and then weighed.

The pods per plant measurement were taken during pod filling. Ten branches in total were chosen at random and the number of pods per branch was counted. Seeds per pod were measured prior to harvest by randomly selecting ten pods per plot and counting seed. The plots were harvested at full senescence with a plot harvester on September 14th in 2005 and September 20th in 2006. The seed was then cleaned with a Carter Day Dockage Tester (Seedburo Equipment Company Chicago, IL) using a 4 x 19 mm slotted sieve with both the pea and weed seeds being weighed. The individual seed weights were then determined by separating out three reps of 200 seeds.

4.2.3 Statistical analysis

ANOVA using Statistical Analysis Software (SAS) mixed model analysis (SAS Institute 1999) was conducted to determine if there were significant differences between the cultivars. The random effects of site and year were combined into one random variable, site-year, resulting in four site-years of data with replicate nested in year. Levene's test was conducted initially to determine among site-years homogeneity of variance. The fixed and random variables along with their interactions were then inspected to determine if the site-years could be combined. In situations where there was a significant interaction affect, individual site-years were examined and compared with one another to determine if combining the site-years would alter in the interpretation of the data. The cultivars as well as weedy and weed-free plots were declared to be significant at $P < 0.05$.

4.3 Results and discussion

4.3.1 Emergence

The fixed and random variables for plant emergence are displayed in Table 4.2 indicating there was only an interaction between site-year and cultivar ($P < 0.05$). With this being the only site-year interaction, the site-years were combined for analysis. The ANOVA also indicated that there were no differences among cultivars ($P = 0.56$), weeds ($P = 0.41$) or cultivar by weeds interaction ($P = 0.24$). This suggests that all cultivars had similar emergence rates between the weed-free and weedy plots with average emergence rate being 89%. This indicates that the presence of weeds did not change field pea emergence rates and thus comparisons can be made between cultivars in weedy and weed-free plots.

4.3.2 Branching

The random and fixed variable interactions for pea branching are displayed in Table 4.2. A highly significant site-year by cultivar interaction suggests that the site-years should not be combined for analysis. However, when examining the individual site-years (Appendix E), it was determined that there were no major differences in the interpretation among the sites. The main alteration in interpretation occurred at Rosthern in 2006 where the cultivar *CDC Acer* had fewer branches and *40-10* had more branches, compared to the other cultivars.

A significant difference in the degree of branching occurred among the cultivars for the combined weed treatments ($P < 0.01$, Table 4.4). The weedy and weed-free plots were combined because there were no significant differences between weeds or cultivar x weeds interaction. This suggests that the presence of weeds did not alter the branching potential of pea cultivars. Differences among cultivars indicated that *Courier* (0.19 branches per plant) had the least amount of branching (Table 4.4). The remaining cultivars were not different from one another with the exception of 40-10 (0.63 branches per plant) being different ($P < 0.05$) from *CDC Acer* (1.22 branches per plant) which had the most branches. The branching means in this experiment were similar to the branching means from the plant population study with the exception of fewer

TABLE 4.2 ANOVA for field pea emergence, branching, yield, weed biomass and crop biomass affected by cultivar and weeds assessed at Kernen and Rosthern in 2005 and 2006.

Source	df	Emergence	Branching	Yield	Weed Biomass	Crop Biomass
		plants m^{-2}	no. per plant	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Site-Year	3	NS	NS	NS	NS	NS
Weeds/No Weeds (Weeds)	1	NS	NS	**	-	**
Cultivar	7	NS	**	NS	***	***
BLOCK	3	NS	NS	NS	NS	NS
BLOCK x Weeds	3	NS	NS	NS	-	NS
Site-year x Cultivar	21	*	**	NS	NS	NS
Site-year x Weeds	3	NS	NS	NS	-	NS
Cultivar x Weeds	7	NS	NS	*	-	*
Site-year x Weeds x Cultivar	21	NS	NS	*	-	NS

*, **, ***, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

TABLE 4.3 ANOVA for field pea podding, seeds per pods, seed weight and vine length as affected by cultivar and weeds assessed at Kernen and Rosthern in 2005 and 2006.

Source	df	Podding	Pea Seeds	Seed Weight	Vine Length
		no. per branch	seeds per pod	mg per seed	cm
Site-Year	3	NS	NS	NS	NS
Weeds/No Weeds (Weeds)	1	NS	NS	NS	NS
Cultivar	7	*	*	***	**
BLOCK	3	NS	NS	NS	NS
BLOCK x Weeds	3	NS	NS	NS	NS
Site-year x Cultivar	21	NS	NS	**	*
Site-year x Weeds	3	NS	NS	NS	NS
Cultivar x Weeds	7	NS	NS	***	NS
Site-year x Weeds x Cultivar	21	NS	NS	NS	**

*, **, ***, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

TABLE 4.4 Field pea cultivar branching of weedy and weed-free plots at six node stage analyzed by an ANOVA assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	**Branches (no. per plant)**	**Standard Error**	**Group†**
CDC Acer	1.21	0.205	a
CDC Bronco	1.19	0.205	ab
CDC Striker	1.12	0.205	ab
Alfetta	1.07	0.205	ab
CDC Sonata	1.03	0.205	ab
Carrera	0.90	0.205	ab
40-10	0.63	0.205	b
Courier	0.19	0.205	c

† Means with the same letters are not significantly different ($P < 0.05$) by LSD.

differences detected among the cultivars due to reduced statistical power. The mean number of branches in this experiment was less than the plant population experiment since data was collected only from plant density five plant densities in the plant population experiment.

