A physiological study of weed competition in peas (*Pisum sativum* L.)

A thesis
submitted in fulfilment of the
requirements for the degree of

Doctor of Philosophy

at

Lincoln University

Canterbury

New Zealand

by

Z. Munakamwe

Lincoln University

2008

Abstract

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Peas dominate New Zealand grain legume production and they are a major export crop. However, weeds are a major problem particularly under organic production, where the use of synthetic chemicals is prohibited. To address this limitation, a research program to study weed control in peas was done to provide both conventional and organic farmers a sustainable weed management package. This was done through three field experiments over two growing seasons, 2006/07 and 2007/08. Experiment 1, (2006/07) evaluated the effect of 50, 100 and 400 plants m^{-2} on crop yield, and weed growth of Aragon, Midichi or Pro 7035 with and without cyanazine. Experiment two explored the physiology of two pea genotypes, the leafed (Pro 7035) and the semi leafless (Midichi) sown at three dates. A herbicide treatment was included as a control. In the third experiment Midichi, was used to investigate the effect of different pea and weed population combinations and their interaction on crop yield and weed growth. All crops were grown at Lincoln University on a Templeton silt loam soil.

In Experiment one, herbicide had no effect on total dry matter (TDM) and seed yield (overall mean seed yield 673 g m^{-2}). There was also no significant difference in mean seed yield among the pea genotypes, Aragorn, Pro 7035 and Midichi, (overall mean, 674 g m^{-2}). The lowest average seed yield, 606 g m^{-2} was from 400 plants m^{-2} and the highest, 733 g m^{-2}, from 50 plants m^{-2}, a 21% yield increase. A significant herbicide by population interaction showed that herbicide had no effect on seed yields at 100 and 400 plants m^{-2}. However, cyanazine treated plots at 50 plants m^{-2} gave 829 g m^{-2} of seed. This was 30% more than the 637 g m^{-2}, from plots without herbicide. In Experiment 1 pea cultivar and herbicide had no significant effect on weed counts.

In Experiment 2 the August sowing gave the highest seed yield at 572 g m^{-2}. This was 62% more than the lowest yield, in October. Cyanazine treatment gave a mean seed yield of 508 g m^{-2}, 19% more than from unsprayed plots. There was a significant (p < 0.05) sowing date x genotype interaction which showed that in the August sowing genotype had no effect on seed yield. However, in September the Pro 7035 seed yield at 559 g m^{-2} was 40% more that of Midichi and in October it gave 87% more. Weed spectrum varied over time. Prevalent weeds in spring were *Stachys* spp, *Achillea millefolium* L*.,* and *Spergular arvensis* L*.* In summer they were *Chenopodium album* L., *Rumex* spp, *Trifolium* spp and *Solanum nigrum* L. *Coronopus didymus* L*., Stellaria media* and *Lolium* spp were present in relatively large numbers throughout the season.

In Experiment 3 seed yield increased significantly (p < 0.001) with pea population. Two hundred plants m^{-2} gave the highest mean seed yield at 409 g m^{-2} and 50 plants m^{-2} gave the lowest (197 g m^{-2}). The no-sown-weed treatment gave the highest mean seed yield of 390 g m^{-2}. This was due to less competition for solar radiation. There was no difference in seed yield between the normal rate sown weed and the 2 x normal sown weed treatments (mean 255 g m^{-2}).

It can be concluded that fully leafed and semi-leafless peas can be sown at similar populations to achieve similar yields under weed free conditions. Increased pea sowing rate can increase yield particularly in weedy environments. Early sowing can also increase yield and possibly control problem weeds of peas (particularly *Solanum* spp), which are usually late season weeds. Herbicide can enhance pea yield but can be replaced by effective cultural methods such as early sowing, appropriate pea genotype and high sowing rates.

Additional key words: *Pisum sativum* L., semi-leafless, fully leafed, cyanazine, pea population, weed population, sustainable, TDM, seed yield, weed, weed counts, sowing date, weed spectrum, seed rates.

DEDICATION

This page is dedicated to my wife Rufaro and son Tanaka in acknowledgment of the understanding, sacrifice and full time support during the course of this study.

LIST OF PUBLICATIONS

Munakamwe, Z., McKenzie, B. A. and Hill, G. D. (2007). Can canopy architecture of field peas influence weed population and dry matter production? Poster presented at the 6th European Conference on Grain Legumes-Lisbon Portugal (2007).

Munakamwe, Z., McKenzie, B. A. and Hill, G. D. (2008). Effect of sowing date on weed spectrum in field peas. Abstract submitted to Agronomy New Zealand.

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LIST OF ABBREVIATIONS USED

Symbols	Descriptions
$A	Australian dollar
$NZ	New Zealand dollar
a.i.	Active ingredient
ANOVA	Analysis of variance
CA	Competitive ability
CGR	Crop growth rate
CHI	Crop harvest index
C_m	Maximum crop growth rate
cv	Cultivar
CV	Coefficient of variation
d	Day
DAE	Days after emergence
DM	Dry matter
DUR	Duration of crop growth
FAR	Foundation for arable research
Ha	Hectare
HI	Harvest index
hr	Hours
K	Potassium
-k	Extinction coefficient
KPa	Kilopascals
L	Litre
LAD	Leaf area duration
LAI	Leaf area index
LSD	Least significant difference
m	Metre
MAF	Ministry of Agriculture and Fisheries
mg	Milligram
MJ	Mega joule
MLP	Maximum Likelihood Programme
N	Nitrogen

N_2	Atmospheric Nitrogen
PAR	Photosynthetically active radiation
PAI	Photosynthetic area index
PHI	Plant harvest index
r^2	Coefficient of determination
RUE	Radiation use efficiency
spp	Species
Si	Total incident PAR
TDR	Time Domain Reflectometry
TDM	Total dry matter
WMAGR	Weighted mean absolute growth rate

Chapter 1

1.0 General Introduction

1.1 Background

Field peas are grown specifically for use as dried peas. They are an important rotation crop in many parts of the world including New Zealand. Peas are the major grain legume exported from New Zealand with over 35,000 t being exported earning more than $NZ 50 million in 2005 (Horticulture New Zealand, 2005). They are a major source of cheap protein. Dried peas have been a good source of nutritious food since Neolithic times (Gane, 1985). Humans have been modifying plants for a considerable period of time and there is evidence that peas may have been cultivated in the near East for nearly as long as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) (Zohary and Hopf, 1973). However, in New Zealand peas are a relatively minor crop compared with cereals (Ministry of Agriculture and Forestry, 2006) although they are grown over a wide area extending from Southland to Hawke's Bay (Jermyn, 1987). Canterbury is the region where pea production is substantial with 11,400 ha sown in 2002 producing 57,000 t (Annual Review of New Zealand and Canterbury Agriculture and Horticulture, 2002).

New Zealand has grown peas since early in the 20th century and there has been a substantial, and relatively stable, export trade in peas (Lough, 1987). Up to and including the 1960s, New Zealand grew 10,000 – 12,000 ha of dry peas producing 20,000 – 25,000 t of peas (Lough, 1987). By the 1970s, the pea area had expanded to 20,000 ha which produced more than 50,000 t of peas. Recent statistics indicate that in 2006, 24,100 t of pulses (almost all peas) were produced in New Zealand (FAR, 2007). Three quarters of this production was in Canterbury because Canterbury had grower expertise and a suitable climate for production of high quality peas and good port facilities for export (Lough, 1987; Moot, 1993). The above figures include both conventional and organic pea production.

Organic food production and consumption is rapidly gaining in popularity worldwide. Expansion of the organic industry in Australia and New Zealand is premised on continued institutionalisation of what was once considered to be a marginal 'unscientific' approach to farming (Lyons and Lawrence, 2007). Estimates indicate that

the Australian organic industry increased in value from $A 28 million in 1990 to $A 200 million in 1999. In New Zealand the industry has grown from $NZ 1.1 million in 1988 to $NZ 33.5 million by 1996 (Saunders *et al.*, 1997; Kinnear, 1999) and by 2004 total exports of organic products were worth $NZ 75 million (BioGro, 2007). This is a substantial increase and shows the potential of organics to contribute to the national economy. Unfortunately there are few recent statistics on organic pea production is New Zealand.

Despite the great potential of the pea industry (both conventional and organic) and lucrative markets, New Zealand farmers only grow about 20,000 ha of peas (FAR, 2007). This is attributed to some drawbacks in pea production, the major limitations being weeds (White and Hill 1999), and unstable yields (McKenzie, 1987; Moot and McNeil, 1995). According to White and Hill (1999), common fathen (*Chenopodium album* L.), black nightshade (*Solanum nigrum* L.), Californian thistle (*Cirsium arvense* L.) and stinking mayweed (*Anthemis cotula*), are major weeds of peas. Weeds can cause severe yield losses if crops are not monitored closely, particularly during the early stages of weed emergence (Freeman, 1987). Farmers usually use conventional herbicides to manage weeds but the use of synthetic herbicides is not allowed in organic production systems and weed control is a real constraint in these systems.

As pea crops are expensive to establish, compared with cereals, it is essential to achieve as high a yield as possible through correct paddock selection or by extending the rotation to at least six years (Freeman, 1987). Paddock selection can be based on field history. Freeman (1987) stressed that consistent yields of around 4 t ha^{-1} are necessary for peas to be a viable crop. According to Moot (1993) and White and Hill (1999), high pea yields can be produced under favourable conditions. However, peas have poor yield stability (McKenzie, 1987; Moot and McNeil, 1995).

As weed competition can seriously affect pea yield and impede crop harvest, increased demand for a high quality product has placed greater emphasis on the control of weeds that affect crop yield and that can contaminate the crop at harvest (Gane, 1985; Bithel, 2004). The fact that weeds reduce pea yields is common knowledge. However, there is little published information on the extent to which the competitive ability of different pea canopies can affect weed growth and crop yield. There is also very little known about the physiology of competition between peas and weeds as influenced by radiation interception, crop canopy and sowing date. This research program seeks to provide explanations for these complex interactions.

1.2 Research Objectives

The research objectives were set in response to the above concerns: The major objective of the research was to quantify the competitive ability of different pea canopy architectures in relation to pea genotype, pea population and sowing date, grown with and without herbicide, on crop yield and weed growth and also to potentially provide advice for organic pea growers.

This study was planned specifically to:

- Quantify the competitive ability of different pea canopy architectures, created by combinations of different pea genotypes and populations, grown with and without herbicide.

- Determine the influence of the interaction between different crop populations and weeds on the physiology of pea and weed growth.

- Determine the effect of varying the crop sowing date on weed growth, weed spectrum and crop yield.

This thesis reports three field experiments and is presented in seven chapters. Chapter 2 is a review of literature; Chapter 3 describes the materials and methods used in the three field experiments. Chapters 4, 5 and 6, give the results and discuss Experiments 1, 2 and 3 respectively. A general discussion, conclusions and recommendations for further work drawn from the whole research program are presented in Chapter 7.

Chapter 2

2. 1. Literature Review

2.1.1 Introduction

Peas (*Pisum sativum* L.), are grown worldwide (Table 2.1) but because of their sensitivity to climate extremes they are largely confined to temperate regions and to higher altitudes or cooler seasons in the tropics (Gane, 1985). The United States and the United Kingdom have traditionally been the largest producers but recently Canada, China and France have taken the top positions in pea production (FAOSTAT, 2008). Average yields in France and the United Kingdom are 4.23 and 3.57 t ha^{-1}, respectively (FAOSTAT, 2008).

In New Zealand peas have been grown since the start of arable farming (Claridge 1972; Jermyn 1983). They are fifth in importance as an annual cash crop but occupy less than half the area of either wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.). In 2006, 230,000 t of barley, 285,000 t of wheat, 209,000 t of maize (*Zea mays* L.), 83,000 t of herbage seeds and 24,000 t of pulses (almost all peas), were produced in New Zealand (FAR, 2007). New Zealand normally grows over 30,000 ha of peas annually, of which about 70% are threshed as dry peas and the rest are harvested as vined peas (White and Hill, 1999). Average pea yield in New Zealand was 2.8 t ha^{-1} in 1979-1981 (Davies *et al*., 1985) and 3.05 t ha^{-1} in 2006 (FAOSTAT, 2008) indicating a minimal increase. White and Hill (1999), claimed that New Zealand pea yields are high by world standards, with dry peas averaging 3.5-3.8 t ha^{-1}. They also reported that crop yields of up to 6 t ha^{-1} were possible.

Canterbury is the most important district for production of both threshed and vined peas (Jerymn, 1983; White, 1987) followed by Hawke's Bay (White and Hill, 1999). Although dry pea yields, in common with other grain legumes, are unstable, they are one of the few grain legumes for which the world average yield has improved over the past 25 years (Davies *et al*., 1985). In 2006 world pea production was 10,563,000 t (FAOSTAT, 2008).

Farmers grow peas as a cash crop, as a break crop for disease control such as take all of wheat (*Gaeumannomyces graminis* var *triticus* L.) (Blair, 1952; Lemerle *et al*., 2006) and to improve soil fertility in cereal rotations (Askin *et al*., 1985; White,

1991). In New Zealand peas are used in the food and the animal feed industries (Hill, 1991; White and Hill, 1999). Peas are commonly considered to increase soil nitrogen (N) levels for subsequent crops. The amount of N fixed, in Canterbury, has been estimated at 17 – 83 kg ha^{-1} (Askin *et al.,* 1985). Less N is removed in seed when peas are vined, but if pea vines or pea straw are also removed the only N returned to the soil will be from roots and abscised leaves.

The direct costs of growing peas are higher than for cereals, largely due to the cost of seed. However, pea gross margins compare favourably with barley, although they are sometimes less than for wheat (White, 1987).

Table 2.1: Area, yield and production of dry peas in different countries in 2006 (FAOSTAT, 2008).

Region/country	Area (1,000 ha)	Yield (t ha^{-1})	Production (1,000 t)
Australia	342	1.05	360
Canada	1,378	2.04	2,806
China	900	1.30	1,140
France	239	4.23	1,010
New Zealand	11	3.05	32
United Kingdom	56	3.57	200
United States.	358	1.67	599
World	6,730	1.57	10,563

2.2. Agronomic Requirements for Pea Production

Field peas require cool, moist growing conditions and can withstand heavy frost once established. Optimum growth is achieved with a diurnal temperature range of 8 – 12 ^{o}C minimum and 16 – 24 ^{o}C maximum (White and Hill, 1999). These conditions occur in eastern districts of the South Island of New Zealand where peas are grown. Growth is reduced in hot (average of > 25 ^{o}C) weather and they are not suitable as a summer crop in hot areas (Blixt, 1977). Germination occurs at temperatures as low as 3°C, although optimal germination and growth temperatures are 4.4 – 16 °C (Olivier and Annandale, 1998). White and Hill (1999) supported this and reported the base temperature for pea development was 4.4 ^{o}C. Development continues to increase at a steady rate up to a mean daily temperature of 20 ^{o}C. Depending on cultivar, it takes 700 – 1,000 ^{o}C days above a base temperature of 4.4 ^{o}C to mature a pea crop (White and Hill, 1999).

Peas require well drained (White 1987), sandy to loamy soils that warm quickly in the spring to facilitate early sowing. They are not tolerant of waterlogged soils (Sprent, 1979; Greenwood and McNamara, 1987), which reduce plant growth (Jackson, 1979). Early lodging reduces photosynthetic efficiency and consequently yield (White 1987). Crops may be 'drowned out' and fail to recover when waterlogged for more than 48 h, particularly when peas are near or at flowering (White and Hill, 1999). Water logging just before flowering is the most damaging. Waterlogging during and after flowering has less effect and is of least importance during vegetative growth (Greenwood and McNamara, 1987). What causes this is not yet clear. Nitrogen fixation is also reduced by waterlogging (Michin and Pate, 1975). Inadequate drainage starves roots of oxygen and normal root respiration cannot occur, N-fixing bacteria do not function efficiently and root rot organisms become more destructive. Wiersum (1979) attributed waterlogging effects to inadequate root oxygen supply.

Peas prefer well-limed soils with a pH of about 6.0 – 6.5 (White and Hill, 1999). Pea soils should have uniform fertility and adequate organic matter to retain soil moisture and prevent drought (Jensen, 1996). In New Zealand peas are not responsive to phosphate (P); responses being more often in increased vegetative growth rather than seed yield (White and Hill, 1999). It is suggested that if Olsen quick test P levels are much below 20 (i.e. 10 – 15) then an economic yield increase may occur (White and Hill, 1999). A soil test will also indicate whether potassium (K) is needed (quick test < 3). On the yellow-grey earth soils of Canterbury, where K reserves are high, owing to high levels of illite/hydrous mica clay minerals, K fertilisers are not required, but a response to K may occur on yellow-brown earth and pumice soils in districts such as Nelson and Hawke's Bay.

According to Davies *et al*. (1985), the relatively short pea-growing season varies from 80 – 100 d. Growing seasons of 95 to 100 d are typical in semi-arid regions of Canada and the Middle East, but in humid temperate areas such as the United Kingdom and New Zealand the growing season can extend to 150 d (Davies *et al.,* 1985). Seed maturity (from anthesis to harvest) requires 40 – 45 d in southern Australia, New Zealand, Canada and England but only 30 – 35 d in India (Davies *et al.,* 1985). However, thermal days, an expression of temperature accumulation relative to a base temperature, measured in degree days, is a more useful measure of pea growing seasons. At a base temperature of 4.4 ^{o}C, a pea crop required 100 ^{o}C d for emergence, 260 ^{o}C d to reach the 4 leaf stage, 380 ^{o}C d to the 7 leaf stage and 730 ^{o}C d to reach 14

leaf stage (Olivier and Annandale, 1998). Thermal time required from sowing to flowering ranged from 770 to 889 ^{o}C d for different pea cultivars and from sowing to maturity (tenderometer reading of 130) from 1,370 to 1,450 ^{o}C d (Olivier and Annandale, 1998).

All agronomic requirements need to be optimised for maximum yield and viable pea production. Also of significant importance in cropping systems is the effect of peas on subsequent crops.

2.3. The Effect of Peas on Subsequent Crops

There is little recorded on the effect of peas on the yield of subsequent crops. However, trials in Canterbury showed that Tama ryegrass (*Lolium multiflorum* Lam) or wheat both grown after peas (where all pea residues were removed) yielded 42% or 67% more respectively than after barley (Askin *et al*., 1985). Yields after peas and after fallow were similar, which indicated that N level was maintained by the peas rather than increased. When grown alone and incorporated or killed in the spring, field pea residues decompose rapidly and can contribute N to a following crop. Rapid spring field pea growth suppresses spring weeds and reduces the C:N ratio of spring crop residues, speeding decomposition and preventing competition from soil microbes for plant-available N (Armstrong *et al.,* 1994).

Ganeshan (1998), in an experiment to determine the effect of incorporation or removal of dry matter (DM) of a cereal or legume on the DM yield of a following crop, reported that the N content (%) of *Lolium multiflorum* L. (Italian ryegrass) varied with the preceding crop species and the amount of residue incorporated. It declined over the period of ryegrass growth. There was no significant difference in the N content of ryegrass after lentils (*Lens culinaris* Medik) or peas despite a significant yield difference. He reported that the N (%) of ryegrass was always higher after *Lupinus angustifolius* L. (narrow-leafed lupins) than after lentils or peas and the differences were usually highly significant. Following the four crops and fallow in his investigation, ryegrass after barley always had the lowest N%. Ganeshan *et al.* (1999), concluded that the growth of lentils, peas or narrow-leafed lupin in a rotation increased the DM yield of succeeding non-legumes, ryegrass and forage maize, by increasing soil fertility and improving soil chemical and physical properties.

2.5. Analysis of Yield Components

According to Wilson (1987), in agronomic research the yields of pea crops are usually analysed in terms of four yield components whose product is the seed yield per unit area (Y):

$$Y = \text{plants m}^{-2} \times \text{pods plant}^{-1} \times \text{seeds pod}^{-1} \times \text{mean seed weight.} \ldots\ldots\ldots\text{Equation 2.1}$$

Much of the potential yield of peas is based on the number of pods per plant and the number of peas per pod (White, 1987). Consequently abortion of flowers or ovules during development may represent a major loss of yield and is common in many pea crops. The reasons for these losses are not fully understood although water stress or shortage of photosynthates may be involved. The number of pods per plant and ovules per pod vary considerably between varieties and thus heritable characteristics (White, 1987). Yield components are mutually interdependent and crop management aims to maximise yield by achieving a balance where each components is maximised. For example the grower can directly control plant population by changing the sowing rate.

As the plant population is increased there is corresponding progressive decrease of the other components. The consequence is that yield increases with increasing population until an optimum is reached, and it then declines. The optimum population varies among cultivars and with growing conditions. Other yield components can be controlled though choice of cultivars because genotypes vary in their propensity to produce pods per plant and peas per pod and in their mean seed weights. Breeders aim to produce higher yielding cultivars by exploiting this variation (Wilson, 1987).

2.5.1. Plants Unit Area^{-1}

In field crops there is usually a close relationship between plant population and seed yield. Falloon and White (1978) found an asymptotic response of seed yield to plant population of field pea cv Huka and a parabolic response for cv Whero. At 25 plants m^{-2} seed yield of both cultivars was about 210 g m^{-2}. However, at an increased population of 47 plants m^{-2}, the seed yield of Huka was 410 g m^{-2} and it did not increase significantly at higher populations. This consistent yield was due to compensatory reduction in pods plant^{-1} from 8.4 to 3.7 and seeds pod^{-1} from 4.1 to 3.6 as population

increased. Seed yield of Whero at 47 plants m^{-2} was 317 g m^{-2} but it reached a maximum of 348 g m^{-2} at 89 plants m^{-2}. Seed yield was reduced with further population increases. Heath *et al.* (1991) also reported asymptotic and parabolic responses of seed yield to plant population in three cultivars of semi- leafless field peas sown at 20 to 160 plants m^{-2}.

2.5.2. Pods Plant^{-1}

Seed yield has been shown to be influenced by the number of pods plant^{-1} (Saxena *et al.,* 1983; White, 1987). The difference in the number of pods plant^{-1} generally depends on cultivar (Ayaz *et al*., 2004). However, the number of pods plant^{-1} produced or maintained to final harvest depends on a number of environmental and management practices (Knott, 1987).

Dapaah *et al*. (1999) showed an irrigation effect on yield and yield components in pinto beans (*Phaseolus vulgaris* L.) in Canterbury, New Zealand. Pods plant^{-1} increased by 21 and 41% respectively, over two growing seasons, when compared to an unirrigated crop. Pods plant^{-1} was consistently and strongly correlated with seed yield, and irrigation accounted for an increased numbers of pods plant^{-1} because it increased the number of branches plant^{-1} (Dapaah *et al*., 1999). They found that a low plant population gave a greater number of pods plant^{-1} in a November sowing in Canterbury. This inverse relationship of increased pods plant^{-1} with decreased plant population was also reported in chickpea (*Cicer arietinum* L.) (Hernandez and Hill, 1985), lentil (McKenzie, 1987) and in lentil, chickpea, pea and narrow-leafed lupin (Ayaz *et al*., 1999) in Canterbury.

2.5.3. Seeds Pod^{-1}

Pea pods normally contain 5 or 6 seeds, but there may be more, depending on cultivar and growing conditions (Knott, 1987). In dry land Canterbury soil, White *et al.* (1982) found that irrigation of peas at flowering and during pod development increased seed yield by 78% and this yield increase was due to increased pods plant^{-1}, seeds pod^{-1} and a higher mean seed weight.

2.5.4. Mean Seed Weight

Mean seed weight usually depends on management and growing conditions. Castillo *et al.* (1994) found that December sown peas in New Zealand had a lower seed weight (219 mg) than November sown plants (237 mg). However, mean pea seed weight varies from 30 mg to more than 410 mg seed^{-1} depending on cultivar, although most cultivars produce seed in the range 180-300 mg (Davies *et al*., 1985).

Apart from being used to examine the effects of different plant populations and cultivars, the yield component approach has also frequently been used to describe the effects on yield on many other treatment such as sowing time, weed control, fertiliser and irrigation. In all the results, plasticity among components has been widely reported. As one component responds directly to the treatment, another may exhibit a great capacity to compensate by either increasing or decreasing so that yield changes caused by the treatment are often relatively small (Wilson, 1987).

Despite its common use, the yield components approach has a major disadvantage in that it does not explain the yield variations apart from documenting them by describing the structure of seed yield per unit area. The result of an experiment are always specific to the site and the season in which it was conducted, and variability among sites and season is usually much greater than among the treatments in each experiments so extrapolation of experimental results to predict likely responses to the same treatments under other conditions is not possible (Wilson, 1987). This problem cannot be overcome by the traditional approach, which is to repeat experiments at several sites and or over several seasons.

There are however, alternative approaches of yield analysis, which take account of environmental effects to produce results with more general applicability. One of them is the functional crop growth analysis. The functional approach analyses yield using simple models based on physical and physiological traits (Monteith, 1977). In the functional approach, seed yield unit area^{-1} (Y) can be expressed as the integral of the crop growth rate with time multiplied by the HI (Monteith, 1977):

$$Y = \int CGR \, dt * HI$$ ……………………………………………..Equation 2.2

where HI is the harvest index, CGR is the daily rate of aboveground DM production and dt is the time duration of growth. Crop growth is related to the amount

of photosynthetically active radiation (PAR) intercepted by the crop assuming that the crop has adequate water and nutrients and is free of weeds, pests and diseases. The daily rate of above ground DM production (CGR) can be estimated using the following equation:

$$CGR = RUE \times Sa \quad \text{…………………………………………….Equation 2.3}$$

where RUE is the efficiency with which a crop uses PAR to produce DM and Sa is the amount of PAR intercepted or absorbed by the crop canopy. Therefore growth and yield variation can be interpreted in terms of change in four parameters: HI, RUE, Sa and the duration of growth.

The ultimate aim is to develop quantitative relationships between crop performance parameters and environmental factors, by using simple models with physical and physiological bases to analyse and interpret the results of experiments in order to understand the causes of yield variations, by separating crop responses to treatments from variable site and seasonal factors. The approach uses general principals, which makes it possible to predict likely crop responses in other untested circumstances and to explain the causes of yield variations, both among agronomic treatments and different sites and seasons.

Considerable progress has been made in the use of models to analyse the growth, development and yield of cereal crops (Wilson, 1987). However, few, or none of these, have quantified the competitive ability of the different crop canopies created, which are affected by crop genotype, population and sowing date and their effect on weed growth, hence affecting other yield components.

2.6. Pea Morphology

Pisum has been considered to be a monospecific genus (Blixt, 1972) but two species are now recognised taxonomically. Wild forms are designated as races or ecotypes, since all can be intercrossed and the progeny are at least partially fertile. Leaves in standard genotypes are compound pinnate. From the junction with the stem, where there are two (pseudo-) stipules, a petiole carrying one or more pairs of leaflets terminates in a simple or compound tendril. Leaf form changes during ontogeny from one to two or three pairs of leaflets. Leaf size usually increases up to the first flowering node, and then decreases (Hedley, and Ambrose, 1981). Thirty-three genes are known

to modify the size or form of pea leaves (Blixt, 1977). The most important of these are the *af* and *st* genes. The gene *af* (replacement of leaflets with tendrils (Davies *et al.,* 1985) produces the 'semi-leafless' pea which has the advantage of improved standing ability through interplant support, more uniform ripening, and reduced susceptibility to pathogen attack. The 'leafless' pea results from the combined effects of the *af* and *st* genes (reduced stipule size). This has formed the basis of new plant ideotypes and their potential is being evaluated in drier areas because of their possible lower water requirements compared with standard-leafed pea types (Hedley, and Ambrose, 1981). The background genotype influences the size of the vestigial stipules (*st*) and tendril vigour and profusion in *af* plants.

Leaflessness may cause plants to be poor competitors with an inherently low yield plant^{-1} (Davies *et al.,* 1985). Other evidence indicates that this may not necessarily be so, and may be related to the background genotype of the plant (Ali, 1980). Despite their excellent standing ability, leafless peas (*afafstst*) have not been an agronomic success (Ali, 1980). Their inherently low growth rate requires relatively high, uneconomic sowing rates. In contrast semi- leafless peas (*afafStSt*) do not require higher populations compared to conventionally leafed peas (*AfAfStSt*) to optimise their yield. The combination of improved standing ability and increased yield has resulted in the successful uptake of semi-leafless pea cultivars. However, in contrast to this, Ali (1980) reported future potential agronomic limitations of weak stems and disease susceptibility, which could restrict their use, particularly in wet seasons.

This research gives particular attention to semi-leafless peas compared to conventional peas.

2.7. Pea Yield Stability, Plant Harvest Index and the Pea Ideotype

Pea crops exhibit poor yield stability compared with other crops, particularly cereals (McKenzie, 1987; Wilson, 1987; Moot and McNeil, 1995; Timmerman-Vaughan *et al.*, 2005). Moot (1993) reported that variable harvest index (HI) is an important contributor to yield instability among grain legumes. Husain *et al.* (1988), McKenzie *et al.* (1989) and Moot (1993) reported HIs in grain legumes, which varied from 0.00 to 0.74. In high-yielding pea crops, 95% of the plants had a plant harvest index (PHI) ranging from 0.40 to 0.74. In low-yielding genotypes PHI varied between 0 and 0.70 (Ambrose and Hedley, 1984). Moot and McNeil (1995) reported variable HIs

in pea cultivars, in a single plant study, which ranged from 0.53 to 0.62. Also in New Zealand, McKenzie and Hill (1995) observed a low crop HI of 0.25 in May sown chickpea. Highest crop yields were achieved when chickpeas were sown in November. Ayaz (2001) found pea crop HI ranged from 0.49 – 0.69 over different seasons at different plant populations.

Average pea yields over a range of growing conditions are relatively low, even though they can produce high yields under favourable conditions (Moot, 1993). The measurement and use of the PHI approach as opposed to crop HI has been reported by Moot (1993) to be more useful hence his advocacy for that and a proposed pea crop ideotype based on this parameter.

Donald (1968), proposed the use of crop ideotypes as a basic approach to plant breeding. The fundamental idea was that successful crop ideotypes would be weak competitors relative to their mass. These ideotypes would therefore make a minimum demand on the resources per unit DM, and compete to a minimum degree with neighbouring plants in a crop community. Sedgley (1991), concluded that this approach, based on the definition of weak competitors, had potential for defining the characteristics of high yielding new crop cultivars in new environments. Ambrose and Hedley (1984), hypothesised that vigorous or highly competitive field pea phenotypes may have the most variation in plant harvest index (PHI) when grown in crop communities with a few dominant plants contributing the majority of the seed yield. Many small plants with low PHI values would also be present, and consequently the CHI would be low. They suggested that for a field crop to produce stable high yields, it might be best for most of individual plants in the community to be weak competitors.

Moot (1993), deduced that although these individuals may perform poorly as single plants, they may give more uniform PHI values when grown in a community. In summary, Ambrose and Hedley (1984) suggested that a preferred field pea ideotype should be: non branched or late branched (so interplant competition would suppress branch development), relatively early flowering (so assimilate was partitioned to reproductive structures when competition among plants was low), of indeterminate habit (to increase the duration of assimilate partitioning to seed and reduce competition among yield components), bear a single pod at each reproductive node, and have seeds with low assimilate demand per unit time. Thus Wilson (1987) concluded reduced yield instability, to improve average yield, is an important research objective in agronomy,

crop physiology and plant breeding. What then is the optimum population that a pea ideotype should be sown at to suppress weeds and give the best pea yield?

2.8. Population Density Versus Yield

Weed growth is suppressed by increased pea density (Martin *et al*., 1992). McKenzie *et al.* (1989) and Ball (1997) showed this concept of weed suppression by a lentil crop was relevant. McKenzie *et al.* (1989) reported that high lentil populations significantly reduced weed yield from 400 g m^{-2} at 100 plants m^{-2} to 178 g m^{-2} at 500 plants m^{-2}. The development of selective herbicides eliminated the need to grow peas in wide rows, so full advantage could be taken of the benefits of a more even plant distribution. Peas sown in 40 cm rows yielded 20% more than in 60 cm rows and peas in 20 cm rows yield 24% more than those in 40 cm rows (Gane, 1985). However, pea yield variation and instability as determined by population, continues to concern agricultural scientists. To address this problem of yield instability, pea crop breeding incorporating leafless genes into conventional peas to create improved semi-leafless peas has been successfully done in many countries e.g. New Zealand, Holland, Denmark and Sweden (Gent, 1987).

The new ideotypes produced have a modified canopy architecture and increased yield. The semi-leafless pea crop canopy is as efficient photosynthetically as that of conventional pea genotypes but they are superior in standing ability (Gent, 1987). Semi-leafless phenotypes are a major factor contributing to potentially higher and more stable pea yields. In the United Kingdom pea yields of 5 t ha^{-1} are becoming common and the average yield increased to 3,600 kg ha^{-1} during the 1980s (Heath *et al*., 1994). Over the same period average pea yields in France were 4,600 kg ha^{-1} (Heath *et al*., 1994; FAOSTAST, 2005). In the United States, plant breeders released 240 new pea cultivars between 1902 and 1977. These showed an average annual rate of genetic gain of 18.8 kg ha^{-1} (Heath *et al*., 1994). Growing semi-leafless peas using optimum populations to minimise competition amongst plants should increase crop HI (Moot, 1993). A cumulatively high PHI will give a high-yielding ideotype. This was also illustrated by Martin *et al*. (1992).

Martin *et al*. (1992) showed that at similar plant densities, all pea phenotypes converted intercepted radiation into DM with equal photosynthetic efficiency, i.e. the foliage of leafless peas was not a photosynthetic disadvantage. However, they explained

that the photosynthetic area plant^{-1}, in leafless peas, was reduced to such an extent that individual plants had an inherently lower growth rate than semi-leafless or conventionally leafed peas (Hedley and Ambrose, 1981). As a result the foliage modification of leafless, but not that of semi-leafless peas, is a physiological disadvantage relative to conventionally leafed peas. In terms of their yield density response, leafless peas respond to increased plant density (Hedley and Ambrose, 1981; Heath and Hebblethwaite, 1987). Relatively high plant densities (e.g. 100 – 150 plants m^{-2}) were required for leafless peas to give a canopy of sufficient photosynthetic area index (PAI) to maximise crop growth rate and attain reasonably high yields. At these densities seed costs, which are more than 50% of the variable costs of growing peas, become prohibitive. This is why completely leafless phenotypes are unlikely to ever be a viable option.

Comparative field studies in England (Heath *et al.,* 1991) and Scotland (Taylor *et al.,* 1991) demonstrated that the optimum plant density for semi-leafless peas was not necessarily higher than that for conventionally leafed peas. Semi-leafless peas, like leafed peas, were relatively unresponsive to plant density, i.e. they maximised yield per unit area over a wide range of densities by compensatory increases in branch and pod production.

Martin *et al.* (1992) reported that a plant density over 150 plants m^{-2} was not associated with a higher seed yield, although it did increase straw production. In their experiments, plots sown at high populations had higher evapotranspiration during early growth and low-density plots had higher evapotranspiration during late growth. This means that the open canopies exhibited better water economy than closed ones as the former saved more water, to be utilised during final crop maturity. Both genotypes gave similar seed yields. Minimum and maximum population densities of 25 and 200 plants m^{-2} seemed unfavourable for seed yield and gave 873 and 799 kg ha^{-1} . They concluded that it was not advisable to have populations of 150 plants m^{-2} in dry environments. In New Zealand, White and Hill (1999) recommended an optimum population of 70 plants m^{-2} on shallower soils, 90 plants m^{-2} on deeper soils and 100-120 plants m^{-2} for irrigated crops. McKenzie *et al.* (1999), reported optimum populations of 90 – 100 plants m^{-2} for dry peas. Most results indicate that an average of 100 plants m^{-2} is the optimum population.

2.9. Dry Matter Accumulation

Dry matter accumulation of most grain legumes begins very slowly (Ayaz, 2001). Dapaah (1997) and Thompson and Siddique (1997) reported a sigmoid growth curve with slow DM accumulation after seedling establishment. This is followed by a near exponential growth phase until the onset of pod set. Growth then slows and in some crops reaches zero. In some crops a decline in weight is observed, while other crops reach their maximum total DM near maturity (White and Izquierdo, 1991). Dry matter accumulation is often increased at high plant populations (Ayaz, 2001). However, this can be species dependent (Ayaz *et al*., 1999). In *Phaseolus vulgaris* L. (pinto beans) (Dapaah, 1997), lentils (McKenzie, 1987), *Vicia faba* L. (field beans) (Attiya, 1985) and *Lupinus angustifolius* L. (Herbert, 1977) there was a slow initial DM accumulation. McKenzie and Hill (1991) and Ayaz *et al.* (1999), in a range of grain legumes species, found that higher populations accumulated more DM as canopy closure was more rapid at high plant populations. This gave greater interception of incoming solar radiation. However, DM accumulation at higher populations usually peaked earlier and was higher than at low populations (Herbert, 1977) and increased interplant competition leading to variability in PHI so high plant populations were at a disadvantage with regard to seed yield.

2.10. The Concept of Competitive Ability and Crop Species Variation

Competition occurs in communities when two or more plants seek common resources within limited space for resources such as nutrients, light and water. This can be among individuals of the same species or (intraspecific) or among individuals of different species (interspecific). The term interference describes an induced effect by an individual plant on a neighbouring plant through changes in the environment brought about by the proximity of neighbours. This includes competition and allelopathy (production of toxins) (Harper, 1977). Different pea varieties have different competitive abilities (CA). The CA of a crop can be measured either as suppression of weed growth and seed production by the crop or as crop yield loss. Crop tolerance is the ability of the crop to tolerate weeds and maintain seed yield (Goldberg, 1990). Weed suppression may be considered the most agronomically desirable trait, since it controls weed populations into the future and therefore has long-term implications for weed management. However, this will depend on its effectiveness, and use by farmers, in

combination with other agronomic tactics (Lemerle et al., 2001). In current rotations pea farmers in New Zealand often encounter common fathen, black nightshade, Californian thistle and mayweed (White and Hill, 1999) as problem weeds.

