Chapter 7

The critical time for weed control

7.1 Introduction

The logical objective for an integrated weed management package is to identify the optimum time for weed control (Hall *et al.* 1992). The term *critical period* has been used to describe the time in an annual crop's lifecycle, which if kept weed-free, ensures no significant loss of yield (Zimdahl 1988, Kropff *et al.* 1993, Van Acker *et al.* 1993). The rationale in identifying a critical period is to help reduce the need for long-term residual chemical control, and assist in the timing of herbicide applications (Weaver & Tan 1983, Hall *et al.* 1992, Van Acker *et al.* 1993). Strategic applications of herbicide may also reduce the required concentration of active ingredient and quantity of herbicide required, and in so doing, reduce the environmental stress of agricultural chemicals and selection pressure for the development of herbicide resistant weeds (Swanton & Weise 1991).

The critical period of weed control has been determined for many crops (Haizel & Harper 1973, Weaver & Tan 1983, Weaver 1984, Hall *et al.* 1992, Van Acker *et al.* 1993, Dunan *et al.* 1995, Berti *et al.* 1996). It involves two separate factors: (a) the length of time weeds can remain in a crop before interference begins; and (b) the length of time over which weed emergence must be prevented, so that subsequent weed growth does not reduce crop yield (Weaver & Tan 1983). Impacting on this determination is a range of biological factors including crop and weed growth rates, competitive ability, habit, and environmental factors such as seasonal rainfall, temperature, and day-length (Swanton & Weise 1991). The influence of these constraints is often overlooked, since few detailed growth analyses are combined with critical period studies (Weaver & Tan 1983). The focus of most critical period studies has been to identify the point where weeds should be removed to reduce yield loss (Weaver 1984, Swanton & Weise 1991). On occasions, these studies have inferred that the critical period is when weeds are actively competing with the crop (Singh *et al.* 1996).

Historically, critical periods have been determined by mean separations; this has been described as the classical approach (Berti *et al.* 1996), which requires two components: (i) the crop is kept free from weeds for a certain time after which weeds are allowed to grow; and (ii) weeds are allowed to grow until a certain time, after which they are removed until the end of the growth cycle (Zimdahl 1988, Singh *et al.* 1996). The resulting yield means for each weed or weed-free period are analysed by multiple comparison tests, and the critical period determined statistically (Cousens 1981, Berti *et al.* 1996). Multiple comparison tests are not suited to structured data and are therefore an inappropriate method for the analysis of a quantitative series of treatments (Cousens 1981). Also, the classical method measures the point at which losses are observed not when they begin, which can mean the existence of periods with no statistically detectable yield loss (Cousens 1981, Berti *et al.* 1996).

Cousens (1981) discussed the inherent problems of the classical approach and modified it to what is termed the "statistical" approach, which uses regression analysis. The type of statistical analysis used in the classical approach can identify periods of weed infestation that cause no yield loss; however, the statistical approach, does not show any evidence of periods displaying no yield loss (Cousens 1981). The difference between the two methods is the type of analysis. The statistical method recognises a continuous relationship between crop yield loss, time of weed emergence and time of weed removal (Berti *et al.* 1996). The result of this continuous relationship means that the identification of the critical period of weed control requires an acceptable yield loss "threshold" (Cousens 1981). The critical period is when the expected yield loss is equal to the threshold. The way critical periods were calculated resulted in the conclusion that early weed control or pre-emergence weed control was not necessary (Berti *et al.* 1996). This idea is in contrast with much current thinking and chemical marketing which extols the virtues of good pre-sowing weed control and the use of residual herbicides for early weed control (Zimdahl 1988).

The inclusion of a threshold level suggests an acceptable economic loss, and hence led to the term "economically derived critical periods of weed control" (Dunan *et al.* 1995, Berti *et al.* 1996). These methods examine the cost of control and the expected return for the crop in order to define a level of weed infestation that is unacceptable (Cousens 1987). The determination of such a level is not simple and, as described by Cousens (1987), is often complicated by vague and confused literature. The use of economic thresholds in identifying critical periods of weed control focuses on reducing the weed population during the current growing season of the crop. This approach does not recognise that the degree of control also affects future infestations, because those plants that are not controlled ("escape") may mature and add to the soil seed bank (Medd 1995). The concentration of research on identifying the critical period of weed control has focused weed management decisions on killing weeds to prevent yield loss due to competition, rather than on reducing the long-term weed population to improve yield of subsequent crops (Medd 1995, Medd *et al.* 1995).

The critical weed-free period in many situations, but especially in broad-scale agriculture, is often unobtainable, because weed seed germinating immediately after a weed control action prevents a weed-free period occurring. To achieve a weed-free period of any length of time, more than one weeding would be required. Inadvertently, when some authors describe a weed-free period, they are suggesting the optimum time when a single weeding can be applied (Weaver & Tan 1983), but the application of a single weeding does not necessarily produce a weed-free period. Some residual herbicides will produce a weed-free period, but residual herbicides must be applied at a strategic time to avoid phytotoxicity in the crops and their effectiveness is often limited by the need for incorporation in the soil, which can depend on climatic conditions. The use of residual herbicides affects plant-back dates, and thus may reduce future cropping options. In addition, it is unlikely that the critical herbicide application time and incorporation requirements of a residual herbicide would align with the critical weed-free period for many crops. For the majority of crops, the only control strategies available are those used at a single point in time, and in practice, this usually means the use of a herbicide.

Herbicides need to be applied at specific times that correspond to weed susceptibility and crop tolerance (Medd 1995). Variable timing of weed emergence and development means that achieving complete control with herbicides is unlikely (Medd 1995, Jones & Medd 1997). Some plants will survive the control method while others will either emerge after it has been carried out, or be missed. I believe that as a result of these "escapes", in practice, creating a weed-free period by means of single point control methods (e.g. herbicides) is unlikely and the determination of a weed-free critical period is pointless without the control methods to create it. The weed-free period is a possibility in intensive forms of agriculture where single control methods (e.g. hand weeding) can be followed up or easily repeated during the period. However, in broad-acre situations, it is difficult to effectively create a weed-free period. On the other hand, identification of "critical times of weed control" may be much more useful in extensive broad-acre agriculture. The "critical time of weed control" is the optimum time for applying a weed control strategy to prevent yield loss and to reduce the size of the potential weed population in future seasons.

The varieties of chickpea grown in the northern grain region of NSW have a slow initial growth rate and do not compete well with weeds (Knights 1991, Medd 1995), and the few post-emergence herbicides that are available are expensive (Whish *et al.* 1996). Control of grass weeds is important in chickpea to limit the carryover of weed seed and disease to the following cereal crops (Whish *et al.* 1996). Only group "A" herbicides ("fops" and "dims") are available for post-emergence grass control (Medd 1995, Mullen & Dellow 1998), so they must be used strategically to minimise the risk of resistance. Herbicide resistance in some grass weeds of the eastern Australian grains region already exists (Felton pers. comm.). Despite this fact, the weak competitive ability of chickpea and the competitive ability and high fecundity of late emerging wild oat cohorts can require split or double applications of herbicides (Medd 1995). Some pre-emergence herbicides are available, but these do not provide control for the whole of the growing season.

To reduce the pressure for increasing herbicide resistance, strategic times must be calculated for herbicide applications that offer the maximum benefit to the current crop while limiting carry over of seed and disease for following crops. The point where crops and weeds begin to compete is often incorrectly described as the critical period of weed control (Weaver & Tan 1983, Weaver 1984); however, to correctly identify this point, the relative growth rates of the crop and the specific weed must be examined (Weaver & Tan 1983). Wild oat (*A. fatua* L.) has been shown to have a slow initial growth rate and a competitive ability similar to barley (Cousens *et al.* 1991). Martin *et al.* (1987) showed *A ludoviciana* to have a competitive ability similar to wheat.

In competition experiments, wild oat was shown to be less competitive than wheat and barley for a major part of the growing season, and only out-competed the wheat and barely crops late in the season (Cousens *et al.* 1991). This delayed exhibition of competitive ability in wild oat, and the slow initial growth rate of chickpea could imply that the point of competition between wild oat and chickpea crops is late in the season. If this were the case, delaying the control of wild oat until this time would ensure better control. Late season control reduces the extent of post-control weed emergence (Medd 1995). In order to test the validity of these arguments, the relative growth rate of the chickpea with and without the presence of weeds must be known, and the effect of removing weeds at specific times on chickpea yield also needs to be determined.

Turnip weed is a common broad-leaved weed of chickpea in the north eastern Australian grain region (Storrie pers. comm.). Few chemical solutions exist for the control of this weed (Whish *et al.* 1996) but, as with the wild oat, if control can be timed to be as late as possible in the crop's life-cycle, but prior to the onset of competition, then more effective control will be achieved.

Unfortunately, weeds are easier to control both mechanically and chemically when they are young (Medd 1995).

The experiment described in this chapter investigated the critical times of wild oat and turnip weed removal in chickpea with the aim of identifying the optimum time for applying weed control methods. The experiment also examined the weed seed returned to the seed bank at crop harvest following each weed removal treatment. The examination of crop and weed growth together will help identify the observed point of weed competition.