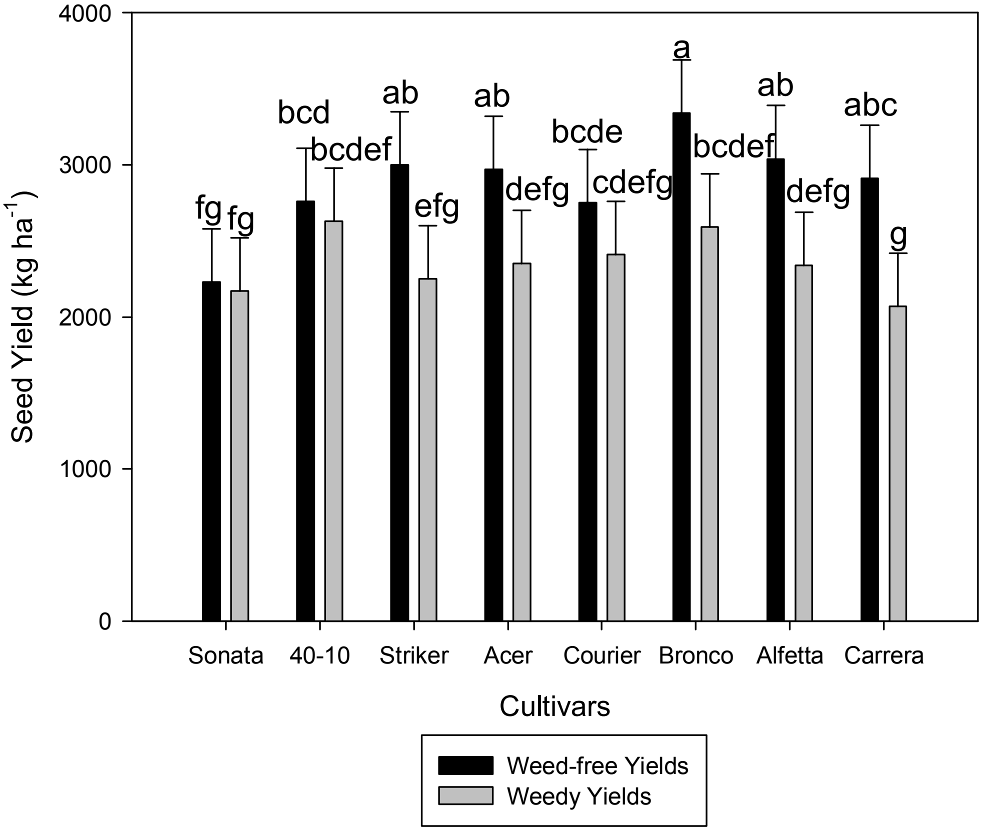
4.3.3 Seed yield and seed yield loss

The ANOVA on yield (Table 4.2) indicated a significant ($P < 0.05$) site-year by cultivar by weeds interaction however, with this being the only site-year interaction the data for the four site-years were combined. There was a significant weed effect ($P < 0.01$) and cultivar by weed interaction ($P < 0.05$) inferring the two weed treatments should not be combined. The differences between these weed treatments (Figure 4.1) showed that *CDC Sonata, 40-10* and *Courier* were the cultivars that did not differ ($P < 0.05$) between the weed-free and weedy yields. This suggests that these cultivars were able to maintain their yield potential under the pressure of weeds.

The yields in the weed-free plots ranged from 3330 kg ha^{-1} in *CDC Bronco* to 2230 kg ha^{-1} in *CDC Sonata* (Figure 4.1). *CDC Sonata* yield was lower than the other cultivars indicating it has the lowest weed-free yield potential. Of the non-silage cultivars, all were similar except that *Courier* (2750 kg ha^{-1}) was lower yielding than *CDC Bronco* (3330 kg ha^{-1}). This suggests that *CDC Bronco* has the highest yield, while *Courier* has the lowest yield and would not be recommended under weed-free conditions.

A key aspect with regard to competitiveness is the mean yield in the weedy plots and how that yield compares to the yield potential in the weed-free plots. The yield in weedy plots ranged from 2630 kg ha^{-1} in *40-10* to 2070 kg ha^{-1} in *Carrera*. The lowest yielding cultivar *Carrera* (2070 kg ha^{-1}) was significantly lower from the higher yielding cultivars *40-10* (2630 kg ha^{-1}) and *CDC Bronco* (2590 kg ha^{-1}). Thus, *CDC Bronco* would be the best cultivar to grow and *Carrera* would not be recommended.

The percentage of yield loss exhibited by the cultivars under weedy conditions ranged from 3% in *CDC Sonata* to 29% in *Carrera* (Figure 4.1). The two normal leaf type silage cultivars, *CDC Sonata* and *40-10* had the lowest loss in yield with 2% and 5%



*comparisons are made within weed treatments and between cultivars with similar letters indicating no significant difference ($P < 0.05$) between scores.

FIGURE 4.1 ANOVA of field pea cultivar seed yield in weedy and weed-free plots assessed at Kernen and Rosthern in 2005 and 2006.

respectively. These cultivars produced relatively low grain yield under weed-free conditions so when weeds were present, they had less percent yield loss. Of the non-silage cultivars, *Courier* had the lowest yield loss with 12% while *Carrera* had the most yield loss with 29%. Wall et al. (1991) noted that 20 wild mustard plants m^{-2} caused a yield loss in pea from 2 to 35 %. Wall and Townley-Smith (1996) found yield losses due to weeds differed among cultivars.

There were no correlations detected between number of branches and either weedy yields or yield loss of the cultivars ($r = 0.11$, $P = 0.80$ and $r = 0.12$, $P = 0.77$, respectively). *CDC Acer* had the most branches but did not smallest yield loss or greatest yield in the presence of weeds. *Courier* had the fewest branches but did not have the greatest yield loss or the lowest yield in the presence of weeds. Thus, branching is not one of the major traits in field pea that will indicate cultivar competitiveness.

4.3.4 Weed biomass

The ANOVA for weed biomass (Table 4.2) indicated that there were no site-year by cultivar interaction so the site-years were combined. Weed biomass was different among the cultivars ($P < 0.001$). The least amount of weed biomass was present in *40-10* (540 kg ha^{-1}) and was lower than all the other cultivars ($P < 0.05$, Table 4.5). *CDC Sonata* (960 kg ha^{-1}) had the second least amount of weed biomass, lower ($P < 0.05$) than all of the cultivars except for *Courier* (1240 kg ha^{-1}). This suggests that normal leaf type cultivars were better able to limit weed growth as compared to the other cultivars. The reason for this could be due to their vigorous vegetative growth and also because they were the only two cultivars in the experiment that had normal leaf type. The greatest weed biomass production was 1980 kg ha^{-1} in *Carrera* however when compared to the other non-silage cultivars, it was only greater than *Courier* (1240 kg ha^{-1}). *Carrera* was the least competitive cultivar with respect to limiting weed biomass production, with the silage cultivars being the most competitive.

TABLE 4.5 ANOVA of field pea cultivar weed biomass at early senescence in weedy plots assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	Weed Biomass (grams m^{-2})	Standard Error	Group†
Carrera	1980	266	a
CDC Acer	1860	268	ab
CDC Striker	1840	268	ab
Alfetta	1780	266	ab
CDC Bronco	1540	268	ab
Courier	1240	268	bc
CDC Sonata	960	266	c
40-10	540	268	d

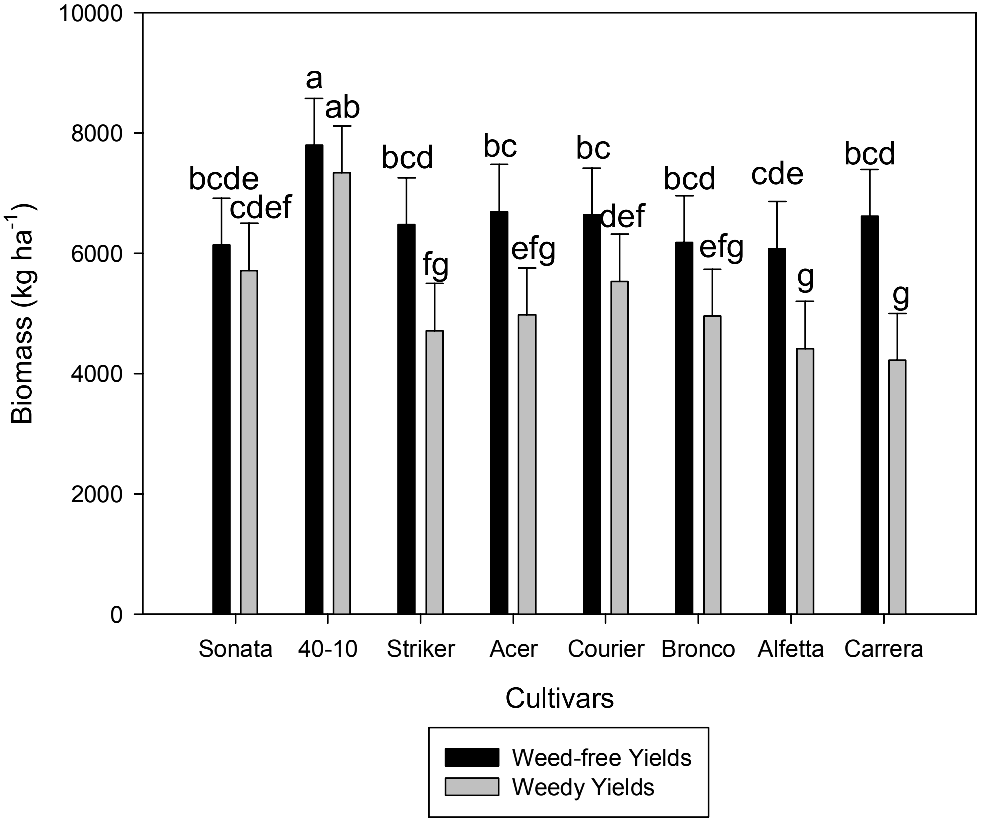
† Means with the same letters are not significantly different ($P < 0.05$) by LSD.