Many studies have examined the competitiveness of various crop species. Blackshaw et al. (2007) reported that poorly competitive crops are generally short in stature with low early vigour, such as legumes like lentils. They further reported that generally, cereal crops are more competitive than grain legumes, and oilseed crops are intermediate. In the United Kingdom, cereal rye (*Secale cereale* L.) and oat (*Avena sativa* L) both had a superior CA to wheat and grain legumes (Millington *et al.,* 1990), whereas barley was more competitive than oil seed rape (*Brassica napus* L.) or field peas (Lutman *et al.*, 1994). In Denmark, Melander (1993), ranked peas and oilseed rape as being less competitive than rye, wheat or barley. In the Australian wheat belt, crop yield loss from *Lolium rigidum* (Gaud). infestation ranged from less than 10% in the most competitive species, to 100% in the weakest. The species ranking for competitiveness from strong to weak were oats, cereal rye, triticale (x *Triticosecale* L.), oilseed rape, barley, wheat, field pea, and narrow-leafed lupin (Lemerle *et al.*, 1995). Generally broad-acre crops such as the cereals particularly oats, cereal rye, and barley are more competitive than wheat or oilseed rape, and pulses are poor competitors. Considerable variation exists in the measured CA of different crops. This is partly due to crop variety, weed species, plant density, and the environmental factors examined in each study (Lemerle et al., 2001).

Harker (2001) reported that peas were generally less competitive than most weeds and had higher yield losses than barley or oilseed rape. However, early weed removal can considerably increase pea yields (Harker *et al.*, 2001). This is partly because legume seedlings require N from the growth medium within 10 d of germination to achieve early vigour (Kriegel, 1967; McWilliam *et al.,* 1970) so there is bound to be crop-weed nutrient competition if weeds are present. There is a strong correlation between the quantity of N fixed and soil N balance, i.e. the difference between fixed N and N harvested in legume seed (Evans *et al.*, 2001). Since DM production and the amount of N fixed by a legume are well correlated (Armstrong *et al.,* 1994), weed competition, by reducing crop growth, may influence symbiotic N_2 fixation in peas and thus N balance. Keatinge *et al.* (1988) reported that hand weeding increased total N uptake and the amount of N fixed in several legumes. However, the effects of genotype, herbicide and population density and their interactions on pea yield, as

influenced by crop-weed competition, for N and other available nutrients, light and space has never been documented.

2.11. Pea-Weed Competition

In general, weeds compete with crops for environmental resources available in limited supply i.e. water, nutrients and light. As a consequence of competition weeds may reduce yield significantly and impair crop quality, resulting in a financial loss to the grower or farmer (Froud-Williams, 2002). In general the earlier the emergence of the weed relative to the crop, the more competitive it is likely to be. Initial infestations of weeds usually have little effect on final yield provided that they are removed early, before competition occurs. In the same way if the crop is maintained weed-free initially, then later emerging weeds will exert little competitive pressure (Froud-Williams, 2002).

There is usually competition between peas and weeds, which emerge before and after pea seedlings. Peas, and most other grain legumes, by nature of their being poor competitors, should be sown into a clean weed free seedbed, if possible. The more weeds present at sowing the more severe competition the crop will suffer. The severity of growth reduction and survival of crop seedlings as a result of competition from other species (weeds) for light may depend on two things. The weed density, the weed species and/or how rapidly light attenuates through their canopy on the one hand, and the light requirement of the crop or how it responds to reduced light levels on the other (Cowett and Sprague, 1963).

The best time to control weeds in peas is before sowing (Harker *et al*., 2001). Crop yield can be compromised through competitive interactions with the weeds and indirectly by reducing crop yield by contamination (Bithell, 2004). With nightshade fruit the problem is the mixing of a contaminant that is similar, in shape, size and colour, to the harvested pea crop (Knott, 1986). Removal of the contaminant increases processing requirements and leads to crop loss e.g. mustard (*Sinapis arvensis* L.) capsules can be an increased contamination risk (Gane, 1972; Knott, 1986). Fields for peas should be chosen based on the absence of a major weed contamination problem. This means knowledge of the farm history is important to pea growers.

2.12. Crop lodging and harvesting difficulties

Peas, traditionally, have had poor standing ability for combine harvesting. In conventional indeterminate pea crops the canopy progressively sags during development and by plant maturity the haulm frequently lies flat on the ground. Lodging reduces the ease, efficiency and timeliness of combine harvesting (Heath and Hebblethwaite, 1985a; Beeck *et al.,* 2006). Harvesting peas is physically hard on combines. It is often necessary to operate the table of the combine close to the soil surface, which increases the risk of damage from picking up stones and soil clods. The need to operate the combine reel close to the cutter bar when harvesting lodged peas increases the likelihood of harvest losses from pod shatter at the front of the combine. Inability to pick up lodged stems and pods further contributes to harvest losses. Lodging is the result of weakness in the basal regions of the stem in relation to the weight of the upper parts of the plant and is exacerbated by wind and canopy weight (Beeck *et al.,* 2006).

Harvesting can be time consuming, particularly when it is necessary to harvest a severely lodged crop in one direction only, or at a reduced speed. Lodging is even more serious if it is wet at harvest (Heath and Hebblethwaite, 1985a; Beeck *et al.,* 2006). A lodged crop dries slowly and peas are stained when pods come in contact with moist soil, reducing their quality for human consumption. Lodging also promotes disease infestations (e.g. *Botrytis, Ascochyta* spp.), particularly under moist conditions. Genetic improvement in lodging resistance of field peas has become a major goal of most pea breeding programs (White, 2003). Much of the pea breeding done in New Zealand has been to reduce harvesting problems. At present there are a range of determinate conventional and semi-leafless cultivars available that are more resistant to lodging than older pea varieties (White, 1987).

2.13. Leaf Area Index

The importance of leaf growth, or leaf area, is closely related to solar radiation interception influencing PAI and final yield. From many studies radiation interception in legume crops depends on leaf orientation, the PAI and incident radiation. In chickpea, leaves are the most important photosynthetic organ (McKenzie and Hill, 1995). In field peas it is leaves, stipules and tendrils. For high yields, crops should quickly produce enough LAI to intercept most of the incident light (Ayaz, 2001) after

which they should maintain high levels of interception and partition as much assimilate as possible to reproductive organs (Gardner *et al*., 1985).

2.14. Radiation Interception and Utilisation

Leaf area index and LAD are the most important plant characteristics determining radiation interception (Monteith, 1977; Gallagher and Biscoe, 1978). Leaf area index directly influences the proportion of radiation intercepted. The amount of solar radiation entering the plant's environment establishes, in the absence of other climatic constraints, the upper production limit (Monteith, 1977; Sinclair and Muchow, 1999). Radiation is usually measured as a flux of energy per unit horizontal surface expressed as $MJ\ m^{-2}\ d^{-1}$ (Monteith, 1972). Total solar radiation consists of two wavebands; the visible spectrum $0.4 - 0.7\ \mu m$ and the infrared ($0.7 - 3.0\ \mu m$). About half of total solar radiation is photosynthetically active (Sinclair and Muchow, 1999). This is where most light absorption (in the blue and red regions of the spectrum) by the chlorophyll pigments occurs for photosynthesis.

Dry matter production and crop yield can be defined in terms of the amount of total solar radiation intercepted by the crop canopy and its utilisation for DM production (Monteith, 1977). The amount of DM accumulated by a crop is strongly related to the total intercepted solar radiation, by the crop, over the growing season (Monteith, 1977; Sinclair and Muchow, 1999). The relationship is linear and the slope of the line is the efficiency of conversion of solar radiation to DM (RUE).

2.15. Leaf Area Duration and Sowing Time

Leaf area duration (LAD) expresses the magnitude and persistence of LAI over the period of crop growth (Gardner *et al.,* 1985). It is the integral of LAI over time (McKenzie, 1987). There are reports in the literature of high yields being related to a long LAD (Zain, 1984). Thompson and Siddique (1997) reported that maximum biomass yield of grain legumes was closely related to LAD. Legumes such as *Vicia faba*, V. *narbonesis* L., and *Pisum sativum* quickly developed LAI and during the growing season had the highest LADs from emergence to maximum biomass (Ayaz, 2001). However, some workers found only a weak relationship between yield and LAD, especially in crops where the LAI produced was far higher than the critical LAI (Herbert and Hill, 1978; McKenzie, 1987). This is because a LAI greater than the

critical LAI will increase LAD while it will have no effect on yield because there will be no increase in radiation interception.

Pea yields depend on crop duration (Wilson, 1987). This, in turn, depends on the rate of crop development, which can differ considerably among cultivars. Knowledge of the crop development rate is important when selecting a cultivar most suited to the environment. There are two distinct important aspects of crop development, phenological and canopy development. The former refers to the rate of progress through growth stages and depends on temperature and photoperiod. Canopy development, which determines the rate of canopy formation, its duration and its senescence, depends mainly on temperature (Wilson, 1987). However, it is sensitive to environmental stresses and crop management.

Technically, LAD is mainly related to temperature, which in turn is influenced by time of sowing. Most field peas are spring sown in New Zealand i.e. between August (on lighter soils) and October, but some crops on lighter soils are autumn sown in May or June. Jamieson *et al.* (1984) reported that changing the sowing date significantly affected both total DM production and seed yield in peas. Sowing on 30 September, in Canterbury gave the highest yield. Growth duration from emergence to complete senescence was 99 d, RUE was 2.6 g DM MJ^{-1} PAR and CHI was 0.58. These were intermediate values for the sowing date treatments. However, the total amount of radiation intercepted was highest in this treatment because the crop was actively growing for longer in January when incoming radiation was greatest. Lowest yield was from a 27 October sowing, which had a 94 d duration, a PAR conversion efficiency of 2.3 g MJ^{-1} and a CHI of 0.54. These factors outweighed the advantage of the high incident radiation in January. A 2 September sowing did not give the highest yield, even though it had a 103 d duration, a PAR conversion efficiency of 3.1 g MJ^{-1} and a CHI of 0.64. Most of its growth was early in the season when radiation was lower and it had senesced before the period of highest radiation in January.

2.16. Pea Weeds

Fathen, black nightshade, Californian thistle, mayweed (White and Hill, 1999), velvetleaf (*Abutilon theophrasti* L.), redroot pigweed (*Amaranthus retroflexu*s L.), and common ragweed (*Ambrosia artemisiifolia* L.) are annual broadleaf weeds that are commonly found in pea fields in New Zealand (Hance and Holly, 1990). All of these

weeds are competitive with peas because they grow taller than the peas, and compete for light, nutrients and water. Fathen and redroot pigweed are highly prolific and produce tens of thousands of seeds plant[-1]. Velvetleaf and common ragweed are not as prolific, but still produce many thousands of seed plant[-1]. Annual grass weeds are also competitive with peas, especially at high densities. Of the grasses, foxtails (*Setaria* spp.), wild oat (*Avena fatua.* L.) and *Lolium multiflorum*, are commonly found in New Zealand pea crops (Hance and Holly, 1990). Annual grasses can be controlled by several soil-applied or post-emergence herbicides. However, foxtails are prolific seed producers and seed persists for many years in the soil seed bank. Annual grass weeds will be present in each year's pea crops (Hance and Holly, 1990). Integrated weed management is important particularly to organic pea growers.

Weeds which cause contamination problems are surrey, thistles and nightshades (*Solunum* spp). The most problematic hence most important under pea production systems is nightshade.

2.16.1. Nightshades

Black and hairy nightshade (*Solanum physalifolium* L.) are common annual broadleaf weeds that cause special problems in peas at harvest. Nightshades are not as competitive as other broadleaf weeds because of their short stature (Isaac, 2001). Black nightshade is common in most Canterbury fields. Nightshades have sympoidal growth (dicototymous branching), where the lateral meristems overtake the apical meristem (Bassett and Munro, 1985). A thermal time study of *S. nigrum* and *S. ptycantum* growth (spaced at 0.3 x 0.9 m) reported that both species exhibited their most rapid growth after 900 ^{o}Cd. (base temperature 6°C) (McGiffen and Masiunas, 1992).

Solanum nigrum is a spring and summer annual weed with a worldwide distribution (Edmonds and Chiweya, 1997). Its growth form varies from spreading to erect (Bithell, 2004). It has a fibrous root system with slender, herbaceous stems. Leaf and stem shape are highly variable and are strongly affected by environment and genotype (Ogg *et al*., 1981). Seed maturity of *S. nigrum* was recorded as requiring approximately 1000 ^{o}Cd (base temperature 6°C) (McGiffen and Masiunas, 1992). Mean seed number fruit[-1] in New Zealand was reported to be 70 in *S. nigrum* plants grown in a *Phaseolus vulgaris* L. crop (Hartely, 1991). *Solanum nigrum* produces fewer fruit in

response to increased shade. At 50% shade fruit production was half of that under full sun (Fortuin and Omta, 1980).

Studies of *S. ptycanthum* gave similar results with the reduction in fruit number being identified as the result of fewer peduncles produced rather than a reduction in the number of fruit peduncle^{-1} (Croster *et al*., 2003). Early sowing of peas (spring or autumn sowing) can give almost complete control of nightshades because they are late weeds with a high base temperature (6°C) for both germination and growth (Bithell, 2004).

2.17. Chemical Weed Control

For most arable crops there is a range of selective herbicides that can be used for weed control (McKenzie *et al.,* 1999). Selective pre-emergence herbicides are applied between crop sowing and crop emergence. The herbicide remains active in the soil for some time killing weeds as they establish yet leaving crop seedlings unharmed. Selective post-emergence herbicides can also be applied to the crop and weeds, once they have established.

Pre-emergence herbicides are applied after planting the crop but before the crop and weeds emerge or before either the weed only or the crop only emerges (Begeman, 1996). They lay down a chemical barrier over the soil, which either prevents weed seeds from germinating, or kills them shortly after they do. Ross and Lembi (1985) reported that there is greater crop safety with pre-emergence herbicides due to spatial separation of the herbicide treated soil layer and the crop seed. Furthermore, there is a longer residual control as pre-emergence applied herbicides are not as subject to leaching below the weed seed germination depth as incorporated herbicides. The pre-emergence herbicide therefore gives the crop a good start, by eliminating early weed competition.

The most severe limitation for pre-emergence herbicide treatments is the requirement for rainfall or irrigation water to move the herbicide into the soil to achieve effective weed control. High rainfall however can move a concentrated band of herbicide from the soil surface to the root zone and result in crop injury (Begeman, 1996).

2.17.1. Cyanazine (Bladex 50 SC)

Cyanazine is one of the most common herbicides used on grain legumes in New Zealand. It is used for the selective control of broadleaf weeds in peas, maize, sweet corn, lentils and lucerne (*Medicago sativa* L.) (Young, 2008). Bladex 50 SC contains 500 g l^{-1} cyanazine in the form of a suspension concentrate. It is primarily absorbed by roots, but there is some scorching of foliage in susceptible weeds. Following uptake it inhibits photosynthesis resulting in plant yellowing and death. In peas 3 l in 300 l of water ha^{-1} should be applied at emergence. Best results are obtained when it is applied to moist soils.

2.17.2. Other Herbicides

Basagran is a selective post-emergence herbicide for use in peas, onions *(Allium cepa* L.), cereals, clover, new pastures, lucerne and dwarf beans. It is a nitrogen compound and it contains 480 g l^{-1} bentazone in the form of a soluble concentrate as the active ingredient. It controls chamomiles (*Matricaria matricarioides* L.), stinking mayweed (*Anthemis cotula* L.) and cleavers (*Gallium aparine* L.). Other broadleaf weeds controlled include black nightshade, chickweed (*Cerastium fontanum* L.), red dead nettle (*Lamium purpureum* L.), fumitory (*Fumaria officinalis* L.), redroot (*Amaranthus powellie* L.), shepherd's purse (*Capsella bursa-pastoris* L), spurrey (*Spergula arvensis* L.), thorn apple (*Datura stamonium* L.) and wild turnip (*Brassica rapa* ssp. Nigra). Basagran is not active in soil, so does not control weeds, which germinate after spraying. It is also highly temperature dependent.

Centurion 240 EC, is a selective post emergence herbicide for annual and perennial grass control in broadleaf crops. The active ingredient is 240 g l^{-1} clethodium as an emulsifiable concentrate. It is not compatible with other herbicides. Beacon is a selective post-emergence water-soluble herbicide and suppresses couch (*Elytrigia repens* L.) and Californian thistle. It contains 750 g kg^{-1} of primisulfuron as water dispersible granules, as the active ingredient (Young, 2008).

Other herbicides recommended for use with peas in New Zealand are Fusilade, Gallant and Gesagard 50 WP and 500 FW (Young, 2008).

Cyanazine was used in this research because it is the herbicide commonly used with legumes by New Zealand farmers.

2.18. Non-Chemical Weed Control

The limited availability of suitable post-emergent herbicides for peas and the lack of competition from the crop (Preston, 2002) means that weed management is an important agronomic issue in pea crops (Materne *et al*., 2002). Non-chemical weed control is being preferred as farmers seek more sustainable and environmentally friendly farming methods. Successful long term weed management requires a shift away from simply controlling problem weeds to systems that reduce weed establishment and minimise weed competition with crops (Blackshaw *et al*., 2007). According to them general non-chemical weed management practices that are useful in crops are; crop rotation, manipulating crop competition, crop species and cultivar selection, the use of appropriate planting patterns, row spacing and crop density, transplanting, delayed seeding, flooding, crop fertilization, green manure and cover crops, intercropping, timing of weed control and the integration of some of the above. Using a false seedbed should also be considered.

Although not practical for large-scale farming, hand weeding such as hoeing may also be considered where labour is not limiting. It does not require costly and sophisticated machinery and chemicals (Burrill and Shrenk, 1986). Although hoeing is laborious and time consuming, it is very effective in controlling weeds in the rows where fertilizer is usually placed. According to Chivinge (1984) old methods like hand hoeing and inter-row cultivation will never be completely replaced as it is becoming clear that some mechanical cultivation is still necessary particularly with herbicide resistant weeds. Hoeing increases soil aeration breaks up surface crusts and also increases rainfall penetration (Pleasant *et al*., 1994).

Klingman and Ashton (1982) reported that hoeing and cultivation are only effective when the soil is dry to promote desiccation of weeds. Cultivation or hoeing while soil is too wet simply transplants the reproductive organs of perennial weeds. Hoeing and cultivation have also been criticized for increasing the activity of bacteria in the soil, which results in rapid destruction of organic matter and corresponding loss of exchange capacity in the worked layer of the soil (Anderson, 1983). Furthermore cultivation creates favourable conditions for germination of weeds near the soil surface. It is safe to say manual weed control is not viable in large scale production sysyems.

Crop rotation can be another effective technique for weed control but the rotations should be done carefully to be effective. Weed problems can increase if

inappropriate rotations are used (McKenzie *et al.*, 1999). Including cereals like winter wheat in the rotation can help reduce weed density during the year peas are grown. When pea populations are low (< 50 plants m^{-2}, for most varieties), they are more susceptible to weed competition. Early sowing can aid weed suppression by having the peas, a cool season crop, emerge prior to some of the weeds. This improves the pea's competitive ability against the weeds. In many high-value horticultural crops and for organic production, mechanical inter-row cultivation is common (McKenzie *et al.*, 1999).

2.19. Positive effects of weeds

Weeds are not always as bad as assumed (French, 1989; Zimdahl, 2007). There are some general positive effects of weeds humans can make use of. Deep-rooted weeds can bring up leached elements from deep in the soil where shallower-rooted plants can't reach. As these weed leaves break down, those nutrients are returned to the topsoil where shallow-rooted plants can use them. Weeds also stabilise disturbed soils, prevent loss from rain and water from ploughed areas and stop moisture loss with increased leaf cover. Some weeds do fix N into the soil.

Another important use of weeds is that some weed species can indicate soil conditions. For example Red sorrel (*Rumex acetosella* L.) indicates that the soil pH is low; bracken (*Preridium esculentum* L.) means the soil is N deficient and thistles mean high N levels (French, 1989). Weeds also help to control crop pests. Background weed populations can have a dramatic effect on the number and range of predators available year round to attack insect pests. The weeds provide a haven for pests and their predators so that when pest numbers build up on a planted crop, predator number can rise to match them (French, 1989). On the other hand weeds are a source of mulch and a source of slow-acting organic fertilisers.

2.20. Organic Pea Production

The total area under organic peas in New Zealand is approximately 300 ha. Sixty six percent of the area is run by Heinz Watties (Anthony White, 25 May 2006, Personal communication). Domestic and global demand for certified organic products has been increasing rapidly over the last two decades (BioGro, 2007). BioGro currently trademarks over $NZ 100 million worth of organic products each year, of which > $NZ

80 million is exported. The global market sale of organic products is currently about $US 30 billion, which is almost 3% of the total world food and beverage market. Exports of organic products from New Zealand have grown rapidly in the past but growth has slowed in the last 3 years due to strong growth in the domestic market (Table 2.2).

Although the popularity of non-chemical farming practices is increasing substantially, organic pea production has its share of constraints. Mitchell (1987) described these constraints mostly as being market-related. The potential for organic producers to capitalise on overseas markets is mainly hampered by production shortfalls.

Table 2.2: Value of New Zealand exports of organic produce (BioGro, 2007).

Year	Export sales ($NZ x 10^6) (approximate)
1997	12
1998	23
1999	35
2000	60
2001	65
2002	70
2003	75
2004	75

2.21. Summary

Several problems, which hinder successful pea production, are linked to weed management. Early research tended to ignore cultural weed management options labelling them uneconomic or impractical (Upadhyaya and Blackshaw, 2007). The lack of research on non-chemical options for weed management has made weeds a serious problem in organic farming. Currently, there is interest in sustainable effective weed control methods. It has been argued that integrated weed management, which includes herbicide use, is the answer. However, increased awareness of environmental problems associated with chemical use is making farmers revert to old non-chemical husbandry practices and many are making a complete change to pure organics. Sustainable weed management is an integral part of the equation, in both conventional and organic production systems. This is the focus of this research. It examines the physiology of weed-crop competition as it relates to crop canopy radiation interception and weed

suppression. It aims to give pea producers (both conventional and organic) a package to effectively control weeds based on crop physiology and weed interactions.

2.22. Conclusions

- Field peas are the major grain legume grown in New Zealand.

- Pea production area is still low in New Zealand (20 000 ha) despite the great potential of the pea industry and lucrative markets.

- Organic production is rapidly gaining popularity worldwide.

- A pea crop is expensive to establish compared to cereals.

- Pea yields are unstable.

- All agronomic requirements need to be optimised for maximum yield for viable pea production.

- Weed competition can seriously affects pea yield and impede crop harvest.

- Semi-leafless peas do not require higher plant populations compared to conventional leafed peas to optimise yield.

- Crop genotype can influence pea yield and weed suppression.

- Pea population can influence weed growth and crop yield.

- There is a knowledge gap concerning the competitive ability of different pea canopies.

Chapter 3

3.0. Materials and Methods

The main aim of this research was to quantify the competitive ability of different pea canopy architectures in relation to pea genotype, pea population and sowing date, grown with and without herbicide, on weed growth and crop yield and potentially to provide advice on weed control to organic pea growers.

With regards to these objectives, three field experiments were designed:

- In 2006 a field trial was conducted to determine the effect of herbicide, population and genotype on pea yield and weed growth.

- In 2007 a second field trial examined the effect of sowing date, herbicide and genotype on pea yield and weed growth.

- A further field experiment in 2007 investigated the eco-physiology of pea-weed interactions.

All the trials were conducted on a Templeton silt loam soil (New Zealand Soil Bureau, 1968) at the Horticulture Research Area, Lincoln University, Canterbury, New Zealand (43 ^{o} 38'S, 172 ^{o} 28' E.). Experiment 1 was conducted in the 2006/07 growing season in paddock H14. Moata rye grass (*Lolium multiflorum* L.) was grown in the paddock in 2005/2006 and common beans (*Phaseolus vulgaris* L.) in 2004/2005. Experiments 2 and 3 were grown in paddock H3 in 2007/08. A perennial rye grass (*Lolium perenne* L.) / white clover (*Trifolium repens* L.) pasture had previously been grown in the paddock. MAF soil quick tests were done in both paddocks to establish actual soil available nutrient levels (Table 3.1).

Table 3.1: MAF soil quick test for paddocks H14 and H3, Horticulture Research Area, Lincoln University.

Experiment	pH	Olsen-soluble P (μg ml^{-1})	Ca	Mg	K	Na	Sulphate (μg g^{-1})
1	6	23	8	21	9	9	3
2 and 3	6	15	7	21	10	6	4

Ca, Mg, K, and Na as mg/g of soil

3.1. Experimental Design and Methods

3.1.1. Experiment 1

The treatments were arranged in a split plot design with three replicates. Main plots were two herbicide treatments (cyanazine at 0 or 500 g a.i. ha^{-1}). Subplots were a factorial combination of three pea genotypes; conventional (Pro 7035), semi-leafless branched (Aragorn) and semi-leafless unbranched (Midichi) and three plant populations; 0.5 x recommended sowing rate (50 plants m^{-2}), recommended sowing rate (100 plants m^{-2}) and 4.0 x recommended sowing rate (400 plants m^{-2}). Controls consisted of plots without peas, but sprayed or unsprayed with cyanazine, giving a total of 60 plots. Each plot was 2.1 m wide x 8 m long.

3.1.2. Experiment 2

In experiment 2 treatments were also arranged in a split plot design with three replicates. Main plots were sowing dates of 9 August, 13 September and 15 October 2007. Sub-plots were a factorial combination of two pea genotypes, conventional (Pro 7035) and semi-leafless (Midichi) and two herbicide treatments (cyanazine at 0 and 500 g a.i. ha^{-1}). The total number of plots was 54 (36 plots with peas and 18 no pea control plots). Each plot was 2.1 m wide x 10 m long.

3.1.3. Experiment 3

In Experiment 3 treatments were a factorial combination of four pea populations 0, 0.5 x recommended sowing rate (50 plants m^{-2}), recommended sowing rate (100 plants m^{-2}), 2.0 x recommended (200 plants m^{-2}), and three sown artificial weed populations 0, 1/3 recommended (referred to here as normal) and 2/3 recommended (2x normal) seed rates of each weed. 400 plants m^{-2} was dropped in preference of 200 plants m^{-2} because was the later was found to be more practical to farmers. The sown artificial weeds were a mixture of *Brassica napus*, *Lolium multiflorum* and *Vicia sativa* which had recommended sowing rates of 3, 25 and 30 kg ha^{-1} respectively. This translated into 80, 667 and 60 plants m^{-2} respectively. This was a good representation of a broad spectrum of weeds commonly found in most fields. The experiment design was a randomised complete block with three replicates. The total number of plots was 36.

Each plot was 2.1 m x 6 m long. The field pea variety used was Midichi (a semi-leafless type).

3.2. Husbandry

3.2.1. Experiment 1

Land was prepared using conventional methods i.e. disking, rolling and harrowing. It was tilled to a depth 25 cm. A pre-emergence spray of cyanazine at 500 g a.i.ha^{-1} was applied in 237 l water ha^{-1} to 30 of the 60 plots to create the main plots. Wakil, a formulated mixture of Metalaxyl, Fludioxonil and Cymoxanil for the control of *Peronospora* spp (downy mildew), *Pythium* spp and *Ascochyta* spp, was applied to all seed at the equivalent of 2 kg t^{-1} of seed before sowing. Seed was drilled with an Öyjord cone seeder at a depth of 5 cm. Seed was sown on 12 September, 2006 in 15 cm rows with varying interrow spacing to achieve the required pea populations of 50, 100 and 400 peas m^{-2}. Sowing rates were corrected for germination percentage and expected field emergence.

Irrigation was applied to the trial based on crop requirement as determined by Time Domain Reflectometry (TDR) in the 0 – 20 cm soil layer, when the soil reached 50% of field capacity. This happened once on 20 December 2006. A mini boom irrigator applied 50 mm of water. The peas were sprayed with Alto (cyproconazole) 100 SL at 250 ml ha^{-1} to combat powdery mildew (*Erysiphe* spp) on 15 December 2006 and with copper oxychloride at 1 kg ha^{-1} for downy mildew on 18 December.

3.2.2. Experiments 2 and 3

Land was again prepared by conventional methods i.e. disking, rolling and harrowing. It was tilled to a depth 25 cm and sulphur super 30 (N_0 P_7 K_0 S_{30}) fertilizer was applied at 300 kg ha^{-1} on 2 August 2008. Wakil, fungicide was applied to seed as in 3.2.1 before sowing. An Öyjord cone seeder was again used to drill seed at a depth of 5 cm. Seed was sown in 15 cm rows and was sown at 100 plants m^{-2} (Sowing rate was corrected for germination percentage and expected field emergence for each pea variety). Sowing rate was 525 kg ha^{-1} for Midichi thousand seed weight (TSW) 447 g, expected field emergence 85% and 265 kg ha^{-1} ha for Pro 7035 TSW 232 g, expected field emergence 88%. Cyanazine was applied pre-emergence to target plots at 500 g a.i. ha^{-1} with a knapsack sprayer.

In Experiment 3 seed was sown in 15 cm rows with varying interrow spacing to achieve pea populations of 50, 100 and 200 plants m^{-2}. The sown weed seed was then broadcasted onto plots and a lightly harrowed to incorporate them into the soil.

In Experiments 2 and 3, irrigation was applied based on crop requirement determined by Time Domain Reflectometry (TDR) in the 0-20 cm soil layer, when soil reached 50% of field capacity. This occured on 2, 13 and 29, November 2007. A mini boom irrigator applied 30 mm of water at each irrigation, a total of 90 mm during the season. In experiment 2 the TDR probes were placed at the centre of the first sowing date. The peas were sprayed with Alto 100 SL at 250 ml ha^{-1} to combat powdery mildew on 23 November 2006 and with copper oxychloride 1kg ha^{-1} for downy mildew on the same date.

3.3. Radiation Measurements

3.3.1. Radiation interception

The amount of photosynthetically active radiation (PAR) intercepted was calculated from Szeicz (1974):

$$Sa = Fi \times Si \times 0.5 \dots\dots\dots\dots\dots\dots..\text{Equation 3.1}$$

Where the Sa is the PAR and Si is the total incident solar radiation, which was recorded at Broadfields Meteorological station from crop emergence to crop physiological maturity.

The proportion of radiation intercepted (Fi) by the canopy was calculated according to Gallagher and Biscoe (1978):

$$Fi = 1.0 - T_i \dots\dots\dots\dots\dots\dots\dots\dots.\text{Equation 3.2}$$

Where T_i is the amount of radiation transmitted through the canopy.

Radiation use efficiency (RUE) was obtained from the slope of regressions of crop DM on intercepted PAR from seedling emergence to crop maturity. Irradiance intercepted by each species was calculated from the mixed sward irradiance intercepted model originally derived by Ross *et al*. (1972) and refined by Thornley and Johnson (1990) (Appendix 1).

In Experiments 2 and 3 functional growth analysis was done using the maximum likelihood program (MLP) from Rothamsted Experimental Station, United Kingdom (Ross *et al*., 1987). Generalised logistic curves were fitted to the majority of the growth analysis data using the method of Gallagher and Robson (1984).

$$Y = C / (1 + T \exp(-b(x-m)))^{1/T} \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.4}$$

where Y is yield, C is the final above ground DM and T, b and m are constants.

The values of C, T, b and m were used to derive the weighted mean absolute growth rate (WMAGR - the mean growth rate over the period when the crop accumulated most of its DM), duration of exponential growth (DUR - duration of crop growth over which most growth occurred) and the maximum crop growth rate (C_m) using the following equations:

$$WMAGR = bC / 2(T + 2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Equation 3.5}$$

$$C_m = bC / (T+1)^{(T + 1/T)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.6}$$

$$DUR = 2(T + 2) / b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... \text{Equation 3.7}$$

The remaining data were fitted to a Gompetz function (Equation 3.8) (Causton and Venus, 1981).

$$Y = C \exp(-\exp(-b(x-m))) \ldots\ldots\ldots\ldots\ldots\ldots..\text{Equation 3.8}$$

where Y is the yield, C is the final DM and b and m are constants.

The WMAGR, DUR and Cm for TDM were derived from the below equations: (Pagelow Jr. *et al*., 1977).

$$WMAGR = bC/4 \ldots\ldots\ldots\ldots\ldots\ldots............\text{Equation 3.9}$$

$$DUR = 4/b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 3.10}$$

$$Cm = bC/e \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... \text{Equation 3.11}$$

where e is the natural logarithm base and equals approximately 2.71828.

3.3.2. Yield measurements

Final dry total DM and seed yield were estimated from 1 m^2 samples. A 1 m^2 quadrat was used. Plants were cut at ground level and weighed. They were hand threshed and the seeds weighed. Five plants were selected from the bulk sample and were used to calculate yield components.

3.3. Analysis

3.3.1. Experiments 1, 2 and 3

All data were subjected to analysis of variance (ANOVA). Genstat 10.1. Copyright 2007, Lawes Agricultural Trust (Rothamsted Experimental Station) was used for statistical analysis. Means were separated at the 5% level of significance using least significance difference (LSD) for herbicide main effects, population, type and interactions effect in Experiment 1, for sowing date main effects, herbicide, genotype and interactions effect in Experiment 2 and for pea population, weed population main effects and interaction effects in Experiment 3.

Chapter 4

4.0. The Effect of Herbicide, Population and Genotype on Pea Yield and Weed Growth

4.1. Introduction

The desire to use environmentally friendly farming, coupled with increased demand for organic produce is leading farmers, worldwide, to explore alternatives to chemical weed control. In conventional pea crops weeds are routinely controlled by herbicides but there is growing environmental concern of ecological problems and contamination of ground and surface water (Isaac, 2001). Two, of several natural methods of weed control in pea production are manipulation of plant population and plant genotype. Varying plant densities and genotypes may result in the creation of canopies with different competitive abilities to suppress weeds. The use of a higher than normal seeding rate of 90 seed m^{-2} for conventional growing may be necessary to give a higher competitive ability in organic pea production (Grevsen, 2003). Crop genotype has an important role to play in a weed control strategy (Isaac 2001; Blackshaw *et al*., 2007). Putnam (1986) reported that the intensity of weed suppression depended principally on the morphology and rate of crop growth.

The major objective of this experiment was to create distinctively different pea canopies with different abilities to suppress weeds and to find out how and why this affected final crop yield. The experiment used a range of populations and different pea genotypes to create a range of distinct canopies. A herbicide treatment was used to give comparisons of the canopies under weedy and weed free conditions.

4.2. Specific Objectives

The specific objectives of this experiment were to:

- Quantify the competitive ability of different pea genotypes and different pea populations in relation to canopy architecture.
- Determine the effect of pea genotype, pea population and herbicide, and their interactions, on weed growth and crop yield.

4.3 Materials and Methods

Only a brief description of the measurements taken is given here as other details are in Chapter 3 (Materials and Methods).

4.3.1. Crop Measurements

Leaf area index (LAI) was measured non-destructively using a LICOR LAI 2000 Plant Canopy Analyser at 3-week intervals throughout the growing season. Two readings were randomly taken above and eight below the crop canopy from each plot. This was done on either a cloudy day or at dusk. A 0.25 m^2 sample was taken from each plot using a 0.25 m^2 quadrat at three-week intervals starting at 42 DAE. The samples were used for measurement of pea and weed DM. Samples were oven dried for 24 – 48 h to constant weight. Yield and yield components were measured at harvest. Final harvests were taken when pea crops reached a moisture content of 15 – 18%.

4.3.2. Weed Measurements

Weed DM was sampled using a 0.25 m^2 quadrat. Samples were cut at ground level at three-week intervals. This started at 21 DAE. Samples were put in a forced draught oven for drying for 24 – 48 h at 60^oC and weighed. Measurements of weed total DM accumulation were taken at 21, 42, 63, 84,105 and 126 DAE. At 21 DAE, weeds were sorted by taxa (species or genus, depending on similarity) and counted. Uncommon taxa were pooled and their total count recorded.

4.4. Results

4.4.1. Climate

Climate data was obtained from Broadfields Meteorological Station, Lincoln University located about 1.5 km from the experimental site. There was only 3 mm of rain in September, which was 7.5% of the long-term average (40.1 mm) (Figure 4.1). There was also very little rain in January and February; both months with just over 30% of long term averages. However, there was substantial rain in December (110.6 mm) and October (97.6 mm), when almost double the long-term average fell (Figure 4.1). Rain in November (68.6 mm) was similar to the long-term average (54.9).

The weather, throughout the growing season, tended to be cooler than long-term averages except in September (Figure 4.1). This coupled with good rains late in the

season tended to extend the growing season taking the pea crop longer than normal to mature. Solar radiation receipts were slightly higher than long term averages in the first half of the growing season i.e. September, October November and slightly lower in the second half of the season i.e. December, January and February (Table 4.1). Vapour pressure deficits were all lower than the long-term averages during the growing season except in September.
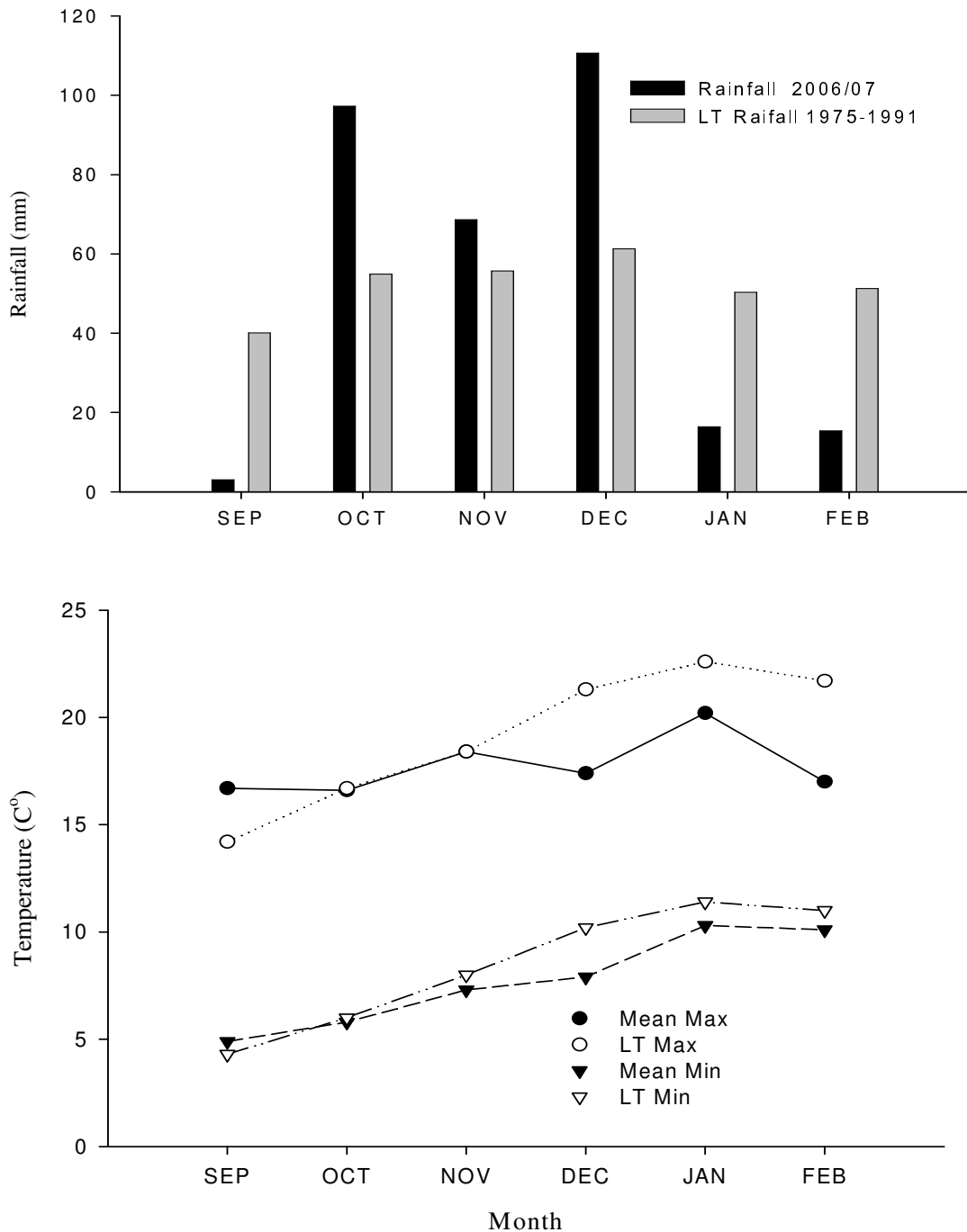
Figure 4.1: Rainfall and temperature data for Canterbury in the 2006/07 growing season and long-term mean (1975 – 1991).