7.2 Materials and Methods

7.2.1 Sites

The "time of weed control" experiment was conducted during 1997 at two sites (Tamworth and Warialda). Descriptions of the climatic conditions and features of the two sites are discussed in Chapter 3. The experimental areas at both sites were sown with the same no-till planter with five rows per plot spaced at 64 cm.

7.2.2 Plant material

The source of chickpea, wild oat, and turnip weed seed was the same as that used in the experiments described in Chapter 5.

7.2.3 Sowing

Chickpea was sown at Warialda on the 4/6/97 and Tamworth on the 12/6/97. The sowing procedures were generally the same as those used in the 1997 experiments described in Chapter 5. The only difference was the inclusion of wild oat and the use of a single weed density (8 plants m^{-2}).

7.2.4 Experimental design

The experiment used a randomised complete block design consisting of 12 weed removal times x two weed species, wild oat and turnip weed whose seeds were sown at a rate to achieve a density of 8 plants m^{-2}.

Four "times" of weed removal were selected and combinations of two of these times and weeding at all four times plus an unweeded control constituted the 12 treatments (Table 7.1).

Table 7.1 Description of time of weed removal treatments

Treatment	Code	Description
1	T1234	Weeds removed at each of the 4 times
2	T1	Weeds removed Time 1
3	T12	Weeds removed Time 1 and Time 2
4	T13	Weeds removed Time 1 and Time 3
5	T14	Weeds removed Time 1 and Time 4
6	T2	Weeds removed Time 2
7	T23	Weeds removed Time 2 and Time 3
8	T24	Weeds removed Time 2 and Time 4
9	T3	Weeds removed Time 3
10	T34	Weeds removed Time 3 and Time 4
11	T4	Weeds removed Time 4
12	T0	No weeds removed

The weed removal times for Tamworth were: T1, 60 days after sowing (DAS); T2, 83 DAS; T3, 123 DAS; and T4, 152 DAS. The weed removal times for Warialda were: T1, 54 (DAS); T2, 84 DAS; T3, 118 DAS; and T4, 146 DAS.

7.2.5 Measurements

At each time of weed removal, non-destructive relative cover measurements were made. The methods used to record relative cover were the same as in Chapter 6. Destructive samples to calculate dry weights were also taken at this time over a 1 m section from each of the three centre crop rows and oven dried at 80°C for 48 hours. A 1 m section of the two centre inter-row spaces was sampled to determine total weed dry matter, weed density, and composition. These samples were also dried at 80°C for 48 hours.

7.2.6 Removal

To remove weeds in the wild oat plots at each specific removal time, the plots were sprayed with 106-g fluazifop-p ha^{-1} (Fusilade). Broad-leaved weeds were removed by hand pulling as no effective herbicide was available to control these in the turnip weed plots. The hand pulling involved removing the weeds and the root system, this did disturb the soil, but this disturbance was less than a light tillage operation.

7.2.7 Maintenance

Very few additional broad-leaved weeds occurred in the plots during 1997. Grass weeds, however, were a problem, especially at Tamworth where two large flushes of *Phalaris paradoxa* occurred. Grass weeds were controlled in the turnip weed plots with 106 g fluazifop-p ha^{-1} (Fusilade). Herbicide was applied once at Warialda, on 27/8/97, and two time at Tamworth, on 13/8/97 and 15/10/97. On all occasions, herbicide was applied through a hand held 3-m boom spray, a pressure of 172.4 kPa with an output of 80 L ha^{-1}.

Two flushes of *Phalaris paradoxa* affected the number of grass plants in the wild oat plots. Selectively removing the *P. paradoxa* was not possible, so weed counts of these plots included *P. paradoxa* as part of the grass component.

7.2.8 Harvest

The final harvest of the plots followed the same sampling procedure as for each of the harvests made at the weed removal times. The number of wild oat tillers on each mature plant was counted to estimate the proportion of seed returned to the seed bank (i.e. assumed seed returned to the seed bank proportional to the no of tillers. 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, the samples were passed through a stationary thrasher and the chickpea grain yield was recorded. One hundred seeds were randomly selected from each plot and weighed to give a 100 seed weight. Turnip weed and wild oat samples were also dried at 80°C for 48 hours and weighed. The dried turnip weeds were then passed through a stationary thrasher and the collected seed weighed to give an estimate of seed number returned to the seed bank.

7.2.9 Statistical analysis

The statistical software package S-plus 4.5 (Mathsoft 1998) was used for all analyses. Yield responses from the different weed removal treatments were compared by analysis of variance and the results displayed as "box and whiskers plots" (Tukey 1990). The yield responses of the weeds that remained until harvest displayed a Poisson distribution, were analysed by fitting a generalised additive model, and compared using contrast analysis. These results are also displayed in box plots. The observed point where chickpea growth is affected by the growth of weeds was determined by fitting curves to the accumulated dry matter yields from weed-free and weed infested plots. The results were analysed using a generalised additive model, and curves fitted as a smoothing spline using four degrees of freedom and a single loess degree. These curves were plotted against degree-days on the *x* axis for comparisons between the two sites of Tamworth and Warialda, the base temperature for growth used for the chickpea, wild oat and turnip weed being 5°C (Cousens *et al.* 1994). The accumulated growth of the weeds was analysed in this same manner. The collection of relative cover measurements using surface photographs as a means of non-destructively measuring plant growth were compared with the dry matter measurements using linear regression.

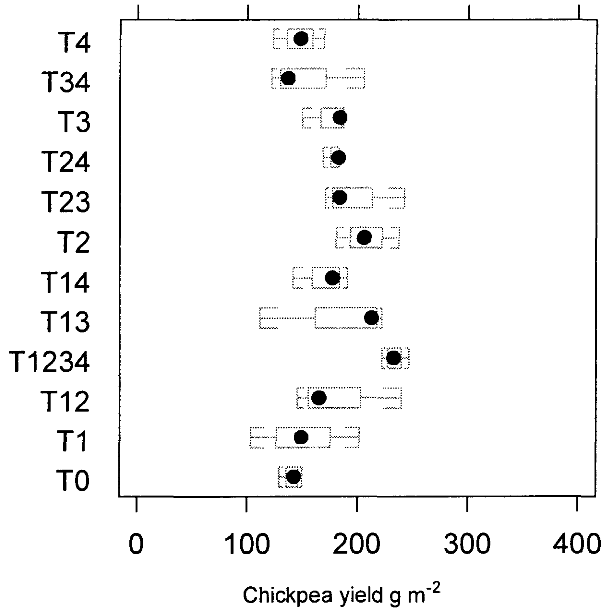
7.3 Results

At Tamworth and Warialda a period of dry weather following sowing reduced the emergence of weeds with the population being 2-4 plants m^{-2} instead of the planned 8 plants m^{-2}. The disease *Botrytis* root-rot reduced the chickpea population to 20-25 plants m^{-2} from the intended 35 plants m^{-2}.

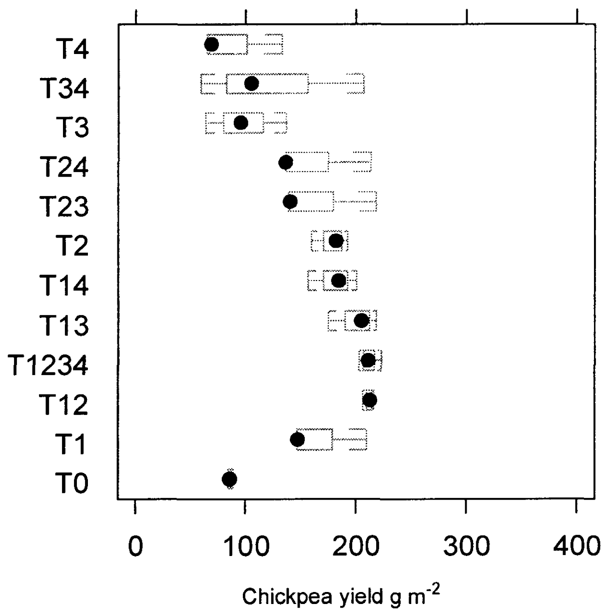
7.3.1 The effect of weed removal times on chickpea yield

The twelve combinations of weed removal times investigated in this experiment showed marked differences in their ability to influence crop yield even though no significant differences were found in the chickpea 100 seed weights. The multiple weeding treatment, hereafter referred to as weeded control T1234 (weeds removed four times during the season), produced the maximum crop yield, irrespective of weed type or site at which the crop was growing. The effect of removing turnip weed at different times at Tamworth (Fig. 7.1 A) shows a degree of variation within treatments which can be seen in the box plot. However, examination of Fig. 7.1 in association with the table of means (Table 7.2) allows clear identification of the ideal weed removal times. Removing weeds at T2 (83 days after sowing) gave yield results within 11% of the continual weeding.

The effects of wild oat on chickpea yield differed from turnip weed. Weeded control (T1234) was not significantly different from the best other multiple weed removal treatments (Table 7.2). Multiple weeding gave the best crop yields (Fig. 7.1 B) with weeds removed at T12 and T13 producing chickpea yields within 5% of the weeded control treatment.