4.3.5 Crop biomass

The ANOVA of crop biomass (Table 4.2) indicated no site-year interactions suggesting that the four site-years could be combined. There were a significant cultivar ($P < 0.001$) and weed ($P < 0.01$) effects and cultivar by weed interactions ($P < 0.05$). When comparing the different weed treatments among the cultivars (Figure 4.2), only the two silage cultivars*, CDC Sonata* and *40-10* did not differ ($P > 0.05$) between the weed-free and weedy plots (7% and 9% respectively). The non-silage cultivars ranged from 21% biomass loss in *Courier* to 35% in *Carrera*. Nelson and Nyland (1962) recorded biomass weight losses of up to 71% due to presence of wild mustard plants, which was larger losses than seen in these experiments. Based on the data, non-silage cultivars exhibited significant losses in biomass in the presence of weeds where the silage cultivars did not. This suggests that the silage cultivars are more competitive than the non-silage cultivars with regards to biomass production and likely explains their ability to maintain seed yield under weedy conditions.

Weed-free biomass ranged from 6080 kg ha^{-1} in *Alfetta* to 7810 kg ha^{-1} in *40-10* (Figure 4.2). *40-10* had more ($P < 0.05$) biomass than the other cultivars with remaining cultivars not differing from one anther. The reason that *40-10* had more biomass could be that it was one of the two normal leaf type cultivars in this experiment, with *CDC Sonata* being the other normal leaf cultivar. The other six cultivars are classified as being semi-leafless. Thus, *40-10* had the most weed-free biomass and this could be explained by its long vines and normal leaf type.

When examining the pea biomass in the presence of weeds, the weights ranged from 4230 kg ha^{-1} in *Carrera* to 7330 kg ha^{-1} in *40-10*. *40-10* (7330 kg ha^{-1}) had significantly more biomass than the other cultivars. As with the weed-free biomass, this might be explained by its vine length and normal leaf type characteristic. *CDC Sonata* (5710 kg ha^{-1}) had the second most biomass with significantly more than *Alfetta* and *Carrera* (4420 and 4230 kg ha^{-1} respectively). The two silage cultivars, *40-10* and *CDC Sonata* had the best ability to maintain their biomass under weedy conditions. This could be attributed to their vigorous vegetative growth. The biomass of *Alfetta* and *Carrera* was most reduced by the presence of weeds.



*comparisons are made within the weed treatments and between cultivars with similar letters indicating no significant difference ($P < 0.05$) between scores.

FIGURE 4.2 Field pea cultivar crop biomass at early senescence in weedy and weed-free plots assessed at Kernen and Rosthern in 2005 and 2006.

Strong correlations were not detected between branching and any of the biomass results including weed biomass (r = 0.50, P = 0.21), crop biomass loss (r = 0.16, P = 0.70) weed-free biomass (r = -0.52, P = 0.19) and weedy biomass (r = -0.44, P = 0.28). This suggests branching did not predict losses in biomass under weedy conditions. However, there was a strong association between the reduction in plant biomass and the increase in weed biomass with a correlation of r = 0.93 (Figure 4.3). *40-10* and *CDC Sonata* had the least loss of biomass and also had the least amount of weeds present. *Carrera* had the greatest loss in biomass (2390 kg ha^{-1}) and the most weed biomass present (990 kg ha^{-1}). There appears to be a trade off between plant biomass and weed biomass. If the pea plants are able to reduce the amount of weed biomass present, benefits will be realized in their own biomass production. If the weeds are able to thrive and produce biomass, they will do so at the expense of the plant's biomass. Nelson and Nyland (1962) mentioned that the biomass weight of the pea crop is probably a more accurate indicator of the competitive effects of the mustard on the pea than is the yield. With competitive ability and competitive response being highly correlated, either weed biomass or crop biomass loss could be used as an indicator of the competitive ability of pea plants.

4.3.6 Yield components

Three yield components were examined in this experiment: pods per branch, seeds per pod and seed weight. The fixed and random variables for the three traits are displayed in Table 4.3. No site-year interactions were observed in the pods per branch or seeds per pod data sets indicating that the site-years could be combined for analysis. A significant site-year by cultivar (P < 0.01) interaction was detected for seed weight suggesting that the site-years should not be combined. Upon examination of results by site-year (Appendix F), the main difference in results was is at Saskatoon in 2006. At this location, CDC Sonata had higher seed weight when compared to the other cultivars and other site-years. Based on this, the site-years were combined.

No differences in pods per branch in the weedy and weed-free plots (P = 0.22) were detected signifying that the presence of weeds did not alter the number of pods per

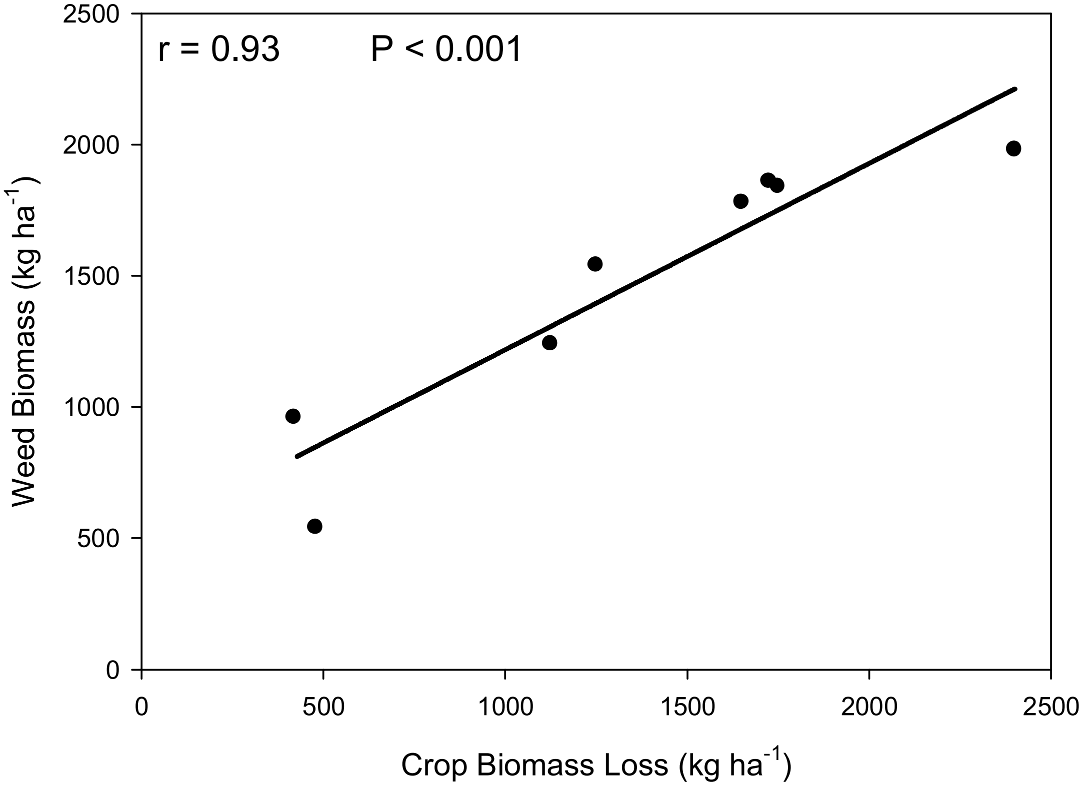


FIGURE 4.3 Correlation association between field pea cultivar crop biomass loss and weed biomass at early senescence assessed at Kernen and Rosthern in 2005 and 2006.