Table 4.1: Weather data for the 2006/07 growing season and long-term averages for Lincoln University, Canterbury.

Month	Solar Radiation (MJm^{-2} month^{-1})	VPD (Pa)	Penman ETp (mm)
September	375.1 (339.0)	9.2 (9.1)	87.5 (68.6)
October	542.9 (508.4)	9.4 (10.1)	120.8 (104.6)
November	633.3 (603.0)	10.8 (11.8)	127.7 (123.9)
December	648.8 (672.7)	11.3 (13.1)	126.1 (142.7)
January 07	585.5 (669.6)	13.7 (13.7)	115.2 (153.0)
February 07	511.1 (515.2)	14.1 (13.7)	102.8 (117.6)

Long-term means (in brackets) are for the period 1975-1991
VPD = Vapour pressure deficit ETp = Evapotranspiration

4.4.2. Total Dry Matter Accumulation over Time

Midichi had the highest mean total DM at 42 DAE (525 g m^{-2}), followed by Aragorn (385 g m^{-2}) and Pro 7035 (333 g m^{-2}) the least (Fig 4.2). Total DM increased significantly ($p < 0.01$) from 240 g m^{-2} at 50 to 663 g m^{-2} at 400 plants m^{-2} at 42 DAE (Fig 4.3). There were similar differences throughout the season until 105 DAE. From then until final harvest, no factor influenced TDM production.

However, by final harvest (126 DAE), there was a significant ($p < 0.05$) herbicide by population interaction (Figure 4.4). There was no significant difference in total DM production in sprayed and unsprayed plots at 100 and 400 plants m^{-2}. However, at 50 plants m^{-2} sprayed peas produced 30% more DM (1,517 g m^{-2}) than unsprayed peas (1,162 g m^{-2}).

4.4.3. Seed Yield

Herbicide had no effect on seed yield and the overall mean was 673 g m^{-2}, (Table 4.2). There was also no significant mean seed yield difference among the pea genotypes, Aragorn, Pro 7035 and Midichi. In response to population the lowest average mean seed yield, 606 g m^{-2}, was from 400 plants m^{-2} and the highest, 733 g m^{-2} at 50 plants m^{-2}, a 21% increase.

There was a significant ($p < 0.05$) herbicide by population interaction on mean seed yield (Figure 4.5). Herbicide had no effect on seed yield at 100 and 400 plants m^{-2}. However, at 50 plants m^{-2} cynanazine treated plots produced 829 g m^{-2} of seed, which was 30% more than the 637 g m^{-2}, produced without herbicide treatment.

4.4.4. Crop Harvest Index

Herbicide had no effect on mean crop harvest index. Aragorn had the lowest mean HI (0.48) followed by Midichi (0.52) and Pro 7035 at 0.55. There was a significant increase of 17% from the lowest HI at 400 plants m^{-2} to the highest at 50 plants m^{-2} (Table 4.2).

Figure 4.2: Total dry matter accumulation of field pea over time grown in Canterbury in the 2006/07 growing season, variety. (Bars are LSD at $p < 0.05$); ($\bullet$) = Pro 7035, ($\circ$) = Aragorn, ($\blacktriangledown$) = Midichi.

Figure 4.3: Total dry matter accumulation of field pea over time grown in Canterbury in the 2006/07 growing season, population. (Bars are LSD at $p < 0.05$); ($\bullet$) = 50 plants m^{-2}, ($\circ$) = 100 plants m^{-2} ($\blacktriangledown$) = 400 plants m^{-2}.
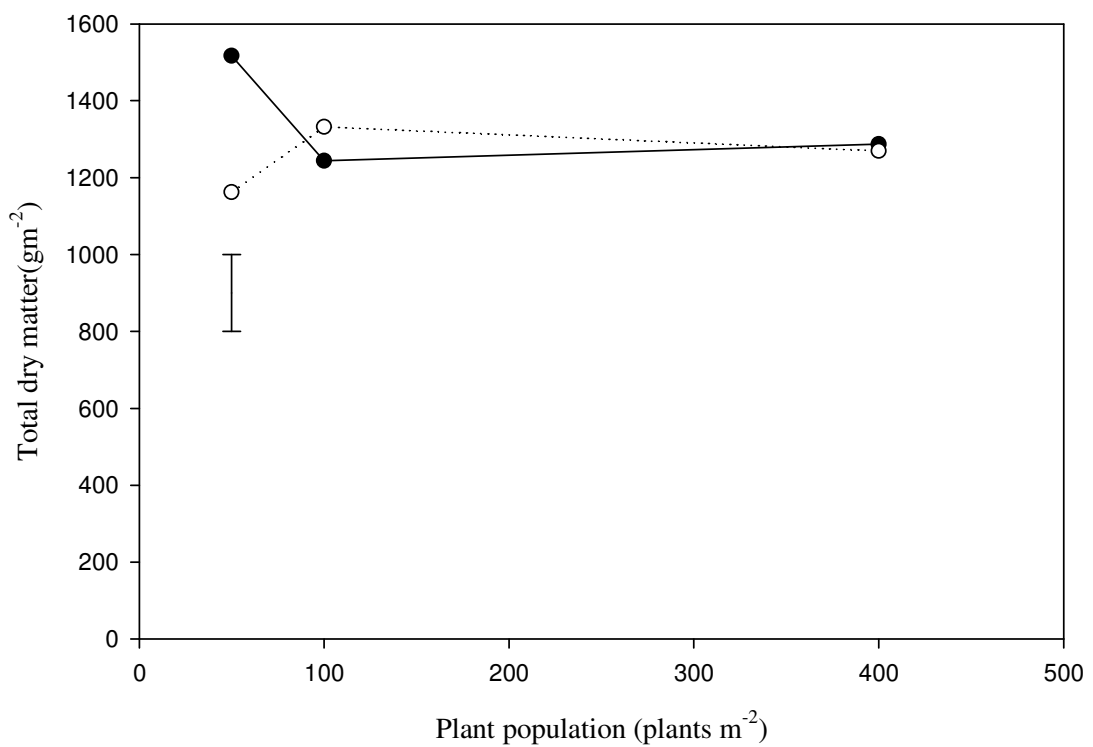
Figure 4.4: The herbicide x population interaction on total dry matter, at harvest, of field peas grown in Canterbury in the 2006/07 growing season. (Bar is LSD at $p < 0.05$); ($\circ$) = 0 g a.i. ha^{-1}, ($\bullet$) = cyanazine at 500 g a.i. ha^{-1}.

Table 4.2: Total dry matter (TDM), seed yield, and crop harvest index (HI) at final harvest (126 DAE) of field peas grown in Canterbury in the 2006/07 growing season.

	TDM (g m^{-2})	Seed yield (g m^{-2})	HI
Herbicide (H)			
0 g a.i.ha^{-1}	1,255	647	0.52
500 g a.i.ha^{-1}	1,349	700	0.52
Significance	NS	NS	NS
LSD	-	-	-
Population(P) (plants m^{-2})			
50	1,339	733b	0.55c
100	1,288	681ab	0.53b
400	1,278	606a	0.47a
Significance	NS	*	***
LSD	-	89	0.02
Type(T)			
Pro 7035	1,322	729	0.55c
Aragorn	1,321	628	0.48a
Midichi	1,262	663	0.52b
Significance	NS	NS	***
LSD	-	-	0.02
CV (%)	19.1	19.5	6.1
Significant interactions	HxP*	HxP*	Nil
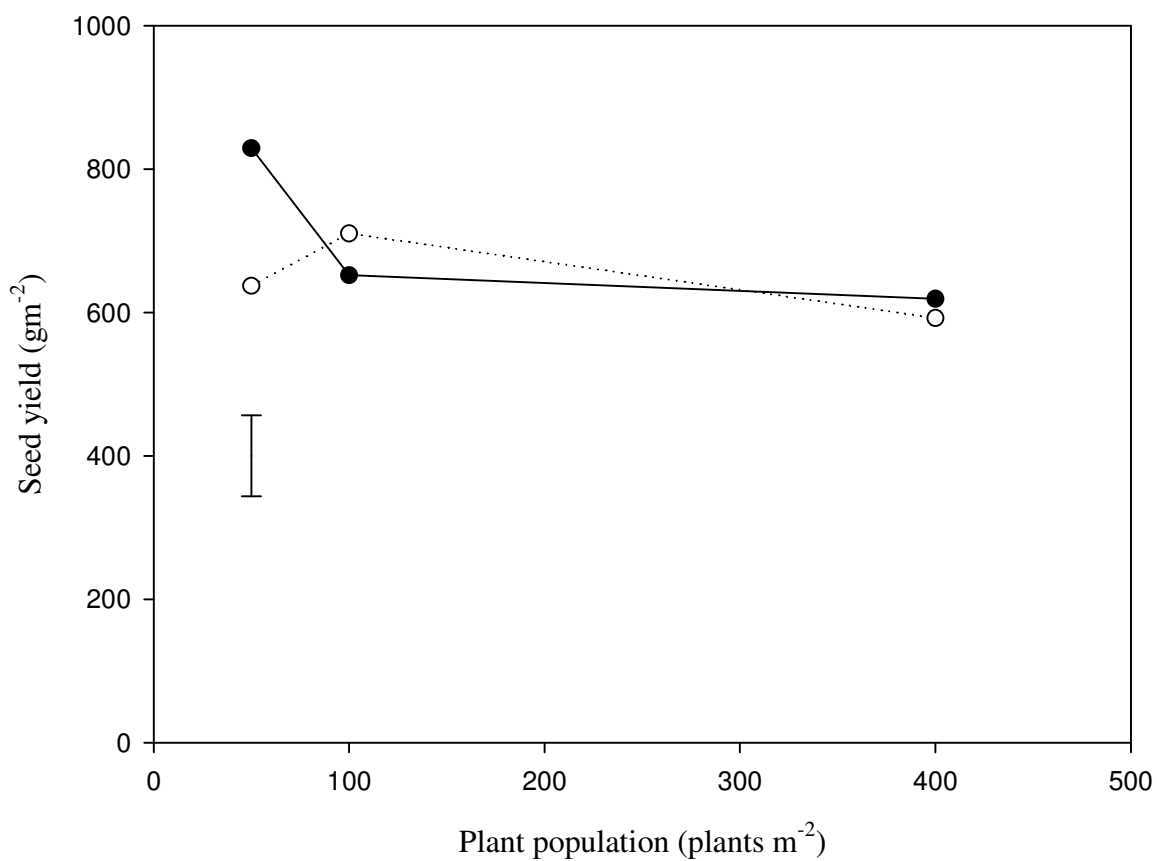
Figure 4.5: The herbicide x plant population interaction on pea seed yield in Canterbury in the 2006/07 growing season (g m^{-2}). (Bar are LSD at p < 0.05); (○) = 0 g a.i. ha^{-1}, (●) = cyanazine at 500 g a.i. ha^{-1}.

4.5. Yield Components

4.5.1. Plant Population

All crop populations were lower than sown. While actual populations at 50 and 100 plants m^{-2} were 98 and 93% respectively, of the target population, at 400 plants m^{-2}, there were only 69% of sown plants present at final harvest (Table 4.3).

4.5.2. Pods Plant^{-1}

There was a significant (p < 0.001) reduction in the mean number of pods plant^{-1} with increased pea population (Table 4.3). Plots sown at 50 plants m^{-2} gave the highest mean number of pods plant^{-1} (13.42) and those at 400 plants m^{-2}, the least (3.37), a drop of 75%. There was a significant difference (p < 0.001) in the number of pods plant^{-1} produced by Aragon and Midichi. Herbicide alone had no significant effect on the mean number of pods plant^{-1}. There was however a significant (p < 0.01) herbicide x population effect on pods plant^{-1} (Table 4.4). As with seed yield, there was no effect of herbicide on the pods plant^{-1} at 100 and 400 plants m^{-2}. However, at 50 plants m^{-2} cyanazine treated plants produced 14.96 pods plant^{-1}. This was 26% higher than the 11.96 pods plant^{-1} without herbicide.

4.5.3. Seeds Pod^{-1}

While the number of seeds pod^{-1} was similar at 50 and 100 plants m^{-2} there was a 25% reduction in the number of seeds pod^{-1} as a result of increasing the population from 50 to 400 plants m^{-2} (p < 0.001). Cultivar Pro 7035 had the highest mean number of seeds pod^{-1} (4.58) and Midichi, the least (3.60).

4.5.4. Number of primary branches

The number of primary branches plant^{-1} was inversely proportional to plant population (Table 4.5). Aragorn had the highest number of primary branches plant^{-1} (1.84), followed by Pro 7035 (1.51) and Midichi (1.01). Herbicide had no effect on branching. There were significant interactions with population x pea type and herbicide x pea population (Figure 4.6 and 4.7 respectively).

Table 4.3: Yield components of field peas grown in Canterbury in the 2006/07 growing season.

	Plants m^{-2}	Pods plant^{-1}	Seeds pod^{-1}
Herbicide (H)			
0 g a.i.ha^{-1}	146.2	8.04	3.94
500 g a.i.ha^{-1}	131.6	8.61	3.94
Significance	NS	NS	NS
LSD	-	-	-
Population (P) (plants m^{-2})			
50	48.8a	13.42c	4.35b
100	92.9b	8.19b	4.21ab
400	274.9c	3.37a	3.26a
Significance	***	***	***
LSD	20.15	1.18	0.35
Type (T)			
Pro 7035	138.2	8.19ab	4.58b
Aragorn	132.3	9.67b	3.65a
Midichi	146.2	7.12a	3.60a
Significance	NS	***	***
LSD	-	1.18	0.35
CV%	21.4	20.9	13.2
Significant interactions	Nil	HxP**	Nil

Table 4.4: The interaction herbicide by population on pods plant^{-1} of field peas grown in Canterbury in the 2006/07 growing season.

	Population (plants m^{-2})		
Herbicide	50	100	400
0 g a.i. ha^{-1}	11.89c	8.58b	3.64a
500 g a.i. ha^{-1}	14.96d	7.80b	3.09a
Significance		**	
LSD		2.44	
CV (%)		20.9	

At 400 plants m^{-2} pea genotype had no effect on branching. At 100 plants m^{-2}, Aragorn had 1.7 primary branches plant^{-1} whereas Midichi and Pro 7035 had a mean of 1.15 branches plant^{-1}. At 50 plants m^{-2}, Aragorn produced more than twice the number of branches than Midichi (Fig 4.6).

At 400 and 100 plants m^{-2} herbicide had no effect on branching. However, at 50 plants m^{-2} cyanazine sprayed plants had 2.27 branches plant^{-1}. This was 26% more than on unsprayed plants at 1.80 (Figure 4.7).

Table 4.5: The number of primary branches plant^{-1}, thousand seed weight (TSW) and seed plant^{-1} of field peas grown in Canterbury in the 2006/07 growing season.

	Primary branches plant^{-1}	TSW (g)	Seeds plant^{-1}
Herbicide (H)			
0 g a.i. ha^{-1}	1.41	296	33.1
500 g a.i. ha^{-1}	1.50	282	36.3
Significance	NS	NS	NS
LSD	-	-	-
Population (P)			
(plants m^{-2})			
50	2.03c	299b	58.4c
100	1.33b	296b	34.5b
400	1.00a	273a	11.1a
Significance	***	**	***
LSD	0.18	17.86	6.44
Type (T)			
Pro 7035	1.51b	263b	39.9b
Aragorn	1.84c	245a	36.6b
Midichi	1.01a	360c	27.5a
Significance	***	***	***
LSD	0.18	17.86	6.44
CV%	18.3	9.1	27.3
Significant interactions	HxP**	Nil	HxP*
	PxT***		
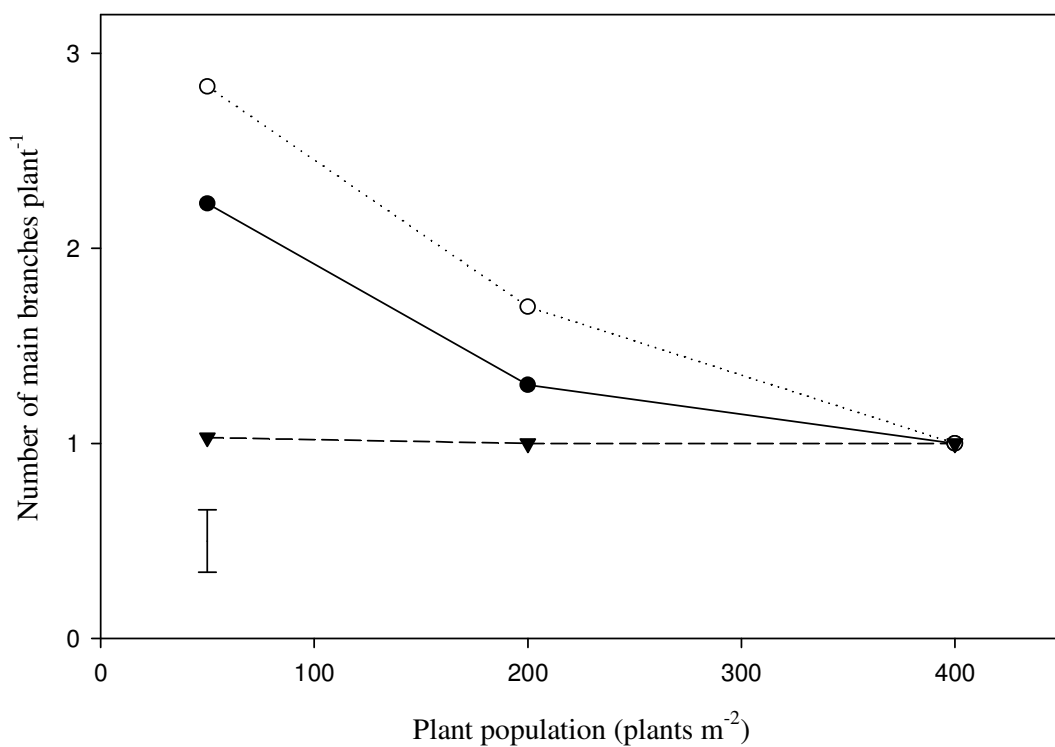
Figure 4.6: The interaction plant population by pea cultivar on number of primary branches plant^{-1} of field peas grown in Canterbury in the 2006/07 growing season. (Bar is LSD at $p < 0.05$); (●) = Pro 7035, (○) = Aragorn, (▼) = Midichi.
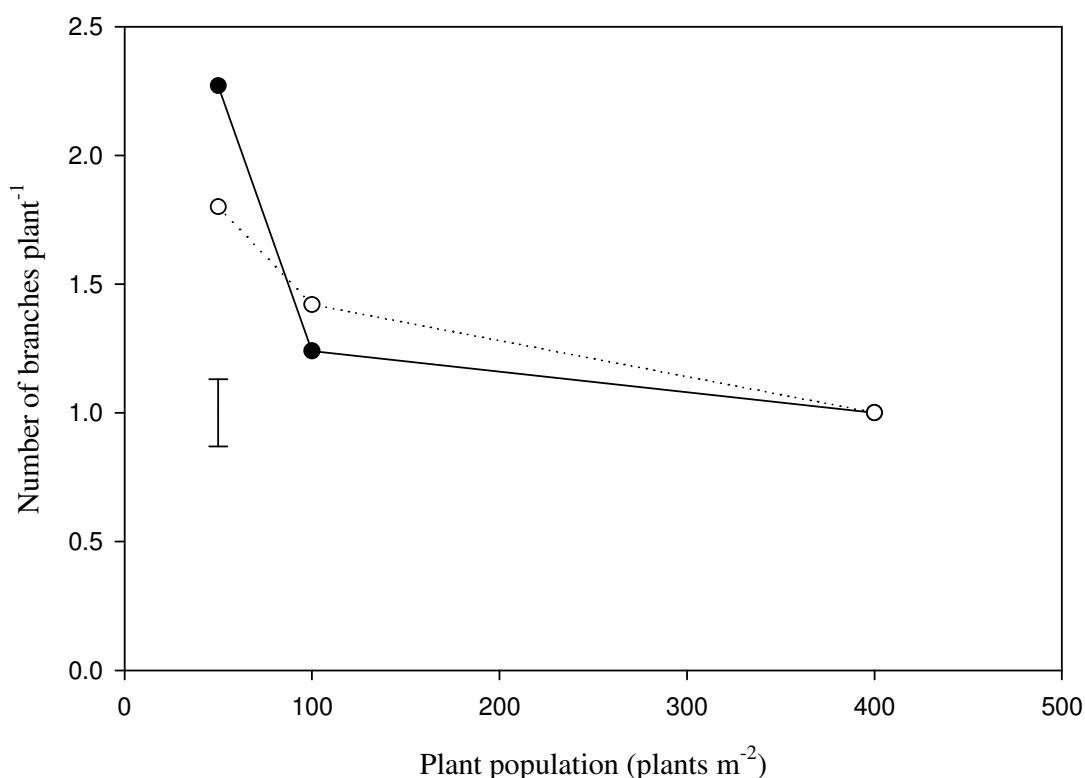
Figure 4.7: The interaction of herbicide by population on primary branches of field peas grown in Canterbury in the 2006/07 growing season. (Bar is LSD at p < 0.05); (○) = 0 g a.i. ha^{-1} (●) = cyanazine at 500 g a.i. ha^{-1}.

4.5.5. Thousand Seed Weight

The two lowest populations had the same thousand seed weight (TSW) (297 g), which was higher (p < 0.01) than the TSW at the highest plant population (273 g). Aragorn had the lowest TSW at 245 g, followed by Pro 7035 at 264 g and Midichi at 360 g.

4.5.6. Seeds Plant^{-1}

The mean number of seeds plant^{-1} was inversely proportional to population density. It almost doubled as population declined from 400 to 100 plants m^{-2}. There was an additional increase of 69% as population went from 100 to 50 plants m^{-2}. Pro 7035 and Aragon produced similar numbers of seeds plant^{-1} and the two cultivars produced significantly more than Midichi (p < 0.001).

There was a significant herbicide x population interaction on mean number of seeds plant^{-1} (Figure 4.8). Sprayed and unsprayed plants were not significantly different

at 100 and 400 plants m^{-2}. However, sprayed plants at 65.8 seed plant^{-1} produced 29% more than the unsprayed plants at 51 (p < 0.001).
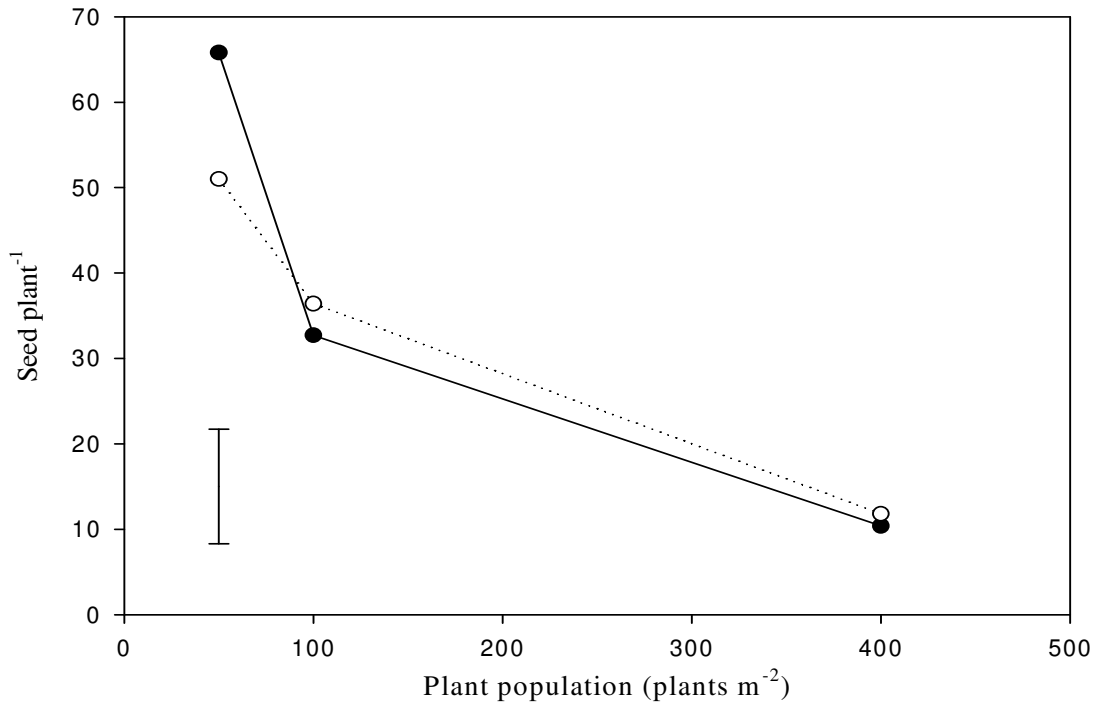
Figure 4.8: The interaction of herbicide by population on seeds plant^{-1} of field peas grown in Canterbury in the 2006/07 growing season. (Bar is LSD at p < 0.05); (○) = 0 g a.i. ha^{-1} (●) = cyanazine at 500 g a.i. ha^{-1}.

4.6. Leaf Area Index over Time

At 21 DAE Midichi had the highest mean LAI at 2.12, which was 34% higher than the lowest LAI in Pro 7035 at 1.58 (Fig 4.9). At 21 DAE the mean LAI was 3.04 at 400 plants m^{-2}, which was more than three times the mean LAI at 50 plants m^{-2} (Fig 4.10). There was a significant herbicide x population interaction at 21 DAE (Table 4.6). Herbicide on its own had no effect on LAI at 50 and 100 plants m^{-2}. However, at 400 plants m^{-2}, unsprayed plants had a 31% higher LAI than the sprayed plants.

The LAI increased with time, up to 63 DAE and then decreased. Plant population and pea genotype had no effect on LAI from 105 DAE. From that point there was no significant difference as a result of herbicide, plant population or pea type.
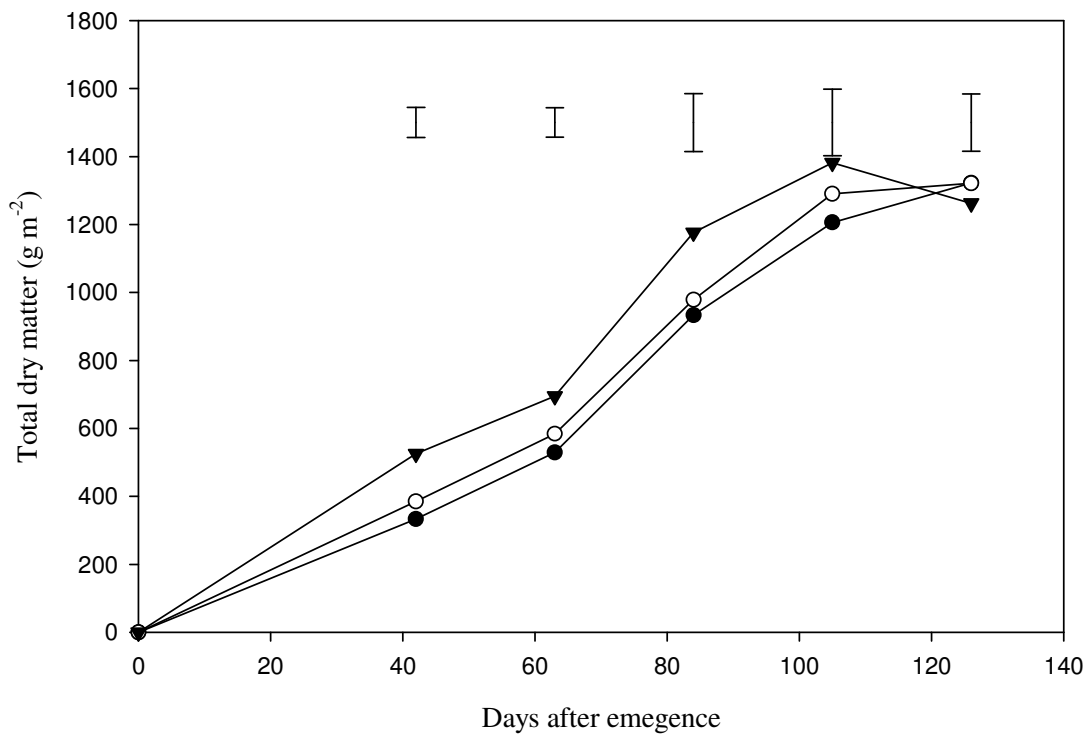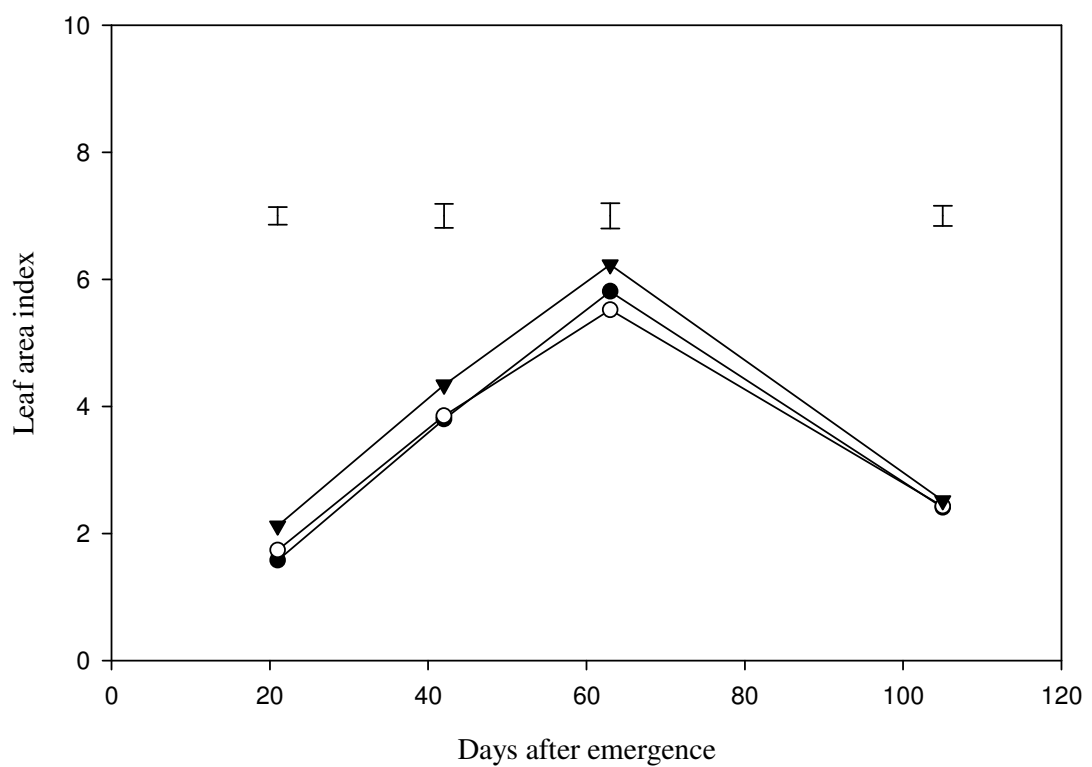
Figure 4.9: The leaf area index of field peas over time grown in Canterbury in the 2006/07 growing season, variety. (Bars are LSD at $p < 0.05$); ($\bullet$) = Pro 7035, ($\circ$) = Aragorn, ($\blacktriangledown$) = Midichi.
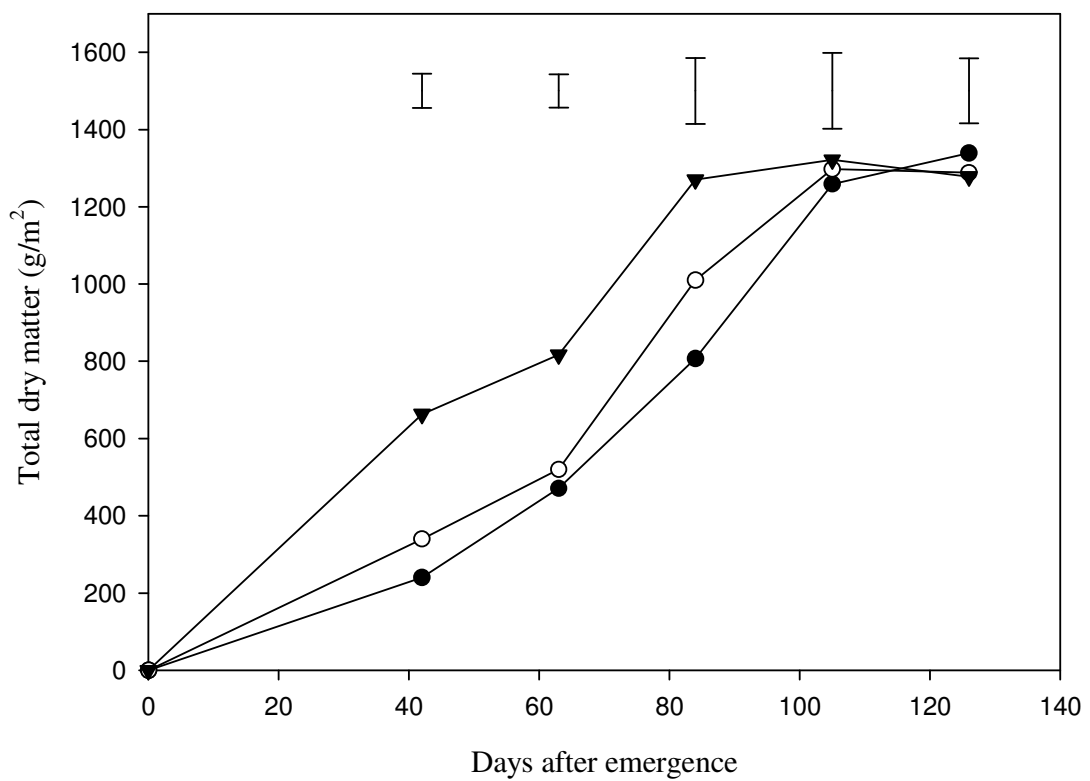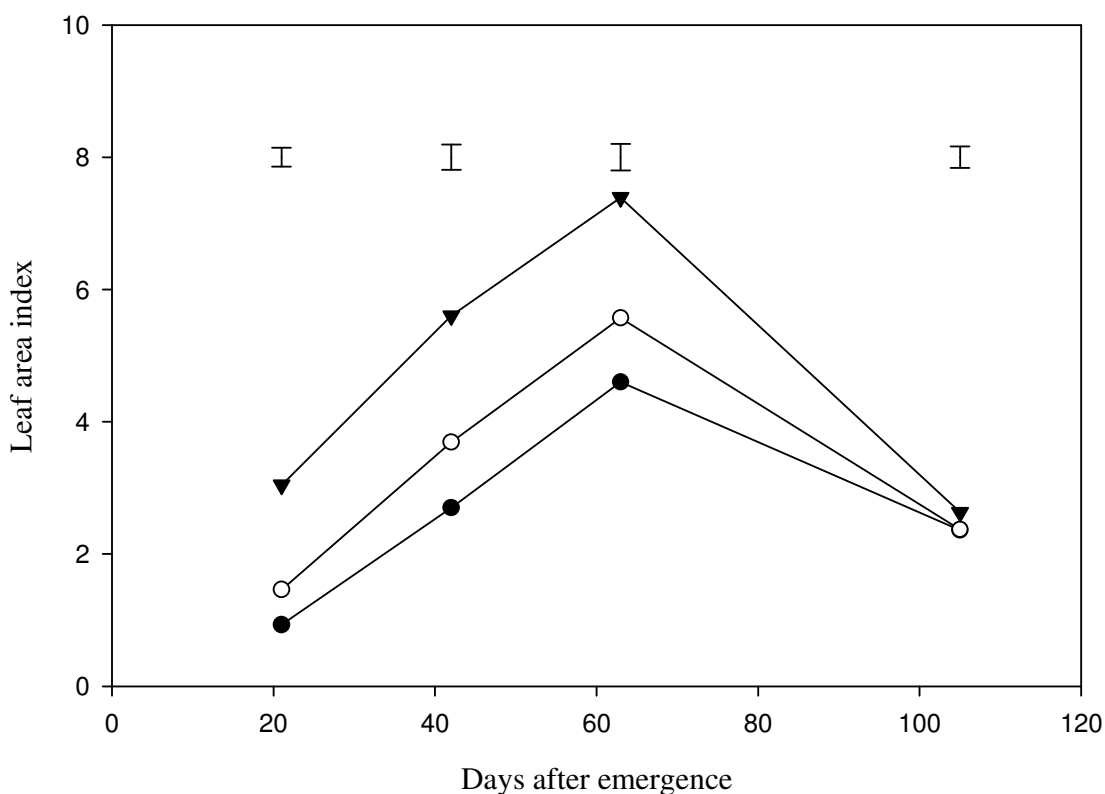
Figure 4.10: The leaf area index of field peas over time grown in Canterbury in the 2006/07 growing season, population. (Bars are LSD at p < 0.05); ($\bullet$) = 50 plants m^{-2}, ($\circ$) = 100 plants m^{-2} ($\blacktriangledown$) = 400 plants m^{-2}.

