Chapter 5

The effect of row spacing and weed density on the yield loss of chickpea

5.1 Introduction

The work described in this chapter pertains to two sections (row spacing and weed density) of experiments, run over two years. The final section of this experiment (predictive modelling) is discussed in Chapter 6.

Over the last three decades, agricultural production has expanded around the world, with greater areas of crop being managed by fewer people. Chemical weed control is one of the main reasons that such an expansion has been possible (Kropff & Lotz 1992b). However, perceptions of the value of herbicides are rapidly changing. Herbicide resistance, economics, environmental concerns, and community attitudes are combining to reduce the use of herbicides in some agricultural systems (Glauninger & Holzner 1982, Lutman *et al.* 1994, Lotz *et al.* 1995). Despite the desire of our society to reduce herbicide use, the need for broad-scale agricultural production remains, and for agricultural production to continue successfully, weed populations in crops must be reduced.

In natural ecosystems, individual plant populations compete for resources and dominance of each niche. This same fight for dominance occurs in agriculture, the only difference being that the agriculturist has a vested interest in the crop being dominant. To ensure that the desired crop population succeeds, management practices must favour the crop to the detriment of all other plant populations. Success relies on a thorough understanding of the interactions between the crop and weed populations.

5.1.1 Competition

The term "competition" has been used in agricultural literature to refer to the interference interactions that occur between plants generally, and in a weed context, the interaction of weeds and crops (Kropff & Lotz 1992b). The process of weed competition could more accurately be described as interference between weeds and crops (Glauninger & Holzner 1982). This in itself is a contradiction, but for the sake of uniformity (Glauninger & Holzner 1982) "interference" will be considered under the term "competition" for the remainder of this chapter.

Competition for the essential plant resources of light, water and nutrients is the key process in plant ecology (Kropff & Lotz 1992b). Early agriculturists were the first to recognise inter-plant competition, but the first published record was in the 14th Century (Grace & Tilman 1990, cited by Kropff 1993). The concept of plant competition is unchallenged, but as specific areas of competition were studied, different definitions of the term have been developed. Grime (1979) proposed the idea that plant competition is the capacity of a plant to quickly capture and utilise limited resources. Tilman (1987, cited by Kropff 1993) defined the process as the capture and utilisation of limited resources by two or more species, but it could equally include each individual plant, no matter what species. These theories are not contradictory but complementary (Grace 1990, cited by Kropff 1993) and depend on the availability of resources. In environments with high resource availability, the competitive ability of the plant is determined by its resource-capture capacity (Kropff 1993). In resource-limited environments, competitive ability is determined by the plant's ability to tolerate low resource availability (Kropff 1993). Agricultural ecosystems are generally resource-rich so the form of competition is generally determined by resource-capture capacity. However, in Australia and particularly the northern grain region of eastern Australia, winter crops are grown on stored moisture (as opposed to current rainfall), which may result in periods of water stress occurring during the season (Felton *et al.* 1994). Under these circumstances, the plant's ability to tolerate low resource availability is what governs its competitive advantage.

Competition between two plant species or between individual plants of the same species occurs throughout a plant's life cycle (Kropff & Lotz 1993). Competition studies usually relate the growth and competitive features of plant "A" to the yield or yield loss of plant "B" (Cousens *et al.* 1991). In most cases this relationship is justified, but it does not show how the plants have interacted during their life cycles. Cousens *et al.* (1991) investigated the interactions between wild oats (*Avena fatua*), barley, and wheat. Their results show that, for a large part of the season, both barley and wheat were more competitive than wild oats. They concluded that this dominance was due to delayed germination and the slow initial growth of the wild oat plants. Wild oats showed its competitive ability towards the end of the season by elongating and developing above the wheat and barley. Overall, Cousens *et al.* (1991) ranked barley and wild oats as equal competitors and wheat as the least competitive of the three.

Chickpea (*Cicer arietinum*), unlike wheat and barley, develops slowly during the initial stages of the season (Amor & Francisco 1987, Knights 1991). This growth pattern is similar to wild oat. However, unlike wheat and barley that spend part of the season as the dominant plant type (Cousens *et al.* 1991), chickpea may remain suppressed for the whole of the season. To determine the competitive ability of wild oats, barley, and wheat, Cousens *et al.* (1991) used a replacement series experiment with a number of harvest times. Replacement series experiments which maintain one density, but change the individual plant ratios were first proposed by de Wit (1960), and since this time have been used in an array of situations for measuring competition between species (Kropff & Lotz 1993). As with all experimental methods, the replacement series was designed to answer specific questions. Unfortunately, misuse of the design provoked criticism so work utilising the method was not accepted by many journals (Cousens 1991, Kropff & Lotz 1993, Cousens 1996).

In agricultural systems, researchers are less interested in the competitive ability of plant species "A" compared with plant species "B" *per se*, than under what conditions will crop "A" be more competitive than plant "B". For this reason, under these conditions the replacement series type experiment has been rejected by many in favour of the additive model experiment. Additive models better mimic the realities of agricultural production. They use a single fixed density of crop "A" and a variable density of plant "B", which means as the density of "B" is increased the overall population density increases (Kropff & Lotz 1993, Cousens 1996). The change in population density associated with additive models means that this model will not determine which plant species is more competitive, but it will show the density at which plant species "B" significantly reduces the yield of crop "A" (Cousens 1991, Lotz *et al.* 1995, Cousens 1996).

In recent years, a third weed competition model has been developed, being a combination of the replacement series and the additive model. The surface model incorporates a third dimension and can provide an improved understanding of the competitive interactions between plants (Cousens 1991). The major limitation of the surface model is the size of the experiment and the resources needed to maintain it.

Each experimental design is suited to answering specific questions about plant interactions, but to utilise the design correctly, the results must be analysed in a meaningful way. Additive models have been assessed by analysis of variance, and this form of analysis in the absence of raw data plots, caused people to believe that the response of a crop plant "A" to varying densities of plant "B" was sigmoidal (Cousens 1985a). The shape of this relationship is not sigmoidal and the use of linear and non-linear regression can describe the density relationship in a far more meaningful and biologically correct manner (Cousens 1991, Kropff *et al.* 1993). The rectangular hyperbolic model is the non-linear function that over many different data sets has best described the competitive relationship between two plant species (Cousens 1985b). However, the rectangular hyperbolic model has limitations for the predictions of yield responses (Kropff 1988). It utilises crop density to predict yield, but weed size does not always correlate with density, and the early and late emerging weeds of different sizes are treated as having equal competitive ability. For these reasons, the Cousen's (1985a) hyperbolic model has been designated a descriptive model, not a predictive model (Kropff 1988, Kropff & Spitters 1991, Lotz *et al.* 1996).