branch. The average number of pods per branch was highest in *CDC Acer* and *Courier* (5.1 pods per branch each) and lowest in *CDC Striker* (3.1 pods per branch, Table 4.6). *CDC Acer* and *Courier* differed significantly from all the cultivars except *CDC Bronco* and *CDC Sonata* (4.8 and 4.7 pods per branch, respectively). *CDC Bronco* and *CDC Sonata* only had more pods than *CDC Striker* (3.1 pods per branch). This podding data shows that each cultivar has a genetically inherent number of pods per branch with *CDC Acer* and *Courier* having the most and *CDC Striker* having the least and that weed competition does not alter pods numbers. Lawson (1982) found that weeds did not reduce the number of pods, observing that flowers numbers were reduced but not pods.

The number of seeds per pod also showed similar trends to pods per branch in that the number of seeds per pod did not differ between the weedy and weed-free plots (P = 0.19). *Courier, 40-10* and *CDC Acer* had the most seeds per pod, significantly more than the other cultivars (Table 4.7). Lawson (1982) also found that seeds per pod were not affected by weed presence, yet Nelson and Nyland (1962) found significant differences, with the presence of weeds reducing seed numbers. This data suggests that each cultivar has a genetically inherent set number of seeds per pod and that competition with weeds had no effect on this yield component.

The ANOVA for seed weight indicated no differences between the weed treatments (P = 0.25, Table 4.3). There was a cultivar by weed interaction ($P < 0.001$) because two cultivars, Courier and CDC Sonata, had significantly different weights in the weedy plots than in the weed-free plots (Figure 4.4). This indicated that weeds did not generally alter the seed weight of the field pea. When comparing the weed-free seed weights, *Alfetta* and *Carrera* had heavier weights and were heavier than all other cultivars ($P < 0.05$, Figure 4.4). *CDC Acer* and *40-10* had smaller weights than the other cultivars ($P < 0.05$). In the weedy situation, the results were similar. Lawson (1982) reported that seed weights of pea was not affected by weed presence and Proctor (1972) noted a slight loss in seed weight contributed only in a minor way to the yield losses due to weed competition.

No strong correlation was observed among branching and any of the yield components:

TABLE 4.6 ANOVA of field pea cultivar pods per branch at pod fill in weedy and weed-free plots assessed at Kernen and Rosthern in 2006.

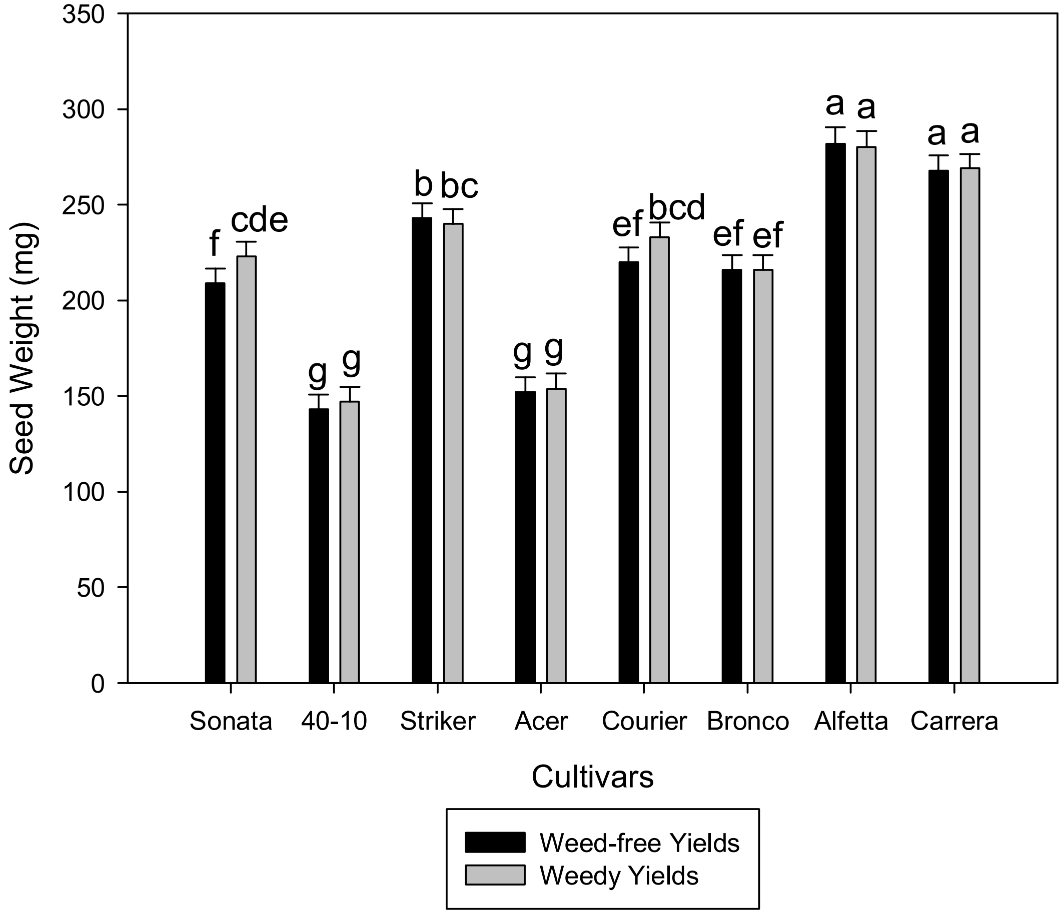
Cultivar	**Pods per Branch**	**Standard Error**	**Group†**
CDC Acer	5.1	0.41	a
Courier	5.1	0.40	a
CDC Bronco	4.8	0.41	ab
CDC Sonata	4.7	0.40	abc
Alfetta	4.1	0.40	bc
Carrera	3.9	0.40	cd
40-10	3.8	0.41	cd
CDC Striker	3.1	0.40	d

† Means with the same letters are not significantly different ($P < 0.05$) by LSD.

TABLE 4.7 ANOVA of field pea cultivar seeds per pod prior to harvest in weedy and weed-free plots assessed at Kernen and Rosthern in 2006.

Cultivar	**Seeds per Pod**	**Standard Error**	**Group†**
Courier	5.9	0.25	a
40-10	5.8	0.25	a
CDC Acer	5.7	0.25	a
CDC Striker	5.3	0.25	ab
CDC Bronco	4.8	0.25	b
CDC Sonata	4.7	0.25	b
Alfetta	4.6	0.25	b
Carrera	4.6	0.25	b

† Means with the same letters are not significantly different ($P < 0.05$) by LSD.



Comparisons are made between weed treatments and between cultivars with the same letters not being significantly different ($P < 0.05$).