Table 4.6: Interaction of herbicide by population on leaf area index at 21 DAE of field peas grown in Canterbury in the 2006/07 growing season.

	Population (plants m^{-2})		
Herbicide	50	100	400
0 g a.i. ha^{-1}	1.01ab	1.45b	3.45d
500 g a.i. ha^{-1}	0.86a	1.46b	2.64c
Significance		*	
LSD		0.51	
CV (%)		22.2	

4.7. Weed Counts

Pea genotype had no effect on weed counts and herbicide had little effect on weed counts (Table 4.7). However, there was almost five times more *Coronopus* spp in sprayed than in the unsprayed plots and almost 50 times more *Stachys* spp at 21 DAE. Herbicide had no effect on the number of other weeds.

Generally weed counts were inversely proportional to crop population except for *Coronopus* spp. For example there was a 16 times increase in *Chenopodium* plant numbers as the pea population decreased from 400 to 100 plants m^{-2}. There was a further 47% increase as pea population decreased to 50 plants m^{-2}.

Table 4.7: Weed counts m^{-2} at 21 DAE of field peas grown in Canterbury in the 2006/07 growing season.

	Weed species					
	Coronopus spp.	*Chenopodium* spp.	*Lolium* spp.	*Stachys* spp.	Others	Total counts (All spp)
Herbicide (H)						
0 g a.i. ha^{-1}	53.2	9.62	2.22	9.5	10.9	36.1
500 g a.i. ha^{-1}	11.5	0.37	0.37	0.2	2.8	9.4
Significance	*	NS	NS	*	NS	NS
LSD	31.0	-	-	8.77	-	-
Population (P) (plants m^{-2})						
50	1.9 a	8.70c	2.40b	0.6a	13.3c	44.4c
100	50.1 b	5.92 b	1.11ab	9.2b	6.3b	20.9b
400	45.0 b	0.37 a	0.37 a	4.8 ab	0.9 a	3.1a
Significance	***	***	*	*	***	***
LSD	20.93	4.15	1.4	5.8	5.2	17.32
Type (T)						
Pro 7035	25.0	7.40	0.56	3.7	8.3	27.7
Aragorn	26.8	4.63	1.85	5.5	6.3	20.9
Midichi	45.1	2.96	1.48	5.4	5.9	19.7
Significance	NS	NS	NS	NS	NS	NS
LSD	-	-	-	-	-	-
CV (%)	95.4	122.2	158.9	175.2	111.9	111.9
Significant interactions	Nil	Nil	Nil	Nil	Nil	Nil

4.8. Total Weed Dry Matter

Weed DM increased throughout the growing season. After the first harvest at 21 DAE the trend was for there to be more weed DM in unsprayed plots than in sprayed plots up to 84 DAE. However, from 84 DAE to 126 DAE there was no difference in weed DM. Pea population had a highly significant effect ($p < 0.001$) on weed DM in plots sown at the two high populations. At only two harvests was there a difference in response to pea genotype.
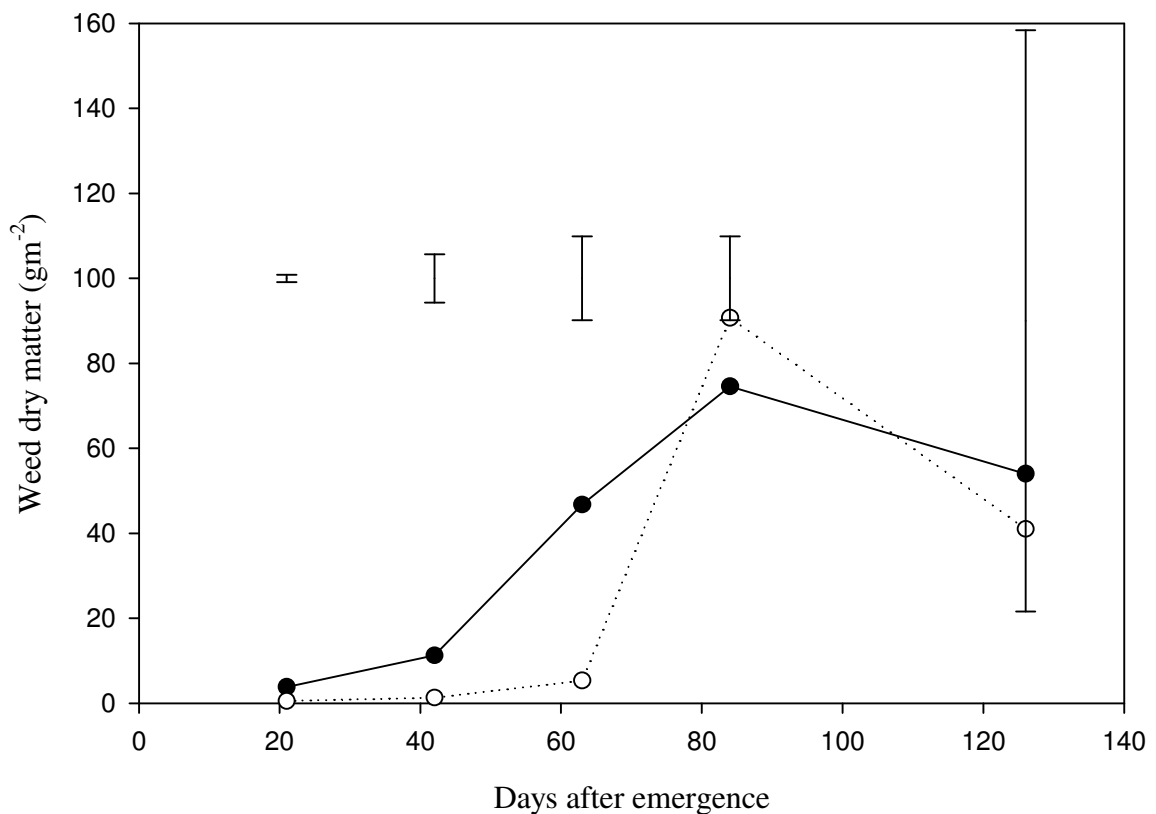
Figure 4.11: Weed dry matter accumulation over time of field peas grown in Canterbury in the 2006/07 growing season, herbicide. (Bars are LSD at $p < 0.05$); ($\bullet$) = 0 g a.i. ha^{-1} ($\circ$) = cyanazine at 500 g a.i. ha^{-1}.
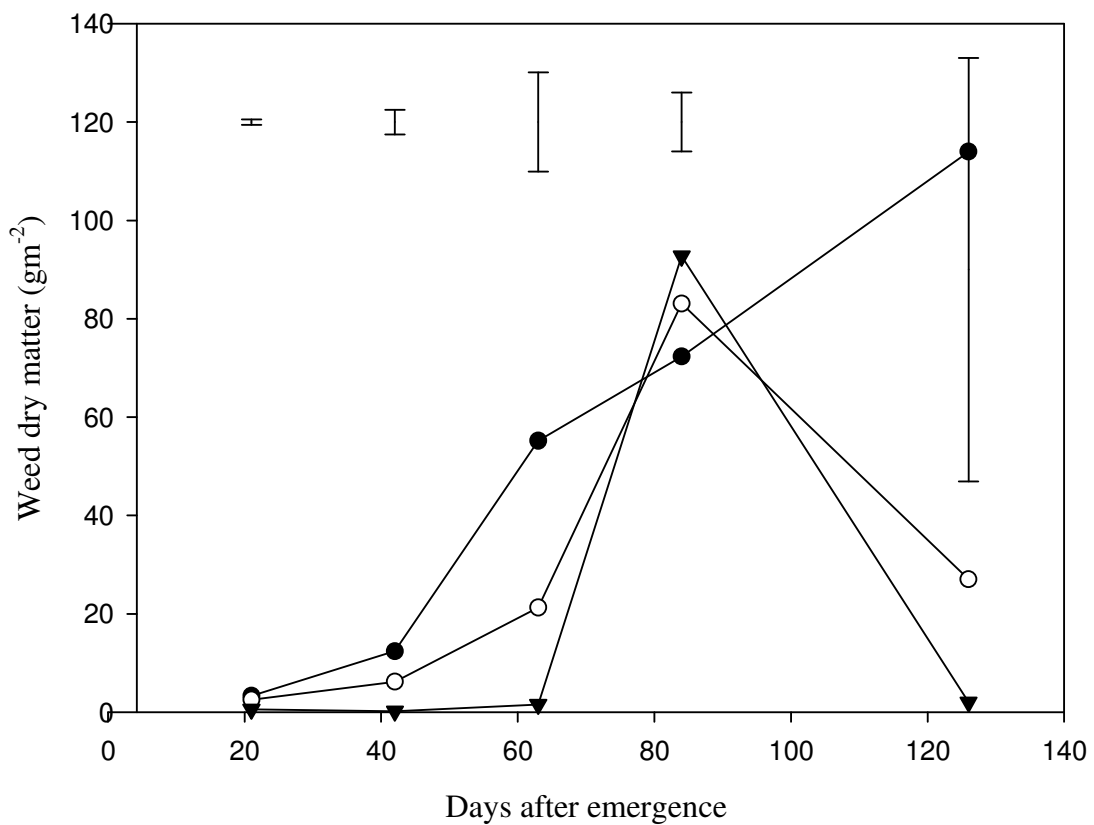
Figure 4 12: Weed dry matter accumulation over time of field peas grown in Canterbury in the 2006/07 growing season, population. (Bars are LSD at p < 0.05); (●) = 50 plants m^{-2}, (○) = 100 plants m^{-2} (▼) = 400 plants m^{-2}.
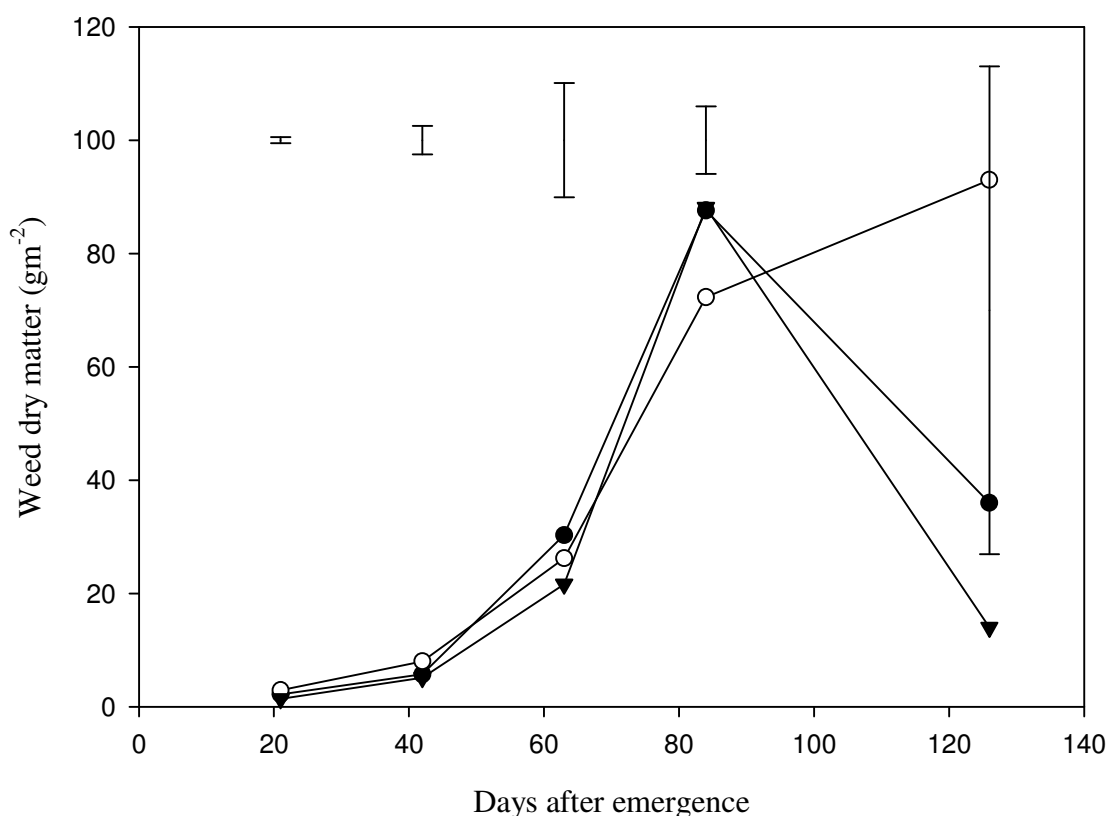
Figure 4 13: Weed dry matter accumulation of field peas grown in Canterbury in the 2006/07 growing season, cultivar. (Bars are LSD at p < 0.05); (●) = Pro 7035, (○) = Aragorn (▼) = Midichi.

4.8.1. Herbicide by population interaction on total weed dry matter

At both 21 and 63 DAE herbicide had no effect on total weed DM at 400 plants m^{-2} (Tables 4.8 and 4.9 respectively). There was more than 5 times more weed DM at 100 plants m^{-2} in unsprayed than in cyanazine sprayed plots at 21 and 63 DAE. At 50 plants m^{-2} there was more than 14 times more weed DM in unsprayed than in sprayed plots at 21 DAE and more than 9 times at 63 DAE.

Table 4.8: The herbicide by population interaction on weed total dry matter at 21 DAE (g m^{-2}).

	Population (plants m^{-2})		
Herbicide	50	100	400
0 g a.i. ha^{-1}	6.22c	4.17b	1.00a
500 g a.i. ha^{-1}	0.44a	0.89a	0.17a
Significance		***	
LSD		1.55	
CV (%)		73.3	

Table 4.9: The herbicide by population interaction on weed total dry matter at 63 DAE $(g\ m^{-2})$.

Herbicide	Population (plants m^{-2})		
	50	100	400
0 g a.i. ha^{-1}	99.5c	37.8b	2.9a
500 g a.i. ha^{-1}	11.0a	4.8a	0.2a
Significance		***	
LSD		25.16	
CV (%)		114.2	

4.9. Discussion

4.9.1. Total Dry Matter Accumulation over Time

At 42 DAE, total pea DM increased significantly ($p < 0.01$) from 240 g m^{-2} at 50 to 663 g m^{-2} at 400 plants m^{-2}. It increased by 42% as population increased from 50 to 100 plants m^{-2} and almost doubled as population increased from 100 to 400 plants m^{-2}. This was because the higher populations closed their canopies faster than the lower populations and hence intercepted more radiation in their canopy. The results support findings by McKenzie and Hill (1991) who reported that high lentil plant populations close their canopies quickly and hence intercept more sunlight more rapidly than low populations. According to them, this results in early rapid growth rates, which can be sustained if crops have adequate soil moisture and fertility (See Chapter 5 for details).

No factor significantly influenced TDM production at harvest. The highest population, 400 plants m^{-2} produced more TDM early in the season but all three populations achieved canopy closure (LAI of 4) and at the end the other populations had similar LAIs. Ambrose and Hadley (1984) found similar results, at harvest, confirming that planting density often has no effect on the biological yield of peas. However, there was a significant ($p < 0.05$) herbicide by population interaction (Figure 4.4). There was no significant difference in total DM production in cyanazine sprayed and unsprayed plants at 100 and 400 plants m^{-2}. However, at 50 plants m^{-2} cyanazine sprayed peas produced 30% more DM than unsprayed peas. The lower DM production in the unsprayed plots was a result of more weeds and more weed competition at the lowest pea population (Tables 4.8 and 4.9).

4.9.2. Seed Yield

There was no significant difference in mean seed yield among the three pea genotypes, Aragorn, Pro 7035 and Midichi. The overall mean yield was 674 g m^{-2}. This is very high by world standards and is attributed to the ideal environment the crop grew in and to good management. Late rains in December and January extended the growing season allowing the crop to take advantage of the high radiation associated with that time of the year. There was a significant ($p < 0.05$) herbicide by population interaction on mean seed yield. Herbicide had no effect on seed yield at 100 and 400 plants m^{-2}. The no herbicide effect at the two highest populations was attributed to low weed pressure in this experiment. As with total DM weed competition effect was more pronounced at the lowest pea population where the cyanazine sprayed peas produced 30% more seed yield than unsprayed peas.

Comparative studies in England (Heath *et al.,* 1991) and Scotland (Taylor *et al.*, 1991) demonstrated that the optimum plant density for semi-leafless peas was not necessarily higher than for conventionally leafed peas. Semi-leafless peas, like leafed peas, were relatively unresponsive to plant density. This is similar to the results obtained here where semi-leafless peas gave seed yields similar to the leafed variety.

The lowest average seed yield of 606 g m^{-2} was from plants at 400 plants m^{-2} and the highest, 733 g m^{-2} from plants at 50 plants m^{-2}, a 21% increase. The highest yield was obtained at 50 plants m^{-2} because of lower plant-to-plant competition for available nutrients, light, water and space. Assimilates were partitioned to reproductive organs when competition was at a minimum. It is presumed that from the reproductive stage onwards, the 50 plants m^{-2} population was partitioning more assimilates to seed sinks rather than competitively using them for continuous vegetative growth and increased height as occurred at the higher populations. Also, plots sown at the lowest population had the highest mean number of pods plant^{-1} and seeds pod^{-1}. This then overall resulted in the highest number of seeds plant^{-1}. Reduced plant-to-plant variation has generally been shown to increase the yield in seed crops (Ambrose and Hedley, 1984).

Despite the high yields obtained in this research, pea yields have often been reported to be variable (Wilson, 1987; Moot, 1993; Moot and McNeil, 1995; Timmerman-Vaughan *et al.*, 2005). Hedley and Ambrose (1981) reported that variation in a dried pea crop was likely to be the major cause of the relatively low and

unpredictable yields. In their research they deduced that there was variation in overall plant size in the crop population and for the proportion of plant biomass partitioned to seed. They concluded that as with other crops, it is possible to reduce variability by lowering planting density and by increasing the uniformity of spacing between plants. The results of this experiment support this; the highest seed yield was produced at 50 plants m^{-2}.

According to Ambrose and Hedley (1984) residual variability in the crop still remains, after agronomic causes of variation have been reduced. If morphological and physiological plant characters can be identified which correlate with this residual variation, then this information can be used to produce crop plant ideotypes for plant breeders (Timmerman-Vaughan *et al*., 2005). Ambrose and Hedley, (1984) give evidence to show that the level of this residual variation differs among pea genotypes.

4.9.3. Crop Harvest Index

Variable crop harvest index (CHI) is an important contributor to yield instability among grain legumes (Wilson, 1987; Moot, 1993; Moot and McNeil, 1995; Timmerman-Vaughan *et al*., 2005). In this study, Aragorn had the lowest mean CHI (0.48) followed by Midichi (0.52) and Pro 7035 had the highest mean CHI (0.55). These values were high. Previous research has shown variable CHIs. For example Askin, (1983) reported peas had a HI ranging from 0.17 to 0.44; Anderson and White (1974) showed variability in HI ranging from 0.16 to 0.24 based on shelling percentage. McKenzie *et al.* (1989) and Moot (1993) reported HIs in grain legumes, which varied from 0.00 to 0.74. The high values in this research are attributed to a prolonged growing season giving a longer crop duration hence more photosynthetic time and partitioning of assimilates to seed (Ayaz *et al*., 1999).

Crop harvest index was inversely proportional to plant population. Assimilates tend to be partitioned to reproductive organs when competition is at a minimum. High plant–to–plant competition at 400 plants m^{-2} resulted in assimilates being used for vegetative growth and induced tall plants and early canopy closure. However, the canopy did not last long. It experienced high self-thinning. The result was that at the end all populations had the same LAI. This explains why the 400 plants m^{-2} population did not give the highest seed yield despite having the fastest DM accumulation during the growing season.

4.9.4. Pods Plant^{-1}

Generally, variation in the number of pods plant^{-1} depends on species (Ayaz *et al.*, 2004). Aragorn had the highest number of pods plant^{-1} (9.67) and Midichi, the least (7.12). This was probably because Aragon produced the most flowering nodes, a genetically controlled heritable characteristic (White, 1987; Timmerman-Vaughan *et al.*, 2005).

The significant ($p < 0.01$) herbicide x population effect on pods plant^{-1} (Table 4.4) shows that there was no effect of herbicide on the pods plant^{-1} at 100 and 400 plants m^{-2}. This was probably because of the less weed influence at the two highest populations. However, at 50 plants m^{-2} cyanazine treated plants produced 26% more pods plant^{-1} than unsprayed plants because the effect of weeds became more pronounced in the unsprayed plots.

There was a significant ($p < 0.001$) reduction in the mean number of pods plant^{-1} with increased plant population. Plots with 50 plants m^{-2} had the highest mean number of pods plant^{-1} (13.42) and 400 plants m^{-2}, the least (3.37), a fall of 75%. Dapaah *et al.* (1999) found that a low plant population of pinto beans gave a greater number of pods plant^{-1} in a November sowing in Canterbury. Gritton and Eastin (1968) found similar results in peas and reported that increased plant population constantly resulted in a decreased number of pods plant^{-1} each year and over years. The reduction in pods plant^{-1} at high density was due to increased interplant competition. McKenzie *et al.* (1986) reported the same trend in pods plant^{-1} and seeds pod^{-1} in a population study with lentils. In another study, McKenzie and Hill (1995) also reported that pods plant^{-1} decreased as plant population increased in chickpea.

4.9.5. Seeds Pod^{-1}

While the number of seeds pod^{-1} was similar at 100 and 400 plants m^{-2} there was a 25% significant ($p < 0.001$) reduction in the number of seeds pod^{-1} as population increased from 50 to 400 plants m^{-2}. Gritton and Eastin (1968) had similar results and reported the number of seeds pod^{-1} decreased as population increased. The cultivar Pro 7035 had the highest mean number of seeds pod^{-1} (4.58) and Midichi, the least (3.60). As with pods plant^{-1}, this is a heritable characteristic that is genetically controlled (White, 1987; Timmerman-Vaughan *et al.*, 2005) although it also depends on agronomic conditions (Knott, 1987). Herbicide did not affect seeds pod^{-1}.

4.9.6. Primary Branches Plant^{-1}

The number of primary branches plant^{-1} was inversely proportional to plant population. At low populations pea plants tended to develop more primary branches because of less competition for resources. Aragorn had the highest number of branches plant^{-1} (1.84), followed by Pro 7035 (1.51) and Midichi (1.01). However, the extra branches did not increase yield. This was because only main stem pods produced mature seeds. Primary branches contributed to TDM but reduced CHI. (Aragorn had the smallest CHI). In support, Hardwick and Milbourn (1967), reported that lateral branches from the main stem are a comparatively unimportant component of yield and under normal commercial conditions contribute only a small fraction of the total yield. The number of branches is a varietal characteristic, which is plastic, branches being completely suppressed at high plant densities. At 400 and 100 plants m^{-2} herbicide had no effect on branching. However, at 50 plants m^{-2} sprayed plants had 26% more primary branches than unsprayed plants. This interaction shows that weed competition can affect branching of peas especially at low crop populations. Less weed pressure in sprayed plants led to higher primary branch development due to less competition for light, water, nutrients and space.

4.9.7. Thousand Seed Weight

The two lowest populations had the same TSW (297 g), which was significantly ($p < 0.01$) higher than the TSW for the highest population (272.5 g). The higher the population the higher the competitive pressure for filling the increased seeds per unit area. Moot (1993) also reported a decrease in mean seed weight of pea genotypes with increased plant population. Aragorn had the lowest TSW (245 g) followed by Pro 7035 (264 g) and Midichi (360 g). Wilson (1987) and Timmerman-Vaughan *et al*. (2005), reported TSW to be a genetic characteristics and therefore heritable. Castillo *et al*. (1994) reported that the TSW depended on management and growing conditions e.g. irrigation. In this experiment, herbicide did not affect TSW.

4.9.8. Weed Biomass

Throughout the season there were generally very low weed populations, which can be attributed to effective weed control in the paddock in the previous seasons. This

explains why weed levels, which should have been determined largely by experiment treatments, did not have a substantial effect on the parameters studied.

However, there was more than a four fold decline in weed dry weight when pea population increased from 100 to 400 plants m^{-2}. This supports the report, on peas, of Grevsen (2003), who concluded that increasing the seeding rate from the normal 90 to 150 seeds m^{-2} reduced weed plant dry weight at harvest by 50% in 1997 and by 30% in 1998. Similar results have been demonstrated in other crops. In an experiment with ten wheat cultivars, Lemerle *et al.* (1996) found that, on average, doubling the seeding rate reduced DM of the weed *Lolium rigidum* by 25% and increased wheat yield by 10%.

In this experiment increasing the population from 50 to 100 plants m^{-2} had no significant effect on weed biomass. However, Townley-Smith and Wright (1994) reported yield increases and weed DW reduction by raising field pea density from 50 to 100 seed m^{-2}. They concluded that increasing the seeding rate over 100 seeds m^{-2} would be unlikely to give a better result. They reiterated that a 70% increase in the seeding rate to 150 seeds m^{-2} compared with normal at 90 seeds m^{-2} was costly in peas and was not always compensated for by a higher yield. They recommended that the positive effect of a higher seeding rate on reducing weed pressure should be regarded as an investment in weed management in a crop rotation more than an immediate yield payoff. This is only true under the assumption that weed seed return is reduced along with weed biomass (Grevsen, 2003).

Lemerle *et al.* (2006), reported that there was greater financial benefit from increasing seeding rates in the presence of weeds compared with weed-free crops. In weed-free crops they found a financial benefit around $A 100 ha^{-1} (range $A 85-128 ha^{-1}) in all treatments, showing significant incentives for higher seeding rates. In weedy crops the benefits were more variable but were potentially much greater e.g. there was a financial benefit of $A 400 ha^{-1} from increased crop density from 20 – 40 plants m^{-2} in cv Dundale in 1993, compared with a loss of $A 44 ha^{-1} in cv Dinkum in 1995. This support the results of this research that increased seed rates were not beneficial in the absence of a substantial weed load. Weed pressure in this experiment was not sufficient to guarantee increased seed yields with increased seed rates. Lemerle *et al.* (2006) also concluded that while increased seeding rates increased grain yield in wheat, the impact on weed suppression was relatively small. Surviving weeds could produce sufficient seed to replenish the weed seed bank leading to greater weed burdens in the future. This means higher seed rates are unreliable as a sole tactic for long-term weed control in

field pea compared with their use in wheat where substantial benefits have been demonstrated (Lemerle *et al*., 2006).

4.10. Conclusions

- There was no advantage in increasing the seeding rate for semi-leafless peas as conventionally leafed peas and semi-leafless gave the same yield.
- Fully leaved Pro 7035 was no more effective at weed suppression than the two semi leafless genotypes.
- Above average pea yields can be achieved without the use of herbicides at high seeding rates.
- Increasing seeding rates improved weed suppression but did not increase crop seed yield.
- With a herbicide, both conventional and semi-leafless peas can be grown at half the recommended seed rate without compromising yield.
- Weed pressure in this trial was not sufficient to produce adverse effects on the crops.

Chapter 5

5.0. Effect of Sowing Date, Herbicide and Genotype on Pea Yield and Weed Growth

5.1. Introduction

Sustainable crop production requires growers to consider all agronomic and environmental aspects and optimise them to get best yields without degrading the environment. A major determining component for sustainable production is weed management. For optimum yields, peas generally require a higher level of weed management than more competitive crops such as barley (*Hordeum vulgare* L.) or canola (*Brassica napus* L.) (Harker, 2001). In organic production this can be difficult and growers try to control weeds using intercropping (Munakamwe, 2004), crop rotation, mechanical and hand weeding, use of appropriate sowing dates, competitive crop genotypes (Radosevich *et al*., 1997) and, often, high seeding rates.

Sowing date is a major determinant of crop yield as it determines crop duration. The trend in crop production is for early sowing to optimise yield (Barrett and Witt, 1987). Yield is increased because crops have a longer growing season and photosynthesise for longer. Also early growth allows earlier canopy closure and a gives a greater competitive edge to the crop against some weed species. An example of this is that the herbicides used to control foxtail (*Setaria* spp) in wheat can be substituted by crop management practices related to early sowing (Khan *et al*., 1996).

Using the right crop genotype can also enhance yield. Several crops show genotypic differences in their competitive ability (Burnside, 1972; McDonald *et al*., 2007) and different weed species have different competitive abilities with crops (Harker *et al*., 2007). Conscious use of crop interference was reported by Zimdahl (2007), as an effective cultural weed control method. It has recently been shown that semi-leafless peas can be as productive as fully leaved peas (Munakamwe *et al.,* 2007). This type of pea has many advantages such as not lodging, easier disease control and they can also effectively smother weeds. They may also be suitable for organic production systems.

Modern society has concerns about how food is grown and processed and there is increased awareness of the environmental cost of herbicides. These concerns have led to this study, which is an investigation of weed control, in peas, using cultural methods

compared to the use of a herbicide. This trial specifically examines genotype and sowing date effects on pea yield and weed growth in weedy and weed free environments.

5.2. Specific Objectives

The objectives of this study were to:
- Compare canopy performance of conventionally leaved and semi-leafless pea genotypes in weedy and weed free environments.
- Determine the interaction between sowing date, pea genotype and herbicide on weed suppression and pea crop yield.

5.3. Materials and Methods

Only a brief description of the measurements is given. Other details are presented in Chapter 3 (Materials and Methods).

5.3.1. Measurements

Leaf area index (LAI) was measured non-destructively using a LICOR LAI 2000 Plant Canopy Analyser every 7 – 10 days throughout the growing season starting from three weeks after crop emergence. Two readings were taken randomly above and eight beneath the crop canopy from each plot. This was done on either a uniformly cloudy day or at dusk. A 0.2 m^2 sample was taken from each plot using a 0.1 m^2 quadrat every 7-10 days throughout the season starting from three weeks after crop emergence. The samples were used for measurement of pea and weed DM. Samples were dried in a forced draught oven for 24 – 48 h at 60 ^{o}C to a constant weight and then weighed. Weeds were sorted by taxa (species or genus depending on similarity) and counted. Uncommon taxa were pooled and their total count recorded. Weed counts were taken three times during the growing season. Yield and yield components were measured at harvest. Final harvests were taken when crops reached a moisture content of 15 – 18%.

5.4. Results

5.4.1. Climate

Climate data was from Broadfields Meteorological Station, Lincoln University, about 1.5 km from the experimental site. The 2007/08 growing season was generally very dry. August rainfall was 35.4 mm, which was just over 50% of average long-term rainfall (Fig 5.1). January 2008 was also extremely dry and only 19.2 mm fell, which was just 38% of the long-term average. Substantial rain fell at the end of the season in February (104 mm). The season was generally cool and all mean temperatures, except in September, were lower than long-term means.

Solar radiation receipts were higher than the long term averages throughout the growing season (Table 5.1). Vapour pressure deficits were similar to long term averages.
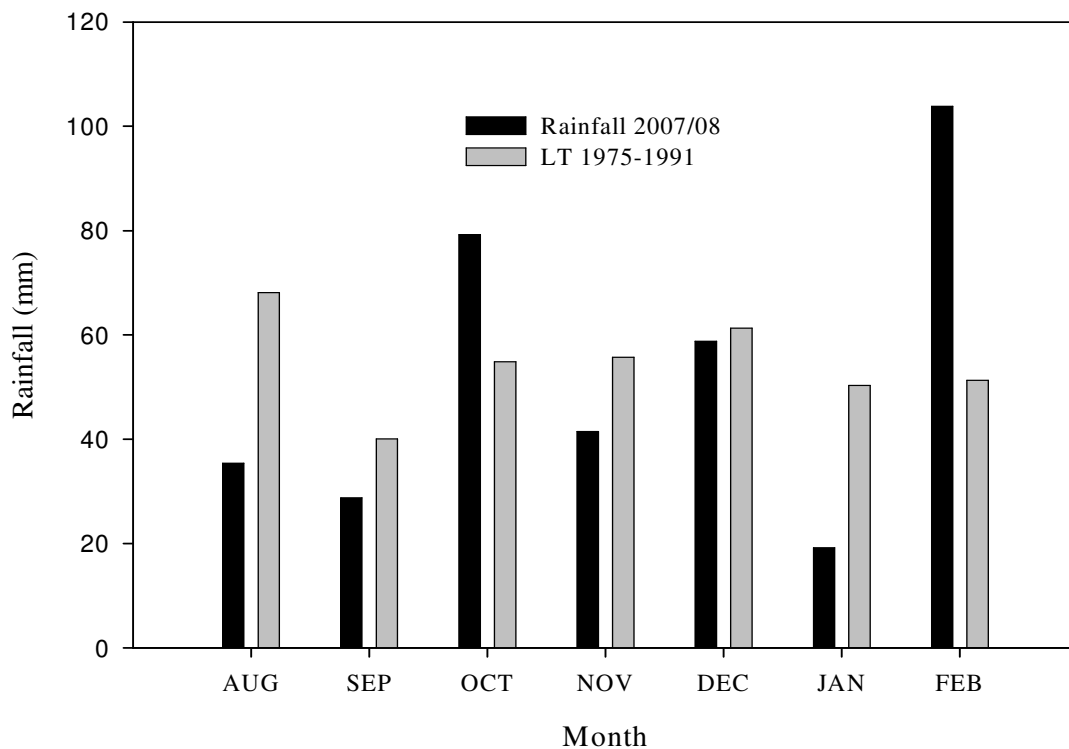
Figure 5.1: Rainfall data for Broadfields, Canterbury in the 2007/08 growing season and long-term mean 1975 – 1991.
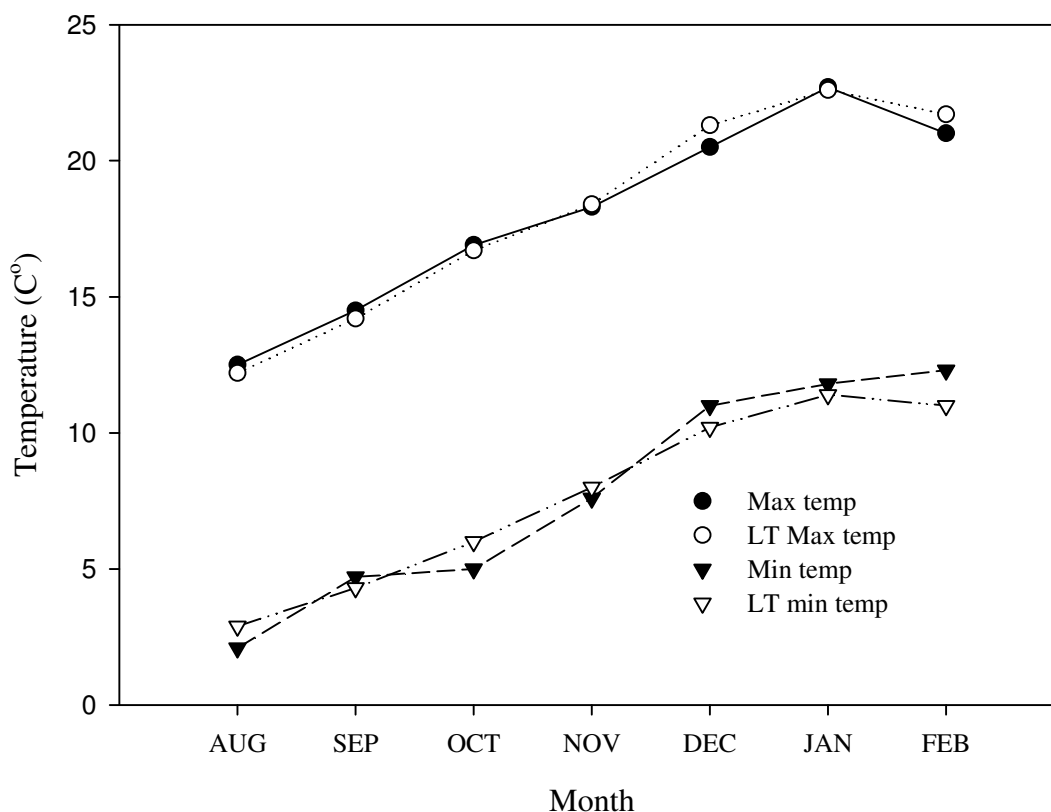
Figure 5.2: Temperature data for Broadfields, Canterbury in the 2007/08 growing season and the long-term mean 1975 – 1991.

Table 5.1: Weather data for the 2007/08 growing season and long-term averages for Broadfields, Canterbury.

Month	Solar Radiation ($MJm^{-2}month^{-1}$)		Vapour Pressure (Pa)		Penman ET (mm)	
August	226.8	(220)	8.3	(8.1)	46.2	(51)
September	369.9	(339)	9.2	(9.1)	73.9	(69)
October	570.0	(508)	9.0	(10.1)	123.5	(105)
November	705.5	(603)	11.0	(11.1)	131.8	(124)
December	711.2	(673)	13.6	(13.1)	141.2	(143)
January/08	698.4	(670)	14.3	(13.7)	151.7	(153)
February/08	530.2	(515)	14.2	(13.7)	113.7	(118)

Long-term means (in brackets) are for the period 1975-1991

5.4.2. Total Dry Matter at Final Harvest

Total DM at final harvest of the August and September sowings were not significantly different (mean 1,018 g m^{-2}) but they were significantly ($p < 0.05$) higher than from the October sowing (Table 5.2). Sprayed plots produced 21% more TDM

than unsprayed plots. There was no significant difference in the mean TDM produced by Midichi and Pro 7035 (911 and 971 g m^{-2}).

5.4.3. Seed Yield

The August sowing gave the highest seed yield (572 g m^{-2}), which was 62% more than the lowest yield in October (Table 5.2). While seed yield from September sown plots was also more than the yield from October plots, there was no significant difference in seed yield between the August and September sowings. Herbicide sprayed peas gave a mean seed yield of 508 g m^{-2}, which was 19% more than the mean pea yield of unsprayed plots. A significant ($p < 0.05$) sowing date x pea genotype interaction (Table 5.3) showed that in the August sowing genotype had no effect on seed yield. However, in September plots sown in Pro 7035 yielded 559 g m^{-2}, which was 40% more than Midichi. In the October sowing it was 87% greater.

Table 5.2: Total dry matter, seed yield, crop and plant harvest indices at final harvest of field peas grown in Canterbury in the 2007/08 growing season.