By utilising the descriptive Cousen's (1985a) model, Kropff and Splitters (1991) replaced the density component with a relative leaf area component. Leaf area incorporates different aged seedlings and has been shown to reliably predict yield loss in many agricultural situations (Kropff & Spitters 1991, Lotz *et al.* 1992, Lutman 1992, Lotz *et al.* 1994, Lotz *et al.* 1996). The role of this form of predictive modelling will be discussed in Chapter 6. However, the Cousen's (1985a) model describes inter-plant competition adequately. When cultural methods, such as varying the crop's row spacing, are manipulated to give the crop a competitive advantage, the hyperbolic model is the ideal form of analysis. It will show the magnitude of any competitive advantage, and for what weed density that advantage is sustained.

5.1.2 Row spacing

In agricultural situations, the desired outcome is for the crop plant to dominate since this usually results in maximum yields. To ensure this result, agricultural practice must favour the crop and disadvantage co-occurring weeds. Agronomic cultural practices are the basic necessities for successful agricultural production, yet are often overlooked for more complicated chemical solutions. As agriculture has become more mechanised, cultural practices have become more general, because the treating of crops individually is uneconomic. The production of different crop species takes place with the same machinery, regardless of the differences between the crop types. As a result of this production streamlining, some cultural practices no longer improve the competitive ability of the crop. Wide row spacing is such an example. The development of no-till farming requires farm machinery to sow crops through a stubble burden. To facilitate sowing through stubble, it is desirable to increase the distance between rows. This technique allows the stubble to easily pass the tine without building up and interfering with the sowing procedure, so it has resulted in an increase in crop row width with little to no consideration of the effect on crop competitive ability.

The pressure to reduce the reliance on herbicides has caused a re-examination of crop cultural practices (Medd *et al.* 1985, Malik *et al.* 1993, Ball *et al.* 1997). In most situations, following crop canopy closure, weed competition is reduced (Swanton & Weise 1991) and a successful crop yield can be achieved. This result suggests that the earlier the crop can reach canopy closure the more it will compete with weeds, thus reducing their effect (Swanton & Weise 1991, Malik *et al.* 1993). This theory has been examined by various authors with markedly differing results. Narrow row spacing has been shown to improve crop yields in both weed-free (Felton 1976, Silim *et al.* 1990, Koscelny 1990) and weedy situations (Holland & McNamara 1982, Koscelny 1990, Hosmani & Meti 1993, Malik *et al.* 1993); however, despite the advantage of using narrow rows to improve competitive ability, the benefits of wide rows must not be overlooked.

The influence of row spacing is usually measured over a short period of 1-2 seasons and yield loss is the only variable that is measured (Felton 1976, Holland & McNamara 1982, Medd *et al.* 1985, Koscelny 1990, Silim *et al.* 1990, Malik *et al.* 1993). In recent times, the understanding of plant inter-relationships has increased and the weed management timeframe has begun to extend beyond the current crop (Jones & Medd 1997). Management decisions made in one season are not necessarily made to improve the yield of that season's crop but of future crops as well (Jones & Medd 1997). With this idea in mind, a re-examination of wide rows shows that they may benefit a crops competitive ability over time. Wider rows may influence not only weed management, but also the farming system as a whole. Wide rows in combination with no-till farming and narrow pointed sowing tines minimise the disturbance of the soil. In Canada, it has been suggested that wide rows and minimal disturbance maintains weed seed on the soil surface, where its life span is greatly reduced by heat, insects and fungal disease (Blackshaw 1998). However, this response to no-till farming may be less applicable to the self-mulching vertosols in the northern grains region.

Including pulse crops in cereal rotations can cause soil management problems, because of the pulse's slow initial growth, and very little residue protection after harvest can leave the soil vulnerable to erosion. Wider rows and no-till farming with narrow pointed tines preserves the cereal stubble, helping to protect the soil (Felton *et al.* 1996). Wider rows can also be an advantage when crops are growing on stored moisture, as the surface drying of the inter-row space reduces evaporation (Holland & McNamara 1982) and may explain the benefit of wide rows for sorghum crops during a poor season (Holland & McNamara 1982). Closed canopies can increase the humidity around the crop leaves, increasing the potential for disease in susceptible plants (Felton 1976, McNeil 1989). Chickpea in the northern grain region is susceptible to several fungal diseases and its slow initial growth (Knights 1991), open canopy architecture, and production on stored moisture makes wide rows the spatial arrangement of choice (Felton *et al.* 1996). Wide rows can also be used to improve access to the crop, and in so doing allow other farming practices such as inter-row cultivation or shielded spraying (Felton *et al.* 1996) that reduce weeds and, therefore, improve the competitive ability of the crop.

During 1996 and 1997, experiments were established at two sites in the northern grain region of eastern Australia, to examine the effect of weed density on chickpea production, and to investigate if manipulation of the crop spatial arrangement would improve its competitive ability. Chickpea was assessed against the dominant broad-leaved weed *Rapistrum rugosum* (turnip weed) and the predominant grass weed *Avena ludoviciana* (wild oat).

5.2 Materials and methods

5.2.1 Sites

Descriptions of the climatic conditions over the two years and features of the two sites (Tamworth and Warialda) are presented in Chapter 3.

5.2.2 Plant material

The chickpea variety Amethyst was used in all four experiments. It was the first chickpea variety bred in Australia and is particularly suited to grain production in northern New South Wales.