FIGURE 4.4 Field pea cultivar seed weight of weedy and weed-free plots assessed at Kernen and Rosthern in 2005 and 2006.

pods per branch ($r = -0.13$, $P = 0.76$) seeds per pod ($r = -0.33$, $P = 0.43$) and seed weight ($r = -0.23$, $P = 0.58$). Thus, branching was not an indicator of how the yield components respond to the presence of weeds. There was an interesting correlation between seed weight and seeds per pod ($r = -0.69$ $P < 0.05$) suggesting that larger seed weights are associated with fewer seeds per pods.

4.3.7 Effect of vine length at flowering on biomass and seed yield loss

The ANOVA of pea vine length resulted in a significant site-year by cultivar ($P < 0.05$) and site-year by cultivar by weed ($P < 0.01$) interaction (Table 4.3) suggesting that combining site-years was not acceptable. However, examination of the site years (Appendix H) indicated that Rosthern 2005 was the only site-year that differed from the others and thus the site-years were combined. Vine length did not differ between the weedy and weed-free plots, inferring that weed treatments could be combined and concluding that the presence of weeds did not influence the vine length of pea.

Cultivars differed, as expected, for vine length ($P < 0.01$, Table 4.8). *40-10* and *CDC Sonata* had the longest vines (75 and 22 cm, respectively) 6 to 10% longer than the other non-silage cultivars. Thus, the silage cultivars had the longest vine length which could be contributed to their vigorous vegetative growth or possible just a genetically inherent trait. Of the non-silage cultivars, *CDC Striker* had the longest vine length (68 cm) and was longer ($P < 0.05$) than *CDC Acer* and *Carrera* (58 cm and 57 cm, respectively), which had the shortest vine lengths. The vine length of the pea cultivars in this experiment were similar to that found by Banniza et al. (2005).

There was a strong negative correlation observed between vine length and yield loss ($r = -0.80$, $P = 0.02$) and vine length and weed biomass ($r = -0.82$, $P = 0.01$) as well as a strong positive correlation between vine length and weedy crop biomass ($r = 0.71$, $P = 0.04$, Figure 4.5). The longer vine cultivars *40-10* and *CDC Sonata* had the least yield loss, least weed biomass and the most crop biomass in the presence of weeds while *Carrera*, the shortest vine cultivar had the most yield loss, most weed biomass and least weedy crop biomass. McDonald (2003) stated that the main factor influencing

TABLE 4.8 ANOVA of field pea cultivar vine length at flowering assessed at Kernen and Rosthern in 2005 and 2006.

Cultivar	**Vine Length (cm)**	**Standard Error**	**Group†**
40-10	75	6.3	a
CDC Sonata	72	6.3	a
CDC Striker	68	6.3	ab
Courier	65	6.3	abc
CDC Bronco	61	6.3	bc
Alfetta	60	6.3	bc
CDC Acer	58	6.3	c
Carrera	57	6.3	c

† Means with the same letters are not significantly different ($P < 0.05$) by LSD.

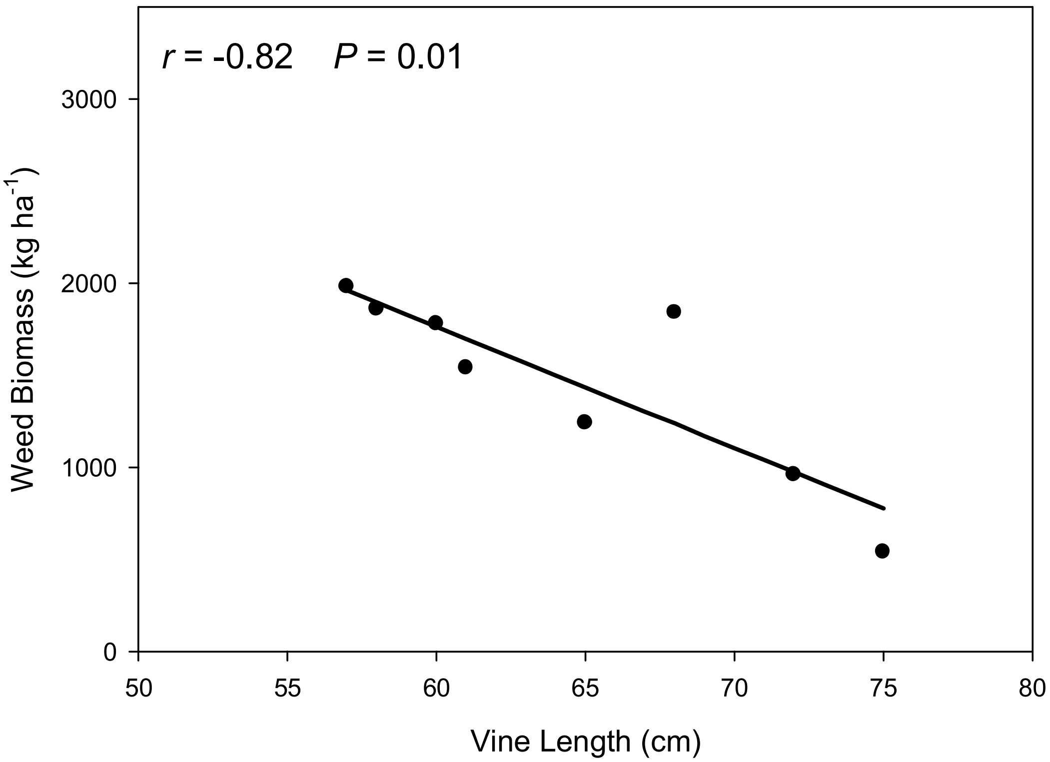


FIGURE 4.5: Correlation association between field pea cultivar vine length at flowering and weed biomass at early senescence averaged at Kernen and Rosthern in 2005 and 2006.

competitiveness was plant height, with the reason being competition primarily for light and moisture (Nelson and Nyland 1962). Thus, longer vines in pea are associated with inhibiting weed biomass while maintaining crop biomass.

The number of branches per plant differed among the cultivars in this experiment as it did in the plant population study. The highest branching cultivars were *CDC Acer* and *CDC Bronco* and *Courier* was the lowest branching. The branching ability of pea cultivars was not correlated with weedy seed yield or seed yield loss. Branching was also not correlated with weed biomass. Thus, branching is not an indicator of pea cultivar competitiveness. Vine length of pea was correlated to weed biomass, yield loss and weedy crop biomass indicating vine length is more accurate in determining a competitive cultivar. However, two of the cultivars had a normal leaf type and vine length can not be determined as the major trait in cultivar competitiveness.

5.0 General discussion

5.1 Influence of field pea branching on optimal plant density

The objective of the optimal plant density experiment was to assess whether cultivars differed in basal branching ability. Results showed that each cultivar has its own genetic potential with respect to branching with *CDC Acer* and *CDC Bronco* having more branching while *Courier* had less branching. This experiment also showed that branching habit of the cultivars responded similarly to increases in plant density by decreasing 0.075 branches for every increase in 10 plants m^{-2}.

The second objective of the optimal plant density experiment was to examine whether branching in field pea influenced the yield-density relationship of the cultivars. The effect of branching on the yield curves showed that branching affected the shape of the yield curve for pea in that more of the potential yield was achieved at lower plant densities in cultivars with increased branching. Cultivars with the ability to branch more, *CDC Acer* and *CDC Bronco*, were able to reach a higher proportion of their potential yield at low plant densities (lower D_{50} values). Conversely, cultivars with a low degree of branching, such as *Courier*, required high plant densities to achieve the same proportion of its potential yield (higher D_{50} values). However, the branching ability of the cultivars was not associated with overall yield potential. This means that branching is only importantly associated with yield response at low plant densities.