	TDM (g m^{-2})	Seed yield (g m^{-2})	CHI	PHI
Sowing date (S)				
August	1005b	572b	0.57b	0.51b
September	1031b	479b	0.47ab	0.37a
October	788a	354a	0.44a	0.39a
Significance	*	**	**	**
LSD	192.9	94.7	0.04	0.05
Herbicide (H)				
0 g a.i. ha^{-1}	852	428	0.50	0.43
500 g a.i. ha^{-1}	1030	508	0.49	0.41
Significance	***	***	NS	NS
LSD	94.4	43.8	-	-
Pea type (T)				
Midichi	911	398	0.43	0.36
Pro 7035	971	539	0.56	0.48
Significance	NS	***	***	***
LSD	-	43.8	0.02	0.02
CV (%)	14.3	13.4	5.6	7.5
Significant interactions	Nil	SxT*	SxT***	SxT**

Table 5.3: The sowing date x pea genotype interaction on seed yield of field peas grown in Canterbury in the 2007/08 growing season.

Pea genotype	August	September	October
		Sowing date	
Midichi	547cd	400b	246a
Pro 7035	597d	559d	461bc
Significance		*	
LSD		96.2	
CV (%)		13.4	

5.4.4. Crop Harvest Index and Plant Harvest Index

PHI was highest in the August sowing and September and October sowings had similar PHIs. The cultivar Pro 7035 had a higher CHI and PHI than Midichi (0.56 and 0.48 respectively). Herbicide had no effect on either CHI or PHI. However, there was significant sowing date x genotype interactions for both CHI and PHI (Table 5.4, 5.5), which showed that in the August sowing there was less difference in CHI and PHI between the two cultivars than at the other two sowing dates.

Table 5.4: The sowing date x pea genotype interaction on CHI of field peas grown in Canterbury in the 2007/08 growing season.

Pea genotype	August	September	October
		Sowing date	
Midichi	0.47 c	0.32 a	0.30 a
Pro 7035	0.55 d	0.42 b	0.48 c
Significance		**	
LSD		0.05	
CV (%)		7.5	

Table 5.5: The sowing date by pea genotype interaction on PHI of field peas grown in Canterbury in the 2007/08 growing season.

Pea genotype	August	September	October
		Sowing date	
Midichi	0.55c	0.40b	0.34a
Pro 7035	0.59d	0.53c	0.55c
Significance		***	
LSD		0.04	
CV (%)		5.6	

5.5. Yield Components

5.5.1. Plant Population

At harvest, plant population varied from 97 to 117 plants m^{-2}. All actual crop populations were slightly higher than sown (Table 5.6) except for the October sowing (97), which was slightly lower than the target population of 100 plants m^{-2}. There was no significant difference in the mean population of all the three treatments. However, there was a significant herbicide x sowing date interaction on plant population (Table 5.7). Herbicide treatment did not affect final population at all sowing dates except in September where sprayed plots contained 19% more plants m^{-2} than unsprayed plots.

5.5.2. Pods Plant^{-1}

The herbicide sprayed peas had 14% more pods plant^{-1} than unsprayed peas and Pro 7035 had 19% more pods than Midichi. Sowing date had no effect.

5.5.3. Seeds Pod^{-1}

Only pea genotype affected the number of seeds pod^{-1}. Pro 7035 had 28% more seeds pod^{-1} (4.26) than Midichi (3.32). Herbicide and sowing date had no effect on seeds pod^{-1}.

5.5.4. Thousand Seed Weight

The TSW decreased with later sowing (Table 5.6). The August sowing gave the highest TSW (325 g) and the October sowing the lowest (250.8 g), a 23% reduction. In response to pea genotype Midichi had a higher TSW (327.8 g) than Pro 7035 (251.7g). Herbicide had no significant effect on TSW. There was a sowing date x pea genotype interaction on TSW (Table 5.8). Midichi had a higher TSW than Pro 7035 at all sowings. However, the greatest difference (41%) was in the August sowing. In the October sowing the difference was only 22%.

5.5.6. Seeds Plant^{-1}

Herbicide sprayed peas produced more seeds plant^{-1} (20.52) than the unsprayed peas 16.58) and Pro 7035 produced significantly (p < 0.001) 53% more seeds plant^{-1} than Midichi. Sowing date had no effect on the number of seeds plant^{-1}.

Table 5 6: Yield components of field peas grown in Canterbury in the 2007/08 growing season.

	Plants m^{-2}	Pods plant^{-1}	Seeds pod^{-1}	TSW (g)	Seeds plant^{-1}
Sowing date (S)					
August	116	4.73	3.82	325.0c	18.23
September	117	4.80	3.67	293.3b	18.20
October	97	4.82	3.89	250.8a	19.22
Significance	NS	NS	NS	***	NS
LSD	-	-	-	11.02	-
Herbicide (H)					
0 g a.i. ha^{-1}	107	4.47	3.65	295.0	16.58
500 g a.i. ha^{-1}	113	5.10	3.93	284.4	20.52
Significance	NS	*	NS	NS	*
LSD	-	0.52	-	-	3.19
Pea genotype (T)					
Midichi	107	4.36	3.32	327.8	14.68
Pro 7035	113	5.21	4.26	251.7	22.42
Significance	NS	**	***	***	***
LSD	-	0.52	0.39	13.07	3.19
CV (%)	12.0	15.4	14.6	6.4	24.6
Significant interactions	SxH*	Nil	Nil	SxT**	Nil

Table 5.7: The sowing date x herbicide interaction on plant population (plants m^{-2}) of field peas grown in Canterbury in the 2007/08 growing season.

	Sowing date		
Herbicide	August	September	October
0 g a.i. ha^{-1}	120bc	107ab	93.0a
500 g a.i. ha^{-1}	111ab	127c	100.7ab
Significance		*	
LSD		21.5	
CV (%)		12.0	

Table 5.8: The sowing date x pea genotype interaction on the TSW (g) of field peas grown in Canterbury in the 2007/08 growing season.

	Sowing date		
Type	August	September	October
Midichi	380.0d	328.0c	275.0b
Pro 7035	270.0b	258.3b	226.7a
Significance		**	
LSD		17.82	
CV (%)		6.4	

5.4.5. DM Accumulation and Functional Growth Analysis

Generally, DM accumulation was slow at the early stages of growth, followed by an exponential growth phase and then a lag again giving a typical sigmoid growth curve (Figures 5.3 – 5.5). No treatment affected the maximum DM and it ranged from 1061 to 1260 g m^{-2} (Table 5.9). A significant ($p < 0.05$) herbicide x pea genotype interaction showed that the maximum DM of Pro 7035 was similar in the cyanazine sprayed and unsprayed peas (Table 5.10). However the max DM of cyanazine sprayed Midichi plots was 31% higher than that of the unsprayed ones. No treatment affected the weighted mean absolute growth rate (WMAGR). The overall mean was 18.3 g m^{-2} day^{-1} (Table 5.9). However, a significant ($p < 0.05$) herbicide x pea genotype interaction showed that Pro 7035 grew 55% faster than Midichi in unsprayed plots but they had an almost equal WMAGR in sprayed plots (Table 5.11). While sowing date and pea genotype did not influence maximum crop growth rate (C_m), sprayed plots had 21% higher maximum growth rate (at 34 g m^{-2} day^{-1}) than the unsprayed ones and there was a significant herbicide x pea genotype interaction (Table 5.12). As with WMAGR Pro 7035 and Midichi had a higher C_m, in unsprayed plots than in sprayed plots (25 and 13% respectively). No treatments affected the duration of exponential growth (DUR) and it ranged from 65 – 72 d.
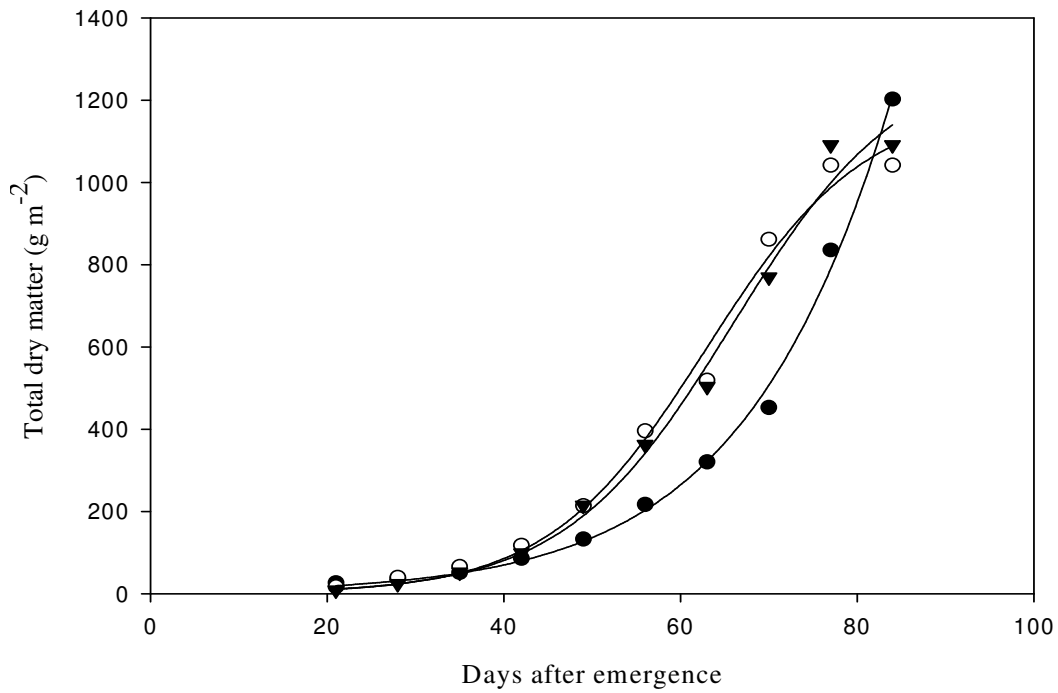
Figure 5.3: Total dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, sowing date.

($\bullet$) = August sowing, $Y = 1660 / (1 + 1.99 \exp(-0.12(x-83.59)))^{1/1.99}$

($\circ$) = September sowing $Y = 1116 / (1 + 1.27 \exp(-0.12(x-63.42)))^{1/1.27}$

($\blacktriangledown$) = October sowing $Y = 1325 / (1 + 0.56 \exp(-0.08(x-64.8)))^{1/0.56}$

Figure 5.4: Total dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, variety.

($\bullet$) = Midichi, $Y = 884 / (1 + 5.21 \exp(-0.24(x-89.6)))^{1/5.21}$

($\circ$) = Pro 7035 $Y = 975.16 / (1 + 2.18 \exp(-0.11(x-92)))^{1/2.18}$

Figure 5.5: Total dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, herbicide.

$(\bullet)$ = Unsprayed $Y = 838 / (1 + 3.32 \exp(-0.16(x-88.9)))^{1/3.32}$

$(\circ)$ = Sprayed, $Y = 938.5 / (1 + 3.03 \exp(-0.14(x-91.11)))^{1/3.03}$

Table 5.9: Functional growth analysis of field peas grown in Canterbury in the 2007/08 growing season.

	Max DM (g m^{-2})	WMAGR (g m^{-2}d^{-1})	C_m (g m^{-2}d^{-1})	DUR (d)
Sowing date (S)				
August	1260	18.58	33.1	71.8
September	1061	18.72	32.7	58.4
October	1161	17.67	27.4	65.0
Significance	NS	NS	NS	NS
LSD	-	-	-	-
Herbicide (H)				
0 g a.i. ha^{-1}	1106	16.92	28.2	67.8
500 g a.i. ha^{-1}	1215	19.74	34.0	62.3
Significance	NS	NS	*	NS
LSD	-	-	4.5	-
Pea genotype (T)				
Midichi	1161	16.68	30.6	71.5
Pro 7035	1161	19.98	31.6	58.6
Significance	NS	NS	NS	NS
LSD	-	-	-	-
CV (%)	19.2	29.7	20.3	30.3
Significant interactions	HxT*	HxT*	HxT*	Nil

WMAGR = Weighted mean absolute growth rate
DUR = Duration of exponential growth
C_m = Maximum growth rate
Max DM = Maximum dry matter

Table 5.10: The herbicide x pea genotype interaction on maximum dry matter of field peas grown in Canterbury in the 2007/08 growing season (g m^{-2}).

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
Midichi	1006a	1315b
Pro 7035	1206ab	1115ab
Significance	*	
LSD	221	
CV (%)	19.2	

Table 5.11: The herbicide x pea genotype interaction on weighted mean absolute growth rate (WMAGR) of field peas grown in Canterbury in the 2007/08 growing season (g m^{-2} day^{-1}).

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
Midichi	13.26a	20.09b
Pro 7035	20.58b	19.38b
Significance	*	
LSD	5.39	
CV (%)	29.7	

Table 5.12: The herbicide x pea genotype interaction on maximum growth rate (C_m) of field peas grown in Canterbury in the 2007/08 growing season.

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
Midichi	25.0a	36.1b
Pro 7035	31.3b	31.9b
Significance	*	
LSD	6.30	
CV (%)	20.3	

5.6. Pea Leaf Area Index over Time

Accumulation of leaf area was sigmoidal in shape (Figure 5.6). Spayed peas had a higher mean LAI throughout the season except at 50 and 110 DAE when it was lower than in unsprayed plots. The difference in the mean LAI for Midichi and Pro 7035 was not significant (mean Midichi 4.9 and Pro 7035 4.5 NS) throughout the season.

A LAI of 2.7 was required to intercept 95% of photosynthetically active radiation regardless of sowing date (Figure 5.7).
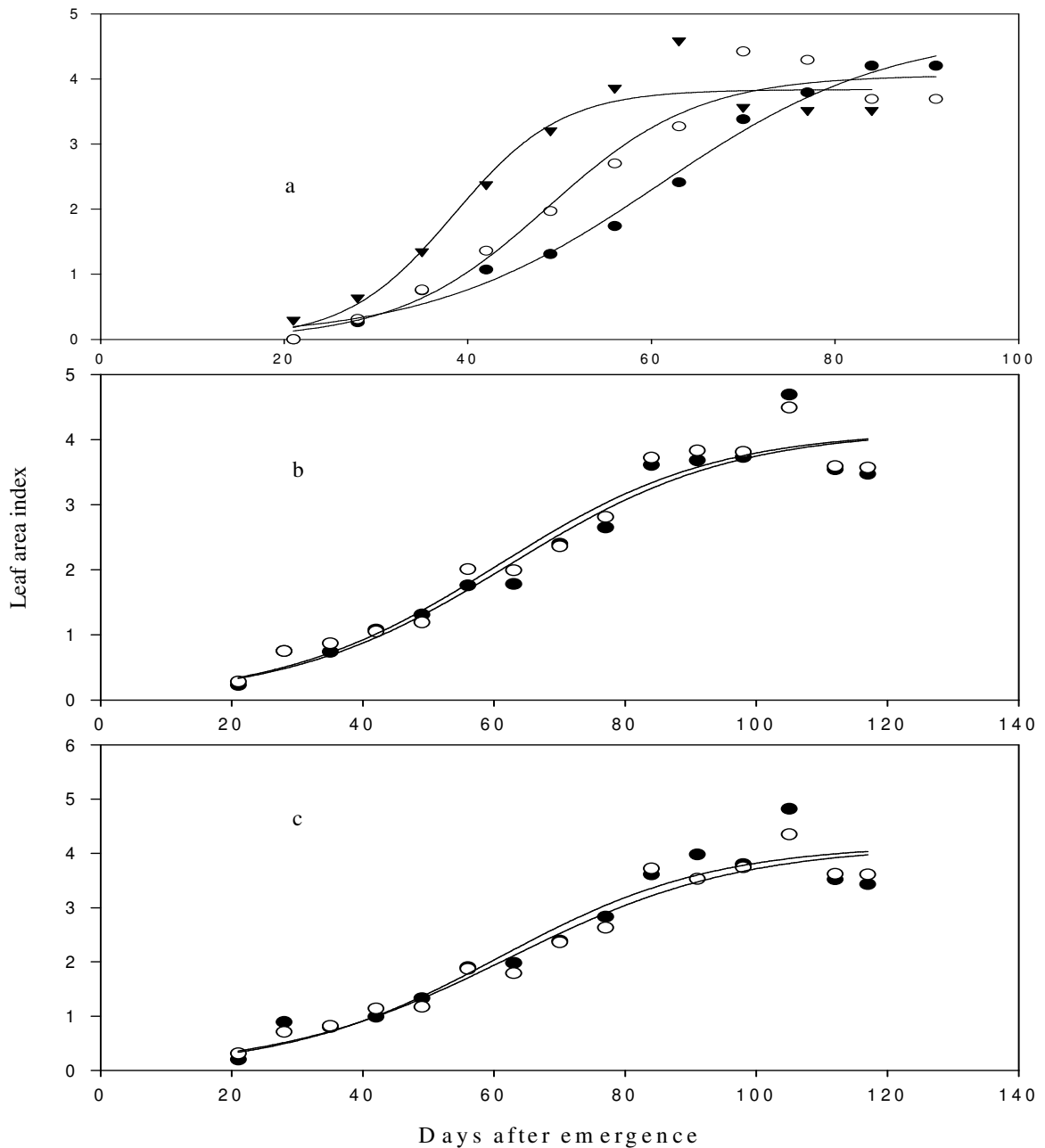
Figure 5.6: Leaf area index accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, sowing date.

a

($\bullet$) = August sowing, $Y = 5.32 / (1 + 0.01 \exp (-0.04(x-49)))^{1/0.01}$

($\circ$) = September sowing, $Y = 4.36 / (1 + 0.33 \exp (-0.08(x-39.69)))^{1/0.33}$

($\blacktriangledown$) = October sowing, $Y = 3.81 / (1 + 2.04 \exp (-0.22(x-40.82)))^{1/2.03}$

b

$\bullet$) = Unsprayed, $Y = 4.58 / (1 + 0.12 \exp (-0.03(x-58)))^{1/0.12}$

($\circ$) = Sprayed, $Y = 4.32 / (1 + 0.48 \exp (-0.04(x-59)))^{1/0.48}$

c

($\bullet$) = Midichi, $Y = 4.45 / (1 + 0.01 \exp (-0.03(x-53.6)))^{1/0.01}$

($\circ$) = Pro 7035, $Y = 4.13 / (1 + 1.06 \exp (-0.06(x-64)))^{1/1.06}$
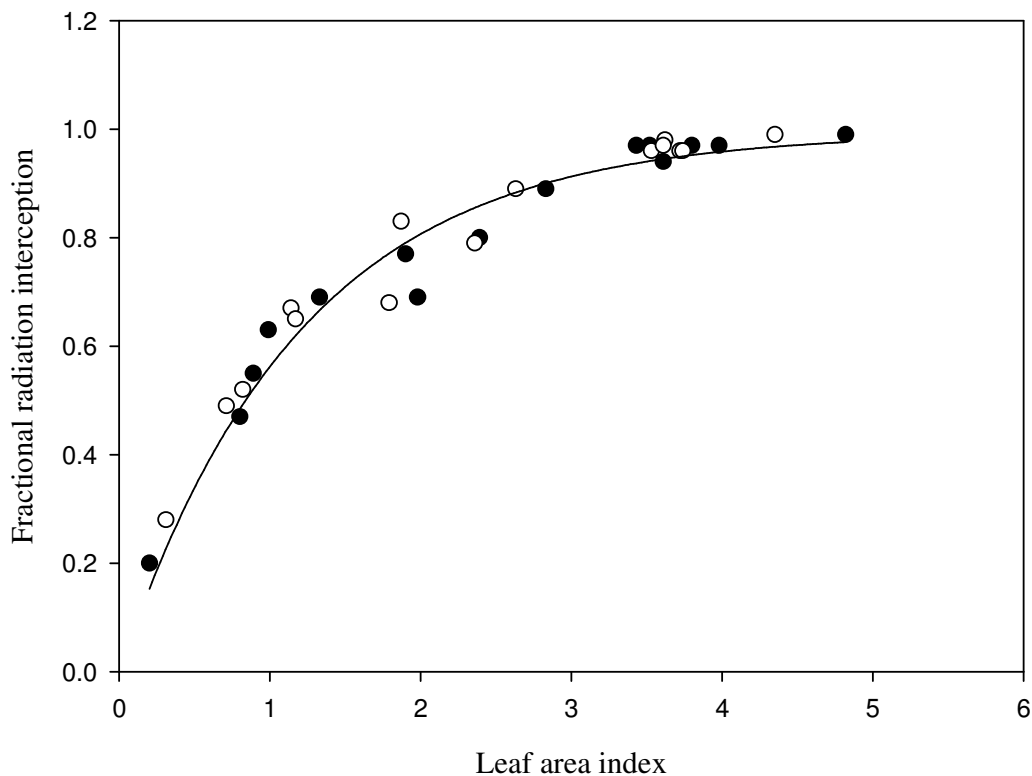
Figure 5.7: Radiation interception and LAI of field peas, over time, grown in Canterbury in the 2007/08 growing season, variety. (●) = Midichi, (○) = Pro 7035 R^2 = 0.98

5.7. Total Radiation Interception

The August sowing had the highest total radiation interception (622.1 MJ m^{-2}) followed by the September sowing (612.9 MJ m^{-2}) (Table 5.13). The October sowing had the lowest at 531.2 MJ m^{-2}. No other factor affected total radiation interception and there were no significant interactions (Table 5.13).

5.8. Radiation Use Efficiency (RUE)

Sowing date did not affect RUE and it ranged from 1.79 g MJ^{-1} in the August sowing to 1.94 g MJ^{-1} in the October sowing (Table 5.13). The two pea genotypes had a similar RUE (mean 1.85 g MJ^{-1}). Sprayed plots had a 12% higher RUE than unsprayed plots. There was a herbicide x pea genotype interaction on RUE (Table 5.14). The mean RUEs of sprayed and unsprayed Pro 7035 plots were not significantly different. However, herbicide sprayed Midichi plots had a 29% higher RUE than unsprayed plots.

Table 5.13: Total radiation interception and radiation use efficiency (RUE) of field peas grown in Canterbury in the 2007/08 growing season.

	Total Radiation Interception (MJ m^{-2})	RUE (g MJ^{-1})
Sowing date (S)		
August	622.1	1.79
September	612.9	1.81
October	531.2	1.94
Significance	*	NS
LSD	51.5	-
Herbicide (H)		
0 g a.i. ha^{-1}	593.1	1.74
500 g a.i. ha^{-1}	584.3	1.95
Significance	NS	*
LSD	-	0.17
Pea genotype (T)		
Midichi	589.0	1.85
Pro 7035	588.4	1.84
Significance	NS	NS
LSD	-	-
CV (%)	4.8	13.4
Significant interactions	Nil	HxT**

Table 5.14: The herbicide x pea genotype interaction on RUE of field peas, grown in Canterbury in the 2007/08 growing season (g MJ^{-1}).

|	Herbicide	
	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
Pea genotype		
Midichi	1.61a	2.08c
Pro 7035	1.87bc	1.81ab
Significance	*	
LSD	0.25	
CV (%)	13.4	
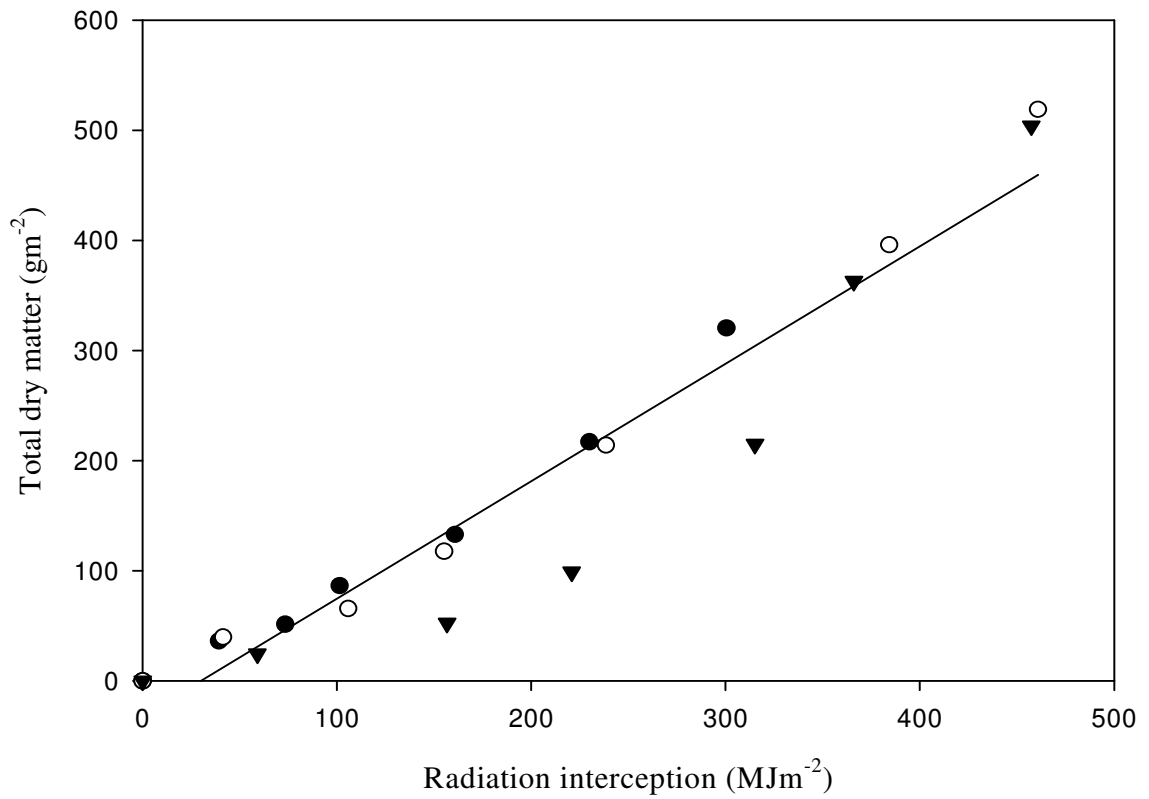
Figure 5.8: Radiation interception and DM accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, sowing date. ($\bullet$) = August sowing,

($\circ$) = September sowing, ($\blacktriangledown$) = October sowing.

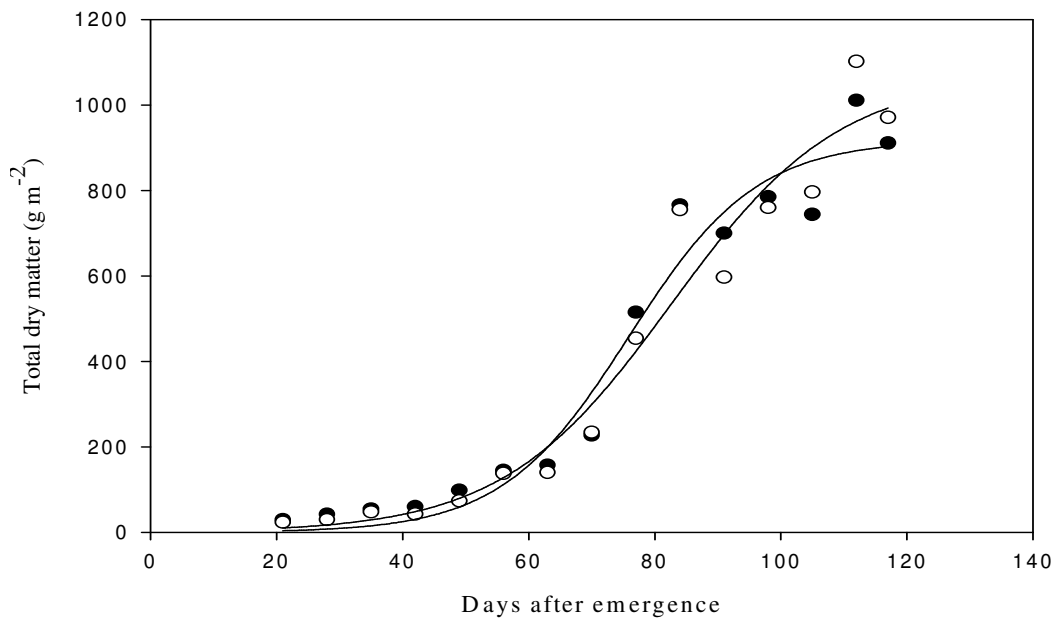$Y = -31.94 + 1.1 \, X \quad R^2 = 0.93$
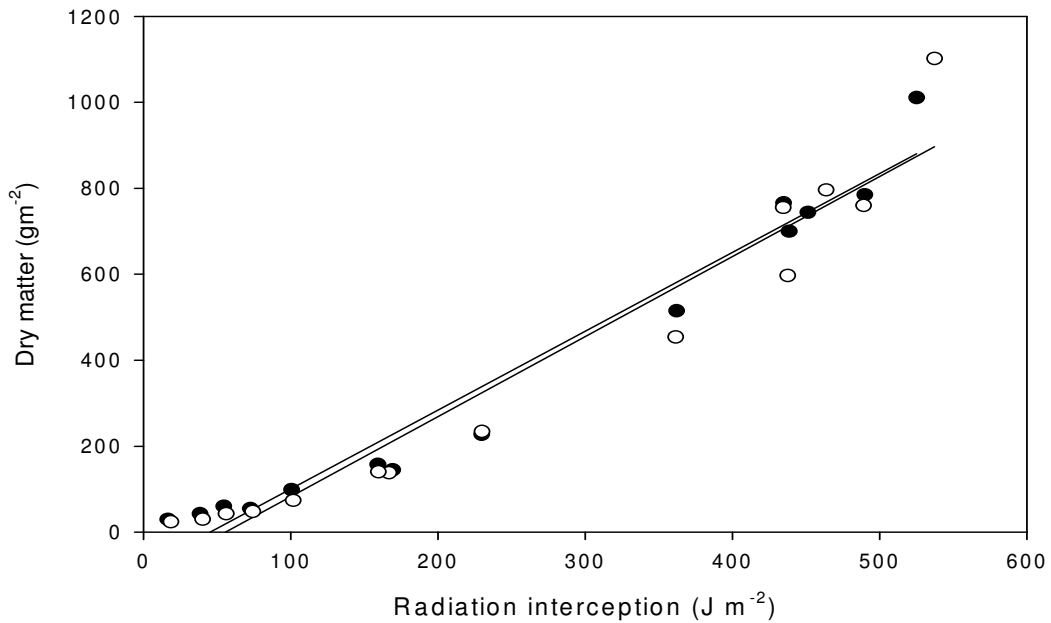
Figure 5.9: Radiation interception and DM accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, variety.

($\bullet$) = Midichi, Y= -83+ 1.84X R^2 = 0.96

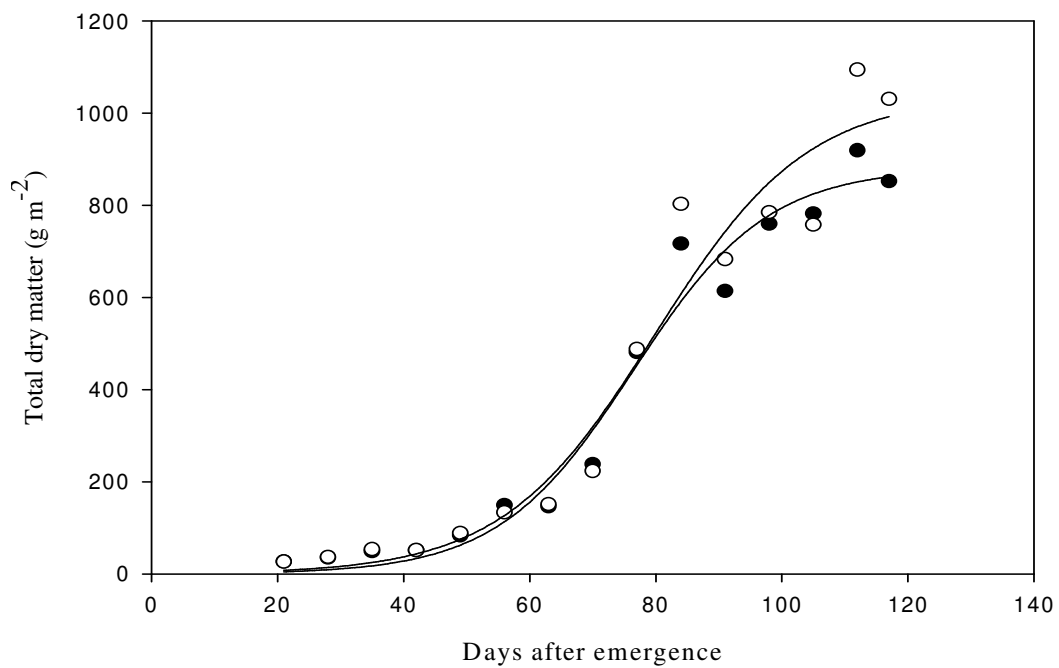($\circ$) = Pro 7035, Y= -102+ 1.87X R^2 = 0.93
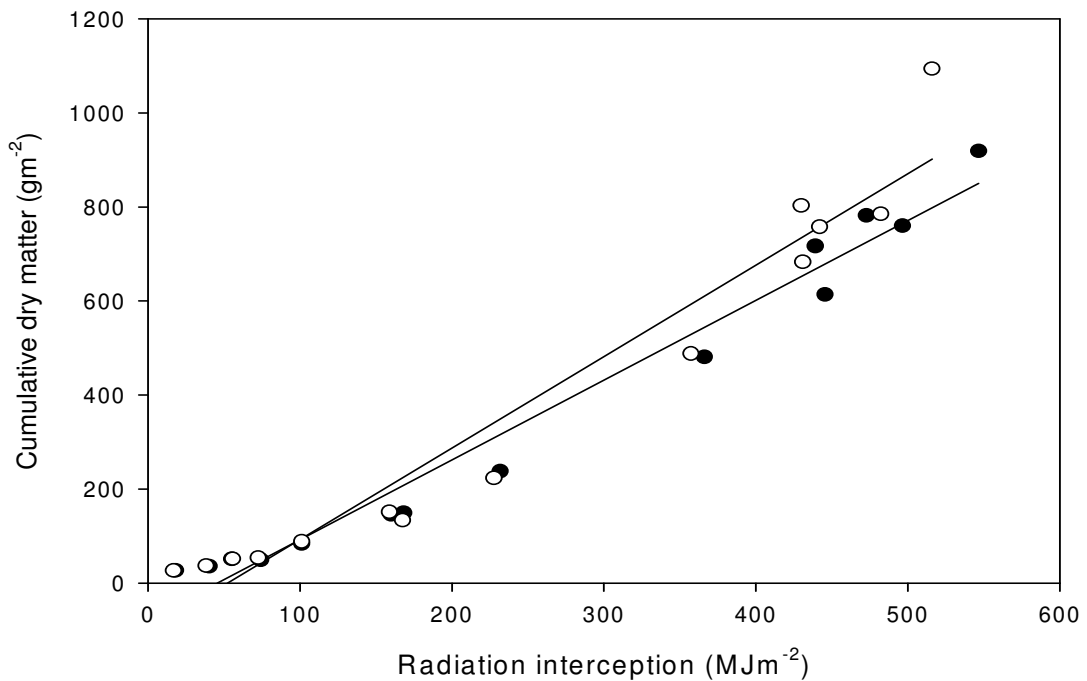
Figure 5.10: Radiation interception and DM accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, herbicide.

($\bullet$) = Unsprayed, Y= -77+ 1.7X R^2 = 0.97

($\circ$) = Sprayed, Y= -101+ 1.94X R^2 = 0.94

5.9. Weed Spectrum

Weed counts were taken three times during the growing season and there was distinct variation in the weed spectrum over time. A weed species was defined as major if it had a mean count of at least 10 m^{-2} and as a minor weed if it had a mean count of at least 2 plants m^{-2} but less than 10 plants m^{-2} (Table 5.15). A weed species was defined as 'Others' if it had a mean of less than 2 counts m^{-2} and these were bulk-counted together. In the October count major weeds were *Coronopus* spp*., Lolium* spp*., Spergular arvensis* (spurrey), *Stellaria media* (chickweed), *Stachys* spp. (Stagger weed) and *Achillea millefolium* (yarrow) was a minor weed. Others species present were *Rumex* spp, *Chenopodium* spp and *Cirsium arvense*. Pea genotype had no effect on counts of all weeds or total count. However, sprayed plots had significantly lower weed counts than unsprayed plots of all but one major weed species and on a minor weed counted *Achillea millefolium*. There were no significant interactions of any of the treatments in the October counts (Table 5.16).

Major weeds in November were *Coronopus* spp., *Stellaria media* (chickweed), *Urtica urens* (nettle), *Rumex* spp. (docks) and *Capsella bursa-pastoris* (shepherd's purse) with means of 38, 18, 14, 19 and 6 plants m^{-2} respectively (Table 5.17). Minor weeds were *Lolium* spp*., Spergular arvensis*, *Dactylis glomerata*, and *Chenopodium* spp. Other weeds present were *Erodium cicutarium* (storksbill), *Cirsium arvense* (Californian thistle), *Taraxacum officinale* (dandelion) *Ranunculus* sp. (Buttercup), *Polygonum aviculare*, *Hordeum murinum* (barley grass), *Bromus willdenowii* (prairie grass), and *Avena fatua*. Generally there were lower weed counts in sprayed than in unsprayed plots and there were several significant herbicide x pea genotype interactions on most major weeds (Appendices 2 – 6). To summarise the interactions, the difference in weed counts between the cyanazine sprayed plots and unsprayed was highest in the no pea control plots, followed by Midichi plots and the lowest was in Pro 7035.

In December weeds recorded as major were *Coronopus* spp*., Chenopodium* spp. *Rumex* spp*., Lolium* spp*., Stellaria media* (chickweed), *Solanum* spp., and *Trifolium repens*. There were no minor weeds and the 'other' weeds were *Erodium cicutarium* (storksbill), *Polygonum convolvulus* (cornbind), *Galium aparine* (cleavers), *Vicia sativa* (vetch), *Poa annua* (annual poa), *Festuca arundinacea* (tall fescue), *Elytrigia repens* (couch), *Taraxacum officinale* (dandelion) and *Avena fatua* (wild oat) (Table 5.18).

As in October, pea genotype did not influence weed counts of any weed. Herbicide had no effect on weeds counted except for *Coronopus* spp*.,* and *Rumex* spp., where unsprayed plots had nearly three and eight times higher counts respectively than sprayed plots.

Table 5.15: Classification of weeds found in field peas in Canterbury in the 2007/8 growing season (Counts m^{-2}).