Wild oat is a weed, which exists in all grain producing areas in Australia; however, there are different species and sub-species. In the northern grains region of eastern Australia the predominant type of wild oat is *Avena sterilis* ssp. *ludoviciana*, while the southern and western grains regions of Australia, are dominated by *A. fatua*. Wild oat seed was collected from a small seed cleaning business (Warialda Seed Cleaners) that predominantly cleans seed from the Warialda area. The seed was graded to produce a non-contaminated wild oat sample that contained 99% *Avena ludoviciana,* and then maintained in a cold store until use. Wild oat seed had a glasshouse emergence of 66% in 1996 and 75% in 1997.

Turnip weed occurs throughout New South Wales, but has been shown to display considerable phenotypic differences and germination behaviour in seed collected from different areas (Cousens *et al.* 1994). As a result of this variation, turnip weed seed for the 1996 experiments was collected from a single patch found outside the Tamworth Centre for Crop Improvement. Seed for the 1997 experiments was collected from the plants grown in the 1996 trials. Turnip weed produces two types of seed. Distal seeds are contained in the turnip weed pod, are difficult to liberate and can display some dormancy (Cousens *et al.* 1994). The second seed is the proximal seed, which does not occur in a pod and has less dormancy than the distal seed (Cousens *et al.* 1994). Distal seeds were used for all experiments in this research. As with the wild oat seed, the turnip weed seed was maintained in a cold store until use and had a glasshouse emergence of 40% in both years.

5.2.3 Sowing

<u>1996</u>

In 1996, chickpea seed was sown at Warialda on 29/5/96 and at Tamworth on 4/6/96. The seeding rate was 140 kg ha^{-1}, the aim being to achieve establishment of 70 plants m^{-2} with a 32 cm row spacing. A no-till planter with 11 narrow pointed tines and press wheels spaced at 32 cm was used to direct drill chickpea seed.

Weed seed was mixed with dry sand and spread across the surface of the plots on 5/6/96 at Warialda and on 18/6/96 at Tamworth. Weed seed was not incorporated by raking, because rain occurred at both sites within 24 hours of sowing. The sowing densities of both weed seeds (wild oats and turnip weed) were 0, 2, 4, 16 and 32 plants m^{-2}.

To achieve the desired row spacing (32 cm and 64 cm) and plant density (35 plants m^{-2}) the experimental plots were thinned. Thinning took place on 4/7/96 at Warialda and on 12/7/96 at Tamworth. Thinning involved the removal of every second row in the wide row plots and every second plant in the narrow row plots. Chickpea removal was achieved by spraying glyphosate at 675g a.i. ha^{-1} (as Roundup CT) through a knapsack sprayer fitted with a 10 cm diameter spray shield and small cone nozzle.

Plant density was measured on 19/7/96 at Warialda and on 1/8/96 at Tamworth to determine the success of the thinning operation. Plant counts of randomly selected 1m sections of crop row in each plot showed an average crop density of 31 plants m^{-2} at both sites.

1997

In 1997, chickpea seed was sown at Warialda on 4/6/97 and Tamworth on 12/6/97. The plots were not thinned. Instead, alternating sowing runs of wide and narrow rows were sown. Wide rows were on 64 cm centres and narrow rows were on 32 cm centres. Both were sown to achieve a chickpea stand of 35 plants m^{-2}. Wide and narrow row spacing plots were sown using the same machine by either seeding through both the front and back gangs of tines (11 narrow rows), or only the front gang (5 wide rows).

Weeds were mixed in dry sand and spread by hand prior to the chickpea sowing, so that the weed seed would be incorporated by the sowing process. Turnip weed was the only weed used in 1997 and it was sown at 3 densities (0, 2, 8 plants m^{-2}).

Both the Tamworth and Warialda sites experienced dry weather following sowing and were infected by a seed borne root fungus (*Botrytis*) that reduced the plant population at Warialda to 15-20 plants m^{-2} and at Tamworth to 20-25 plants m^{-2}. The weed population achieved at both sites (0-4 plants m^{-2}) was well below the expected level (0-8 plants m^{-2}).

5.2.4 Experimental design

During both years, the same additive experimental design was used; however, the treatments in 1997 varied from those of 1996 with only low densities of turnip weed being examined.

In 1996, the density experiment was a factorially-arranged complete randomised block design, with four replicates, two crop row spacings, two separate weed species and four weed densities. The plots were 3.5 m wide by 3 m long and contained five wide-crop rows or 11 narrow-crop rows. The crop density remained static in all plots with only the weed densities varying; this design is consistent with the additive model described by Kropff and Lotz (1993) and Cousens (1996), and is suited to analysis using non-linear regression and the rectangular hyperbolic model described by Cousens (1985a, b).

Equation 5.1 Rectangular hyperbolic model

$$Y_L = \frac{Id}{1 + \frac{Id}{A}}$$

Y_L: percentage of yield lost because of weed competition

d: weed density

A: percentage yield loss as $d \rightarrow \infty$

I: percentage yield loss per unit weed density as $d \rightarrow 0$

The experimental design in 1997 was a factorially arranged randomised complete block, with five replicates, two crop row spacings and three densities of turnip weed. The plots were 3.5 m wide by 8 m long and contained five wide-crop rows and 11 narrow-crop rows. In 1996, the wide and narrow rows were randomly distributed within the block, but in 1997 the wide and narrow rows were mechanically sown, each block contained randomly allocated sowing strips of wide and narrow rows. Apart from these minor modifications, the experiment in 1997 was also additive in design allowing the same use of non-linear regression and rectangular hyperbolic models to describe the crop and weed relationships.

5.2.5 Maintenance

During 1996, the unusually wet season meant that the removal of background weeds was a priority. Broad-leaved weeds were removed by hand chipping in all plots; mid-season emerging wild oats were controlled with fluazifop-p 106 g a.i. ha^{-1} (as Fusilade®) at Warialda on 15/8/96 and at Tamworth on 22/8/96. Only the turnip weed and weed-free plots were sprayed. The wild oat plots were thinned to the desired density by hand pulling of random plants.

Very few broad-leaved weeds occurred in the plots during 1997, and the few that were present were left as a general background weed population. Grass weeds were a problem, especially at Tamworth where two dense recruitment flushes of *Phalaris paradoxa* occurred. Grass weeds were controlled with fluazifop-p at 106 g a.i. (as Fusilade®). Herbicide was applied once at Warialda on 27/8/98, and twice at Tamworth on 13/8/98 and 15/10/98. On all occasions, herbicide was applied through a hand held 3 m boom spray, operating at 172.4 kPa and a water volume of 85 L ha^{-1}.