(A)



(B)

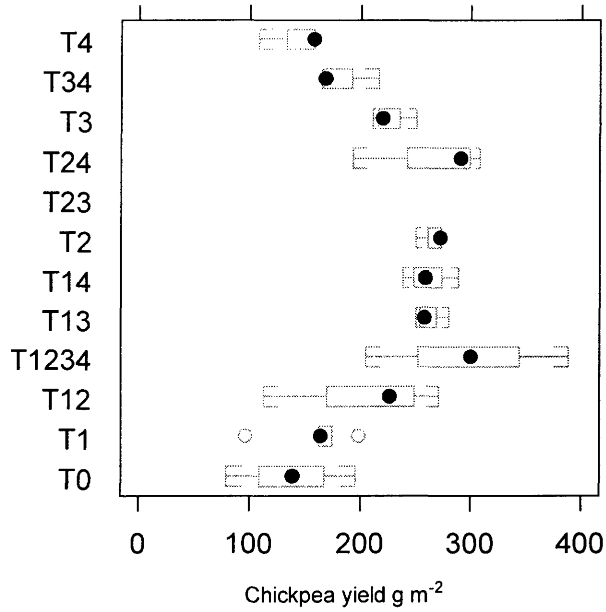
Fig. 7.1 The effect of different times of weed removal on the grain yield of chickpea grown at Tamworth in the presence of turnip weed (A) and wild oat (B). T0 = no weeds removed, T1 = weeds removed 60 days after sowing (DAS), T2 = weeds removed 83 DAS, T3 = weeds removed 123 DAS, and T4 = weeds removed 152 DAS. Other treatments are combinations of these weed removal times. Solid dots (●) represent the median value for each treatment. The box and whiskers show the range of the data. The box shows the Inter-Quartile Range and the whiskers contain 95% of the data. Standard error for the differences of means was 20.

Table 7.2 Mean chickpea yield (g m^{-2}) for each of the time of weed removal treatments

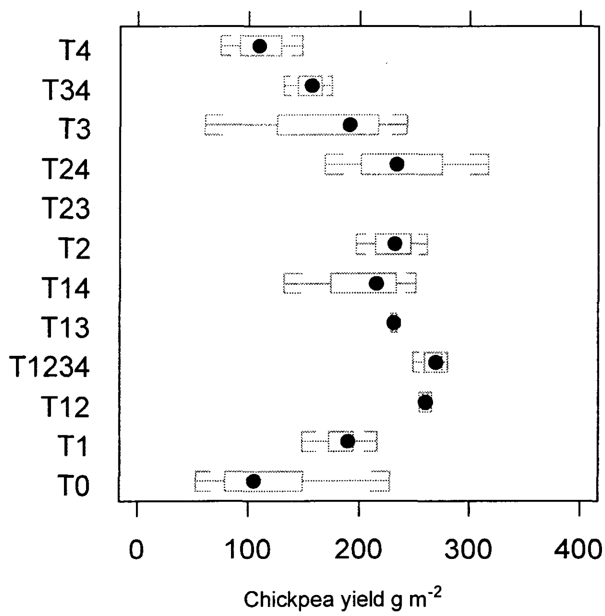
	Tamworth		Warialda	
Treatments	Turnip weed	Wild oat	Turnip weed	Wild oat
T0	140.8	86.2	118.9	87.8
T1	151.4	168.2	178.9	194.2
T12	183.7	211.7	203.4	260.0
T1234	233.7	212.3	297.6	265.9
T13	182.2	199.6	262.5	231.3
T14	169.8	180.6	261.7	199.5
T2	208.3	178.0	264.8	229.9
T23	199.0	166.0	*	*
T24	178.1	162.0	263.9	239.7
T3	173.7	98.7	226.7	164.7
T34	155.2	123.8	183.0	154.4
T4	147.4	88.8	141.5	110.7
Standard error	(± 20.4)	(± 20.4)	(± 26.6)	(± 26.6)

** Due to a sampling error there were no results for T23 at Warialda*

The results from Warialda support those from Tamworth. The mean yields achieved at Warialda were higher than at Tamworth (Table 7.2); however, greater variation existed within the treatments (Fig. 7.2). Removing turnip weeds at T2 (83 days after sowing) gave the closest yields to the weeded control treatment (T1234). Removing weeds at T2 reduced the yield by 11%, and the multiple weeding combinations that included T2 also produced good crop yields (Fig. 7.2 A).



(A)



(B)

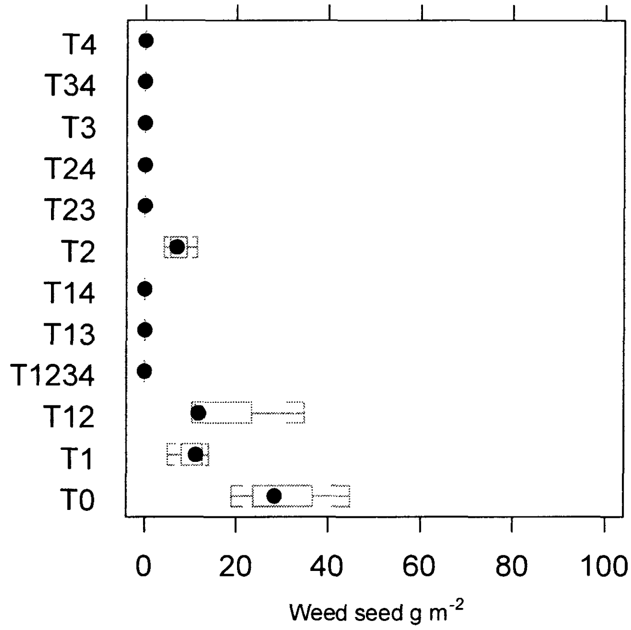
Fig. 7.2 The effect of different times of weed removal on the grain yield of chickpea grown at Warialda in the presence of turnip weed (A) and wild oat (B). T0 = no weeds removed, T1 = weeds removed 54 days after sowing (DAS), T2 = weeds removed 84 DAS, T3 = weeds removed 118 DAS, T4 = weeds removed 146 DAS. Other treatments are combinations of these weed removal times. Due to a sampling error there were no results for T23. Solid dots (●) represent the median value for each treatment. The box and whiskers show the range of the data. The box shows the Inter-Quartile Range and the whiskers contain 95% of the data. Points outside this are displayed as individual points or outliers (o). Standard error for the differences of means was 26.

Multiple weeding of wild oat gave the best chickpea yields at Warialda; weeding at T12 was within 3% of the weeded control. At Tamworth, multiple weeding of the wild oat at T13 and T12 gave similar yields to that of the weeded control (T1234, Fig. 7.1 B); however, examination of the means (Table 7.2) shows that the T12 treatment at Tamworth had the higher mean. The results from Warialda (Fig. 7.2B) show a high median yield and mean (Table 7.2) for the T24 treatment; however, these results have a large variation, while the variation in the T13 treatment is small. Owing to this variation, the results of the T13 treatment could be considered more reliable than the T24 treatment, and the results of weed removal treatments at Warialda the same as Tamworth.

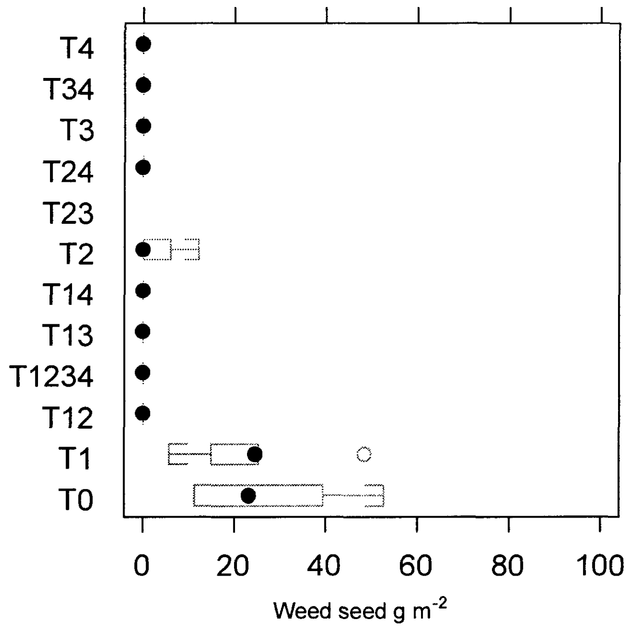
7.3.2 The effect of weed removal times on potential seed return to the seed bank

Identifying the times of weed removal that optimise the potential crop yield are important but if these times are not related to weed seed return then no net improvement in management will occur over time. Early removal of turnip weed at times T1, T2, and T12, and no weed removal (T0), resulted in measurable quantities of weed seed being carried through to harvest for the Tamworth trial (Fig. 7.3 A). The results at Warialda were similar, but the amount of seed from the T2 removal was less and there was no measurable seed at harvest for the T12 treatment. The results from this experiment showed a Poisson distribution, which required a contrast analysis to compare between means. The contrast analysis showed that all treatments which recorded seed at harvest were significantly different (P chi sq < 5%) from those that did not, and that they were all significantly different (P chi sq < 5%) from each other, for each site.

Wild oat plants were removed at each time by applications of herbicide; towards the end of the season the herbicide applications did not affect the wild oat plants because they had reached physiological maturity and were dispersing seed. For this reason, tillers still remained at the time of harvest, and because of the difficulty in distinguishing between mature plants and plants killed by herbicide, all tillers were counted and considered a potential source of viable seed. The weed removal times T3, T34, and T4 were too late in the season to effectively control wild oat with herbicide and reduce the number of seed bearing tillers. At Tamworth (Fig. 7.4 A) the number of tillers remaining at harvest was 10 plants m^{-2} for those plants weeded at T1, and 40-100 tillers m^{-2} for those weeded at or after T3. The remaining treatments apart from the T0 control had no wild oat. The results from Warialda (Fig. 7.4 B) indicate that the Warialda trends are similar to Tamworth, but the Warialda data were more variable.