	October count	November count	December count
Major weeds (> 10)	*Coronopus didymus* *Stellaria media* *Stachys* spp *Spergular arvensis* *Lolium* spp *Spergular arvensis*	*Coronopus didymus* *Stellaria media* *Chenopodium* spp *Urtica urens* *Rumex* spp	*Coronopus didymus* *Stellaria media* *Chenopodium* spp *Rumex* spp *Lolium* spp *Trifolium* spp *Solanum* spp
Minor weeds (10 > x > 2	*Achillea millefolium*	*Lolium* spp *Spergular arvensis* *Achillea millefolium* *Capsella bursa-pastoris*	None
Others (<2)	*Rumex* *Chenopodium* spp *Cirsium arvense.*	*Avena fatua* *Polygonum aviculare* *Taraxacum 0fficinale* *Erodium cicutarium* *Cirsium arvense* *Ranunculus* sp. *Hordeum murinum*	*Galium aparine* *Erodium cicutarium* *Poa annua* *Taraxacum officinale* *Avena fatua* *Elytrigia repens* *Vicia sativa* *Polygonum convolvulus*

5.10. Weed Biomass

There was no difference in weed DM accumulation in response to pea genotype up to 65 DAE (Figure 5.12). From then until harvest, the no pea treatment plots had the highest weed DM. There was more weed DM in unsprayed plots than in sprayed plots throughout the season (Figure 5.13).

Table 5.16: October weed counts (m^{-2}) in field peas grown in Canterbury in the 2007/08 growing season.

	Coronopus spp.	Lolium spp	Spergula arvensis	Stellaria media	Stachys spp.	Others	Achillea millefolium	Total count
Herbicide (H)								
0 g a.i. ha^{-1}	233	43	29	112	18.9	42	3	524
500 g a.i. ha^{-1}	39	9	1	40	3.3	19	2	116
Significance	***	***	**	*	NS	NS	NS	***
LSD	-	14	18	63	-	-	-	95
Type (T)								
No pea	128	20	13	68	15	33	5	282
Midichi	147	22	12	95	10	25	3	372
Pro 7035	133	37	20	65	8.3	33	0	307
Significance	NS	NS	NS	NS	NS	NS	NS	NS
LSD	-	-	-	-	-	-	-	-
Grand mean	136	26	15	76	11	31	3	320
CV (%)	45	52	112	78	160	67	204	28
Significant interactions	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

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Table 5.17: November weed counts (m^{-2}) of field peas grown in Canterbury in the 2007/08 growing season.

	Coronopus spp.	Lolium spp	Spergula arvensis	Stellaria media	Chenopodium spp	Achillea millefolium	Urtica urens	Rumex spp	Capsella bursa-pastoris	Others	Total count
Herbicide (H)											
0 g a.i. ha^{-1}	64	2	7	34	13	1	22	35	10	22	209
500 g a.i. ha^{-1}	12	3	1	2	4	2	6	3	2	21	55
Significance	***	NS	*	***	*	NS	***	***	*	NS	***
LSD	11	-	5	7	9	-	5	6	6	-	26
Type (T)											
No Pea	59	2	7	17	17	1	19	30.6	6	26	184
Midichi	21	3	3	22	3	2	22	16	1	8	101
Pro 7035	34	1	2	16	6	2	1	9	11	29	111
Significance	***	NS	NS	NS	***	NS	***	***	*	**	***
LSD	14	-	-	-	11	-	6	7	8	13	32
Grand mean	38	2	4	18	8	2	14	19	6	21	132
CV (%)	54	134	231	71	199	299	67	55	187	90	36
Significant interactions	HxT*	HxT*	Nil	HxT*	Nil	Nil	HxT***	HxT***	Nil	HxT**	HxT**

Table 5.18: December weed counts (m^{-2}) of field peas grown in Canterbury in 2007/08 growing season.

	Coronopus spp.	Chenopodium spp.	Rumex spp.	Lolium spp.	Stellaria media	Solanum spp	Trifolium spp	Others	Total counts
Herbicide (H)									
0 g a.i. ha^{-1}	61	17	26	20	19	27	66	31	266
500 g a.i. ha^{-1}	22	7	3	9	9	8	27	9	93
Significance	**	NS	***	NS	NS	NS	NS	NS	*
LSD	23	-	10	-	-	-	-	-	105
Type (T)									
No pea	53	12	18	5	12	23	77	20	220
Midichi	40	15	17	23	10	15	10	18	148
Pro 7035	32	8	8	15	20	13	52	22	170
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD	-	-	-	-	-	-	-	-	-
Grand mean	42	12	14	14	14	17	46	20	179
CV (%)	54	172	148	148	155	137	144	129	56
Significant interactions	Nil	Nil	HxT*	Nil	Nil	Nil	Nil	Nil	Nil
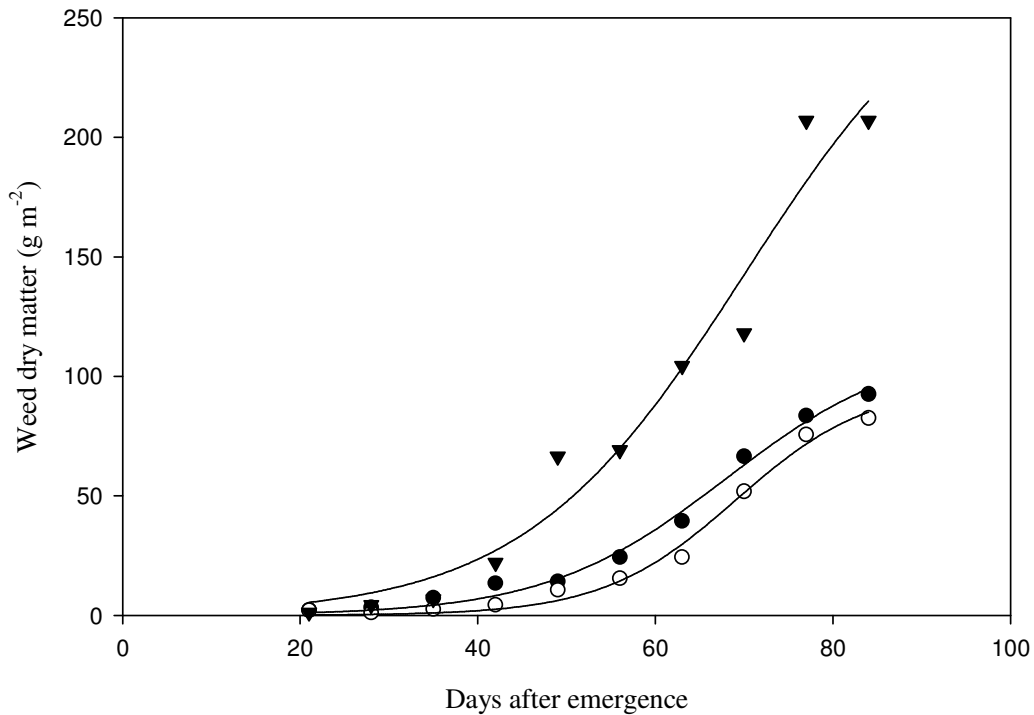
Figure 5.11: Weed dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, sowing date.

($\bullet$) = August sowing, $Y = 778 / (1 + 0.01 \exp (-0.004(x-874)))^{1/0.01}$
($\circ$) = September sowing, $Y = 81.5 / (1 + 5.73 \exp (-0.6(x-65)))^{1/5.73}$
($\blacktriangledown$) = October sowing, $Y = 180 / (1 + 0.26 \exp (-0.09(x-48)))^{1/0.26}$
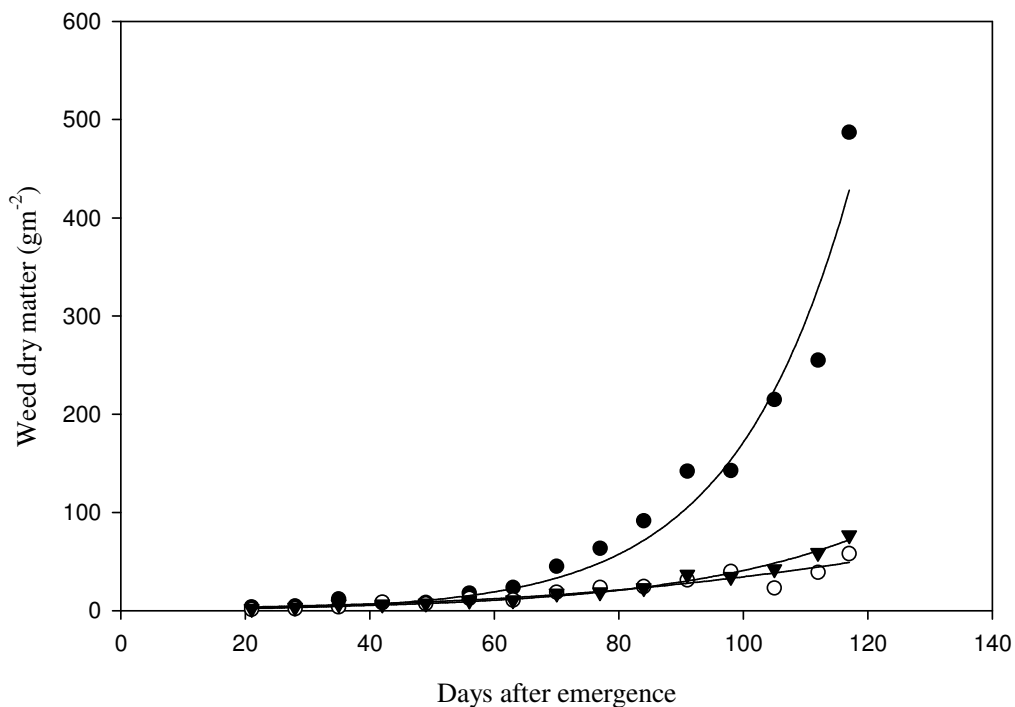
Figure 5.12: Weed dry matter accumulation of field pea over time grown in Canterbury in the 2007/08 growing season, variety.

($\bullet$) = No pea, $Y = 449 / (1 + 4.5 \exp (-0.26(x-106)))^{1/4.5}$
($\circ$) = Midichi, $Y = 84.6 / (1 + 0.01 \exp (-0.02(x-93.3)))^{1/0.01}$
($\blacktriangledown$) = Pro 7035, $Y = 65.7 / (1 + 3.34 \exp (-0.13(x-94.28)))^{1/3.34}$
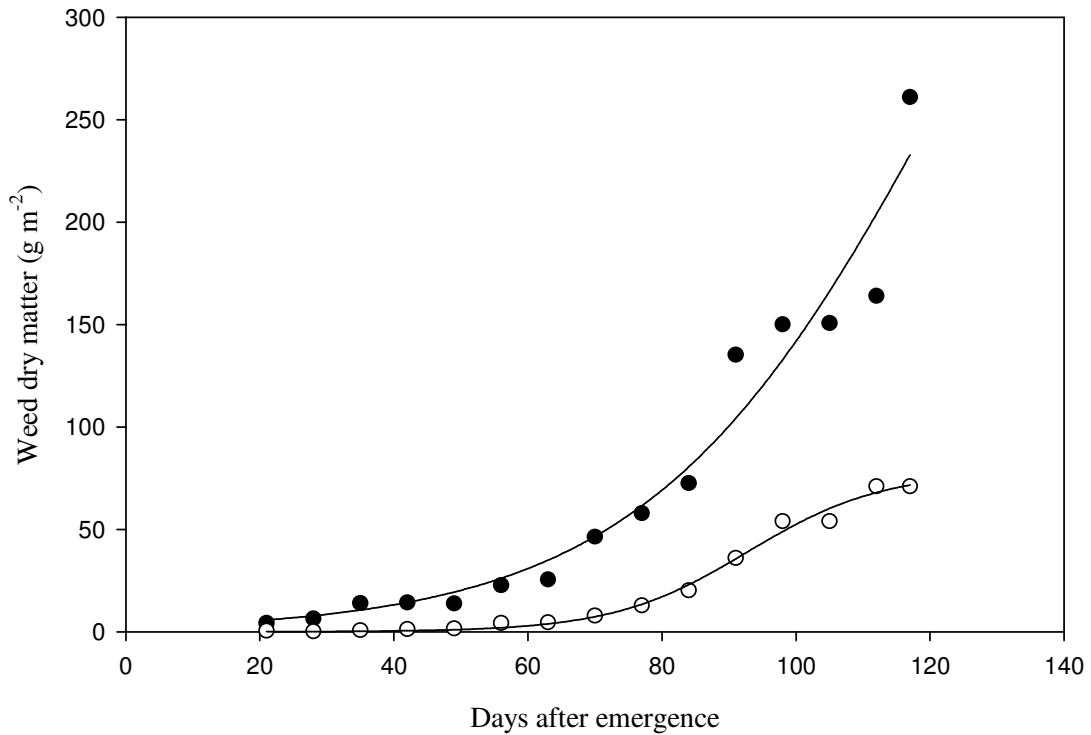
Figure 5.13: Weed dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, herbicide.
($\bullet$) = Unsprayed, $Y = 305.58 / (1 + 2.23 \exp(-0.11(x-102)))^{1/2.2}$
($\circ$) = Sprayed, $Y = 463 / (1 + 0.01 \exp(-0.01(x-251)))^{1/0.01}$

5.11. Discussion

5.11.1. Pea Yield

McKenzie (1987) reported that in temperate countries with even, dependable rainfall, early sowing allows crops to produce large plants which can produce and support many pods, and which intercept maximum solar radiation through longer duration and more rapid early spring growth. The results of this experiment support this but explain it from a slightly different viewpoint. The August sowing gave the highest seed yield (572 g m^{-2}), which was 62% more than the lowest yield in October. This was due to higher total radiation interception accumulated in August. Taweekul (1999) reported similar results on the positive influence of early sowing of peas. Her September sown peas yielded 521 g m^{-2}, which was 90% more than a November sowing.

In this experiment, the August sowing accumulated the most intercepted radiation as a result of the highest the leaf area per unit ground area (LAI). Solar radiation intercepted by a crop depends on the LAI because leaves are the primary photosynthetic organs of plants. The LAI of a crop and plant canopy architecture determine the amount of light intercepted, which is directly related to total DM production (McKenzie, 1987; Sinclair and Muchow, 1999). This in turn can influence seed yield (Muchow *et al.*, 1993). The higher yield associated with the earlier sowing in this experiment was primarily due to increased radiation interception because sowing date had no effect on RUE. The RUE ranged from 1.79 g MJ^{-1} in August to 1.94 g MJ^{-1} in October.

Weed competition seems to have played a crucial role that also affected crop yield in this experiment. That this competition influenced RUE is indicated by sprayed plots having a 12% greater RUE than the unsprayed plots meaning they experienced less weed competition and hence increased radiation conversion efficiency. A reduction in RUE suggests that some competitive pressure of the weeds were below ground e.g. for nutrients and water and that this competition probably reduced photosynthesis.

Pea genotype alone did not affect RUE. This is contrary to the belief that semi leafless peas have an inferior conversion of radiation to DM. This supports Martin *et al.* (1992), who showed that at similar densities, all pea phenotypes converted intercepted radiation into DM with equal photosynthetic efficiency and that the foliage of leafless peas was not a photosynthetic disadvantage. However, the herbicide x genotype interaction on RUE reported here was of paramount importance and helps to explain the crop-weed competition effect on radiation partitioning and hence the effect on crop yield. The mean RUE of herbicide sprayed and unsprayed Pro 7035 plots were not significantly different and this was because of its fully leafed morphology, which gave it greater ability to suppress weeds. Herbicide sprayed Midichi plots had a 29% higher RUE than unsprayed plots. Unsprayed Midichi was disadvantaged by weed competition because of its semi-leafless morphology and hence less ability to smother weeds. Because of the lower weed competition in sprayed Midichi plots it converted PAR into TDM with greater efficiency. A similar herbicide x genotype interaction affected WMAGR and maximum growth rates as will be explained below.

The relationship between TDM and radiation interception was linear with an r^2 of 0.93 to 0.97 and RUEs ranged from 1.79 – 1.94 g MJ^{-1}. Some workers reported similar linear relationships. Wilson *et al.* (1985) showed that cumulative DM production

in peas was linearly related to the amount of PAR intercepted by the crop. They obtained a value of 2.36 g MJ^{-1} for RUE. Heath and Hebblethwaite, (1985b) reported a lower RUE for peas (1.46 g MJ^{-1}). Martin and Jamieson (1996) got an RUE of 1.79 g MJ^{-1} and RUEs were in a range of 1.0 – 2.5 g MJ^{-1} in Zain *et al.* (1983) for a range of irrigation and sowing date treatments. McKenzie and Hill (1991) reported the RUE of lentil to be in a range of 1.6 – 1.8 g MJ^{-1}. Similarly, McKenzie (1987) reported RUEs of 2.05 and 1.51 in irrigated and unirrigated lentil respectively.

Environmental effects such as temperature might have caused the difference in the yield at the different sowing dates. The last sowing date had the lowest yield probably because the canopy did not last long due to the relatively higher temperatures and higher weed competition. The canopies of the earlier sowings (August and September) had a greater competitive advantage over weeds, which were fewer early in the season. This led to earlier canopy closure and hence increased radiation interception. McKenzie *et al.* (1986) had similar results with lentils where late sowing depressed lentil seed yield from 3.3 t ha^{-1} to 0.5t ha^{-1}. This was due to decreased radiation interception.

A significant ($p < 0.05$) sowing date x genotype interaction showed that in the August sowing genotype had no effect on seed yield. However in September sown plots the Pro 7035 seed yield of 559 g m^{-2} was 40% more than that Midichi. By October it was 87% more. This highlights the need to select a suitable genotype to use at different times in the season. Early in the season both genotypes could be used without yield reduction but as the season progressed it was better to use a fully leafed genotype to smother the increased weed spectrum and numbers associated with the later sowing date, although both pea types were significantly better than the control no pea plots. The more competitive ability of Pro 7035 is most likely because of early canopy closure.

Genotype had no effect on seed yield in August because there were fewer weeds, which were slow growing with the low temperatures. This gave both pea genotypes (base temperature 4 ^{o}C) the same competitive advantage over the weeds and hence the effect of weeds was not evident in that sowing. However, there was an increase in weed spectrum and quantity as the season progressed possibly attributable to increased temperatures so the effect of weeds and the differences in pea competitive ability against them of the different genotypes became evident.

Pro7035 achieved a higher CHI and PHI (Table 5.2) than Midichi and that resulted in the higher seed yield even though total DM was not affected. On the other

hand herbicide was effective in reducing weeds. Sprayed plots had a mean seed yield of 508 g m^{-2}, which was 19% more than the mean of unsprayed plots. This shows the effect of weeds on crop yield through competition for nutrients, light, space, and water.

5.11.2. Functional Growth Analysis

Generally the high sowing rates required to obtain an acceptable yield per unit area of leafless peas can be interpreted as a requirement to increase crop growth rate (CGR), especially early in crop development (Hedley and Ambrose, 1981). By definition a crop growing at a maximum GR will have a high LAI, and it is the integral of the LAI over the growth period (leaf area duration) that is often related to biological crop yield (Donald, 1961). In this respect a low growth-rate crop will resemble a late-sown crop, where the integral of LAI will be reduced by the reduction in the growing season. Proctor (1963), claimed that this could be a reason why pea yields declined with sowings made progressively later in the growing season. In this experiment sowing date did not affect WMAGR and the overall mean was 18.3 g m^{-2} day^{-1}. Similarly, Greven, (2000) reported no sowing date effect on the WMAGR of *Phaseolus vulgaris* grown in Canterbury.

The significant (p < 0.05) herbicide x genotype interaction showed that Pro 7035 grew 55% faster than Midichi in unsprayed plots but had a similar WMAGR in cyanine sprayed plots. This could be due to reduced competitive ability of semi-leafless peas against weeds in later sowings because of its semi-leafless morphology. The leafed pea tended to outdo semi-leafless performance in the presence of weeds though their performance was similar in a weed free environment. While sowing date and pea type did not influence maximum crop growth rate (C_m), sprayed plots had a 21% faster maximum growth rate (34 g m^{-2} day^{-1}) than unsprayed plots and there was a herbicide x genotype interaction. The maximum growth rate of Midichi and Pro 7035 were similar in sprayed plots but Pro 7035 had a lot higher growth rate than Midichi in unsprayed plots. Sprayed plots probably grew faster because of less weed interference. Genotype did not affect DUR showing that fully leafed and semi-leafless pea canopies had almost similar growth habits.

Growth analysis showed no variates affected growth rates or DUR except for herbicide and the herbicide x genotype interaction. The factors that had the major effect were radiation interception (Table 5.12) for TDM and HI for seed yield (Table 5.2).

5.11.3. Weed Spectrum

There was variation in the weed spectrum during the growing season. Generally the most common weed species present were *Coronopus didymus, Stellaria media, Lolium* spp, *Stachys* spp, *Achillea millefolium*, *Spergula arvensis, Chenopodium* spp, *Rumex* spp, *Trifolium* spp and *Solanum* spp. This supports Isaac (2001) who reported that *Chenopodium album, Cirsium arvense, Rumex crispus, Capsella bursa-pastoris, Polygonum aviculare, Taraxacum officinale* and *Solanum nigrum* have become very successful weeds in Canterbury pastures and arable lands. In this experiment *Stellaria media* was found throughout the season. It grew well over a wide range of environments. Even early in the season, when temperatures were quite low, it was present in large numbers. This could be due to its low base temperature (-3.3^{o}C) (Storkey and Cussans, 2000). Soil temperature is a primary determinant of seed germination and survival, especially where soil freezes. Air and soil temperature are therefore important determinants of species distribution and ecological interactions. Zimdahl (2007) reported that common chickweed survives well in cold climates because it continues to grow in winter without injury. When the temperature is below freezing common chickweed is often erect, and it continues to flower although flowers are cleistogamous (without petals and closed) and the self-pollinated seeds formed are fertile. Similarly, Harker *et al.* (2007) reported that Red stem filaree (*Erodium* spp) germinated at relatively low soil temperatures and therefore could be a serious competitor of peas.

Another weed of similar interest recorded was *Chenopodium album. Chenopodium album* is one of the most widely distributed weed species in the world and ranks among the top three important weeds of cereals in New Zealand (White and Hill, 1999; Isaac 2001). It can grow to a height of 3 m if it grows in crops such as *Zea mays* L. and *Sorghum bicolour* L. where there is abundant nutrient and water availability. Contrary to the findings of Myers *et al.* (2004) that it is an early weed, in this research it was classified as a mid to late season weed.

Achillea millefolium was also classified as an early to mid season weed, and could have had a major role in reducing the yield of early sown peas. It is considered as a common, successful, aggressive weed on arable land in New Zealand and can cause significant crop losses in a variety of crops by choking them out by its dense growth (Bourdôt and Field, 1988). It is a European species and was introduced into New

Zealand as a pasture plant in the 1800's (Bourdôt and Butler, 1985). It was widely sown in the hill country along with grasses, clovers and other pasture species after scrub and forest clearance. It now occurs in lowland pastures and arable land, particularly in the South Island regions of Southland, Otago and Canterbury, where it can cause harvesting difficulties and yield loss in some crops. According to Kannangara and Field (1985), production of large quantities of seed in summer and autumn, conditional seed dormancy, and their survival when buried down the soil profile are characteristics that may enable yarrow to persist in cultivated arable land for several years. Seed shed in summer and autumn can germinate and form over wintering rosettes.

Hartley *et al.* (1984) reported that the success of this weed is also attributed to its persistent, vigorous rhizomes. Bourdôt and Butler (1985) reported that it grew throughout the year and spread laterally, by rhizome extension, particularly in the winter months in Canterbury. They also reported that its growth and development was restricted by competition from barley. Evidence for the competitive influence of barley was seen in the prolific flowering, which occurred in undrilled gaps in the crop. Barley grain yield increased from 2.91 t ha^{-1} when *A. millefolium* was not controlled to 4.23 t ha^{-1} with good control.

Weeds classified as late were *Trifolium repens and Solanum* spp. Nightshades have a base temperate of 6 ^{o}C (Olivier and Annandale, 1998) and this explains why they usually grow late in the season when temperatures are warmer. Myers *et al.* (2004) also reported nightshades were late weeds. Isaac (2001), reported higher *Trifolium repens* counts in late sown crops than in early sown crops confirming that it is a late weed.

It was also observed that grasses tended to be more prevalent later in the season than earlier. Isaac (2001) reported perennial weeds were more prevalent in late sown crops and these findings support this. These late weeds could do considerable damage to late sown peas. One such grass, *Avena fatua*, caused considerable damage to peas and is referred to as one of the greatest crop competitors of all. Contrary to this Blackshaw *et al.* (2007) reported *Avena fatua* emerged early in the spring in Canada and recommended producers delay seeding of spring sown crops to control the first flush of wild oat seedlings. However, they pointed out that this practice was seldom effective with weed community management because of the diversity of emergence patterns among different weed species.

5.13. Conclusions

- A fully leafed pea produced higher seed yields due to increased HI. However there was no difference in total DM produced.

- There was no difference in total radiation interception between the semi-leafless and the fully leafed pea genotypes.

- Early sowing was associated with greater total radiation accumulation.

- The weed spectrum changed as the season progressed.

- Early sowing could possibly control problem weeds of peas (particularly *Solanum* spp) by avoiding competition from this weed.

- Herbicide application enhanced crop yield but could be substituted for by early sowing and the use of an appropriate pea genotype.

- *Coronopus didymus, Stellaria media* and *Lolium* spp were present in relatively large numbers throughout the season hence they need to be watched throughout the growing season.

Chapter 6

6.0. Eco-Physiology of Pea-Weed Interactions

6.1. Introduction

Increased consumer awareness of food-safety issues and environmental concerns have contributed to the growth of organic farming over the last few years. This call for improved sustainable food production must rely on the major exploitation of native resources, e.g., solar energy, rain, atmospheric nitrogen, and soil organic matter (Caporali and Onnis, 1992). However, one of the greatest challenges, which organic farmers currently face, is sustainable weed control (Wall and Townley-Smith, 1996). Because weeds are active, not passive, participants in the agricultural environment, there is a need to understand them and their environment before attempting to control or manage them. Zimdahl, (2007) suggested that herbicide use has masked the importance of weed prevention and the need to understand weed-crop ecology. Ecology is the study of interactions between organisms and their environment (Zimdahl, 2007). Weed ecology, involves the relationship between weeds, their environment and the crop species involved (Booth *et al*., 2003). Successful weed management programs are developed on a foundation of an adequate ecological understanding.

One of the most fundamental components driving crop growth and its ecology is radiation interception. This in turn is affected by LAI and LAD and to a considerable extent leaf angle. In contrast to water and nutrients, light cannot be stored for later use; it must be used when received or it is lost forever (Donald, 1963). The radiation received by any canopy is shared among the component plants of the canopy; in the case of this experiment peas and weeds. To obtain maximum yield, the crop should competitively acquire as much leaf area early in its growth and achieve maximum canopy cover earlier to intercept as much radiation as possible. Early canopy closure enhances crop competitive ability.

Monteith (1977) showed that DM accumulation, in a range of crops, was strongly correlated to the amount of radiation intercepted. Similarly, Brougham (1956), working on mixed swards of short-rotation rye grass, red and white clovers found that pasture growth was related to the percentage of light intercepted, and leaf area while Zimdahl, (2007) showed that light intensity, quality and duration affected weed presence and survival. In a pea-weed mixture, radiation interception can be partitioned

to the component species and this helps to explain the competition experienced by each component species. This experiment was designed using a combination of a range of different pea and artificial weed populations to evaluate crop-weed interactions and to understand competition for incoming radiation between the crop and weeds.

The specific objectives of this experiment were to:

- Quantify crop-weed competition at different levels.
- Examine the interaction, if any, of pea population and weed population on crop yield and weed growth.
- Understand how radiation interception is partitioned to the component crop and weed canopies and explain how it relates to crop yield and weed growth.
- Evaluate the relationship between LAI, radiation interception as it influences TDM and crop seed yield and component weeds.

6.2. Materials and Methods

Only a brief description of the measurements is given. For other details see the materials and methods chapter (Chapter 3).

6.2.1. Crop and Weed Measurements

Leaf area index was measured non-destructively using a LICOR LAI 2000 Plant Canopy Analyser every 7 – 10 days throughout the growing season starting at two weeks after crop emergence. Two readings were taken randomly above and eight below the crop canopy from each plot. This was done on either a uniformly cloudy day or at dusk. Leaf area for both the crop and weeds was measured destructively using a LI-300 Area Meter four times during the growing season. A 0.2 m^2 sample was taken from each plot using a 0.1 m^2 quadrat every 7 – 10 days throughout the season starting from 3 weeks after crop emergence. The samples were used for measurements of pea and weed DM and leaf area. Samples were dried in a forced draught oven for 24 – 48 h at 60 ^{o}C to constant weight and then weighed. Yield and yield components were measured at final harvest. Yield components were measured using sub samples of 5 plants from each plot. Final harvests were taken when crops reached a moisture content of 15 – 18%.

6.3 Results

6.3.1. Total Dry Matter at Harvest

Total dry matter production was directly proportional to pea population. The highest TDM was achieved at 200 plants m^{-2} (1,120 g m^{-2}), which was more than twice the yield of the lowest pea population (513 g m^{-2}) with weed treatments. The no sown weed treatment gave the highest mean TDM (1,041 g m^{-2}). There was no difference in TDM between normal weed and the twice-normal sown artificial weed treatments (mean, 664 g m^{-2}) (Table 6.1).

6.3.2. Seed Yield

Seed yield increased significantly (p < 0.001) as pea population increased. Two hundred pea plants m^{-2} gave the highest mean seed yield at 409 g m^{-2} and 50 pea plants m^{-2} the lowest at 197 g m^{-2}. On the other hand the no-sown-weed treatment gave the highest mean seed yield of 390 g m^{-2}. There was no difference in seed yield between the normal weed and the twice-normal sown artificial weed treatments (mean, 255 g m^{-2}) (Table 6.1).

6.3.3. Crop Harvest Index and Plant Harvest Index

No factor significantly affected either CHI or PHI. The means were 0.39 and 0.29 respectively (Table 6.1).

6.4. Yield Components

6.4.1. Plant Population

At harvest all plant populations were slightly higher than the target populations (Table 6.2). In sown artificial weed treatments there was a mean of 136 pea plants m^{-2}.

6.4.2. Pods Plant^{-1}

The number of pods plant^{-1} was not affected by pea population with a mean of 3.39 pods plant^{-1}. The no sown weeds treatment had the highest number of pods plant^{-1} (4.07) and there was no significant difference between the two sown artificial weed treatments (mean, 3.05 pods plant^{-1}) (Table 6.2).

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Table 6.1: Total dry matter (g m^{-2}), seed yield (g m^{-2}), crop harvest index (CHI) and plant harvest index (PHI) at final harvest of field peas grown in Canterbury in the 2007/08 growing season.

	Total dry matter	Seed yield	CHI	PHI
Pea population (P) (plants m^{-2})				
50	513a	197a	0.39	0.30
100	735b	294b	0.40	0.30
200	1,120c	409c	0.37	0.28
Significance	***	***	NS	NS
LSD	200.4	71	-	-
Sown weed population (W)				
Nil	1,041b	390b	0.39	0.29
Normal rate	712a	284a	0.40	0.31
2 x Normal	616a	226a	0.37	0.28
Significance	***	***	NS	NS
LSD	200.4	71.0	-	-
CV (%)	25.4	23.7	10.4	12.8
Significant interactions	Nil	Nil	Nil	Nil

6.4.3. Seeds Pod^{-1}

The lowest pea population had the most seeds pod^{-1} (3.39). The two high population means were not significantly different from each other. The sown artificial weed treatments had no effect on the number seeds pod^{-1} (mean 3.03 seeds pod^{-1}) (Table 6.2).

6.4.4. Thousand Seed Weight

The sown artificial weed treatments had no effect on TSW. The highest TSW of 304.4 g was at 100 plants m^{-2}. The 50 and 200 plants m^{-2} populations had similar TSWs (Table 6.2).

6.4.5. Seeds Plant^{-1}

As with seeds pod^{-1}, the lowest population achieved the highest number of seeds plant^{-1} (12.58) and the highest two population means were not significantly different from each other. The highest mean number of seeds plant^{-1} (12.96) was in the no sown artificial weed treatment and the two sown weed treatment means were not significantly different from each other (mean 9.13 seeds plant^{-1}) (Table 6.2).

Table 6.2: Yield components of field peas grown in Canterbury in the 2007/08 growing season.

	Plants m^{-2}	Pods $plant^{-1}$	Seeds pod^{-1}	TSW (g)	Seeds $plant^{-1}$
Pea population (P) (plants m^{-2})					
50	56.7a	3.69	3.39b	283.3a	12.58b
100	121.1b	3.47	2.78a	304.4b	9.80a
200	231.1c	3.00	2.91a	281.1a	8.84a
Significance	***	NS	**	*	*
LSD	23.13	-	0.38	20.15	2.59
Sown weed population (W)					
Nil	147.8	4.07 b	3.16	298.9	12.96 b
Normal rate	126.7	3.20 a	3.15	290.0	10.20 a
2 x Normal	134.4	2.89 a	2.79	280.0	8.07 a
Significance	NS	**	NS	NS	**
LSD	-	0.60	-	-	2.59
CV (%)	17.0	17.7	12.5	7.0	24.9
Significant interactions	Nil	Nil	Nil	Nil	Nil

6.5. Total Dry Matter Accumulation over Time and Functional Growth Analysis

Throughout the season dry matter accumulation was directly proportional to pea population and growth curves for each population had a typical sigmoidal shape (Figure 6.1). The no-sown artificial weed treatment had the highest pea DM throughout the season. The normal and 2 x normal sown artificial weed treatments had similar DM accumulation throughout. However, the two were significantly different from the no sown artificial weed treatment (Figure 6.2). The highest WMAGR (18.4 g m^{-2} d^{-1}) was achieved at the highest pea population (200 plants m^{-2}) and the two lowest populations had no significant difference (mean 9.5 g m^{-2} d^{-1}) (Table 6.3). Sown artificial weed population did not affect WMAGR and the means ranged from 10.8 – 13.2 g m^{-2} d^{-1}. As with WMAGR, the highest C_m (29.1 g m^{-2} d^{-1}) was achieved at the highest pea population (200 plants m^{-2}) and the two lowest populations had no significant difference (mean 14.4 g m^{-2} d^{-1}) (Table 6.3). The sown artificial weed population treatment did not affect C_m and means ranged from 17.2 – 20.9 g m^{-2} d^{-1}.

The highest maximum DM was achieved at 200 plants m^{-2} (1,164 g m^{-2}) and the two lowest populations had similar maximum DM (mean 740 g m^{-2}). The no sown artificial weed treatment gave the highest mean maximum DM (1,169 g m^{-2}). There was no difference in maximum DM between the normal weed and the twice-normal sown artificial weed treatments (mean, 738 g m^{-2}) (Table 6.3). No factor significantly affected DUR and it ranged from 70 – 103 d.

Figure 6.1: Total dry matter accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, pea population.

($\bullet$) = 50 plants m^{-2}, Y = 632 / (1 + 0.44 exp (-0.05(x-65.2)))$^{1/0.44}$

($\circ$) = 100 plants m^{-2}, Y = 840 / (1 + 0.66 exp (-0.07(x-60.9)))$^{1/0.66}$

($\blacktriangledown$) = 200 plants m^{-2}, Y = 1215 / (1 + 0.91 exp (-0.08(x-59.6)))$^{1/0.91}$
(Bars are LSD at $p < 0.05$).
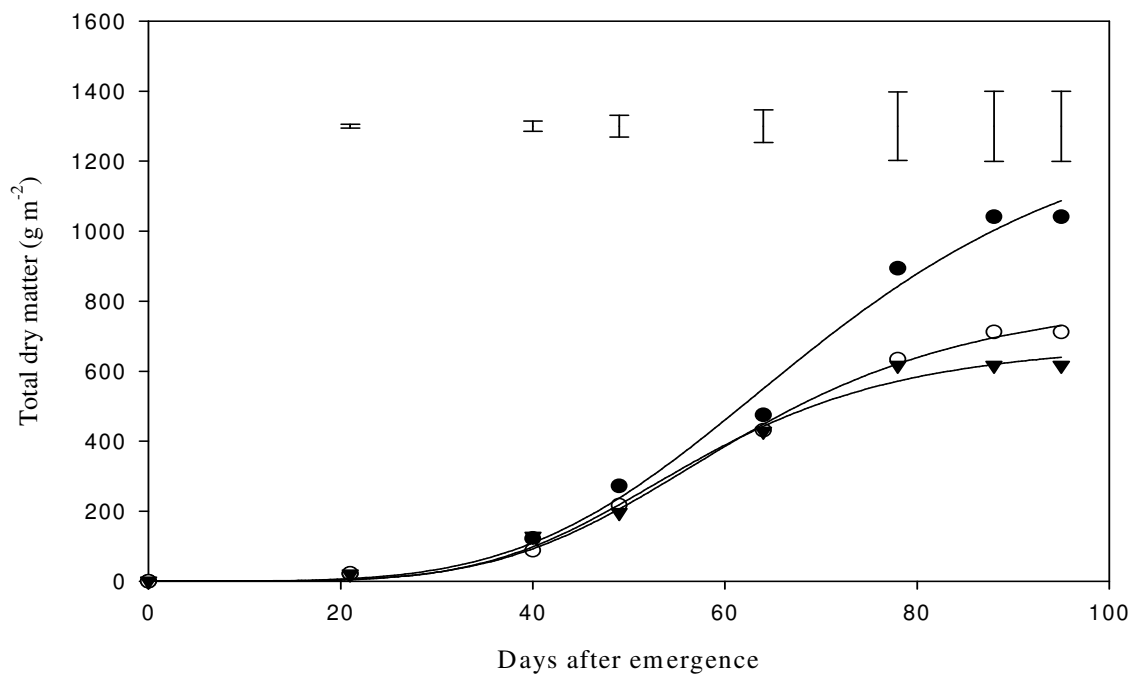
Figure 6.2: Total dry matter accumulation of field pea, over time, grown in Canterbury in the 2007/08 growing season, sown artificial weed population.

($\bullet$) = Nil, Y = 1391 / (1 + 0.35 exp (-0.24(x-67))) $^{1/0.35}$

($\circ$) = Normal, Y = 727 / (1 + 1.44 exp (-0.12(x-61))) $^{1/1.44}$

($\blacktriangledown$) = 2 x Normal weed, Y = 761 / (1 + 0.59 exp (-0.07(x-58))) $^{1/0.59}$
(Bars are LSD at p < 0.05).

Table 6.3: Functional growth analysis of field peas grown in Canterbury in the 2007/08 growing season.