5.2.6 Non-destructive measurements

During both the 1996 and 1997 seasons, a series of non-destructive measurements were made of the relative chickpea ground cover. The methods used and the results of these measurements are presented in Chapter 6.

5.2.7 Harvest

The chickpeas were harvested by hand in December 1996 by cutting two 1 m^2 quadrats from each of the experimental plots. Weeds growing in the quadrat area were collected and counted. Following harvest, the weed and crop samples were dried in a fan forced hydronic mobile drier at 80°C, circulating air at 10 m^3 sec^{-1} for 48 hours. Following drying and weighing, chickpea grain yield was recorded after the samples had passed through a stationary thrasher. Seeds were randomly selected from each sample and weighed to obtain a 100 seed weight. Turnip weeds and wild oats were also dried at 80°C for 48 hours and weighed.

In December 1997, a small plot-harvester was used to harvest the chickpea crop. The harvested section removed three wide rows or five narrow rows from the centre of the 8 m long plot. Weeds were harvested by hand (prior to machine harvesting) from the inter-row space and rows of the 3 or 5 centre crop rows. Harvested weed material was counted and dried (as above). Following drying and weighing, the turnip weed seed production was recorded after the samples had passed through a stationary thrasher. The machine-harvested chickpea grain was also weighed, and its 100 seed weight determined (as above).

5.3.8 Analysis

Results in 1996 and 1997 were analysed by non-linear regression using the maximum likelihood function of the statistical software package Splus-4 (Mathsoft 1997). Comparisons between the non-linear curves were calculated using Hotelling's T^2 test (Anderson 1958). Linear regression was used to relate the individual crop and weed parameters to the selected chickpea yield and weed density parameters. Crop yield loss was calculated against the mean value for the sum of the weed-free controls of either the wide or narrow-crop row treatments. Calculating the yield loss from a single mean yield, for each plot, accounted for potential plot spatial error.

5.3 Results

The effects of weed density on yield for the wide and narrow rows are presented here. Chickpea dry matter was highly correlated with chickpea grain yield for both crops grown in the presence of turnip weed and wild oats at Tamworth and Warialda; R^2 values were between 0.93 and 0.97. Wide and narrow rows had no significant effect on the 100 seed weights of chickpea seed for any of the weed densities examined.

5.3.1 Weed density

In 1996, increasing the weed density caused a significant reduction in chickpea yield. Fitting the rectangular hyperbolic model (Equation 5.1) to yield loss and weed density data accounted for much of the variation (Fig. 5.1). Fig. 5.1 shows the chickpea yield response to increasing weed density for each of the four treatments (wild oats, turnip weed, wide rows and narrow rows) at each site. Differences between the wide and narrow row curves for turnip weed and wild oat were observed at Warialda, but no differences were observed at Tamworth. An estimation of the parameters A and I shows variation in the I parameter between wide and narrow rows, and between sites (Table 5.1). The results from Warialda showed the greatest variation between the I parameters from wide and narrow-crop rows (Table 5.1). The significantly (p chi-squared < 5%) large I value calculated for the narrow row turnip weed treatments suggests that at low turnip weed densities wide-crop rows maintain yield better than narrow-crop rows (Table 5.1). This was also the case for wild oats grown at Warialda (Table 5.1). Comparisons between the fitted values for the wide and narrow-crop rows were confirmed by Hotelling's T^2 test's (Anderson 1958) p chi-squared < 5%. No significant difference was found between non-linear curves produced for the wide and narrow row treatments at Tamworth, but significant differences existed between the wide and narrow-crop row treatments at Warialda (p chi-squared = 0.9% for turnip weed; p chi-squared = 3% for wild oat).

The turnip weed relationships (Fig. 5.1 A & B) show that low density of weeds can cause significant yield losses. A similar, but less dramatic response was seen in the wild oats treatments (Fig. 5.1 C & D) The turnip weed treatments were repeated in 1997 and weed densities were concentrated in the lower end of the range (Fig. 5.2) to try and explain the inconsistency between sites experienced in 1996. The 1997 results showed no difference between sites. The parameters estimated by the rectangular hyperbolic model (Equation 5.1, Table 5.2) of the wide and narrow-crop row treatments were found to be not significantly different using Hotelling's T^2 test.

The *A* parameter estimates for the wild oat treatments in 1996 and the turnip weed experiments of 1997 exceed 100%, which biologically is unobtainable. The *A* parameter can be constrained to ensure that it is less than 100%, but to be consistent with the other fitted curves this was not done. It is, however, acknowledged that yield losses of greater than 100% are not possible, and that constraining the *A* parameter to 100% is more biologically correct. The standard errors of the *A* parameters are large because the majority of data points occur in the low-density range.

The weed-free chickpea yields (Y_{wf}) consistently showed higher yields in the narrow rows; however, this was not evident in the presence of weeds (Table 5.1).

Table 5.1 Estimated values of the parameters for the hyperbolic curves fitted to the 1996 data in Fig. 5.1. Standard errors are given in brackets.

Treatment	Y_{wf} (g m^{-2})	A (%)	I (%m^2 plant^{-1})	s (m^2 plant^{-1})
Tamworth narrow row turnip weed	315.5 (±52.8)	94.8 (±9.3)	29.5 (±7.4)	0.31 (±0.002)
Tamworth wide row turnip weed	273.9 (±38.7)	99.5 (±19.1)	23.8 (±7.9)	0.24 (±0.002)
Tamworth narrow row wild oat	315.5 (±52.8)	158.7 (±41.1)	6.3 (±1.2)	0.04 (±0.0001)
Tamworth wide row wild oat	273.9 (±38.7)	140.6 (±36.3)	8.31 (±2.1)	0.06 (±0.0001)
Warialda narrow row turnip weed	381.2 (±9.7)	76.8 (±3.1)	56.15 (±9.65)	0.73 (±0.03)
Warialda wide row turnip weed	334.2 (±38.9)	78.3 (±8.1)	16.77 (±4.7)	0.21 (±0.001)
Warialda Narrow row wild oat	381.2 (±9.7)	93.4 (±10.1)	16.6 (±3.5)	0.18 (±0.001)
Warialda wide row wild oat	334.2 (±38.9)	105.2 (±12.9)	10 (±2.0)	0.09 (±0.0002)