Branching in pea was also an indicator of mid-vegetative season (flowering) light interception. The cultivars that exhibited a high degree of branching like *CDC Acer* and *CDC Bronco* also had low D_{50} values on the light interception curves. Low D_{50} values signify that the cultivar is able to intercept more light at low plant densities. A low branching cultivar like *Courier* had a high D_{50} value and thus requires higher plant densities to equal the amount of light intercepted by a high branching cultivar.

Branching was also an indicator of biomass production under varying plant densities. Highly branched cultivars like *CDC Acer* and *CDC Bronco* had low biomass D_{50} values. A lower biomass D_{50} values indicates that the cultivar can accumulate more of its potential biomass at lower plant densities. A low branching cultivar like Courier had the highest D_{50} value resulting in the lowest proportion of biomass accumulation at low densities.

High degrees of branching ability indicate a cultivar is able to a) intercept more light at low plant densities, b) accumulate more of its potential biomass at low plant densities and c) achieve more of its potential yield at low plant densities when compared to a low branching cultivar. This suggests that high branching cultivars like *CDC Acer* and *CDC Bronco* are able to sustain high yields at low plant densities where a lower branching cultivar like *Courier* requires higher plant densities in order to achieve the same yield. Based on this I accept the hypothesis that branching in field pea affects the optimal plant density and can state that higher branching cultivars have lower optimal plant densities than lower branching cultivars.

5.2 Influence of field pea branching on weed-crop competition

The branching potential of field pea cultivars in the weed competition experiment was almost identical to those in the seeding rate experiment. The highly branched cultivars in the optimal plant population experiment, *CDC Acer* and *CDC Bronco* were also the highly branched cultivars in the weed competition experiment as well as Courier being the branched cultivar in both experiments. The primary objective of the weed competition experiment was to determine the effect of the branching characteristics on the competitiveness of the cultivars. Competitiveness was measured by yield loss, crop biomass loss and weed biomass presence. Greater yield and crop biomass loss would indicate that the cultivar was less competitive as opposed to a cultivar that had less yield loss.

With no correlations between branching and the measure of competitiveness, I can state that branching was not an indicator of field pea competitiveness. However, vine length had significant negative correlations with the yield loss of the cultivars (-0.86, *P*

< 0.01) as well as with weed biomass (-0.91, $P < 0.01$). This indicates that long vined cultivars like *CDC Striker* and *Courier* were better able to limit yield loss and weed biomass as opposed to shorter vined cultivars like *Alfetta* and *Carrera* that had greater yield loss and more weed biomass present. Since plants compete for light and moisture, it is reasonable to expect that vine length was strongly associated with competitive ability. Cultivars that had longer vines visually had fewer weeds present as well as having less weed biomass and less biomass loss. Fully compounded with vine length, leaf type also had an affect on competitiveness as the two normal leaf type cultivars, *40-10* and *CDC Sonata* had the least amount of weeds present. Thus, I reject the hypothesis that branching significantly affects the competitive ability of field pea cultivars and state that vine length was a more influential factor when it comes to competitive ability.

It has been noted in other studies that leaf type also plays a role in the competitive ability of pea. Larger leaves intercept more light and since light is one of the important factors that with respect to competitiveness, larger leaves would result in less light penetrating through the canopy to the weeds. Based on this fact, leaf type has the potential to significantly affect the competitive ability of pea and thus I cannot entirely rule out or support the idea of leaf type affecting plant competition and by inference, cannot rule in or out vine length either.

5.3 Management implications

Many management implications can be extracted from this research with respect to field pea production. With some of the newer cultivars being introduced into the market that have higher branching ability than some of the cultivars currently on the market, branching becomes a more important aspect to consider. In this study, I have indicated that highly branched cultivars could be targeted at plant densities lower than the current recommendation of 88 plants m^{-2}. The results indicate that the economic optimal plant densities for the cultivars evaluated were *CDC Sonata* (65 plants m^{-2}), *CDC Acer* (77 plants m^{-2}), *CDC Bronco* (82 plants m^{-2}), *Alfetta* (90 plants m^{-2}), *CDC Striker* (91 plants m^{-2}), *Carrera* (102 plants m^{-2}) and *Courier* (106 plants m^{-2}). This indicates that three of the seven cultivars could be planted at densities lower than the recommended 88 plants m^{-2}. This would allow producers to reduce seeding cost and improve net return.

Knowledge of branching ability can aid whether or not it is advisable to target a lower than current recommended plant density. Highly branched cultivars will provide the producers with the option to seed those cultivars at a lower than recommended targeted plant density without the risk of lowering the yield of the cultivar. However, producers have to be aware of the risk of poor emergence and if they are unable to achieve a sufficient plant density to meet the targeted plant density, their yields will be significantly reduced. In situations such as these, it is advisable that the recommended seeding rate be used. Another management tool could be the use of highly branched cultivars in aiding the decision of what cultivar to plant. If a producer has the option to choose between two cultivars with the same yield potential but one maintains greater yield proportion under less that ideal emergence, risk would be reduced by choosing a highly branched cultivar that would not have increased yield loss if plant emergence were less than optimal. Based on this, it would be advisable for producers to choose a highly branched cultivar and plant at the recommended seeding rate to reduce risk of yield loss due to reduced emergence as opposed to reducing the seeding rate of the cultivar.

The competitive ability of pea cultivars is a consideration for weed control. This can be beneficial to organic producers who have fewer tools to control weeds than as conventional producers. One key management tool that organic producers use to control weeds is seeding rate however this tool alone cannot fully limit the yield loss due to weeds. By choosing a more competitive cultivar along with the practice of other weed management tools like increased seeding rate, pea could become more profitable for organic producers by increasing yield return and limiting weed growth.

For conventional producers, increased competitive ability of a cultivar would also translate into increased profits. More competitive crops could reduce the rate and frequency of herbicides used because there are fewer weeds present in the crop. This could also give the crop a longer window for weed control as the pea cultivars may be able to withstand weed pressure for a longer period without significant losses in yield. With average farm size increasing, producers may not have the time to closely monitor their crops as well as spray every field at the optimal time for weed removal. This can therefore allow producers to farm more area efficiently without having to invest added time in management of the crops.

A cultivar that could be recommended to both organic and conventional producers as being highly competitive is *CDC Bronco*. This cultivar had the highest weed-free yield as well as the highest weedy-yield in this research project. *CDC Bronco* also had the lowest loss of biomass in the presence of weeds. The vine length of *CDC Bronco* was moderate yet the weed biomass was near the lowest of the cultivars tested. This cultivar was not identified as being the most competitive cultivar tested with respect to yield loss due to weeds, however, economic yield is the main focus of producers. A cultivar that producers should avoid is *Carrera*. This cultivar had the second lowest weed-free yield and the lowest weedy yield. In addition, *Carrera* had the most weed biomass present and had the highest loss in biomass and yield.

5.4 Future research

This research has provided basic knowledge about branching and competitiveness in field pea cultivars that had not previously been undertaken. New knowledge has been gained in branching ability as well as impacts of branching in field situations. Branching ability could be used as a tool in field pea management.

The plant population study was limited in that only seven cultivars were included in the study. Many other cultivars are available to producers in Western Canada and branching research has not been done intensively on many of these cultivars. In order to get more accurate recommendations for field peas, more cultivars would have to be examined to provide more solid and confident recommendations. By studying more cultivars, assessments of how they rank according to their branching ability could be determined. As well as examining more cultivars, solely concentrating on branching and yield could provide more accurate data as many different measurements were taken from the plots in the plant population experiment allowing for more error to occur during sampling and analyzing.