	WMAGR ($g\,m^{-2}\,d^{-1}$)	C_m ($g\,m^{-2}\,d^{-1}$)	Max DM ($g\,m^{-2}$)	DUR (d)
Pea population (P) (plants m^{-2})				
50	8.4a	12.9a	613a	97
100	10.6a	15.8a	866a	91
200	18.4b	29.1b	1,164b	78
Significance	**	*	***	NS
LSD	6.2	10.7	235	-
Sown weed population (W)				
Nil	13.2	19.8	1,169b	103
Normal rate	13.4	20.9	781a	70
2 x Normal	10.8	17.2	694a	93
Significance	NS	NS	***	NS
LSD	-	-	235	-
CV (%)	49.6	55.4	26.7	46.6
Significant interactions	Nil	Nil	Nil	Nil

WMAGR = Weighted mean absolute growth rate
DUR = Duration of exponential growth
C_m = Maximum growth rate
Max DM = Maximum dry matter

6.6. Weed Dry Matter and Functional Growth Analysis

Throughout the season artificial weed DM always increased with decreased pea population (Figure 6.3). At final harvest, there was a 31% reduction in weed DM with an increase in pea population from 0 to 50 plants m^{-2} and a similar percentage decrease from 50 to 100 plants m^{-2} (Table 6.4). Overall, there was a 51% reduction from 50 to 200 plants m^{-2}. With sown weeds there was an increase in weed DM with increased weed population. The no-sown-weed control plots had the lowest weed biomass throughout the season (Figure 6.4). However, weed DM in the two sown weed treatments were not significantly different from each other but were significantly different from the no-sown artificial weed treatment throughout the season.

No factor significantly affected weed WMAGR and it ranged from 4.1 – 7.0 g m^{-2} d^{-1} (Table 6.5). The same applied to C_m , the range being 7.9 – 11.8 g m^{-2} d^{-1}). Sown artificial weed population had no effect on maximum dry matter. However, the no pea control and 50 pea plants m^{-2} had the highest maximum DM (mean 630 g m^{-2}) and this was more than double the maximum dry matter in the two highest pea populations (mean 304 g m^{-2}) (Table 6.5). There was a sown artificial weed population x pea population interaction on DUR (Table 6.6). There was no significant difference in DUR of the two sown weed populations at all pea populations except in the no pea control plots. In this comparison the normal sown artificial weed population more than doubled the 2 x normal weed population.

Table 6.4: Weed total dry matter (g m^{-2}) at final harvest of field peas grown in Canterbury in the 2007/08 growing season.

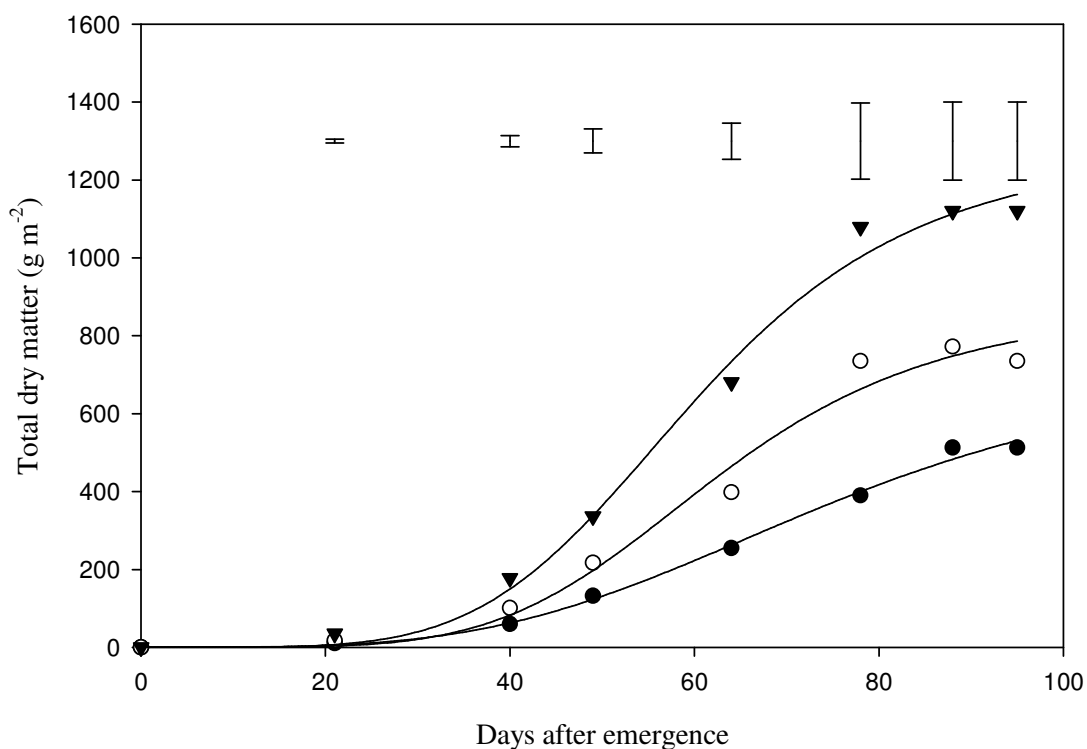| Pea population (P) (plants m^{-2})	Weed total dry matter (g m^{-2})
0	562c
50	387b
100	256ab
200	188a
Significance	***
LSD	136
Sown weed population (W)	
Nil	193a
Normal rate	399b
2 x Normal	454b
Significance	***
LSD	118
CV (%)	40
Significant interactions	Nil
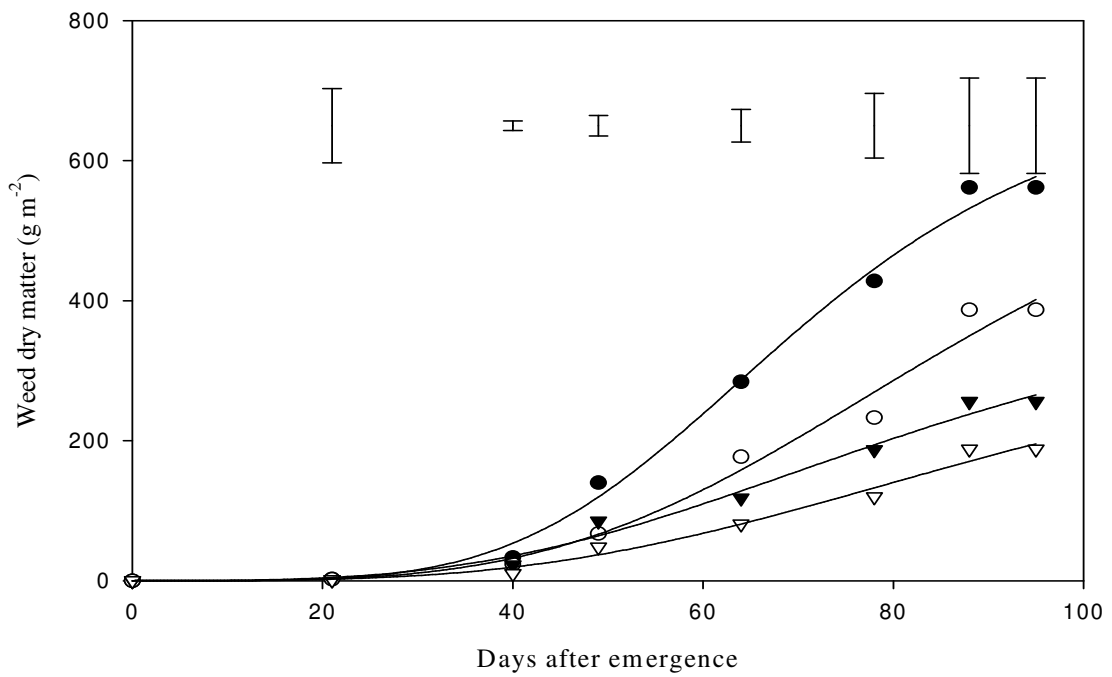
Figure 6.3: Weeds total weed dry matter accumulation in field peas, over time, grown in Canterbury in the 2007/08 growing season, pea population.

($\bullet$) = 0 plants m^{-2}, $Y = 576 / (1 + 0.53 \exp(-0.09(x-61)))^{1/0.53}$

($\circ$) = 50 plants m^{-2}, $Y = 482.98 / (1 + 0.27 \exp(-0.05(x-68.5)))^{1/0.27}$

($\blacktriangledown$) = 100 plants m^{-2}, $Y = 313 / (1 + 0.09 \exp(-0.05(x-62)))^{1/0.09}$

($\triangledown$) = 200 plants m^{-2}, $Y = 436 / (1 + 0.01 \exp(-0.02(x-92)))^{1/0.01}$

(Bars are LSD at $p < 0.05$).
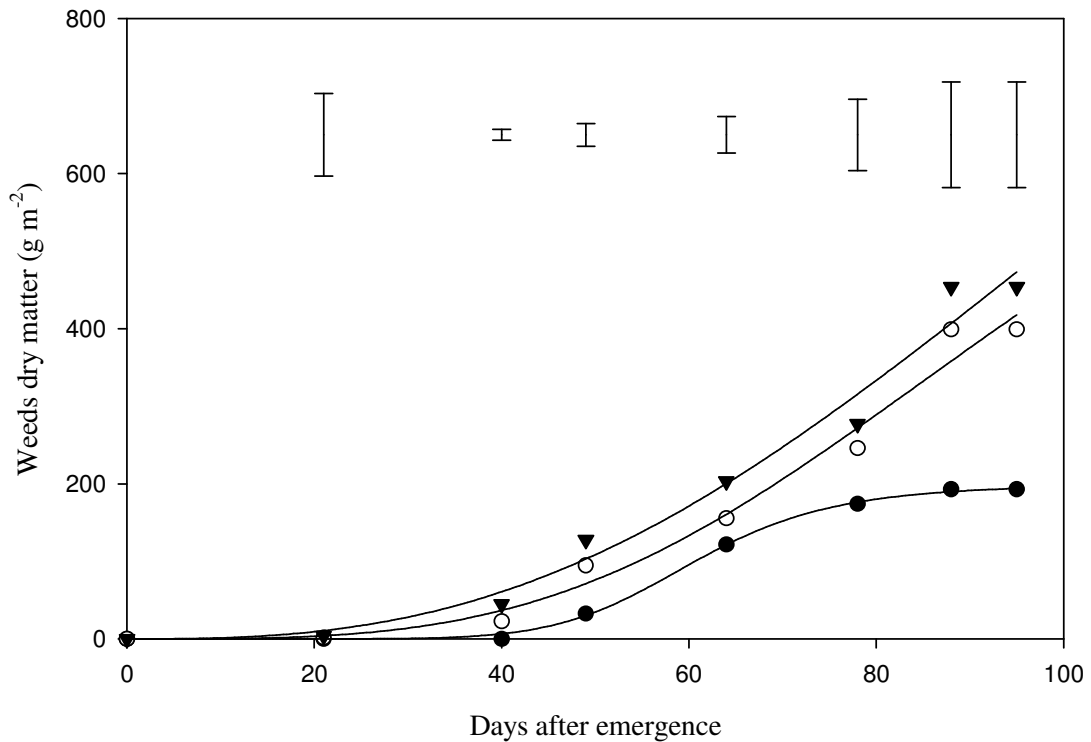
Figure 6.4: Weed total dry matter accumulation in field peas, over time, grown in Canterbury in the 2007/08 growing season, sown artificial weed population.

($\bullet$) = Nil, $Y = 193 / (1 + 3.31 \exp (-0.24(x-40.4)))^{1/3.31}$

($\circ$) = Normal $Y = 36.6 / (1 + 0.01 \exp (-0.02(x-62.6)))^{1/0.01}$

($\blacktriangledown$) = 2 x normal $Y = 99 / (1 + 0.01 \exp (-0.02(x-62.57)))^{1/0.01}$

(Bars are LSD at $p < 0.05$).

Table 6.5: Functional growth analysis of weeds in field peas grown in Canterbury in the 2007/08 growing season.

	WMAGR $(g\ m^{-2}\ d^{-1})$	C_m $(g\ m^{-2}\ d^{-1})$	Max DM $(g\ m^{-2})$	DUR (d)
Pea population (P) (plants m^{-2})				
0	7.9	11.8	659b	112
50	5.5	8.1	600b	114
100	4.4	6.5	346a	91
200	4.1	6.4	261a	75
Significance	NS	NS	**	NS
LSD	-	-	242	-
Sown weed population (W)				
Normal rate	5.3	7.9	470	96
2 x Normal	5.7	8.6	463	100
Significance	NS	NS	NS	NS
LSD	-	-	-	-
CV (%)	55	58	42	38
Significant interactions	Nil	Nil	Nil	PxW*

WMAGR = Weighted mean absolute growth rate
DUR = Duration of exponential growth
C_m = Maximum growth rate
Max DM = Maximum dry matter

Table 6.6: The pea population x sown weed population interaction on duration of exponential growth rate of field peas grown in Canterbury in the 2007/08 growing season (d).

	Weed population	
Pea population (plants m^{-2})	Normal	2 x Normal
0	156c	68ab
50	97ab	130bc
100	60a	122abc
200	71ab	78ab
Significance	*	
LSD	66	
CV (%)	38	

6.7. Pea Leaf Area Index

Pea leaf area was directly proportional to pea plant population throughout the season the highest at 6.42 was reached at 200 plants m^{-2} at 70 DAE (Figure 6.5). The sown artificial weed treatment had no effect on the first and last measurements. The no sown weed treatment had the highest mean LAI (3.21) at 70 DAE and the normal and 2 x normal weed treatment means were not significantly different (mean 2.3) (Figure 6.6).
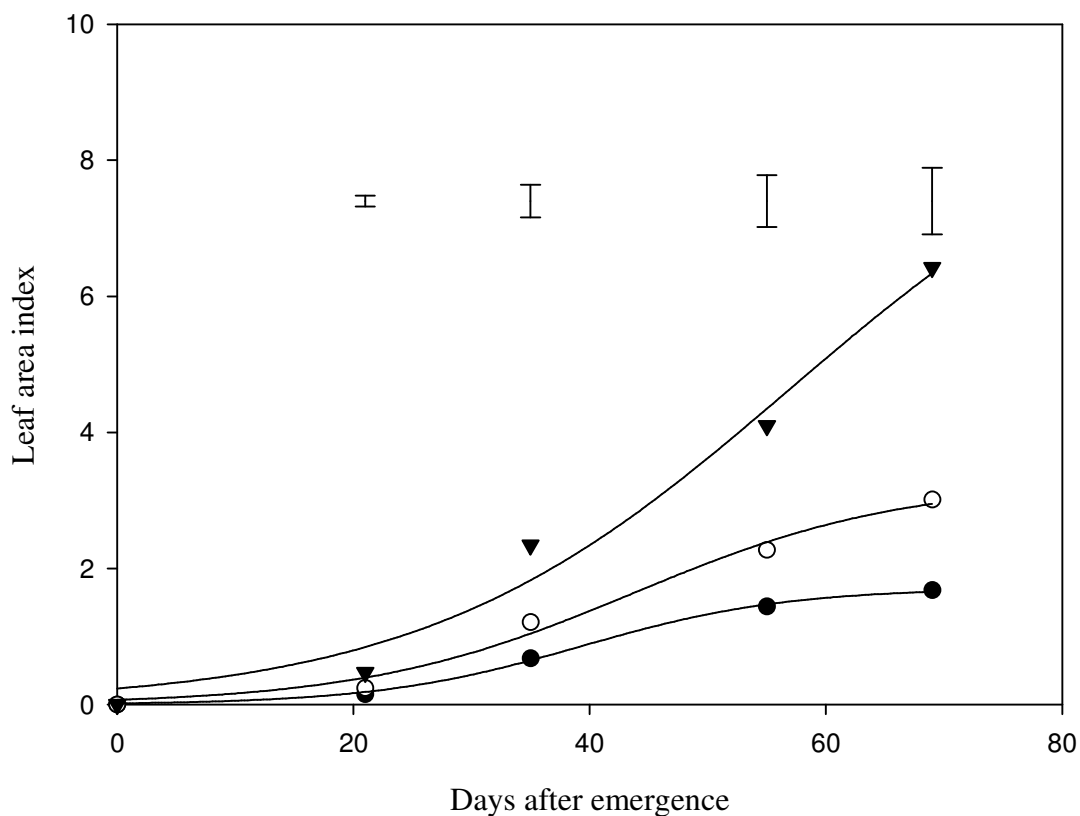
Figure 6.5: Leaf area index of field peas grown in Canterbury in 2007/08 growing season, pea population.

($\bullet$) = 50 plants m^{-2}, R^2 = 0.99

($\circ$) = 100 plants m^{-2}, R^2 = 0.98

($\blacktriangledown$) = 200 plants m^{-2}, R^2 = 0.96

(Bars are LSD at p < 0.05).
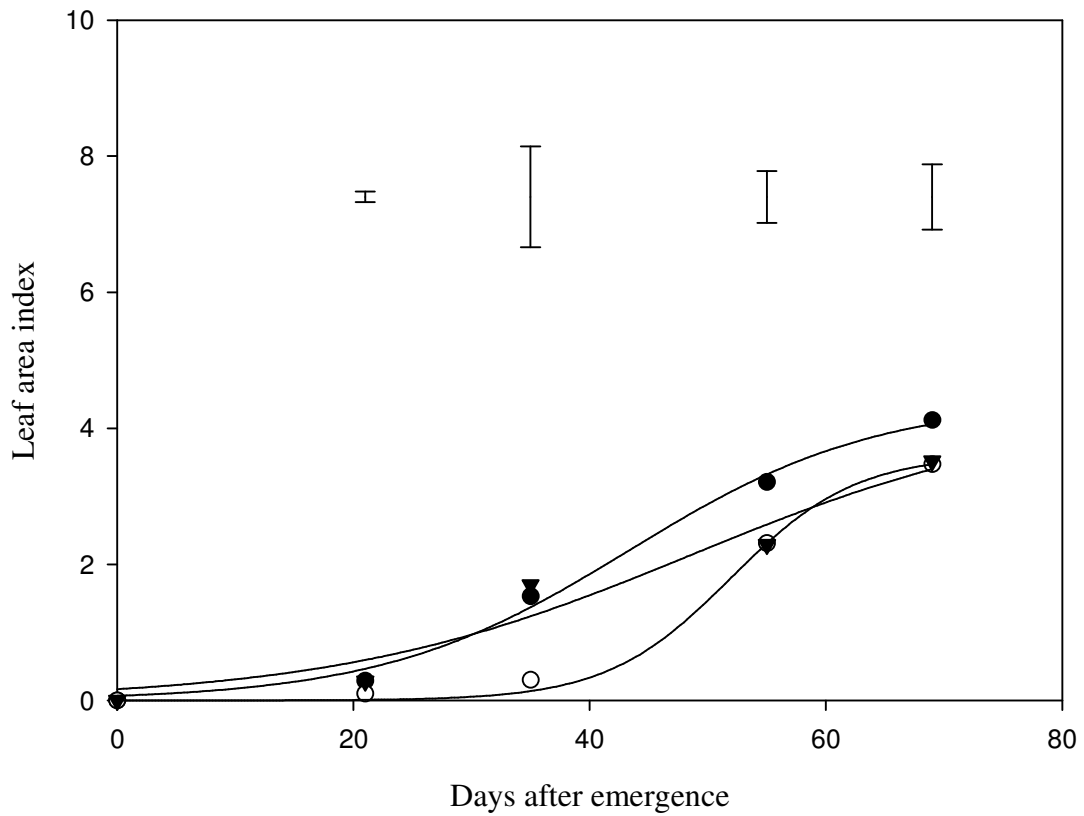
Figure 6.6: Leaf area index of field peas grown in Canterbury in 2007/08 growing season, sown artificial weed population.

($\bullet$) = Nil, $R^2 = 0.99$

($\circ$) = Normal, $R^2 = 0.98$

($\blacktriangledown$) = 2 x Normal, $R^2 = 0.90$
(Bars are LSD at $p < 0.05$).

6.8. Weed Leaf Area Index

Pea population had no effect on weed LAI early in the season but at 55 DAE the no pea control plots had the highest weed LAI (1.12) and the 200 pea plants m^{-2} plots the lowest (0.57) (Figure 6.7). There was a similar trend at 70 DAE. The 2 x normal sown artificial weed plots always had a significantly higher weed LAI except 21 DAE (Figure 6.8).
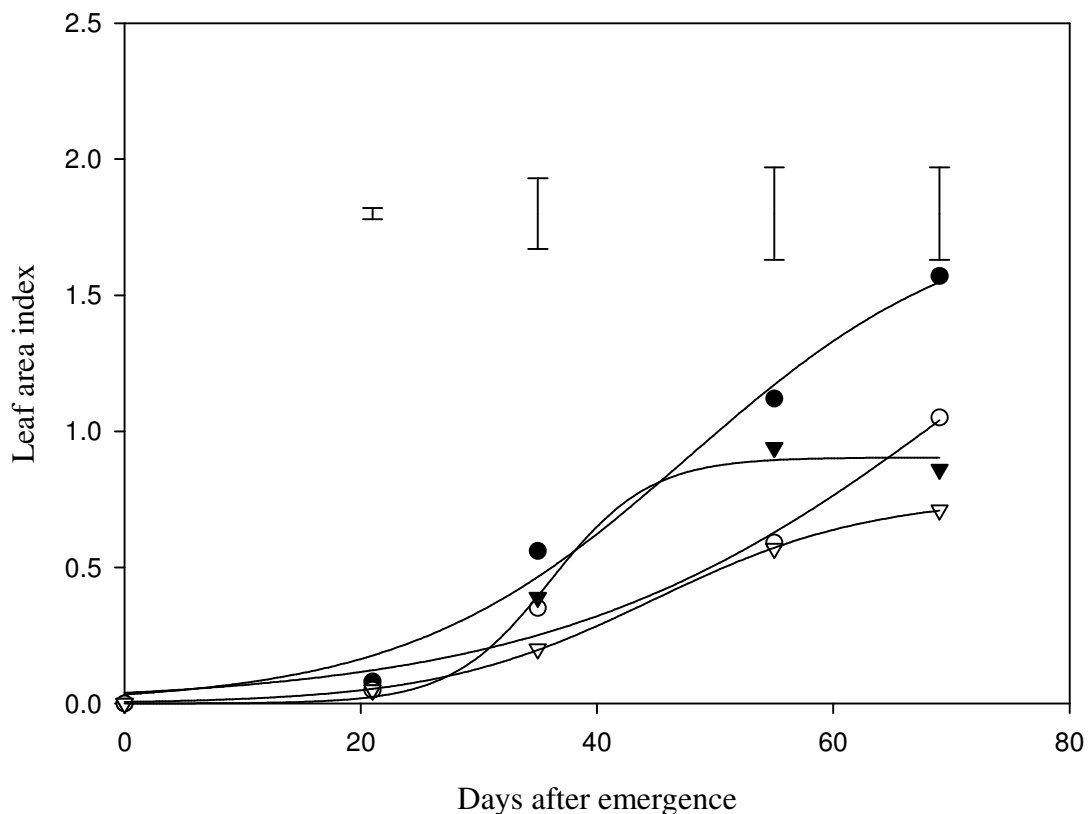
Figure 6.7: Weed leaf area index, over time, in field peas grown in Canterbury in 2007/08 growing season, pea population.

   ($\bullet$) = 0 plants m^{-2}, R^2 = 0.98

   ($\circ$) = 50 plants m^{-2}, R^2 = 0.95

   ($\blacktriangledown$) = 100 plants m^{-2}, R^2 = 0.99

   ($\triangledown$) = 200 plants m^{-2}, R^2 = 0.99

   (Bars are LSD at p < 0.05).
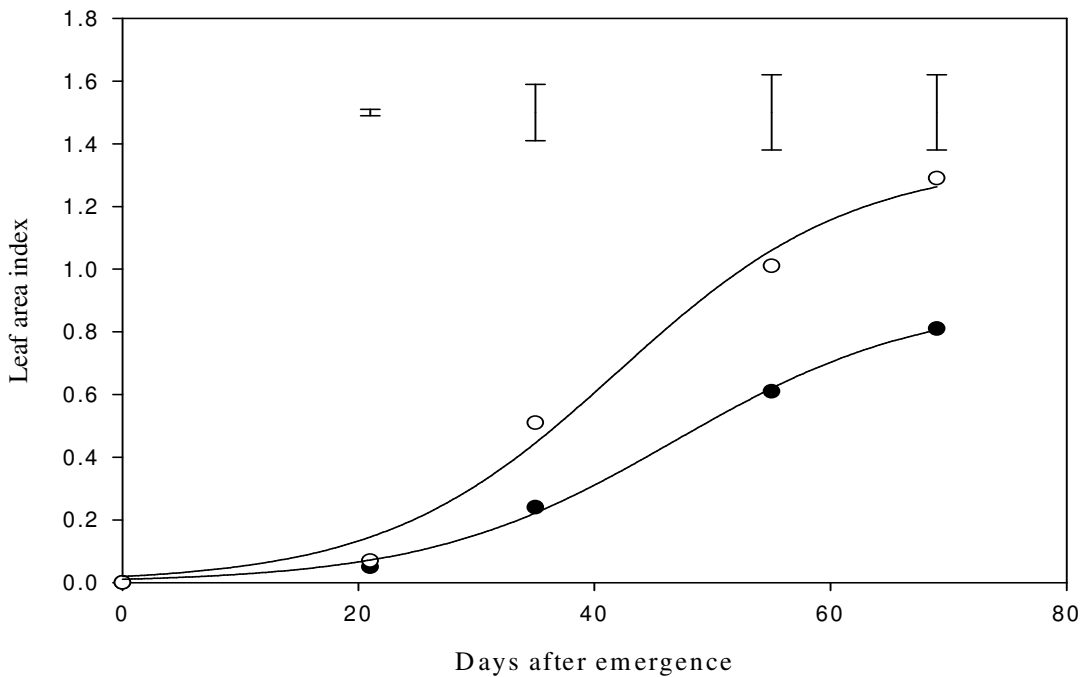
Figure 6.8: Weed leaf area index, over time, in field peas grown in Canterbury in 2007/08 growing season, sown artificial weed population.

($\bullet$) = Normal, $R^2 = 0.99$

($\circ$) = 2 x Normal, $R^2 = 0.98$

(Bars are LSD at $p < 0.05$).

6.9. Cumulative Radiation Interception (Total of Peas and Weeds)

The 50 and 100 pea plants m^{-2} plots had similar cumulative radiation interception in the first, half of the season that was significantly lower than in the 200 pea plants m^{-2} plots. However, in the last half of the season radiation interception was directly proportional to pea population (Table 6.7). The 2 x normal sown artificial weed rate had the highest cumulative radiation interception. The difference in cumulative radiation interception between the nil and the normal sown weed rates was not significant throughout (Table 6.7).

6.10. Cumulative Radiation Interception (Peas Only)

The 50 and 100 pea plants m^{-2} plots had similar levels of cumulative radiation interception in the first, half of the season that was significantly lower than that of the 200 plants m^{-2} plots. However, radiation interception was directly proportional to pea population in the last half of the growing season (Table 6.8). The sown artificial weed

treatment did not affect pea cumulative radiation interception throughout the growing season (Table 6.8).

Table 6.7: Total cumulative intercepted radiation of field pea - weed mixtures grown in Canterbury in 2007/08 growing season (MJ m^{-2}).

	20 October	04 November	17 November	01 December
Pea population (P) (plants m^{-2})				
50	30a	109a	212a	376a
100	38a	135a	254b	430b
200	68b	197b	327c	512c
Significance	***	***	***	***
LSD	17.0	33.2	40.0	47.4
Sown weed pop (W)				
Nil	47ab	143ab	262ab	430ab
Normal rate	39a	132a	246a	419a
2 x Normal	52b	162b	282b	459b
Significance	*	*	*	*
LSD	14	27	33	39
CV (%)	29	16	11	8
Significant interactions	Nil	Nil	Nil	Nil

Table 6.8: Cumulative radiation interception of peas in field pea - weed mixtures grown in Canterbury in 2007/08 growing season (MJ m^{-2}).

	20 October	04 November	17 November	01 December
Pea population (P) (plants m^{-2})				
50	29a	98a	186a	272a
100	36a	125a	229b	380b
200	65b	189b	310c	482c
Significance	**	***	***	***
LSD	18.3	33.4	37.7	82.1
Sown weed population (W)				
Nil	47	143	262	430
Normal rate	37	125	230	385
2 x Normal	50	149	253	371
Significance	NS	NS	NS	NS
LSD	15.0	-	-	-
CV (%)	33	17	11	13
Significant interactions	Nil	Nil	Nil	Nil

6.11. Cumulative Radiation Interception (Weeds Only)

Pea population had no effect on weed cumulative radiation interception throughout the growing season (Table 6.9). While sown artificial weeds had no effect on cumulative radiation interception at the last sampling date, there were effects earlier. The 2 x normal sowing rate did give greater weed radiation interception at the second and third sampling dates.

Table 6.9: Weed cumulative radiation interception of field pea - weed mixtures grown in Canterbury in 2007/08 growing season (MJ m^{-2}).

	20 October	04 November	17 November	01 December
Pea population (P) (plants m^{-2})				
50	1.9	10.7	25.5	104.0
100	1.8	9.5	25.0	51.0
200	1.6	6.6	15.4	29.0
Significance	NS	NS	NS	NS
LSD	-	-	-	-
Sown weed population (W)				
Normal rate	1.2	5.7	15.1	33.0
2 x normal	2.4	12.2	29.0	89.0
Significance	NS	*	**	NS
LSD	-	4.9	8.4	-
CV (%)	71	43	36	125
Significant interactions	Nil	Nil	Nil	Nil

6.12. Radiation Use Efficiency

Sown artificial weed population did not affect RUE and it ranged from 1.03 g MJ^{-1} in the 2X normal weed seed rate to 1.16 g MJ^{-1} in no sown artificial weed treatment (Table 6.10). On the other hand RUE increased with increased pea population. The RUE increased by 48% as population increased from 50 plants m^{-2} to 100 plants m^{-2} and by a further 41% as pea population increased from 100 plants m^{-2} to 200 plants m^{-2}.

There was a linear relationship between radiation interception and dry matter accumulation for all pea populations and the sown artificial weed population treatments (Figures 6.9 and 6.10 respectively).

Table 6.10: Radiation Use efficiency of field peas grown in Canterbury in the 2007/08 growing season.

	Radiation Use efficiency (g MJ^{-1})
Pea population (P) (plants m^{-2})	
50	0.73a
100	1.08b
200	1.52c
Significance	***
LSD	0.25
Sown weed population (W)	
Nil	1.16
Normal rate	1.15
2 x Normal	1.03
Significance	NS
LSD	-
CV (%)	22
Significant interactions	Nil
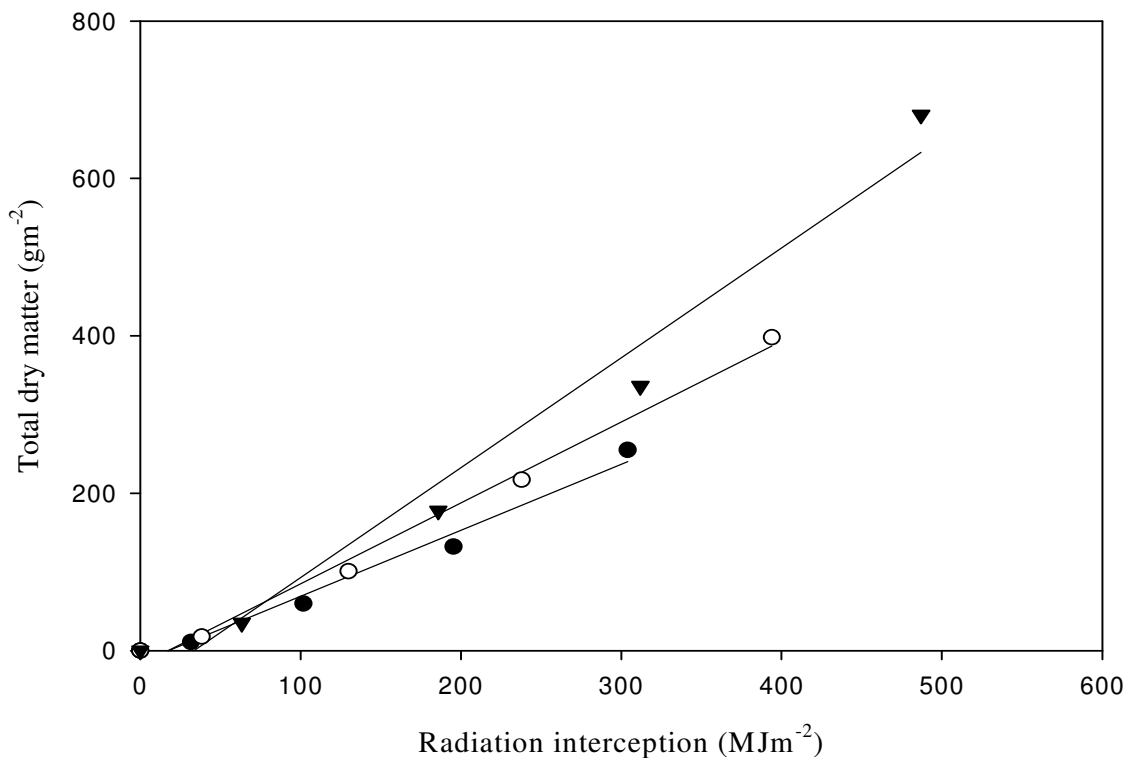
Figure 6.9: Radiation interception and DM accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, pea population.

($\bullet$) = 50 plants m^{-2} Y = 0.84X – 14.5 R^2 = 0.98

($\circ$) = 100 plants m^{-2} Y = 1.03X – 17.7 R^2 = 0.99

($\blacktriangledown$) = 200 plants m^{-2} Y = 1.40X – 46.6 R^2 = 0.97
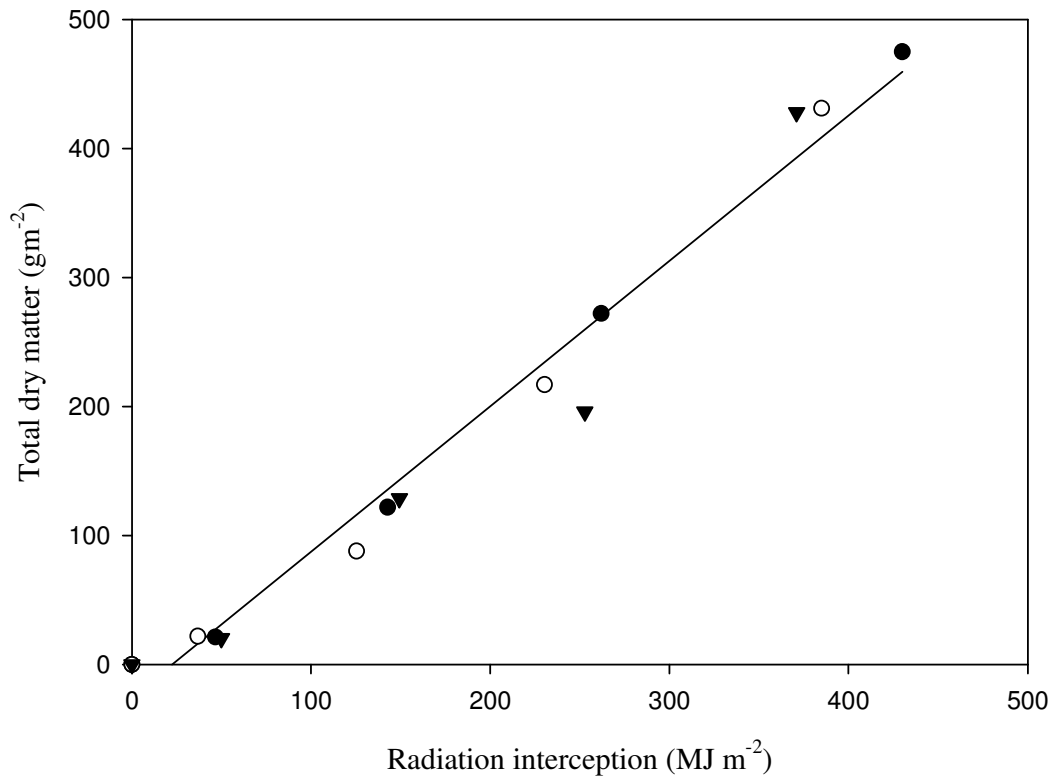
Figure 6.10: Radiation interception and DM accumulation of field peas, over time, grown in Canterbury in the 2007/08 growing season, sown weed population.

($\bullet$) = Nil weeds

($\circ$) = Normal weeds

($\blacktriangledown$) = 2X normal weeds

$Y = 1.13X - 25.2 \ R^2 = 0.98$

6.12. The Relationship of Pea Yield, Total Dry Matter, Sown Population and Weed Dry Matter

There was a linear relationship between both seed yield and population and total DM and pea population (Figure 6.11). There was however, as expected, negative relationships between seed yield and weed DM and total DM and weed DM (Figure 6.12).
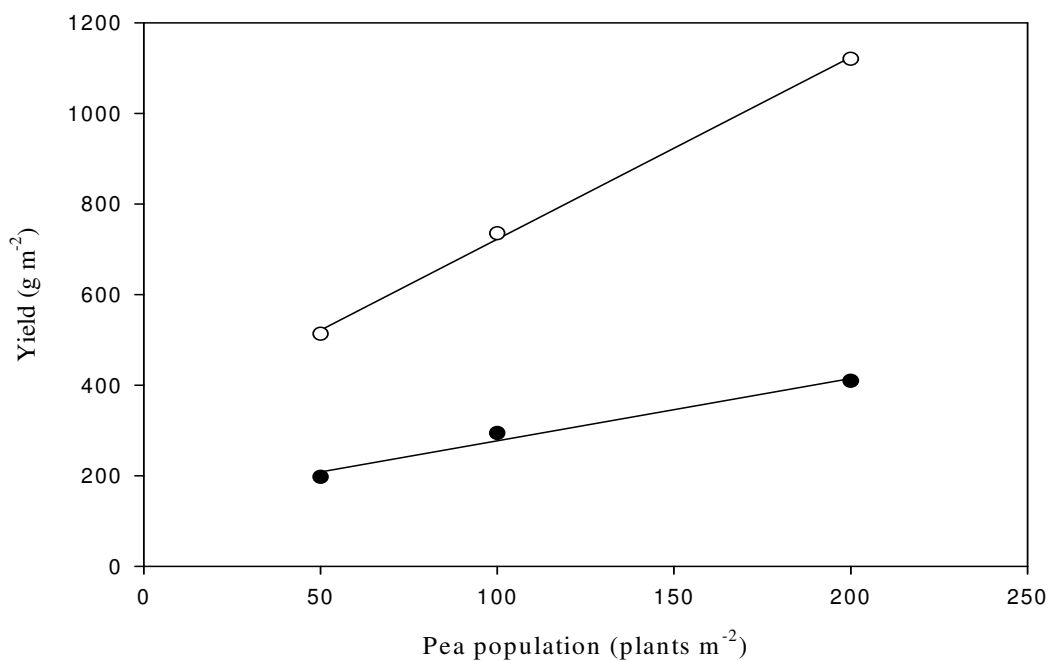
Figure 6.11: Yield-population relationship of field peas grown in Canterbury in 2007/08 growing season.