Y_{wf}: yield in the absence of weeds

A: percentage yield loss as $d \rightarrow \infty$

I: percentage yield loss per unit weed density as $d \rightarrow 0$

s: The quotient I/A

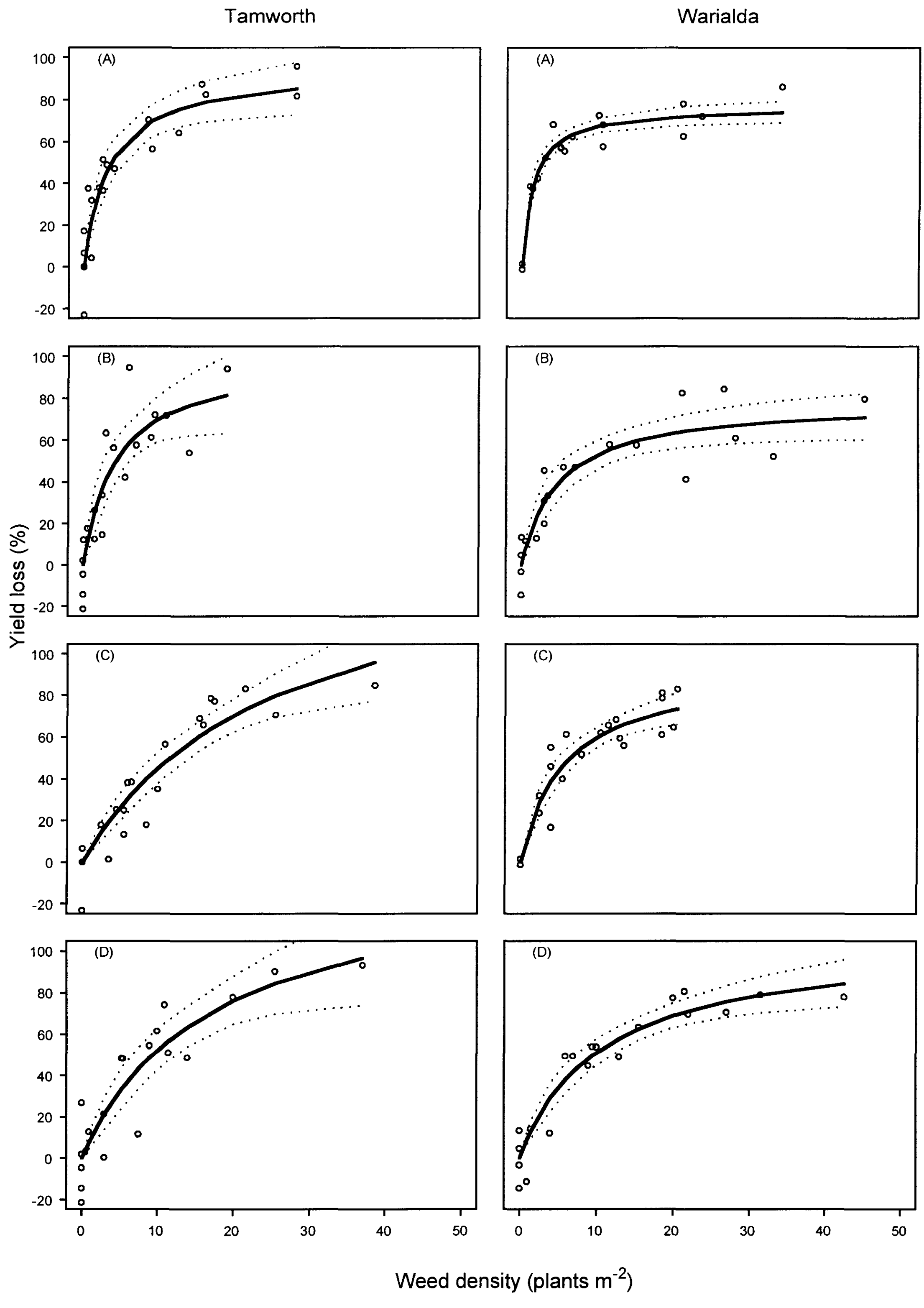

Fig. 5.1 Hyperbolic curves fitted to the density and row spacing data for 1996. Columns of graphs refer to the two experimental sites. Letters denote treatments:(A) narrow row spacing with turnip weed; (B) wide row spacing with turnip weed; (C) narrow row spacing with wild oats; and (D) wide row spacing with wild oats. X axis is the weed density, and Y axis is chickpea yield loss Broken lines indicate the 95% confidence interval.

Table 5.2 Estimated values of the parameters for the hyperbolic curves fitted to the 1997 data in Fig. 5.2. Standard errors are given in brackets.

Treatment	Y_{wf} (g m^{-2})	A (%)	I (%m^2 $plant^{-1}$)	s (m^2 $plant^{-1}$)
Tamworth narrow row	244.7 (±12.5)	124 (±199.9)	27.5 (±17.9)	0.22 (±0.08)
Tamworth wide row	186.4 (±34.8)	105.3 (±187.4)	27.83 (±22.69)	0.26 (±0.09)
Warialda narrow row	326.3 (±26.2)	107.1 (±49.5)	22.9 (±7.0)	0.21 (±0.02)
Warialda wide row	289.2 (±23.2)	118.5 (±35.5)	26.7 (±5.7)	0.22 (±0.01)