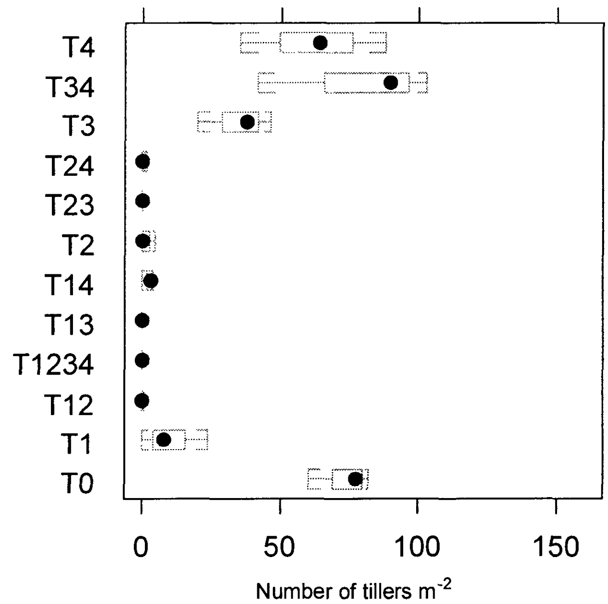


(A)

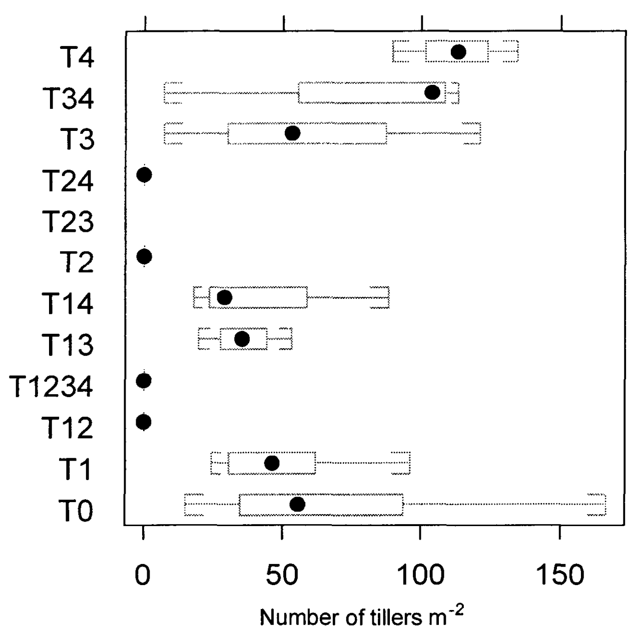


(B)

Fig. 7.3 The effect of different times of weed removal on the seed yield of turnip weed grown at Tamworth (A) and Warialda (B). T1, T2, T3, T4 represent weed removal at 60, 83, 123, and 152 days after sowing (DAS) at Tamworth; and 54, 84, 118, and 146 DAS at Warialda. T0 = no weeds removed. Other treatments are combinations of these weed removal times. Due to a sampling error there were no results for T23 at Warialda. Solid dots (●) represent the median value for each treatment. The box and whiskers show the range of the data. The box shows the Inter-Quartile Range and the whiskers contain 95% of the data. Points outside this are displayed as individual points (o) or outliers (T1 at Warialda).



(A)



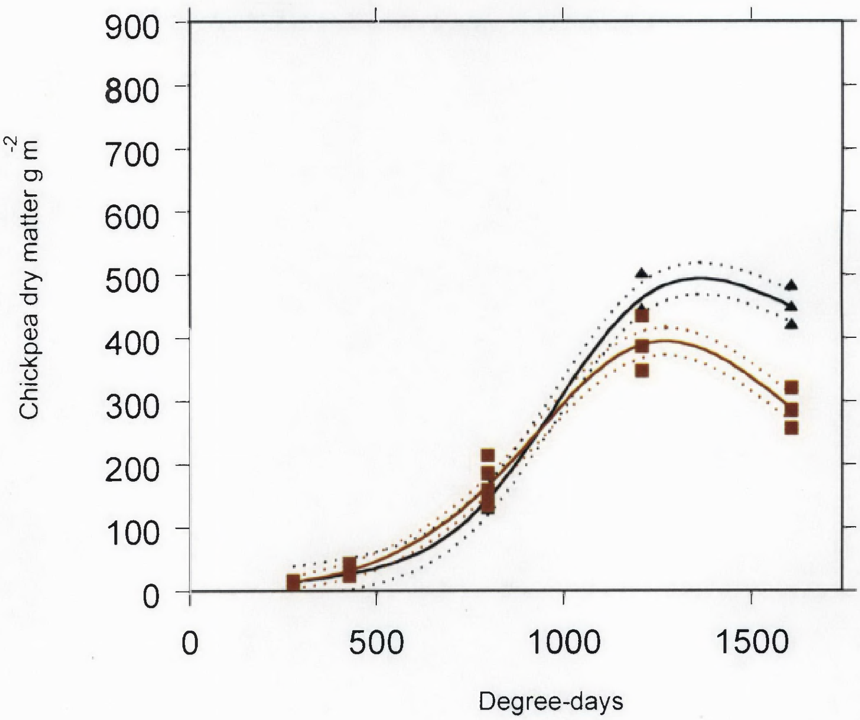
(B)

Fig. 7.4 The effect of different times of weed removal on the number of wild oat tillers grown at Tamworth (A) and Warialda (B). T1, T2, T3, and T4 represent weed removal at 60, 83, 123, and 152 days after sowing (DAS) at Tamworth; and 54, 84, 118, and 146 DAS at Warialda. T0 = no weeds removed. Other treatments are combinations of these weed removal times. Due to a sampling error there were no results for T23 at Warialda. Solid dots (●) represent the median values for each treatment. The box and whiskers show the range of the data. The box shows the Inter-Quartile Range and the whiskers contain 95% of the data.

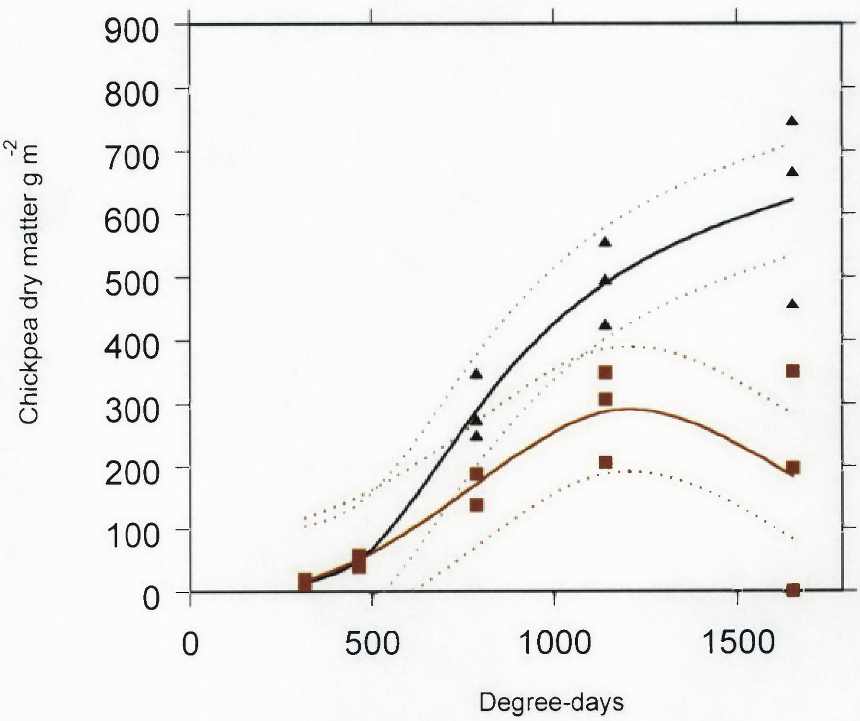
7.3.3 The effect of weeds on chickpea growth

Dry matter accumulation of chickpea during the season produced a classical growth curve; however, when weeds were allowed to grow in competition with chickpea, maximum dry weight was reduced. The point where the values predicted by the curves differed significantly was defined as the point of observed competition and, in the case of turnip weed, this separation occurred at around 1100 degree-days after sowing (Fig. 7.5). The dry matter records were plotted against degree-days to enable comparisons between Tamworth and Warialda, and both sites had an observed competition point between chickpea and turnip weed of the same heat sum. The Warialda data showed greater variation than Tamworth, which resulted in wide confidence intervals for the predicted curves (Fig. 7.5). Examination of the Tamworth and Warialda growth curves shows that rapid chickpea growth commenced at around 500 degree-days after sowing.

The dry matter accumulation for the turnip weed showed a similar pattern to chickpea with the rapid growth period also commencing at around 500 degree-days at both sites (Fig. 7.6). The growth curves of the turnip weed at Tamworth and Warialda were similar. Greater dry matter accumulation occurred at Warialda, which was also observed for the chickpea. The turnip weed and the chickpea crop appeared to accumulate similar amounts of dry matter during the season (Figs 7.5 and 7.6), even though the chickpea stand contained 26 plants m^{-2} and the turnip weed stand was only 2-4 plants m^{-2}.