The weed competition study was limited in that it was conducted at only one plant density, 50 pea plants m^{-2}. This density was chosen so that field pea plant density was high enough to achieve adequate yield but low enough that the weeds could be competitive with the crop. Making assumptions on competitiveness of field pea cultivars based on one plant density does not represent how they would react at other plant densities. Data needs to be collected on more cultivars as well because only eight were included in this study. I speculate that the relative performance of cultivars will be similar at different plant densities as it was at 50 plants m^{-2} but until the research is done, accurate conclusions cannot be drawn.

Further examination into the affect of vine length and leaf type would also aid in assessing if both of these traits determine competitive ability. This study examined vine length but not in great enough detail to suggest whether it was vine length is linked to competitiveness. Previous studies have indicated leaf type as well as vine length could play a role in competitive ability and more research could indicate whether that holds valid. Also assessing whether vegetative growth rate of cultivars influences both competitive ability and optimal plant density could be examined to determine whether this trait has merit in increasing competitive ability or decreasing optimal plant density.

This study serves as a starting point in helping to make pea production more profitable with less management. *CDC Bronco* was the recommended cultivar and it was a moderately tall which resulted in nearly the best weed suppression of the cultivars. *Carrera* should be avoided as it had the shortest vine length as well as the highest weed biomass. A recommendation to plant breeders would be to continue to concentrate their efforts on maximizing yield of field pea as this indirectly selects for highly branched cultivars. Attention could be concentrated on cultivars with increased basal branching as this aids in reducing yield loss to producers under less than optimal emergence and is a risk management tool for them.

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Appendix A – Pea cultivar branching at the six-node stage averaged across plant density at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Branching Intercept	Standard Error	Group†
CDC Acer	1.69	0.105	a
CDC Bronco	1.46	0.102	ab
CDC Sonata	1.45	0.105	ab
CDC Striker	1.33	0.100	bc
Alfetta	1.26	0.105	bc
Carrera	1.08	0.105	c
Courier	0.25	0.110	d

Rosthern 2005

Cultivar	Branching Intercept	Standard Error	Group†
CDC Acer	0.43	0.053	a
Alfetta	0.42	0.053	a
CDC Bronco	0.35	0.054	ab
CDC Striker	0.28	0.054	b
CDC Sonata	0.26	0.055	b
Carrera	0.25	0.053	b
Courier	0.02	0.054	c

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Branching Intercept	Standard Error	Group†
CDC Acer	1.63	0.085	a
CDC Striker	1.50	0.085	ab
CDC Bronco	1.34	0.085	bc
CDC Sonata	1.13	0.087	cd
Alfetta	0.98	0.085	d
Carrera	0.94	0.085	d
Courier	0.31	0.092	e

Rosthern 2006

Cultivar	Branching Intercept	Standard Error	Group†
CDC Bronco	1.79	0.094	a
CDC Sonata	1.66	0.096	ab
CDC Acer	1.59	0.094	ab
CDC Striker	1.48	0.094	b
Alfetta	1.13	0.096	c
Carrera	1.09	0.094	c
Courier	0.46	0.105	c

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix B - Pea cultivar seed yield averaged across plant density at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Yield (kg ha^{-1})	Standard Error	Group†
CDC Striker	3330	108.0	a
Alfetta	3320	105.0	a
CDC Bronco	3130	105.0	a
Carrera	3090	105.0	a
CDC Acer	2790	108.0	b
Courier	2600	113.9	b
CDC Sonata	2250	116.8	c

Rosthern 2005

Cultivar	Yield (kg ha^{-1})	Standard Error	Group†
CDC Striker	3890	132.8	a
Alfetta	3660	119.8	ab
Carrera	3540	117.1	b
CDC Bronco	3430	127.6	bc
Courier	3250	117.1	cd
CDC Acer	3110	114.3	d
CDC Sonata	2200	125.3	e

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Yield (kg ha^{-1})	Standard Error	Group†
Carrera	2600	97.5	a
CDC Acer	2600	95.3	a
CDC Bronco	2490	96.2	ab
CDC Striker	2340	96.7	bc
Alfetta	2340	96.7	bc
CDC Sonata	2180	94.8	cd
Courier	2160	94.8	d

Rosthern 2006

Cultivar	Yield (kg ha^{-1})	Standard Error	Group†
CDC Bronco	3100	85.2	a
CDC Striker	2880	85.2	b
Alfetta	2620	85.2	c
Courier	2610	85.2	c
Carrera	2490	86.8	cd
CDC Acer	2380	85.2	d
CDC Sonata	1710	86.8	e

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix C - Pea cultivar seed weight averaged across plant density at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Seed Weight (milligrams)	Standard Error	Group†
Alfetta	303	3.9	a
Carrera	278	4.2	b
CDC Striker	249	3.9	c
Courier	233	3.8	d
CDC Bronco	216	3.8	e
CDC Sonata	204	3.8	f
CDC Acer	151	3.9	g

Rosthern 2005

Cultivar	Seed Weight (milligrams)	Standard Error	Group†
Alfetta	279	2.1	a
Carrera	262	2.1	b
CDC Striker	239	2.1	c
CDC Bronco	216	2.1	d
Courier	215	2.1	d
CDC Sonata	201	2.1	e
CDC Acer	153	2.1	f

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Seed Weight (milligrams)	Standard Error	Group†
Alfetta	262	2.0	a
CDC Striker	239	2.0	b
Carrera	237	2.0	b
CDC Sonata	235	2.1	b
Courier	226	2.1	c
CDC Bronco	210	2.0	d
CDC Acer	150	2.1	e

Rosthern 2006

Cultivar	Seed Weight (milligrams)	Standard Error	Group†
Alfetta	271	2.3	a
Carrera	250	2.3	b
CDC Striker	237	2.3	c
CDC Bronco	211	2.3	d
Courier	207	2.4	d
CDC Sonata	182	2.4	e
CDC Acer	140	2.3	f

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix D - Pea cultivar vine length at flowering averaged across plant density at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Vine Length (cm)	Standard Error	Group†
CDC Sonata	82.8	1.82	a
Courier	66.5	1.92	b
CDC Acer	65.5	1.78	b
CDC Striker	60.9	1.95	c
CDC Bronco	60.3	1.78	c
Alfetta	58.8	1.78	cd
Carrera	56.5	1.78	d

Rosthern 2005

Cultivar	Vine Length (cm)	Standard Error	Group†
CDC Sonata	89.9	1.30	a
CDC Acer	79.3	1.16	b
Courier	78.1	1.30	b
CDC Striker	76.2	1.11	c
Carrera	70.6	1.11	d
CDC Bronco	70.3	1.11	d
Alfetta	67.1	1.11	e

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Vine Length (cm)	Standard Error	Group†
CDC Sonata	73.8	1.43	a
CDC Striker	72.0	1.45	a
Courier	67.5	1.43	b
CDC Bronco	64.4	1.48	bc
CDC Acer	60.9	1.45	cd
Carrera	59.7	1.43	d
Alfetta	58.3	1.45	d

Rosthern 2006

Cultivar	Vine Length (cm)	Standard Error	Group†
CDC Sonata	70.2	0.99	a
CDC Striker	67.5	1.00	b
Courier	63.4	0.99	c
CDC Bronco	62.0	0.99	c
CDC Acer	57.3	0.99	d
Alfetta	55.9	0.99	de
Carrera	55.0	0.99	e