Y_{wf}: yield in the absence of weeds

A: percentage yield loss as $d \to \infty$

I: percentage yield loss per unit weed density as $d \to 0$

s: quotient I/A

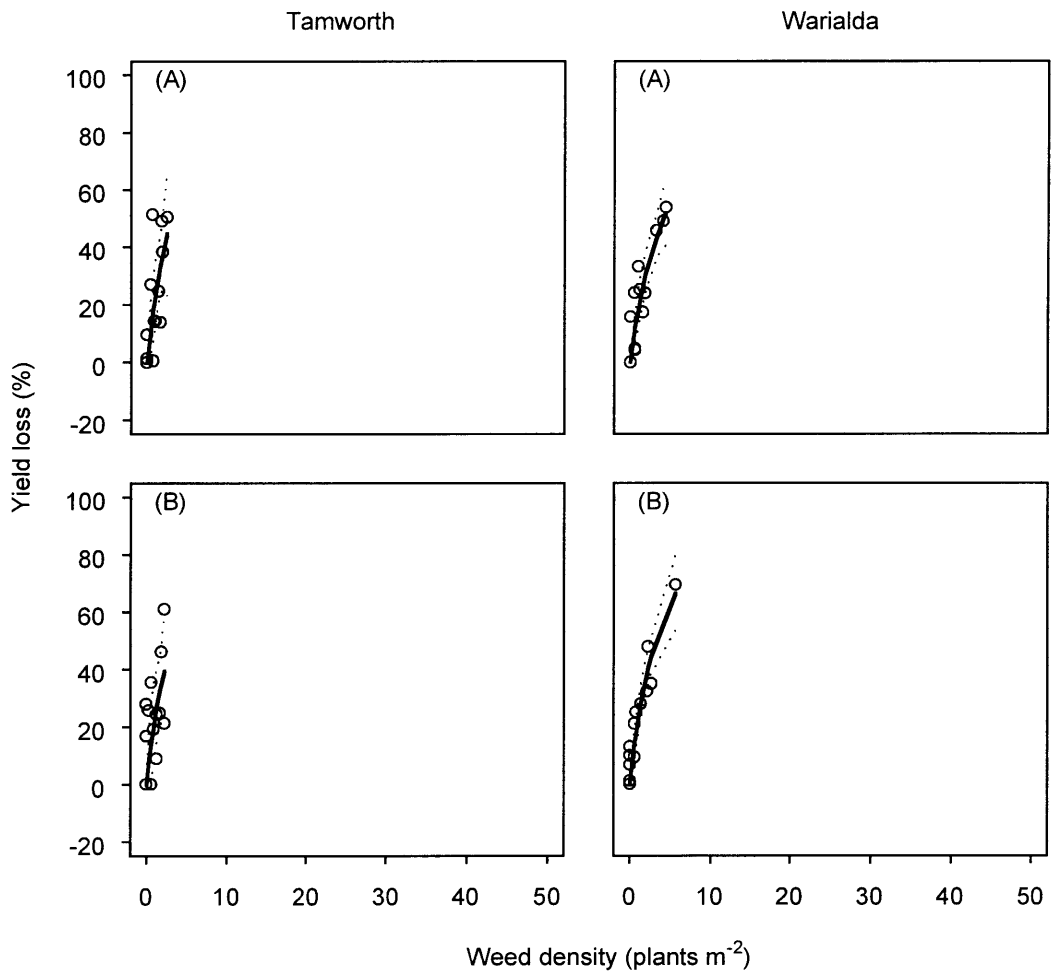

Fig. 5.2 Hyperbolic curves fitted to the density data for 1997. Columns refer to the two experimental sites. Letters denote treatments: (A) narrow row spacing with turnip weed; and (B) wide row spacing with turnip weed. X axis is the weed density, and Y axis is chickpea yield loss Broken lines indicate the 95% confidence interval.

5.3.2 Weed dry matter

The results of using weed dry matter to predict yield loss provided similar results to the use of weed density. The rectangular hyperbolic model (Equation 5.1) adequately accounted for the variation; however, in order for the model to be fitted successfully the *A* parameter had to be constrained to 100% in most cases.

The results form both 1996 and 1997 weed dry matter relationships were similar to the density relationships (Tables 5.3, 5.4). As with the 1996 density relationships the weed dry weight relationships between wide-crop rows and narrow-crop rows showed no difference at Tamworth, and the narrow-crop row treatments increased crop yield loss more than wide-crop rows at Warialda (Table 5.3, Fig. 5.3). In 1997 both the weed density and the weed dry weight relationships responded in a similar fashion with no difference between the wide- and narrow-crop rows (Table 5.4, Fig. 5.4).

Table 5.3 Estimated values of the parameters for the hyperbolic curves fitted to the 1996 data in Fig. 5.3. Standard errors are given in brackets.

Treatment	Y_{wf} (g m^{-2})	A (%)	I (%m^2 plant^{-1})
Tamworth narrow row turnip weed	315.5 (±52.8)	100 -	0.27 (±0.04)
Tamworth wide row turnip weed	273.9 (±38.7)	100 -	0.24 (±0.04)
Tamworth narrow row wild oat	315.5 (±52.8)	100 -	0.52 (±0.08)
Tamworth wide row wild oat	273.9 (±38.7)	100 -	0.54 (±0.1)
Warialda Narrow row turnip weed	381.2 (±9.7)	75.27 (±8.8)	0.62 (±0.31)
Warialda wide row turnip weed	334.2 (±38.9)	100 -	0.16 (±0.02)
Warialda Narrow row wild oat	381.2 (±9.7)	100 -	1.55 (±0.3)
Warialda wide row wild oat	334.2 (±38.9)	92.43 (±12.68)	0.9 (±0.27)