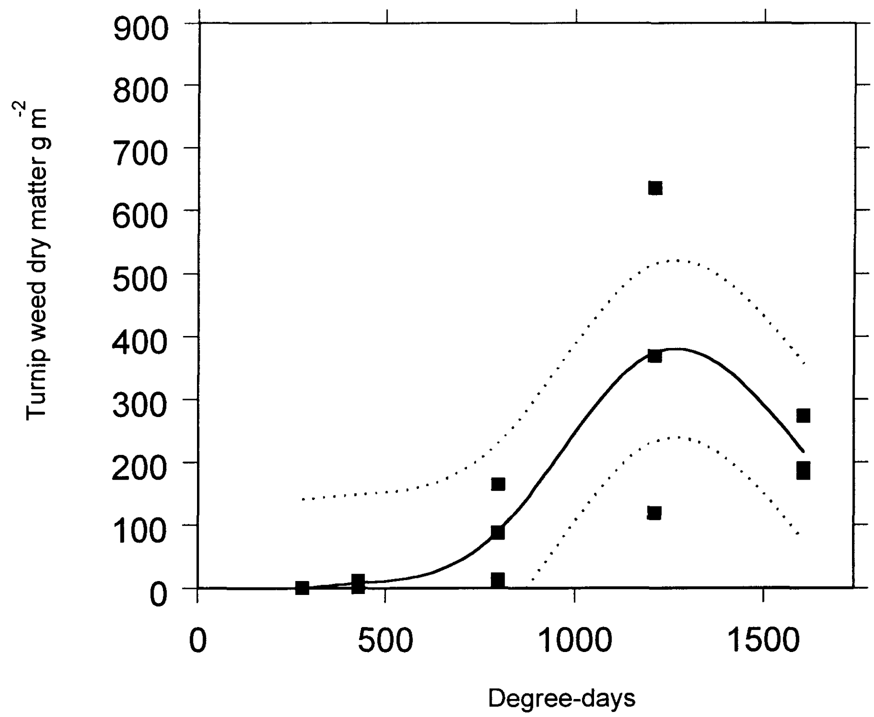


(A)

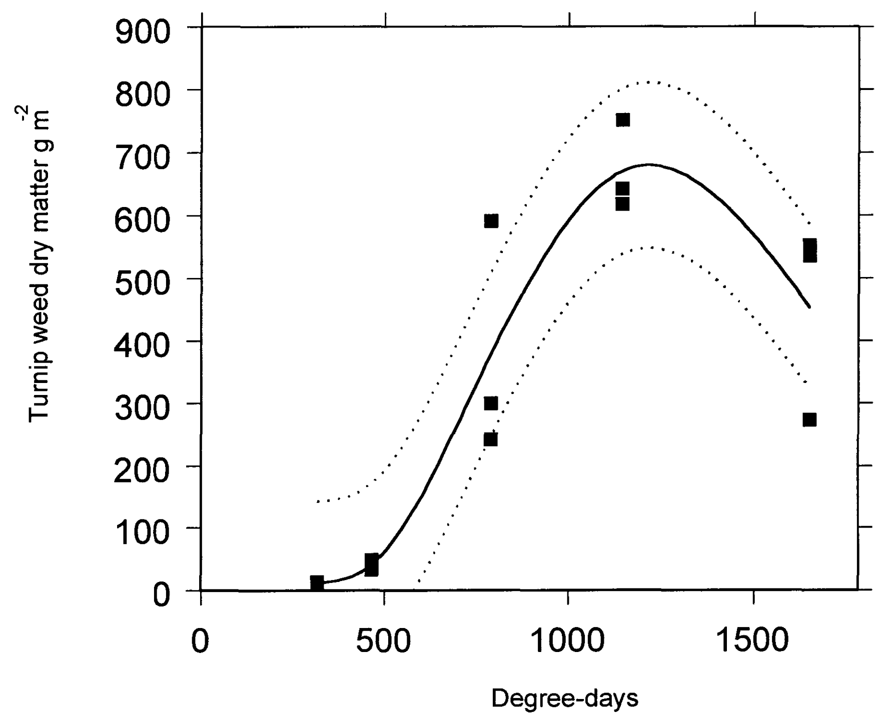


(B)

Fig. 7.5 Chickpea dry matter accumulation as a result of increasing degree-days under weed-free (▲) conditions and in the presence of turnip weed (■) for Tamworth (A) and Warialda (B). Broken lines show the 95% confidence interval for each fitted curve. Degree-days were calculated from sowing assuming a base temperature of 5°C.



(A)



(B)

Fig. 7.6 Turnip weed dry matter accumulation as a result of increasing degree-days when grown in competition with a single density (40 plants m^{-2}) of chickpea (■) for Tamworth (A) and Warialda (B). Broken lines show the 95% confidence interval. Degree-days were calculated from sowing assuming a base temperature of 5°C.

The growth curves produced when chickpea was grown in the presence of wild oat (Fig. 7.7) differ from those produced in the presence of turnip weed. The observed point of competition was significant at around 900 degree-days and the extent of dry matter reduction was greater for wild oat compared with turnip weed, with a greater difference between the weed-free and weedy curves (Fig. 7.5 and 7.7).

The commencement of rapid wild oat growth (Fig 7.8) was similar to the chickpea (Figs.7.5 and 7.7) and turnip weed (Fig. 7.6) at around 500 degree-days.

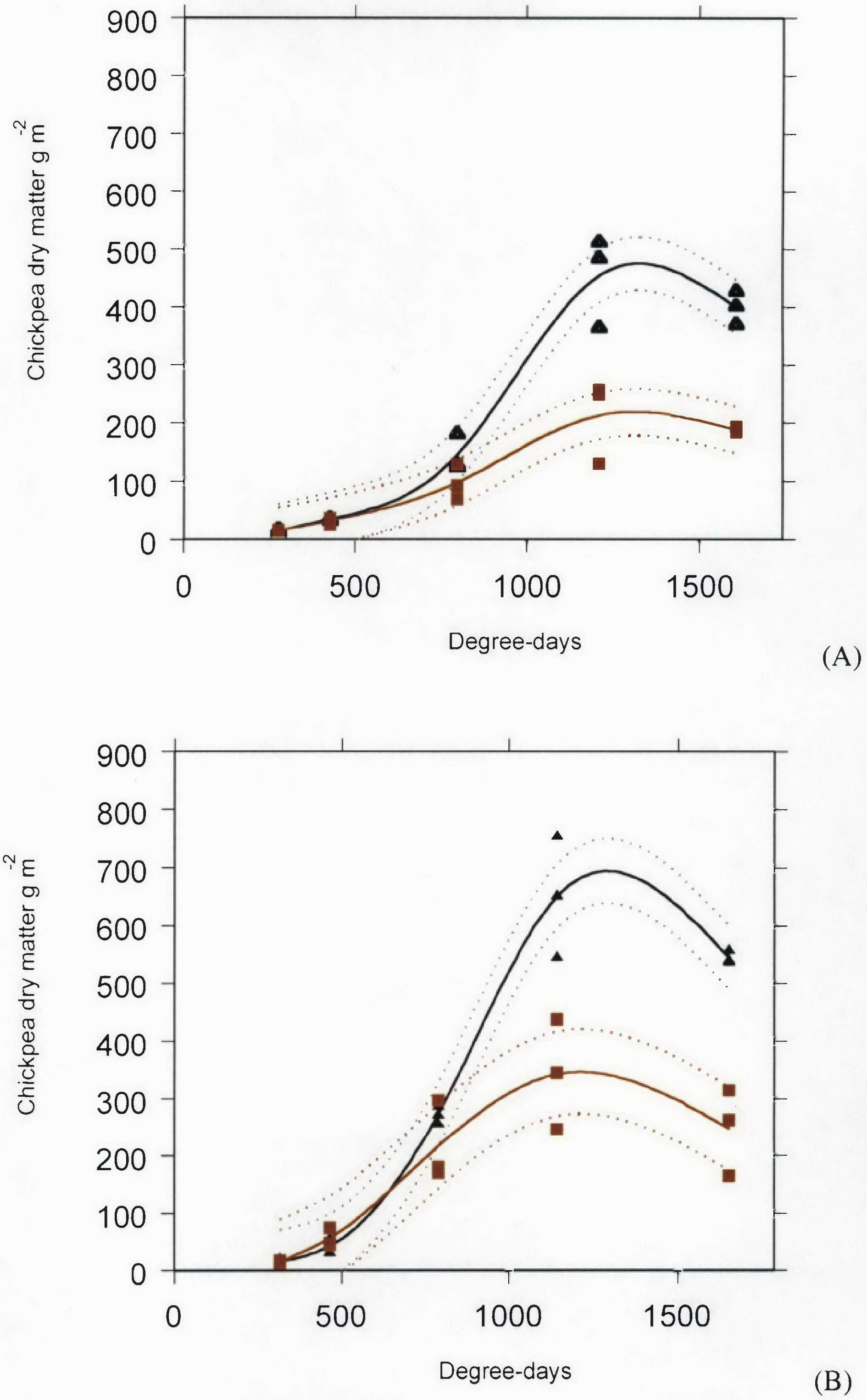
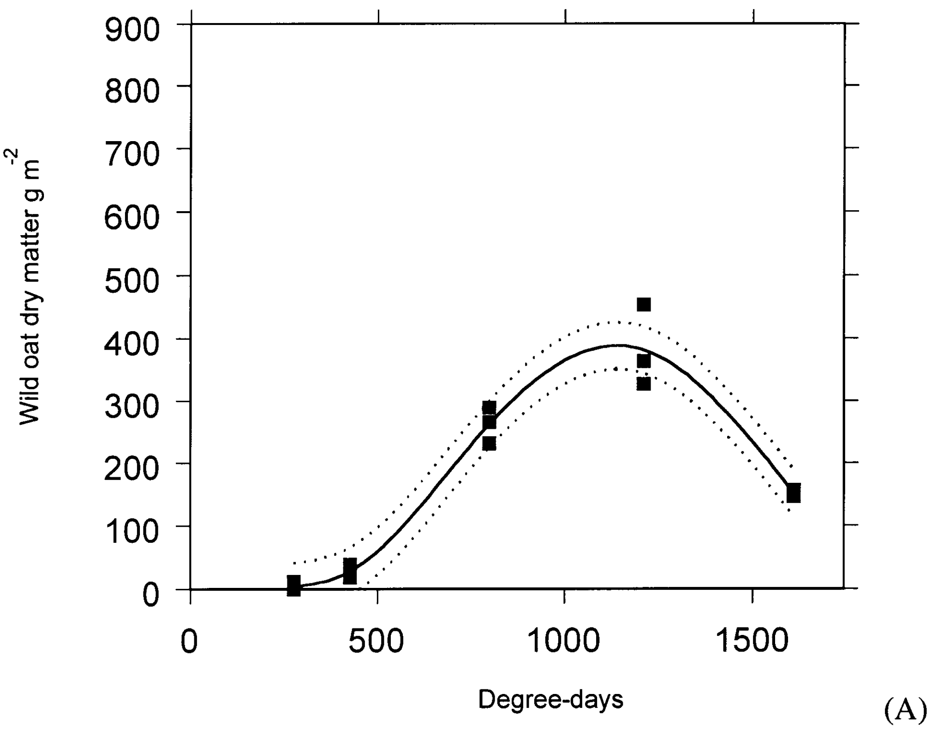