($\bullet$) = Seed yield, $Y = 1.38\,X + 139\;R^2 = 0.98$

($\circ$) = Total dry matter, $Y = 4\,X + 321\;R^2 = 0.99$
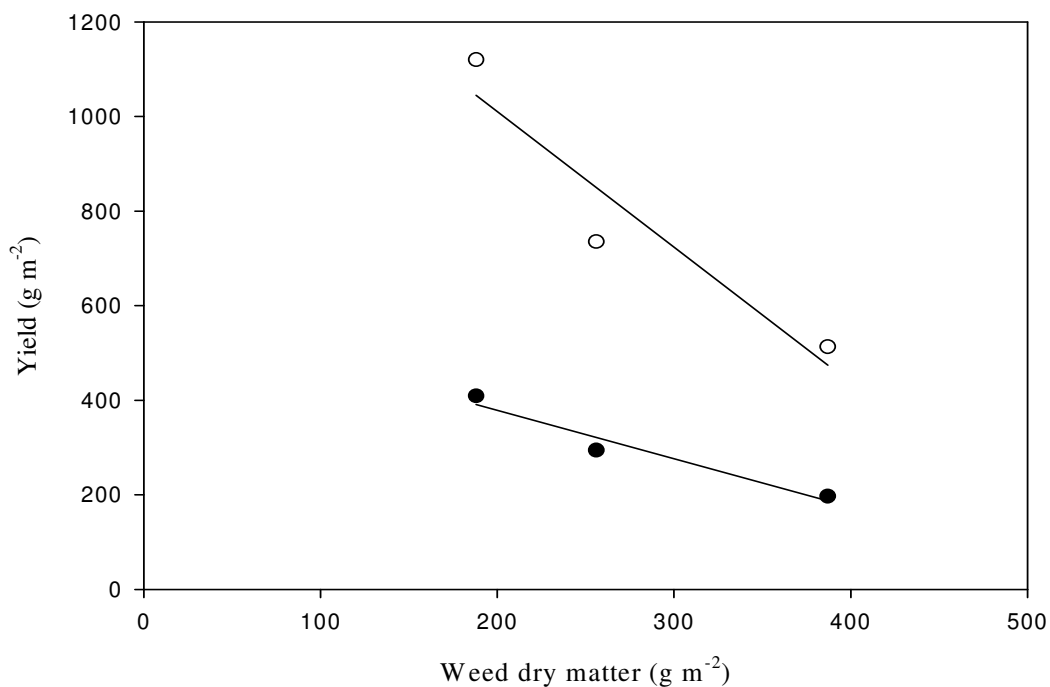
Figure 6.12: Yield-weed total dry mater relationship of field peas grown in Canterbury in 2007/08 growing season.

($\bullet$) = Seed yield, $Y = -0.93\,X + 555\;R^2 = 0.95$

($\circ$) = Total dry matter, $Y = -2.87\,X + 1584\;R^2 = 0.89$

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6.13. Discussion

6.13.1. Seed Yield and Total DM

Seed yield increased significantly ($p < 0.001$) as pea population increased. At 200 plants m^{-2} the highest mean seed yield of 409 g m^{-2} was obtained and at 50 plants m^{-2} it was the lowest (197 g m^{-2}). This correlated with weed DM at different pea populations. Contrary to this, Martin *et al.* (1992) reported that increased plant density above 150 plants m^{-2} was not associated with a higher seed yield, although it did increase straw production. They concluded this was probably because their research had more to do with water relations than anything else. In their experiments, plots sown at high populations had higher evapotranspiration during early growth and low-density plots had higher evapotranspiration during late growth. This meant that open canopies had better water economy than closed ones as the former saved more water, to be utilised during the final days of crop maturity. Similarly, White and Hill (1999) recommended an optimum population of 70 plants m^{-2} on shallow soils, 90 plants m^{-2} on deeper soils and 100-120 plants m^{-2} for irrigated pea crops in New Zealand. In this research moisture was not a treatment and was not allowed to be limiting to growth. McKenzie *et al.* (1999), reported optimum dry pea populations of 90 – 100 plants m^{-2} but did not specify growing conditions.

Weed DM production was inversely proportional to pea population from 42 DAE until final harvest. Increased pea population gave the crop a greater competitive advantage against weeds and a relatively higher TDM production and seed yield. The no-sown artificial weed treatment gave the highest mean seed yield of 390 g m^{-2} because it was almost weed free and hence experienced the least competition. Competition was from indigenous weeds. There was no significant difference in pea seed yield in the normal weed and the 2 x normal artificial weed treatments (mean 255 g m^{-2}). This indicates that TDM and pea seed yield were inversely proportional to weed population up to a certain weed threshold level above which there was no further yield reduction. The reduction in pea TDM with increased weeds was because of competition for light and nutrients. In particular competition between the pea crop and weeds for light is highlighted in Table 6.9, where almost no light was intercepted by weeds at 200 pea plants m^{-2} but over a quarter of all intercepted radiation was by weeds at 50 pea

plants m^{-2}. Peas can clearly out compete weeds for light if sown at a higher than normally recommended population (McDonald *et al.*, 2007).

6.14. Yield Components

6.14.1. Plant Population

At harvest, all plant populations were slightly higher than sown but were proportional to target populations. This was due to excellent management of the trial that optimised growing conditions enhancing treatment factors to be the only limiting factors. Sown artificial weed populations also did not affect target pea populations. Although sown weeds reduced pea seed yield by about 35% this was not due to plant deaths but was caused by a reduction in pods plant^{-1} and seeds plant^{-1}.

6.14.2. Pods Plant^{-1}

Pea population did not affect the number of pods plant^{-1}. This was unusual because this is usually the main yield determinant of all yield components. The reason could be due to the semi-leafless nature of Midichi. There is usually less plant-to-plant competition in semi-leafless peas (Moot, 1993) so higher plant populations tend to have less effect on pods plant^{-1}. However, the number of pods plant^{-1} was directly proportional to population in Experiment 1 of this research where it ranged from 3.37 – 13.42. This was because both semi-leaf-less and fully leafed peas were used in that experiment and Midichi produced the least pods plant^{-1} (7.12). There was no cultivar x population interaction in experiment 1, so this fact alone might not be conclusive.

As expected, in this experiment, the no sown artificial weed treatment gave the highest number of pods plant^{-1} (4.07) but there was no significant difference between the two sown artificial weed treatments (mean 3.05 pods plant^{-1}). This indicates that the sown artificial weeds were partly responsible for the reduced pods plant^{-1} and hence reduced seed yield.

6.14.3. Seeds Pod^{-1}

The lowest pea population gave the highest number of seeds pod^{-1} (3.39) and the two highest pea population means were not significantly different from each other. However, achieving the highest number of seeds pod^{-1} did not result in the lowest pea population giving the highest yield. It suffered the most competition for light from the

high weed pressure it experienced (Table 6.9). The sown artificial weed treatments did not affect the number seeds pod^{-1} meaning the weeds did not change crop physiological and phenological behaviour.

6.14.4. Thousand Seed Weight

Sown artificial weed treatments had no effect on pea TSW for the reasons explained above. The highest TSW of 304.4 g was at 100 plants m^{-2}. The 50 and 200 pea plants m^{-2} populations had a similar TSW.

6.14.5. Seeds Plant^{-1}

The lowest pea population gave the highest number of seeds plant^{-1} (12.58). The two highest pea population means were not significantly different from each other. The highest mean number of seeds plant^{-1} (12.96) was in the no sown artificial weed treatment. The two sown weeds treatment means were not significantly different from each other (mean 9.13 seeds plant^{-1}). Yield components results were not effective in describing pea yield variation caused by the different treatments. This supports Gallagher *et al.* (1983), who reported that despite its common use, yield component analysis, had some limitations. They claimed that the results of an experiment are always specific to the site and season in which it was conducted, and variability among seasons and sites is usually greater than among treatments. Also mutual independence or plasticity among components and the interaction of genetic and environmental factors on the level of expression of each component is a further limitation.

6.15. Total Dry Matter Accumulation over Time and Functional Growth Analysis

The highest WMAGR (18.4 g m^{-2} d^{-1}) was achieved at the highest pea population (200 plants m^{-2}). This was because only 200 plants m^{-2} exceeded the critical leaf area index. This is why the 200 pea plants m^{-2} intercepted more radiation (Table 6.8) and yielded more (Table 6.1). Sown artificial weed population did not affect WMAGR and means ranged from 10.8 – 13.2 g m^{-2} d^{-1}. This explains why the two sown artificial weed treatments had no significant difference in terms of both seed yield and total DM. The above trend was also true for C_m.

The highest maximum DM was achieved at 200 plants m^{-2} (1,164 g m^{-2}) and the two lowest populations had similar maxima DM (mean 740 g m^{-2}). The no sown weed treatment gave the highest mean maximum DM (1,169 g m^{-2}). There was no difference in maximum DM between normal weed and the twice-normal artificial sown weed treatments (mean, 738 g m^{-2}).

The yield results are very consistent in the second year with both seed yield and TDM related to increased growth rate due to increased radiation interception. There was no variation in HI.

6.16. Weed Dry Matter

Marx and Hagedorn (1961) reported that higher seeding rates of peas are effective in reducing weed development and Farshatov (1973) found that raising the sowing rates of peas from 100 – 140 plants m^{-2} reduced the weed population 2.5 fold. In this experiment there was a 31% reduction in weed DM with increased pea population from 0 to 50 plants m^{-2} and a similar percentage reduction from 50 to 100 plants m^{-2}. Overall there was a 51% reduction from 50 to 200 pea plants m^{-2}. Grevsen, (2003) found a similar weed reduction and reported that increasing the seeding rate from the normal 90 to 150 seeds m^{-2} reduced the dry weight of weed plants at harvest by 50% in 1997 and by 30% in 1998. In an experiment with ten wheat cultivars, Lemerle *et al.* (1996) found that doubling the seeding rate, on average, reduced weed DM of *Lolium rigidum* by 25% and increased wheat yield by 10%. Topham and Lawson (1982) reported a major reduction in weed DM at vining harvest in unweeded pea crops compared with equivalent uncropped plots with no peas. At 53 pea plants m^{-2} weed dry weight was reduced by 73% at vining harvest compared to that of uncropped plots and 68% and 74% (Lawson and Topham, 1985).

Townley-Smith and Wright (1994) reported pea yield increases and weed DW reduction by raising field pea density from 50 to 100 seeds m^{-2}, but concluded that increasing the seeding rate over 100 seeds m^{-2} would be unlikely to give a better result. According to them, a 70% increase in the seeding rate (150 seeds m^{-2} compared with normal 90 seeds m^{-2}) was costly in peas and could not always be compensated for by higher yield. Results of this research support weed DM reductions as a result of crop population increases. Increasing weed pressure, beyond a certain weed threshold, in this case the normal weed sowing rate was unlikely to cause a further reduction in crop

yield. The normal and 2 x normal artificial weed pressure affected pea yield equally. According to Townley-Smith and Wright (1994), the positive effect of a higher seeding rate on reducing weed pressure should be regarded as an investment in weed management of a crop rotation rather than an immediate yield payoff. This is only true under the assumption that weed seed return is reduced along with weed biomass (Grevsen, 2003). Goldberg, (1990), reported that ideally, a competitive crop variety both tolerated and suppressed weeds. This research indicates that for peas Midichi could be regarded as an 'ideal' types as it showed those characteristics.

6.17. Weed Dry Matter and Functional Growth Analysis

No factor significantly affected WMAGR of weeds and it ranged from 4.1 – 7.0 g m^{-2} d^{-1}. The same applied to C_m, the range being 7.9 – 11.8 g m^{-2} d^{-1}). It is not clear why these weed growth rates were not affected but the results are highly variable as shown by the high cv's. This is common in weed studies where populations are variable and hence so are yields (Isaac, 2001). The no pea control and 50 plants m^{-2} had the highest maximum weed DM (mean 630 g m^{-2}) and this was more than double the maximum dry mater of the two highest populations (mean 304 g m^{-2}) (Table 6.5). These results show that higher crop populations can provide some control of weeds.

6.18. Radiation Partitioning

Competition for light is an important aspect of competition between weeds and a crop. Therefore in this research project radiation interception was partitioned between the crop and weeds to explain yield performance and interaction effects. Ayalsew (1991) partitioned irradiance into grass and lucerne components and reported that the variation in the amount of irradiance by component species of the three grass lucerne mixtures ranged from only 1.3-fold in Matua-lucerne (in favour of Matua) to 3.8-fold in Nui-lucerne mixtures (in favour of lucerne). He concluded that the differences in the amount of irradiance might indicate the extent of competition one component of a mixture exerted on the other. He also reiterated that competition for light was a major factor limiting the growth of component species. Lantinga *et al.* (1999), used similar methodology to model vertical light absorption in grass white / clover mixtures and reported that the competitive success of clover over grass for light absorption was attributed to its greater contribution to total LAI and a more planofile leaf angle

distribution, related to its higher position in the mixture where maximum leaf area density occurred with regular leaf dispersion in the top layers of the canopy.

In this work radiation interception was determined mainly by the magnitude of the leaf area. Peas accumulated more intercepted radiation because they produced more leaf area than the weeds. The competitive success of the peas over the weeds for light interception could also be attributed to their more planofile leaf angle distribution. This related to their higher position in the mixture where maximum leaf area density occurred and regular leaf dispersion in the top layers of the canopy was similar to what was observed by Lantinga *et al*. (1999), in grass-clover mixtures. The 200 pea plants m^{-2} treatment exerted the greatest competitive pressure on weeds because of the highest LAI, which accumulated the greatest radiation interception at the expense of the weeds (Figure 6.5). This explains why 200 pea plants m^{-2} gave the highest crop yield and why 50 pea plants m^{-2} gave the lowest because radiation interception is the major driver of crop yield. The lack of difference in RI at normal and 2x normal artificial weed rates fits well with total DM production e.g. NS. However the high cvs could mean the ununiformed distribution of weeds was prevalent.

6.19. Conclusions

- Increased pea population increased TDM and seed yield.
- Increased pea population reduced weed DM.
- Increased weed pressure reduced pea yield.
- Increased weed pressure, above the normal weed sowing rate, did not cause a further pea yield reduction.
- Weed and pea population did not affect pea crop and plant harvest indices.
- The semi-leafless pea cultivar Midichi could both tolerate and suppress weeds.
- The LAI and intercepted radiation were directly proportional to pea population.
- The normal weed rate and the 2 x normal artificial weed rate intercepted similar amounts of radiation.
- Pea yield could be increased by increasing pea population especially in weedy environments.

Chapter 7

7.0. General Discussion

7.1. Introduction

There is increased public awareness and concern about the possible presence of undesirable chemical residues in agricultural produce. There is also increased interest in low input sustainable agricultural systems on Canterbury cropping farms, particularly from an economic viewpoint, to reduce production costs (White, 1991). Sustainable farming requires the farmer to understand the biological effect of a crop or management system and how this information can be used effectively in farm programs e.g. integrated pest management. Including grain legumes in such systems is important as they can fix atmospheric nitrogen and break disease and pest cycles. In New Zealand, peas are the major grain legume grown. Compared to cereals, most grain legumes, including peas, are poor competitors with weeds (Blackshaw *et al.,* 2007), which can make organic production systems uneconomic. Most pea growers rely on herbicides for weed control to achieve high seed yields.

Because the worst weeds are broad-leaved, cost of control can be high and in organic production systems the use of synthetic chemicals is prohibited. This places sustainable weed management as a major challenge to both organic and conventional pea growers. This research program explored in detail, some potential sustainable and effective integrated weed control methods that could substantially increase pea yields under both organic and conventional production systems. The use of appropriate sowing date, pea genotype, herbicide application and sowing rate, to control weeds, were evaluated. Crop and weed ecological relationships were examined in detail using a semi-leafless pea as the crop. Specifically this research aimed to quantify the competitive ability of different pea canopy architectures in relation to pea genotype, population and sowing date, when grown with and without the use of a herbicide on pea crop growth, yield and weed growth. The study also aimed at determining the influence of different pea and weed populations, and their interactions, on the physiology of pea and weed growth.

The following hypotheses were tested.

- Fully leafed peas perform better than semi-leafless peas in terms of yield and weed suppression.
- Fully leafed peas intercept more PAR than semi leafless peas and convert that radiation to DM with greater photosynthetic efficiency.
- It is possible to grow peas without the use of herbicides.
- Pea sowing rate can affect crop yield and weed growth.
- Weed population affects pea crop yield.
- The weed spectrum varies during the growing season.

This research program consisted of three field experiments. Experiment 1, evaluated the effect of population, herbicide application and pea genotype on crop yield, and weed growth in the 2006/07 growing season. It was mainly agronomic. This was done to evaluate how the treatments affected pea yield, yield components and weed suppression and to determine appropriate treatments to examine in greater detail in subsequent experiments.

Experiment 2 explored the physiology of two selected pea types, leafed and semi-leafless. A herbicide treatment was included as a control. Three sowing dates evaluated performance under different seasonal growing conditions and evaluated seasonal variation in the weed spectrum. It should be noted that the primary aim was not simply to determine the effect of sowing date but to compare the performance of fully leafed and semi-leafless pea genotypes under different environmental conditions.

Experiment 3 was even finer tuned. One pea genotype, the semi-leafless Midichi, was selected to investigate the effect of combinations of different pea and artificial weed populations on pea crop yield, weed growth and their interactions. A semi-leafless genotype was selected because previous studies had shown that the future of increased pea yield lay in semi-leafless types (Martin *et al*., 1992; Moot, 1993; Heath *et al*., 1994). This is because their yield is stable which is attributed to a more uniform HI. Their erect nature makes them resistant to lodging and they are less disease prone giving them an advantage over conventional pea varieties. This research confirms that they may be the ideal pea 'ideotype'. The aim of this research therefore was to evaluate their interaction with weeds and to determine their competitive ability against different levels of weeds. However, their more open canopy means they leave space and light, which reaches the bottom of the canopy may be conducive to weed growth. Therefore,

is this ideotype suitable for organic systems where farmers often find weed management is their greatest challenge?

7.2. Seed Yield and Total Dry Matter

In Experiment 1 pea seed yield varied from 606 to 733 g m^{-2}. In the next season, 2007/08, seed yield varied from 398 to 572 g m^{-2} in Experiment 2 and from 197 to 409 g m^{-2} in Experiment 3, the sown weed experiment. Yield was highest in Experiment 1 because the 2006/07 season was better climatically (higher rainfall and cooler temperatures) and the paddock contained fewer weeds. Pea seed yield was lowest in Experiment 3 mainly because apart from the high density of indigenous weeds present, the sown artificial weeds were an experimental factor. Therefore, there was higher crop weed competition which affected overall mean pea yield.

Pea plant population affected both seed yield and total DM in all three experiments. In the sown weed experiment (Experiment 3), increasing the pea population from 50 to 200 plants m^{-2} more than doubled seed yield. The increased pea yield was the result of increased weed suppression in higher pea populations resulting in reduced crop weed competition. Marx and Hagedorn (1961) reported that high seeding rates in peas effectively reduced weed development and Farshatov (1973) found that raising the sowing rate of peas from 100 – 140 plants m^{-2} reduced the weed population 2.5 fold. In lentils weed growth has also reported to have been suppressed by increased crop population (McKenzie *et al*., 1989; Ball, 1997). McDonald *et al*. (2007) reported that increasing the sowing rate and genotype manipulation could be used to increase competitive ability. This has been used successfully mostly in cereals (Lemerle *et al.,* 2001). However, McDonald *et al*. (2007) claimed that that there is little information about the effectiveness of these strategies in lentil.

In the other experiments, with no sown weeds and a herbicide treatment, there was a significant ($p < 0.05$) interaction between herbicide and population on mean seed yield (Experiment 1). Herbicide had no effect on seed yield at 100 and 400 plants m^{-2}. However, at 50 pea plants m^{-2} plots treated with cyanazine produced 829 g m^{-2} of seed. This was 30% more than the 637 g m^{-2}, produced from plots without herbicide. This suggests the need to use a herbicide, or some other effective weed control if a pea crop is sown at a very low population and there is no need to use a herbicide if a high pea population is used. However, there is diminished return if the pea population is

increased above a certain threshold particularly if there is reduced crop-weed competition as in this experiment. The 400 pea plants m^{-2} treatment did not give a higher seed yield than the other two pea populations and had the lowest HI. There was self-thinning at 400 plants m^{-2} and this resulted in a final mean plant population of 275 plants m^{-2}. It is therefore advisable to use the lowest possible sowing rate when weed pressure is low because of compensatory effect of yield components. This is important as the greatest cost of pea production is the cost of seed (Askin *et al.*, 1985). Still, based on cost reduction, there is no need to use a herbicide if weed pressure is minimal. The pea seed yield of 637 g m^{-2} from unsprayed plots in Experiment 1 is high (White and Hill, 1999) and this means that the low weed population in this experiment did not cause yield reduction even at the low pea population of 50 plants m^{-2}.

As indicated above low seeding rates usually need to be accompanied by some sort of weed control e.g. mechanical or herbicide. The detrimental effect of using a low population and no other weed control was illustrated in Experiment 3. In the presence of weeds a pea seed yield of only 197 g m^{-2} was achieved at 50 pea plants m^{-2} because of high weed competition. This would be a major problem for growers because this yield is far below the 4 t ha^{-1} that Freeman (1987) stipulated as necessary for peas to be an an economically viable crop in New Zealand. However, a pea population of 200 pea plants m^{-2} more than doubled the mean pea seed yield (409 g m^{-2}). There was a 51% weed DM reduction from 50 to 200 pea plants m^{-2}. Similar weed reductions in response to increased crop population were reported by Townley-Smith and Wright (1994), Lemerle *et al.* (1996), and Grevsen (2003). This confirms the need to use high seed rates when weed pressure is high and when chemical weed control cannot be used. Higher crop populations, by suppressing weed growth, also deplete the weed seed bank for subsequent crops (Grevsen, 2003).

Pea genotype performance differences can best be explained in terms of weed competition. McDonald (2003) reported significant differences in competitive ability among genotypes of field peas. Tall genotypes generally suppressed *Lolium rigidum* and wheat more effectively than short genotypes.

In Experiment 1 semi-leafless peas yielded the same as a conventionally leaved pea. This was because there was very low weed pressure in the paddock used. In Experiment 2, with higher weed pressure, the conventionally leaved pea performed better because of its greater competitive ability against weeds attributed to its leaf morphology. Weeds did not affect its RUE unlike the semi leafless pea type (RUE

reduced by 29% by weeds). This then resulted in it achieving a 55% faster WMAGR than the semi leafless type in the presence of weeds.

A significant ($p < 0.05$) sowing date x pea type interaction showed that in the August sowing pea genotype had no effect on seed yield. Weed pressure was still low at that stage of the season (early spring) so differences in weed suppression by different pea genotypes were not observed. However, by September Pro 7035 seed yield of 559 g m^{-2} was 40% more than that of Midichi and by October it was 87% more. As temperature increased, weed emergence and growth were enhanced and the effect of pea genotype became more pronounced. The higher yield of the fully leaved pea type was due to higher radiation interception because of its better competitive ability against weeds for radiation interception. The difference can also be explained in terms of RUE.

Sowing date did not affect RUE and it ranged from 1.79 g MJ^{-1} in August to 1.94 g MJ^{-1} in October. The two pea types had a similar RUE with a mean of 1.85 g MJ^{-1}. Herbicide sprayed plots had a 12% higher RUE than unsprayed plots. There was a significant ($p < 0.05$) herbicide x pea type interaction on RUE. Pea type on its own did not affect RUE. This is contrary to the belief that semi-leafless peas have inferior conversion of radiation to DM. This supports Martin *et al*. (1992), who showed that at similar densities, all pea phenotypes tested converted intercepted radiation into DM with equal photosynthetic efficiency and the foliage of leafless peas was not at a photosynthetic disadvantage. On the other hand a significant ($p < 0.05$) herbicide x pea type interaction on RUE in this research was of paramount importance and helps to explain the influence of weed competition on crop yield. The mean RUE of herbicide sprayed and unsprayed Pro 7035 plots did not differ significantly. This was because its fully leafed morphology gave it greater ability to suppress weeds resulting in similar competition in unsprayed and sprayed plots. However, herbicide sprayed Midichi plants had a 29% higher RUE than unsprayed ones. Unsprayed Midichi plants were disadvantaged because of its semi-leafless morphology which allowed more radiation to reach the weeds encouraging more weed growth and hence more competition. With less weed pressure, sprayed, semi-leafless Midichi converted PAR into TDM with greater efficiency.

Sowing date influenced total DM production and seed yield. Early sowing gave a significantly ($p < 0.05$) higher mean seed yield (526 g m^{-2}) than an October sowing (354 g m^{-2}). Jamieson *et al.* (1984) obtained similar results and reported that changing the sowing date significantly affected both total DM production and seed yield. In their

research a 30 September sowing gave the highest yield. The duration of growth from emergence to complete senescence was 99 days, RUE was 2.6 g MJ^{-1} and the CHI was 0.58.

In this work sowing date had no affect on WMAGR (mean 18.3 g m^{-2} day^{-1}). Similarly, Greven, (2000) reported no sowing date effect on WMAGR with *Phaseolus vulgaris*. The significant ($p < 0.05$) herbicide x pea genotype interaction showed that Pro 7035 grew 55% faster than Midichi in unsprayed plots but had a similar WMAGR in sprayed plots. This could be due to the lower competitive ability of semi-leafless peas against weeds in unsprayed plots because of its semi-leafless morphology as explained above. In the presence of weeds the leafed pea genotype tended to produce more DM than the semi-leafless peas.

7.3. Radiation Partitioning

One of the most important aspects of weed / crop competition is competition for light. To help explain yield results and competitive pressure in this research programme radiation interception was partitioned into the various components of the sward e.g. crop and weed. This was done four times over the growing season (Tables 6.7 – 6.9). Increased pea population resulted in a much higher proportion of total radiation being intercepted by the pea crop. At the final RI measurement (70 DAE) at 50 plants m^{-2} the pea crop intercepted 272 MJ PAR m^{-2} and the weeds intercepted 104 MJ m^{-2}. At 100 plants m^{-2} the respective values were 430 and 51 MJ m^{-2}, while at 200 plants m^{-2} they were 482 and 29 MJ m^{-2}. This clearly demonstrates the importance of plant population in increasing radiation interception, which is a key driver of growth and yield (Montieth, 1977).

7.4. Harvest Index

An aim of this research was to identify a pea ideotype with a more stable HI as variable harvest indices (CHI) are an important contributor to yield instability in grain legumes (Wilson, 1987; Moot, 1993; Moot and McNeil, 1995; Timmerman-Vaughan *et al*., 2005). In this work CHI ranged from 0.47 to 0.55 in Experiment 1 (2006/07), from 0.43 to 0.57 in Experiment 2 and from 0.37 to 0.40 in Experiment 3. Previous research has reported variable CHI's: For example Askin, (1983) reported peas had HIs ranging from 0.17 to 0.44; Anderson and White (1974) showed HI varied from 0.16 to 0.24

based on shelling percentage. McKenzie *et al.* (1989) and Moot (1993) reported HIs in grain legumes, which varied from 0.00 to 0.74. The lowest HI in this work was in the sown artificial weed experiment (Experiment 3) and this can mostly be attributed to weed competition for radiation since water and nutrients were not limiting.

Crop HI was inversely proportional to plant population in Experiment 1 but population did not affect CHI in Experiment 3. This was because of the higher weed pressure in Experiment 3 due to the sown artificial weeds. Assimilates tended to be partitioned to reproductive organs when competition was minimal. However, with increased competition, more assimilates are often partitioned to vegetative growth (Taylor *et al.*, 1991).

Both PHI and CHI decreased with delay in sowing in Experiment 2. Pro 7035 had a higher CHI and PHI than Midichi (0.56 and 0.48) respectively contrary to the expectation that the semi-leafless pea would have a higher HI. The difference in HI is attributed to lower conversion of photosynthates to reproductive organs, which may be a weakness of semi-leafless peas (Ali, 1980). Herbicide treatment had no effect on either CHI or PHI. However, there were some significant ($p < 0.01$) sowing date x pea type interactions on both CHI and PHI. The interactions showed that in the August sowing there was less difference in CHI and PHI between the two cultivars than at the other two sowings. As with seed yield, the major cause of this was the prevalence of more weeds late in the season and the different capacity of the two pea genotypes to suppress them. Moot, (1993), concluded that growing semi-leafless peas using the optimum population, to minimise competition amongst plants, should increase crop HI. A cumulatively high PHI will give a high-yielding ideotype and this is supported by Martin *et al.* (1992). That maybe correct, but the results of this research are at variance with this. In both seasons the semi-leafless peas had a lower HI than the fully leaved plants in all experiments.

7.5. Weed Spectrum

Sustainable weed management is not a one-size-fits-all model. Specific methods to suit different environments have to be explored and integrated to give the best results. In a sustainable farming system, knowledge of the weed spectrum cannot be underrated. Learning the characteristics of the weed spectrum is a technique every successful farmer needs to be acquainted with. The ability to identify weeds and knowing the times when

specific weeds are likely to be a problem helps a farmer to successfully control weeds using integrated pest management.

In this work there was variation in the weed spectrum during the growing season. In an experiment to determine the effect of reduced metolachlor rates in maize-legume intercrops Munakamwe (2004), reported similar variation in the weed spectrum during the growing season. A number of weeds were identified in this research and there were several weed species that are of major importance to Canterbury arable farmers. Chickweed (*Stellaria media*) with a base temperature for growth of -3.3 ^{o}C, was present throughout the season. It was present in large numbers even early in the season when temperatures were quite low. Air and soil temperature are important determinants of plant species distribution and ecological interactions. Zimdahl (2007), reported that common chickweed survives well in cold climates because it can continue to grow in the winter without injury. The ability to grow under very low temperatures means that chickweed (Zimdahl, 2007) should be monitored closely throughout the season as it can cause considerable yield reduction in a pea crop. *Achillea millefolium* (yarrow) also occurred in early to mid season, and this could have reduced the yield of early sown peas. It is considered to be a successful, aggressive weed common in arable land in New Zealand. It causes significant crop losses in a range of crops by choking them out by its dense growth (Bourdôt and Field, 1988). According to Kannangara and Field (1985), it also produces large quantities of seed in summer and autumn. This seed has conditional dormancy and survives when buried in the soil. These characteristics enable yarrow to persist in cultivated arable land for several years. Seed, shed in summer and autumn, may germinate and form over wintering rosettes.

Weeds identified as late season in this research were *Trifolium repens* and *Solanum* spp. Nightshades have a relatively high base temperate of 6 ^{o}C (Olivier and Annandale, 1998), which explains why they usually come late in season when temperatures are warm. Bithel, (2004) reported that analysis of processing factory nightshade contamination records indicated that nightshade contamination was more common in mid and late season sown peas. For example, mean contamination was 4.8% for crops sown in October and November, while the figures for August and September were 0 and 0.6%. Myers *et al.* (2004) also reported nightshades were late weeds. Although late weeds such as *Solanum* spp may not greatly compete with early sown pea crops, they may influence the acceptability of process peas if berry development has occurred, seriously impacting on profitability.

Isaac (2001) reported higher counts of *Trifolium repens* in late sown crops than in early sown crops confirming it as a late weed. It was also observed that grasses tended to be more prevalent later in the season than earlier. One such grass is *Avena fatua*, which might have caused considerable yield loss in late-sown peas and is referred to as one of the greatest crop competitors of all (Gane, 1972). Isaac (2001) also found that perennial weeds were more prevalent in late sown crops.

Some weeds occurred in relatively large numbers throughout the season. These included *Coronopus didymus, Stellaria media,* and *Lolium* spp. They had high counts throughout the season and need to be watched and controlled at all times. This possibly means they can survive well and reproduce under wide range of environmental conditions. Harker *et al.* (2007) reported *Bromus willdenowii* (prairie grass) was present in all season and claimed that it can germinate throughout the growing season. Much has been said about the negative effects of weeds. Are weeds always detrimental in cropping systems?

Although weeds may negatively affect crop yield, they are important ecological entities which play a crucial role in balancing ecosystems and making them stable. Because of this role they should not be entirely eradicated but only reduced to levels, which are harmless to crops. For example, cultural methods like early sowing of peas can successfully control late weeds without the use of a herbicide. Some weeds are relatively weak competitors and do not do much harm to crops and these weeds could be left to grow and their positive effects exploited e.g. soil protection and harbouring of natural pest enemies (Blackshaw *et al.*, 2007). Gane (1972), reported that relatively weak-growing weeds, such as *Spergula arvensis* and *Capsella bursa pastoris* were not aggressive and could be tolerated in reasonable numbers without affecting crop performance.

In summary pea farmers should not attempt to eradicate all weeds. The aim should be focussed on weed suppression. The results of this research indicate that this could be possible by selection of the right pea genotype sown at an appropriate seed rate on the optimum sowing date; and through an understanding of the weed spectrum and crop-weed interactions throughout the growing season. The avoidance of yield loss from weeds is important for short-term profits, while suppression of weed growth and weed seed production has longer-term implications for managing future weed populations (Goldberg, 1990) and future weed seed banks.

7.6. General Conclusions

- Fully leafed peas and semi-leafless can be sown at similar plant populations to achieve similar yields under weed free conditions.

- Increased pea sowing rates increased TDM and seed yield in weedy environments (Experiments 2 and 3).

- Increased pea sowing rate improved weed suppression.

- Increased weed pressure reduced pea yield.

- A fully leafed pea type produced higher seed yields than semi-leafless type but there was no difference in total DM produced.

- There was no significant difference in total radiation intercepted by semi-leafless and fully leaved pea genotypes.

- Early pea sowing was associated with greater total radiation accumulation.

- Weed spectrum changed over the season.

- Early sowing could possibly control problematic pea weeds, particularly *Solanum* spp.

- Herbicides can enhance yield but could be replaced by other effective cultural methods e.g. early sowing, appropriate pea genotype and high seeding rates.

7.7. Recommendations for Further Studies

- While semi-leafless peas are less prone to lodging than the traditional cultivars, Midichi lodged severely. Further studies targeting yield reduction caused by lodging are recommended.

- The future of effective weed management partly lies in biological or physical control measures especially in organic production. Studies including biological and physical control methods, as part of integrated pest management, are required.

- Generally, semi-leafless types were more susceptible to fungal infection than the conventional genotype. Hence there is a need for further research in this area.

- Further studies using integrated weed control techniques would be useful.

- There is need to investigate further more factorial combinations of pea-weed populations to determine the threshold levels which peas can tolerate without yield reductions.

Acknowledgements

education dad and mum have. Above all, I believe the Almighty God has made this study possible and I thank Him for granting me this special opportunity, which I will forever value.

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Appendices

Appendix 1: Quantifying radiation interception by component species of mixed swards

The amount of irradiance intercepted by component species e.g. peas was calculated using Thornely and Johnson, (1990) equations as:

$$Si, p = I_0 \left[\frac{1 - \exp^{-(k_e l)}}{k_e l} \right] (k_p l_p)$$

$S_{i,p}$ is the amount of irradiance intercepted by pea component of the pea weed mixture. The same expression holds for the weed component except for the need to substitute w for subscripts p. The irradiance intercepted by the combined pea weed canopy is the sum of irradiance intercepted by the component species of the mixture *viz,*

$$S_i = I_0 ((1 - \exp(-k_e L))$$

I_0 is irradiance above the pea / weed canopy and S_i is amount of irradiance intercepted by the combined pea / weed leaf area index L; k_e is effective extinction coefficient for a mixed pea weed sward, calculated as (Thornely and Johnson, 1990):

$$K_e = (k_p L_p + k_w L_w) / L$$

Where $L = L_p + L_w$

And L_p and L_w are leaf area indices of pea and weeds, respectively.

The values of the extinction coefficients for the pea and weeds used were taken from literature.

Assuming the irradiance recorded by the solarimeter below the combined canopy is equivalent to $\exp(-k_e L)$, the fraction of radiation intercepted by each component of a pea weed mixture was computed as follows:

Pea fraction = $(k_p L_p) / ((k_e L)) * (1 - \exp((-k_e L)))$ for pea

And

Weed fraction = $(k_w L_w) / ((k_e L)) * (1 - \exp((-k_e L)))$ for weeds

Appendix 2: The herbicide x pea genotype interaction of *Coronopus* spp of field peas grown in Canterbury in 2007/08 growing season.

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
No pea	102	16
Midichi	38	3
Pro 7035	51	18
Significance	***	
LSD	20	
CV (%)	54	

Appendix 3: The herbicide x pea genotype interaction of *Stellaria media* of field peas grown in Canterbury in 2007/08 growing season.

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
No pea	33	0
Midichi	43	24
Pro 7035	24	7
Significance	*	
LSD	12	
CV (%)	71	

Appendix 4: The herbicide x pea genotype interaction of *Urtica urens* of field peas grown in Canterbury in 2007/08 growing season.

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
No pea	31	7
Midichi	34	10
Pro 7035	0	1
Significance	***	
LSD	9	
CV (%)	67	

Appendix 5: The herbicide x pea genotype interaction of *Rumex* spp of field peas grown in Canterbury in 2007/08 growing season.

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
No pea	60	1
Midichi	32	0
Pro 7035	12	7
Significance	***	
LSD	10	
CV (%)	55	

Appendix 6: The herbicide x pea genotype interaction of *Lolium* spp of field peas grown in Canterbury in 2007/08 growing season.

	Herbicide	
Pea genotype	0 g a.i. ha^{-1}	500 g a.i. ha^{-1}
No pea	1	3
Midichi	2	4
Pro 7035	2	0
Significance	*	
LSD	3	
CV (%)	134	

Appendix 7: Classification, by season, of the weed spectrum in field peas grown in Canterbury in 2007/8 growing season.

All season	Early season	Early to mid season	Mid to late season	Late season
Coronopus didymus *Stellaria media* *Lolium* spp	*Stachys* spp	*Achillea millefolium* *Spergular arvensis*	*Chenopodium* spp *Rumex* spp	*Trifolium* spp *Solanum* spp