Y_{wf}: yield in the absence of weeds

A: percentage yield loss as $d \rightarrow \infty$

I: percentage yield loss per unit weed density as $d \rightarrow 0$

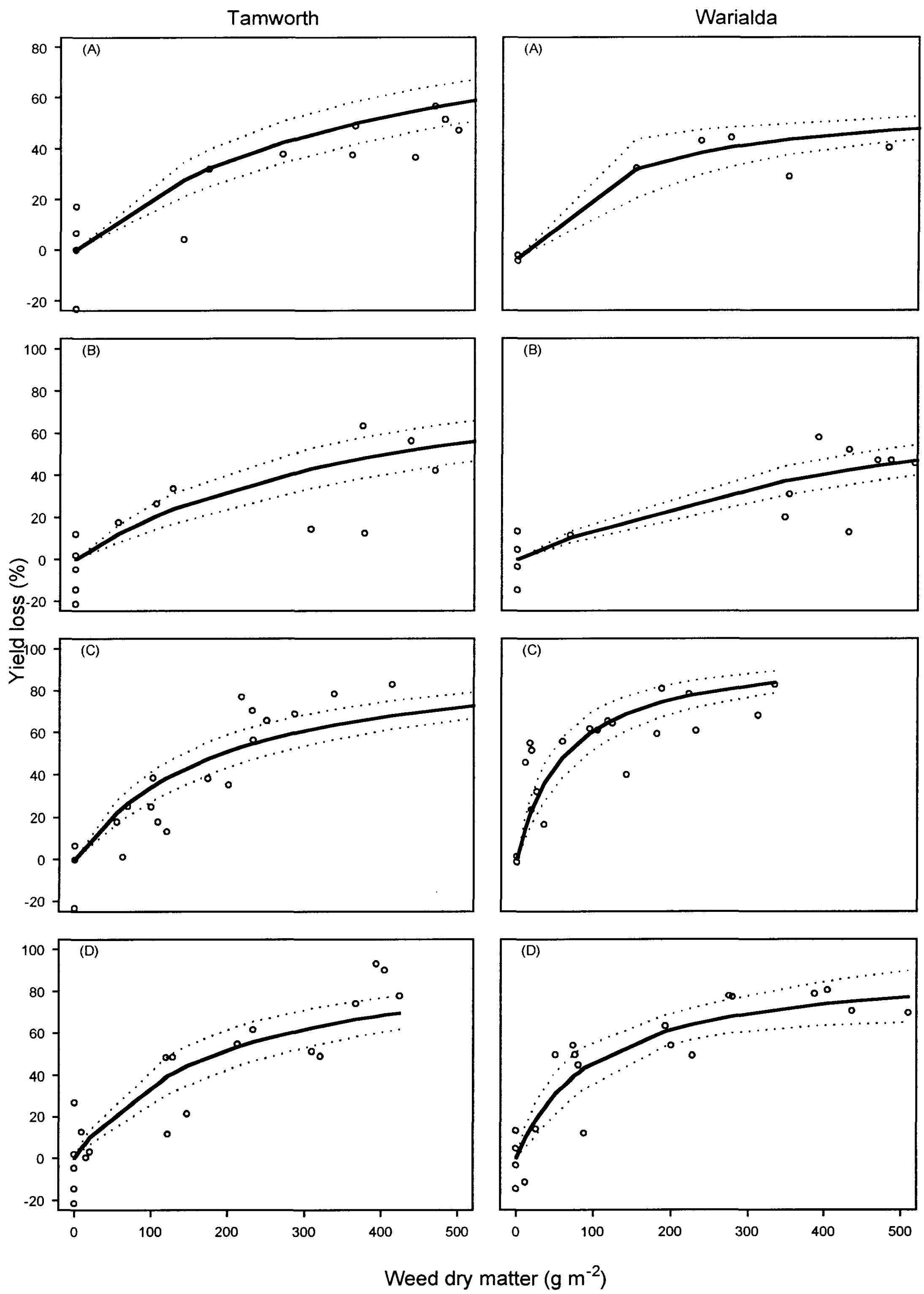

Fig. 5.3 Hyperbolic curves fitted to the weed dry matter and row spacing data for 1996. Columns of graphs refer to the two experimental sites. Letters denote treatments: (A) narrow row spacing with turnip weed; (B) wide row spacing with turnip weed; (C) narrow row spacing with wild oats; and (D) wide row spacing with wild oats. X axis is the weed density, and Y axis is chickpea yield loss Broken lines indicate the 95% confidence interval.

Table 5.4 Estimated values of the parameters for the hyperbolic curves fitted to the 1997 data in Fig. 5.4. Standard errors are given in brackets.

Treatment	Y_{wf} (g m^{-2})	A (%)	I (%m^2 plant^{-1})
Tamworth narrow row	244.7	100	0.16
	(±12.5)	-	(±0.03)
Tamworth wide row	186.4	100	0.13
	(±34.8)	-	(±0.03)
Warialda narrow row	326.3	100	0.20
	(±26.2)	-	(±0.02)
Warialda wide row	289.2	100	0.23
	(±23.2)	-	(±0.03)