Fig. 7.7 Chickpea dry matter accumulation as a result of increasing degree-days under weed-free (▲) conditions and in the presence of wild oat (■) for Tamworth (A) and Warialda (B). Broken lines show the 95% confidence interval. Degree-days were calculated from sowing assuming a base temperature of 5°C.



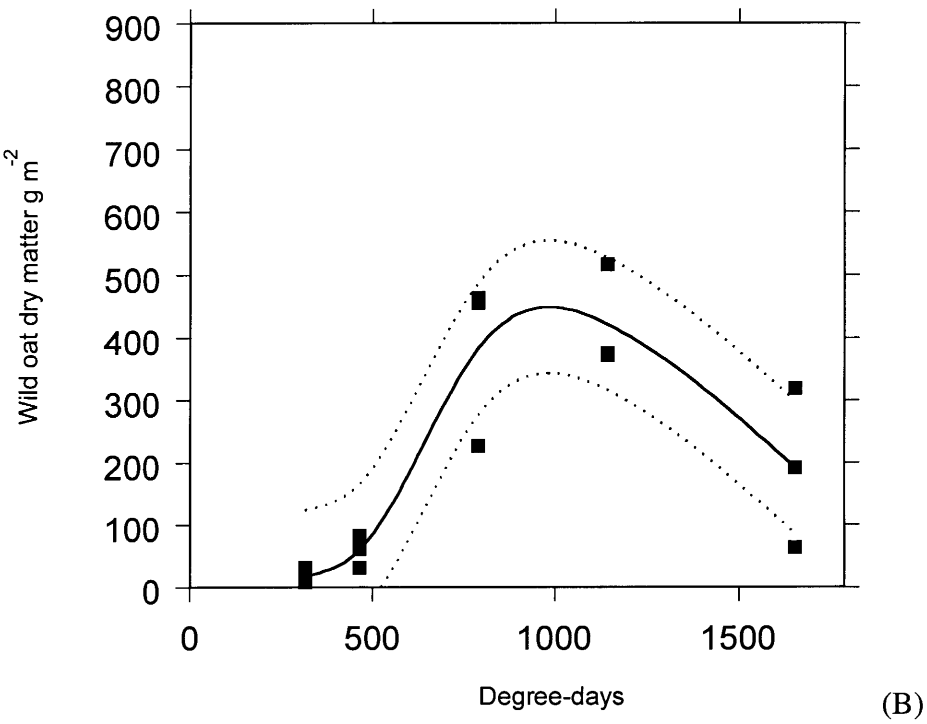


Fig. 7.8 Wild oat dry matter accumulation as a result of increasing degree-days when grown in competition with a single density (40 plants m^{-2}) of chickpea (■) for Tamworth (A) and Warialda (B). Broken lines show the 95% confidence interval. Degree-days were calculated from sowing assuming a base temperature of 5°C.

7.3.4 Using relative cover to predict crop growth

Relative cover measurements can be used as a non-destructive method for predicting crop growth. Chickpea dry matter was highly correlated with chickpea relative cover measurements in the turnip weed plots at Tamworth and Warialda with R^2 values of 0.88 and 0.66, respectively (Fig. 7.9 a). Conversely, chickpea growing in wild oat plots did not show a strong correlation between dry matter and relative cover with R^2 values of 0.40 and 0.11 for Tamworth and Warialda, respectively (Fig. 7.9 b). Relative cover measurements became inaccurate as 100% cover was approached; this was evident in all parts of Fig. 7.9 with the confidence intervals widening as relative cover approached 1.

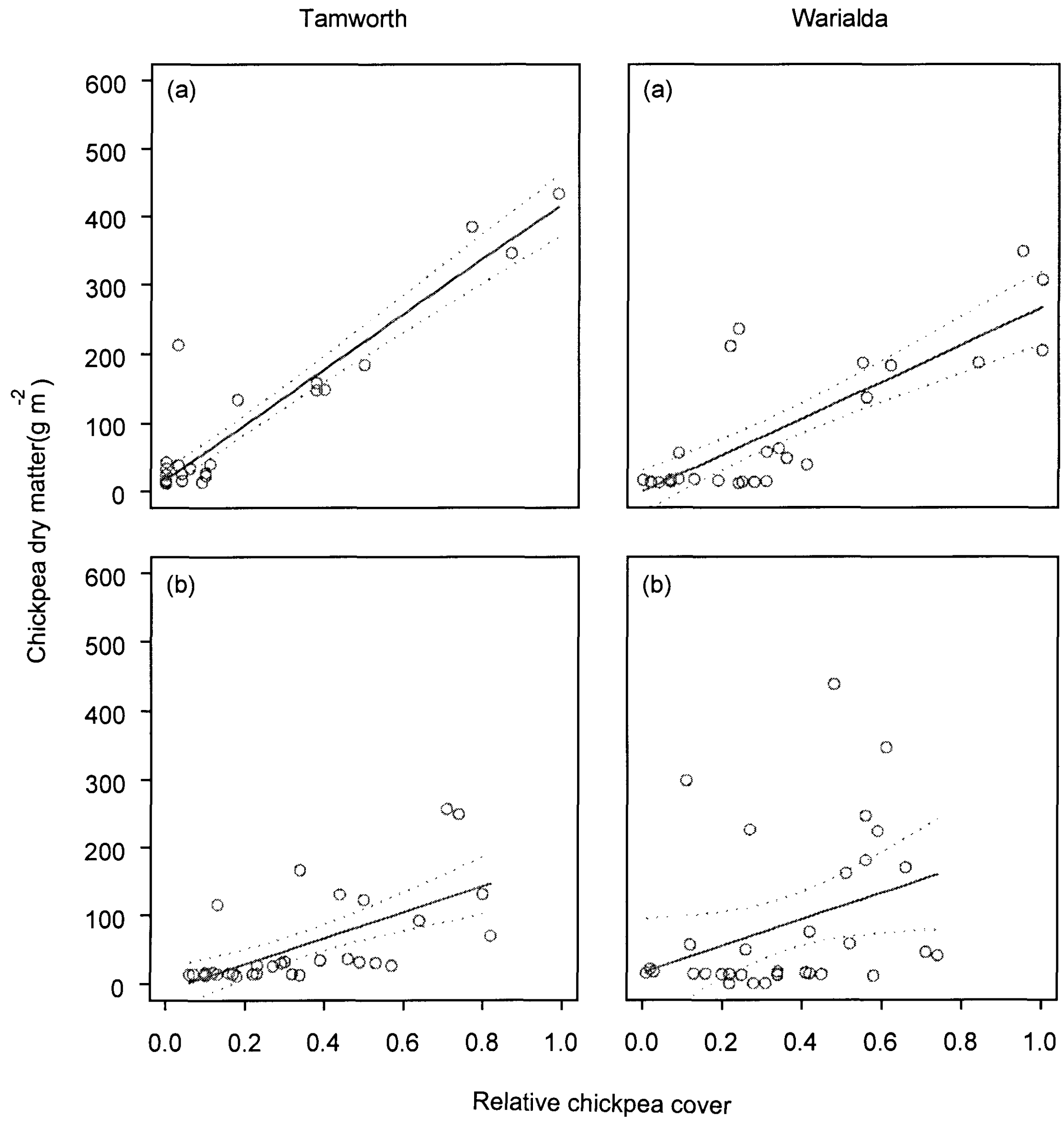


Fig. 7.9 The linear relationship between final chickpea dry weights and photographic measurements of relative cover (taken at the four assessment times) for chickpea crops growing in the presence of turnip weed (a) and wild oat (b).