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix E - Pea cultivar branching at the six-node stage averaged across weed treatments at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Branching (no. plant^{-1})	Standard Error	Group†
CDC Acer	1.91	0.065	a
CDC Striker	1.67	0.061	ab
Alfetta	1.66	0.061	ab
CDC Bronco	1.48	0.061	b
CDC Sonata	1.41	0.061	b
Carrera	1.33	0.061	b
Courier	0.41	0.061	c
40-10	0.20	0.061	d

Rosthern 2005

Cultivar	Branching (no. plant^{-1})	Standard Error	Group†
Alfetta	0.36	0.069	a
Carrera	0.35	0.069	a
CDC Bronco	0.31	0.069	ab
CDC Striker	0.28	0.069	ab
CDC Acer	0.18	0.069	ab
CDC Sonata	0.16	0.069	b
40-10	0.00	0.069	c
Courier	0.00	0.069	c

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Branching (no. plant^{-1})	Standard Error	Group†
CDC Acer	1.81	0.069	a
CDC Bronco	1.50	0.069	ab
CDC Sonata	1.30	0.069	bc
CDC Striker	1.25	0.069	bc
40-10	1.24	0.069	bc
Alfetta	1.13	0.069	bc
Carrera	1.11	0.069	c
Courier	0.18	0.069	d

Rosthern 2006

Cultivar	Branching (no. plant^{-1})	Standard Error	Group†
40-10	2.49	0.065	a
CDC Bronco	1.84	0.065	b
CDC Sonata	1.78	0.065	b
CDC Striker	1.67	0.065	b
CDC Acer	1.55	0.065	b
Alfetta	1.44	0.065	b
Carrera	0.97	0.065	c
Courier	0.41	0.065	d

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix F - Pea cultivar seed weight averaged across weed treatments at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Seed Weight (mg)	Standard Error	Group†
Alfetta	300	6.0	a
Carrera	280	6.0	b
CDC Striker	249	6.0	c
Courier	232	6.2	d
CDC Bronco	223	6.0	de
CDC Sonata	217	6.2	e
CDC Acer	157	6.0	f
40-10	149	6.0	f

Rosthern 2005

Cultivar	Seed Weight (mg)	Standard Error	Group†
Carrera	273	2.4	a
CDC Striker	240	2.4	b
Courier	235	2.4	c
CDC Bronco	215	2.4	d
CDC Sonata	213	2.5	d
CDC Acer	159	2.4	e
40-10	148	2.5	f

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Seed Weight (mg)	Standard Error	Group†
Alfetta	270	2.9	a
Carrera	262	2.9	b
CDC Sonata	251	2.9	c
Courier	234	2.9	d
CDC Striker	233	2.9	d
CDC Bronco	221	2.9	e
40-10	161	2.9	f
CDC Acer	153	2.9	g

Rosthern 2006

Cultivar	Seed Weight (mg)	Standard Error	Group†
Alfetta	272	3.5	a
Carrera	258	3.5	b
CDC Striker	245	3.7	c
Courier	206	3.5	d
CDC Bronco	205	3.5	d
CDC Sonata	184	3.7	e
CDC Acer	142	3.5	f
40-10	123	3.5	g

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix G - Pea cultivar lodging scores prior to harvest averaged across weed treatments at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Lodging Score (%)	Standard Error	Group†
Carrera	94	2.4	a
CDC Acer	91	2.4	a
Courier	90	2.7	a
Alfetta	89	2.4	a
CDC Sonata	78	2.4	b
CDC Bronco	71	2.4	c
CDC Striker	42	2.4	d

Rosthern 2005

Cultivar	Lodging Score (%)	Standard Error	Group†
Alfetta	75	4.0	a
CDC Acer	71	4.0	ab
Carrera	62	3.9	bc
CDC Sonata	60	4.1	c
Courier	58	3.9	c
CDC Bronco	55	3.9	c
CDC Striker	42	3.9	d

† Means with the same letters are not significantly different (P < 0.05).

Kernen 2006

Cultivar	Lodging Score (%)	Standard Error	Group†
Carrera	73	2.7	a
CDC Sonata	70	2.8	ab
Courier	70	2.8	ab
Alfetta	68	2.7	abc
CDC Bronco	66	2.7	abc
CDC Acer	63	2.9	bc
CDC Striker	61	3.0	c

Rosthern 2006

Cultivar	Lodging Score (%)	Standard Error	Group†
CDC Sonata	78	3.8	a
CDC Acer	74	3.8	ab
Alfetta	66	4.3	bc
Carrera	62	3.8	cd
Courier	61	3.9	cd
CDC Bronco	53	3.8	d
CDC Striker	36	4.0	e

† Means with the same letters are not significantly different (P < 0.05).

Appendix H - Pea cultivar vine length at flowering averaged across weed treatments at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Cultivar	Vine Length (cm)	Standard Error	Group†
40-10	87	1.3	a
CDC Sonata	77	1.3	b
CDC Striker	63	1.3	c
CDC Acer	63	1.3	c
CDC Bronco	58	1.3	d
Courier	58	1.3	d
Alfetta	58	1.3	d
Carrera	56	1.3	d

Rosthern 2005

Cultivar	Vine Length (cm)	Standard Error	Group†
CDC Striker	90	1.9	a
CDC Sonata	85	1.9	ab
CDC Courier	85	1.9	b
Alfetta	83	1.9	b
CDC Bronco	77	1.9	c
Carrera	73	1.9	cd
40-10	71	1.9	d
CDC Acer	64	1.9	e

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Cultivar	Vine Length (cm)	Standard Error	Group†
40-10	65	1.5	a
CDC Sonata	58	1.5	b
Courier	55	1.5	bc
CDC Striker	53	1.5	c
CDC Bronco	48	1.5	d
Alfetta	45	1.5	de
Carrera	45	1.5	de
CDC Acer	44	1.5	e

Rosthern 2006

Cultivar	Vine Length (cm)	Standard Error	Group†
40-10	77	1.4	a
CDC Sonata	70	1.4	b
CDC Striker	68	1.4	bc
Courier	65	1.4	cd
CDC Bronco	61	1.4	de
CDC Acer	60	1.4	e
Alfetta	56	1.4	f
Carrera	54	1.4	f

† Means with the same letters are not significantly different ($P < 0.05$).

Appendix I - Pea cultivar emergence rates averaged across cultivars at differing densities at Kernen and Rosthern in 2005 and 2006.

Kernen 2005

Targeted Plants m^{-2}	Actual Plants m^{-2}	Standard Error	Group†
10	9	3.3	a
30	25	3.3	b
90	80	3.3	c
120	100	3.3	d
150	114	3.3	e

Rosthern 2005

Targeted Plants m^{-2}	Actual Plants m^{-2}	Standard Error	Group†
10	17	1.9	a
30	35	1.9	b
90	82	1.9	c
120	105	1.9	d
150	118	1.9	e

† Means with the same letters are not significantly different ($P < 0.05$).

Kernen 2006

Targeted Plants m^{-2}	Actual Plants m^{-2}	Standard Error	Group†
10	13	2.5	a
30	30	2.5	b
90	80	2.5	c
120	90	2.5	d
150	102	2.5	e

Rosthern 2006

Targeted Plants m^{-2}	Actual Plants m^{-2}	Standard Error	Group†
10	14	1.6	a
30	32	1.6	b
90	70	1.6	c
120	83	1.6	d
150	101	1.6	e

† Means with the same letters are not significantly different ($P < 0.05$).