Y_{wf}: yield in the absence of weeds

A: percentage yield loss as $d \rightarrow \infty$

I: percentage yield loss per unit weed density as $d \rightarrow 0$

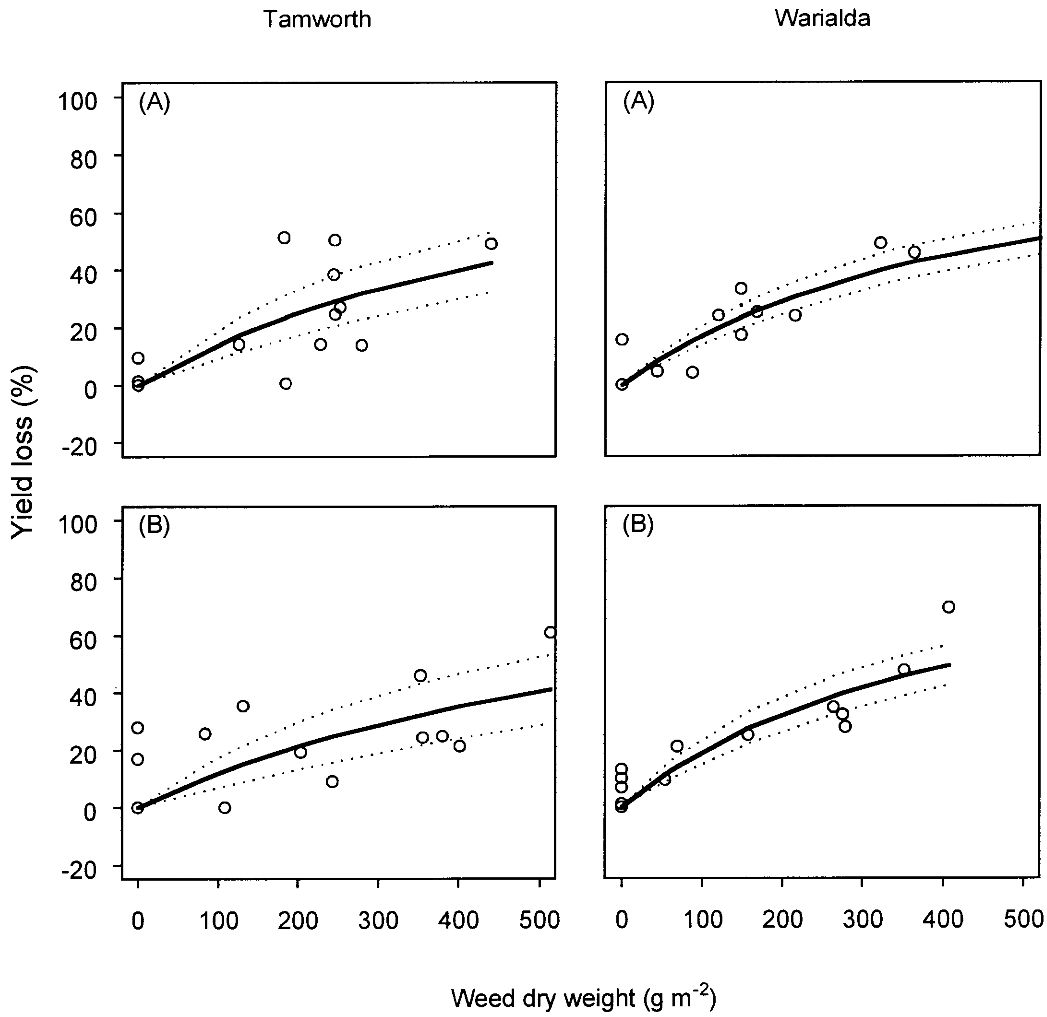

Fig. 5.4 Hyperbolic curves fitted to the weed dry weight data for 1997. Columns refer to the two experimental sites. Letters denote treatments: (A) narrow row spacing with turnip weed; and (B) wide row spacing with turnip weed. X axis is the weed density, and Y axis is chickpea yield loss Broken lines indicate the 95% confidence interval.

5.4 Discussion

The results from 1996 and 1997 showed that increasing the row spacings from 32 cm to 64 cm had no detrimental effect on the yield loss of chickpea, when grown in competition with wild oats or turnip weed. Reduced row spacing shortens the time to canopy closure (Swanton & Weise 1991), causing the crop to compete with the weeds at a much earlier stage. The earlier canopy closure and earlier competition with weeds that results from reduced row spacing has improved the competitive ability of many other crops (Holland & McNamara 1982, Koscelny 1990, Malik *et al.* 1993, Hosmani & Meti, 1993). In these experiments with chickpea this was not the case.

Chickpeas have a fine open canopy that results in incomplete capture of light. Much of the work described in the literature shows that narrow rows improve the competitive ability of crops and has been undertaken with cereal crops (Holland & McNamara 1982, Medd *et al.* 1985, Koscelny *et al.* 1990) or large leafed legumes (Felton 1976, Malik *et al.* 1993). Cereals and large leafed legumes will reduce the light available to late emerging weeds when sown in a dense stand with early canopy closure. Winter cereal crops show fast initial growth compared with weeds (Cousens *et al.* 1991) so, when the canopy is closed quickly, weeds that germinate around the same time as the crop are likely to be more competitive. Chickpeas, however, have slow initial growth (Amor & Francisco 1987, Knights 1991) probably allowing weeds to emerge and establish without any competitive effects. Following establishment, the filtered light passing through the fine canopy of the chickpeas is likely to be sufficient to enable weeds like turnip weed to elongate and compete successfully with the shorter chickpeas for light.

The purpose of an integrated weed management approach to weed control is to find complementary strategies. The use of wide rows for chickpea production had no negative effect on the competitive ability of chickpea. However, if wide rows enable another management practice such as in-row spraying, or inter-row spraying or cultivation, then the use of wide rows will assist in reducing weed competition in chickpea. Wide rows may also improve the health of the crop by improving airflow and reducing disease. Nevertheless, it must be remembered that, if weeds are present in high densities, wide rows will reduce yield losses only when coupled with some other form of weed management.

Increasing the weed density significantly reduced chickpea grain yield. Wild oats and turnip weed produced similar responses in the chickpea crops; however, an examination of the response curves shows that turnip weed had a greater effect on chickpea yields at lower weed densities than did wild oats (Fig. 5.3). This effect may have been a result of late season turnip weed growth shading the chickpea during flowering (the nature of competition between chickpea and turnip weed will be discussed in Chapters 7 and 9). Table 5.3 displays the estimated parameters of the curves. The initial slope of the turnip weed and wild oat curves is high, showing that chickpeas have a low tolerance to competition. Chickpeas will tolerate a slightly higher population of wild oats than turnip weed, but if the population of wild oats or turnip weed exceeds 10 or 5 plants m^{-2}, respectively, about 50 % loss in chickpea yield will occur.

The results from this section of work, in combination with the weed density model (Equation 5.1), have described the chickpea response to turnip weed and wild oat infestation. The data described by Equation 5.1 in this chapter are retrospective as the density and dry matter values were collected at the time of harvest, not early in the season. Prior to the crop reaching maturity, the weed density will have fluctuated as a result of asynchronous germination and death of the weed population. Measurements of weed density do not account for these fluctuations in the weed population or variation in weed maturity, and for this reason its use in early season predictions has been criticised (Kropff & Spitters 1991). Measurements of weed dry matter do account for variation in weed biomass, and as presented in Figures 5.3 and 5.4, fitted models using Equation 5.1 will adequately account for the variation. Destructive measurements are required to measure dry weight, and these can be time consuming and impractical. Plant dry matter is; however, highly correlated with plant leaf area and relative canopy cover which have the potential to be easily measured non-destructively. In an attempt to generate early season predictions, the second half of these experiments examined relative cover measurements, and this work will be discussed in Chapter 6.

Although the experiment described in this chapter was not designed to determine the resources for which the chickpea and weeds were competing, it highlighted a related aspect, shading. The year 1996 was particularly wet and at no time during the season was water apparently limiting to the crop or weeds. Also adequate fertiliser was supplied, which suggests that the crop and weeds may have been competing principally for light. To test if light had a significant effect on the production of chickpeas, a shading experiment was established. The shading experiment and the importance of light to chickpea yield is discussed in Chapter 8.