7.4 Discussion

The results from Tamworth and Warialda show that weed removal at T2 (83 and 84 DAS, respectively) gave the best chickpea yield from a single weed removal time when grown in the presence of turnip weed or wild oat. Several multiple removal times in the turnip weed treatments produced chickpea yields that were not significantly different from T2 (Table 7.2). This aims to reduce both herbicide resistance and herbicide use, so that a suitable single control time is more favourable than multiple applications. Support for T2 being the most appropriate time to remove turnip weed in this experiment can be seen in the yields produced from the multiple weed removal times that included T2. At both sites, a decline in chickpea yield occurred from the single T2 to the T24 removal treatment indicating some damage may have been caused to the chickpea plants during the soil disturbing weed removal process. It was noted that *Botrytis* infection of seed reduced the chickpea population. This reduction would not have influenced the timing of the plants rapid phase of growth, but it may have reduced the competitive ability of the chickpea stand.

Wild oat removal at T2 also gave good chickpea yields, with no significant difference to the weeded control mean at either site (Table 7.2). The multiple control measures (T12, T13) produced higher means and had less variation within the treatments (Table 7.2, Figs 7.1 and 7.2) compared with the T2 treatment but, as already suggested, a single time of weed removal is more desirable. Medd (1995) has suggested multiple control times of wild oat as a successful method in reducing seed return to the seed bank; however, he does acknowledge that if a chemical approach is followed, this would increase the risk of herbicide resistance.

Gemination of *A. ludoviciana* and *Rapistrum rugosum* is reduced when the daily temperatures rise above 20°C (Thurston 1961, Quail & Carter 1968) or 25°C (Cousens *et al.* 1994). For the Tamworth and Warialda experimental sites, an average daily temperature greater than 20°C generally occurs around late August (Figs 3.2 and 3.4, Chapter 3). During 1997, the August temperatures were slightly above average at both sites (Figs 3.3 and 3.5) which may suggest little wild oat germination following the T2 time of removal on 3/9/97 and 27/8/97 at Tamworth and Warialda, respectively. The proposal that little wild oat germination occurred following the T2 time of removal is supported by the tiller counts at harvest (Fig. 7.4) which showed no wild oat tillers at either site.

Turnip weed seed was present at harvest from the T2 removal time. The follow up weed removals at T3 and T4 reduced the turnip weed seed at harvest to an immeasurable quantity (Fig. 7.3); although, multiple control is not desirable, the knowledge that a second control at T3 or T4 will dramatically reduce the volume of seed returning to the seed bank might be a useful management option in some situations.

The single control time T2 during this experiment was the most practical for controlling both wild oat and turnip weed. Controlling weeds at T2 maintained yields and reduced weed seed input into the seed bank. It is noteworthy that T2 was 12 weeks after sowing and halfway through the average north eastern Australian chickpea growing season. Al-Thahabi *et al.* (1994) used the classical critical period method to describe the weed-free period for chickpea under rain-fed Mediterranean conditions. They found the critical period to be between 5 and 7 weeks after emergence, which equates to 7 to 9 weeks after sowing. This supports the findings of this work that the critical time to control weeds in chickpea is not early in the season. Controlling weeds late in the season with herbicides may prove difficult, because the rates and formulations are usually developed for early season application (Medd 1995). Current chickpea production practice is to use a pre-emergence herbicide prior to sowing that may reduce the potential weed burden to be removed at T2. The pre-emergence herbicide might delay the establishment of weeds making late post-emergence sprays more effective. However, this reduces the options of what can be sown if the chickpea fail.

The slow initial growth rate of winter-sown rainfed chickpea is often cited as a reason for early weed control (Amor 1986, Knights 1991, Al-Thahabi *et al.* 1994). It could be assumed that if a crop had a slow initial growth rate and the weeds had a faster initial growth rate, then the weeds would out-compete the crop in the early part of the season, necessitating early weed control. Figures 7.5 to 7.8 show the growth of chickpea, turnip weed, and wild oat over the 1997 season at Tamworth and Warialda. For each plant species and at each site, the period of rapid growth occurred after T2 (≈444 degree-days) showing that all three species have a slow initial growth rate. The competitive ability of wild oat and turnip weed growing with chickpea is associated more with their late season growth and height. Cousens *et al.* (1991) used a different approach to show that late season competition between barley and *A. fatua* was a result of rapid late season growth in the *A. fatua* plants.

Chickpea grain yields and growth, when grown in the presence of turnip weed and wild oat, were reduced by between 40- 60% at Tamworth and Warialda. Unlike the work of Al-Thahabi *et al.* (1994) in a Mediterranean climate, the percentage loss of chickpea grain yield and total dry matter when grown with weeds were similar (Table 7.2, Figs 7.5 and 7.7). The difference in this research is most likely a result of: the summer rainfall helping to fill grain; the above average rainfall experienced during this trial; and the capacity of the soils to store more moisture.

The observed point of competition was defined as that point where the values predicted by the models describing weed-free and weedy chickpea growth differ. (The observed point of competition is the point were reduced growth in the weedy chickpea crop can be measured. It is not the point that competition occurs). At Tamworth and Warialda, the observed point of competition was significant at 1100 degree-days after sowing for turnip weed, and at 900 degree-days for wild oat (because the confidence intervals around the curves were considered). As already described, the ideal time for weed removal was at T2 ($\approx$ 444 degree-days), so it can be assumed that the point where weeds begin to significantly compete with the chickpea crop occurs between 444 and 1100 degree-days for turnip weed, and 444 and 900 degree-days for wild oat. During this potential competition time the chickpea crop reaches full canopy closure; the weeds also reach their mature height and both commence flowering (Plates 6.5 to 6.12, Chapter 6). Although attempting to identify the forms of weed competition that reduce chickpea yield was not a primary aim of this experiment, the competition for light was an important implication of this study's results so must be considered. During 1997, above average rainfall occurred, and as described above, crop weed competition occurred late in the season. Shading usually occurs late in the season and the effect on leaf growth can often produce an overall reduction in growth (Milthorpe & Moorby 1979) similar to that observed in this work (Figs 7.5 and 7.7). The effect of late season shading on chickpea yields is examined in Chapter 8.

The experiment described above used dry matter samples to determine crop and weed growth. This is a slow and destructive process and assumes that all plots across the trial are growing at the same rate. Owing to the success of the relative cover measurements described in Chapter 6, photographs were taken before each dry matter harvest to assess the viability of using relative cover measurements to describe plant growth. The results (Fig. 7.9) showed that chickpea relative cover measurements in the presence of turnip weed gave high correlations with the recorded plant dry weights (R^2 = 0.88 for Tamworth and 0.66 for Warialda); however, the results in the presence of wild oat showed only weak correlations (R^2 = 0.40 for Tamworth and 0.11 for Warialda). This result may have been due to the variable wild oat growth or the difficulty in obtaining accurate counts of wild oat plants from the photograph. This implies that if photographic assessment is to be used to measure biomass, further experimentation is warranted, because a simple accurate measure of plant growth would enable the point of competition between weeds and crops to be more accurately determined.

7.5 Conclusion

Removing weeds at T2 (≈ 444 degree-days) avoided significant yield loss and produced minimal return of weed seed to the seed bank. This time is also prior to the rapid growth phase of chickpea, wild oat, and turnip weed, and the point after which little new weed emergence occurred. This information is not only useful in deciding when to control weeds, but can be used to predict potential yield losses. In Chapter 6, leaf-area models using the relative cover variable were used to predict potential yield loss. Leaf-area models were selected because density models, although being easier to collect data, would not fully account for small and large weeds in combination or for late emergence. However, if weed density were measured at ≈ 444 degree-days, a prediction could be made before rapid plant growth occurred, and before competition commenced with a low chance of new weed emergence. In addition, T2 was the optimum time for applying weed control and, being before the rapid growth and flowering of the crop, reduced mechanical damage. The combination of these factors would allow the weed density to be used as the variable for making more simple predictions of yield loss and weed control in chickpea.

Chapter 8

The effect of late season shading on chickpea yield

8.1 Introduction

During the 1996 and 1997 experiments, observations revealed that turnip weeds reached maximum height around the time of chickpea flowering, and at this point, high densities of turnip weed shaded the shorter chickpea plants. From flowering onwards, plant assimilates are redirected from producing plant biomass to filling seeds (Salisbury & Ross 1978). As with many pulse crops, chickpea has indeterminate flowering that results in very different responses to stresses applied before or at flowering. An environmental stress (e.g. water stress or high temperatures) applied to a determinant plant (e.g. *Zea mays* L.) before the seed has begun to fill reduces individual seed growth rate compared with control plants (Jones & Simmons 1983, Jones *et al.* 1984, Quattar *et al.* 1987). This response to pre-seed filling stress is irreversible even if ideal conditions prevail during seed fill. The response of indeterminate crops to reductions or additions of assimilates during grain filling are not uniform (Munier-Jolain *et al.* 1998). The sequential pattern of reproductive development in indeterminate plants means the whole plant does not respond to a single stress and only seeds developing at that time are affected.

Data from treatments involving the application of shade to chickpea plants in India support this evidence. The application of about 50% shade to chickpea plants at flowering in one season gave no reductions in yield; in fact, a 10-15% grain yield and dry matter increase occurred (Anon. 1977). However, in the following season, when shade was applied at the same time, a significant yield reduction was recorded (Anon. 1979, Saxena & Krishnamurthy 1979). The aim of applying shade to maturing chickpea at flowering was to delay senesence and thus improve yield by reducing temperature at grain filling (Saxena & Krishnamurthy 1979). The shade was applied at 50% flowering; a time that was most likely to reduce the incidence of flower abortion and aid seed filling.

Weed growth is determined by the availability of resources and the weeds' ability to utilise those resources. Shading from weeds will usually occur when the height of the weeds is greater than the chickpea. In observations of crops grown at Tamworth and Warialda with the chickpea variety Amethyst, turnip weed plants began to shade the chickpea when they achieved about 50% flowering (16 weeks after sowing). Weeds can reduce crop yield by competing for resources; however, during the experiments described in Chapters 5, 6, and 7, competition between turnip weed and chickpea appeared to occur late in the season. In both the 1996 and 1997 seasons, adequate nutrition was supplied and above average rainfall occurred, suggesting that yield reductions may have resulted from late-season competition for light.

The aim of this experiment was to determine whether shading at different levels, and at an equivalent time to when turnip weeds begin to shade the chickpea crop, could produce equivalent chickpea yield loss to the turnip weed density trials (Chapter 6).

8.2 Materials and Methods

8.2.1 Sites

This experiment was conducted solely at Warialda during 1997. Descriptions of the climatic conditions are given in Chapter 3. The experiment was sown with a no-till planter with 11 tynes spaced at 32 cm.

8.2.2 Plant material

The chickpea plant material was the same as that used for the experiments discussed in Chapter 5.

8.2.3 Sowing

Chickpea seed was sown at Warialda on 4/6/97. The plots were sown in alternating strips of 32 and 64 cm rows as for the density experiment discussed in Chapter 5. Both were sown to achieve a chickpea stand of 35 plants m^{-2}. Wide and narrow row spacing plots were sown with the same machine by either seeding through both the front and back gangs of tynes (11 narrow rows), or only the back gang (5 wide rows).

A seed borne root fungus (*Botrytis*) reduced the chickpea plant population to between 15 and 20 plants m^{-2}.

8.2.4 Experimental Design

The experiment was a split plot design, with five replicates. The main plots contained two-row spacing of 64 cm (wide row 5 rows per plot) and 32 cm (narrow rows 11 rows per plot), and the sub-plots had three shade treatments (0%, 50%, and 80% shade).

8.2.5 Shading

The shading treatments were implemented at about 50% flowering (16 weeks after sowing). Green woven plastic shade cloth (VP Industries, Beenleigh, Qld, Australia) with mesh sizes to produce 50% and 80 % shade were fixed to wooden poles in a 2.5 m long by 3.5 m wide strip across each plot. The shade cloth was held 1 m above the ground and about 30 cm above the chickpea canopy (Plate 8.1). The ambient light at the crop canopy surface was 300 W m^{-2}. Under the 50% shade treatment, the reading was 150 W m^{-2}, whilst at 80 % shade it was 50 W m^{-2}. All readings were taken at midday under full sun.

Plate 8.1 Shade shelters. Foremost left side shelters have 50% shade and narrow row spacing (32 cm); right side shelters have 80% shade and wide row spacing (64 cm).

8.2.6 Maintenance

Maintenance was the same as in the 1997 Warialda trials discussed in Chapter 5. Very few broad-leaved weeds occurred in the plots, and grass weeds were controlled with fluazifop-p at 106 g a.i. ha^{-1} (as Fusilade). Herbicide was applied on 27/8/98, through a hand held 3 m boom spray, operating at 172.4 kPa and water volume of 80 L ha^{-1}.

8.2.7 Harvest

The chickpeas were hand harvested by removing a 1 m section from under the shade shelter of each of the centre three crop rows (wide rows) or centre five rows (narrow rows). Following harvest, the 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, weighing, and the passing of samples through a stationary thrasher chickpea grain yield was recorded. One hundred seeds were randomly selected from each sample and weighed to give a 100 seed weight.

8.2.8 Statistical analysis

The chickpea grain yield and the total plant dry weight data were not normally distributed and so were analysed using generalised linear models. The distribution of the chickpea grain yield data was described by the quasi family method and the total plant dry matter data by the Gamma log family. Mean separations were determined by a contrast analysis. The 100 seed weight data was normally distributed and balanced, enabling the use of analysis of variance and the determination of standard errors of the mean (Fig. 8.3). All analyses used the statistical software package S-plus 4.5 (Mathsoft 1998).

8.3 Results

Shade significantly reduced the grain yield of chickpea plants (P chisq < 5%) (Fig. 8.1). The application of 50% shade reduced the chickpea grain yield by approximately 50%. The 80% shade treatment reduced chickpea yield by about 86%. The shade free controls showed variation within the treatment; not all of this variation could be associated with the experiment, because some samples were damaged by rodents following harvest.

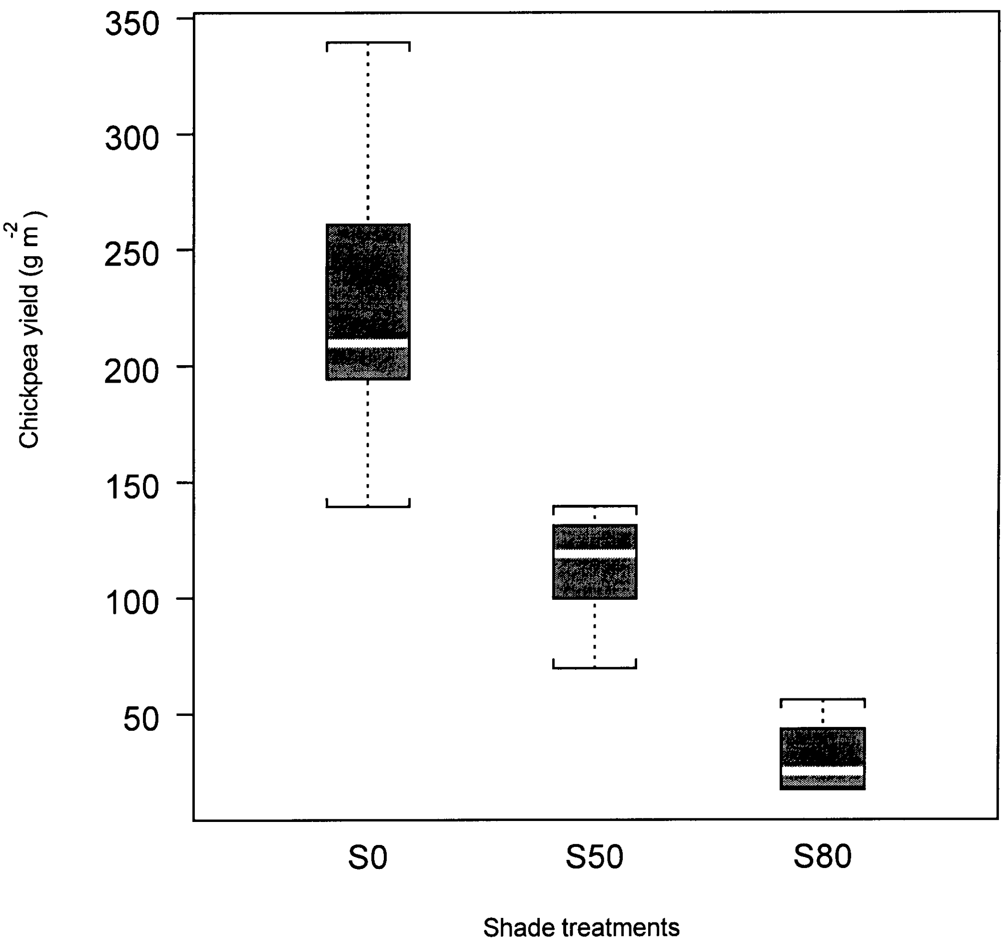


Fig. 8.1 The effect of different levels of shade on the grain yield of chickpea grown at Warialda: S0 = no shade applied; S50 = 50% shade cloth applied; S80 = 80% shade cloth applied. White bars represent the median for each treatment. The box and whiskers show the range of the data. The box shows the inter-quartile range and the whiskers contain 95% of the data.

The dry matter production of chickpea plants under varying levels of shade produced a similar response to that of grain yield. Dry matter was significantly reduced by 50% and 80% shade at flowering (P chisq < 5%). The magnitude of the reduction was less than that of the grain yield; 50% shade reduced total dry matter by 20 %, and 80% shade reduced dry matter by 40% (Fig. 8.2).

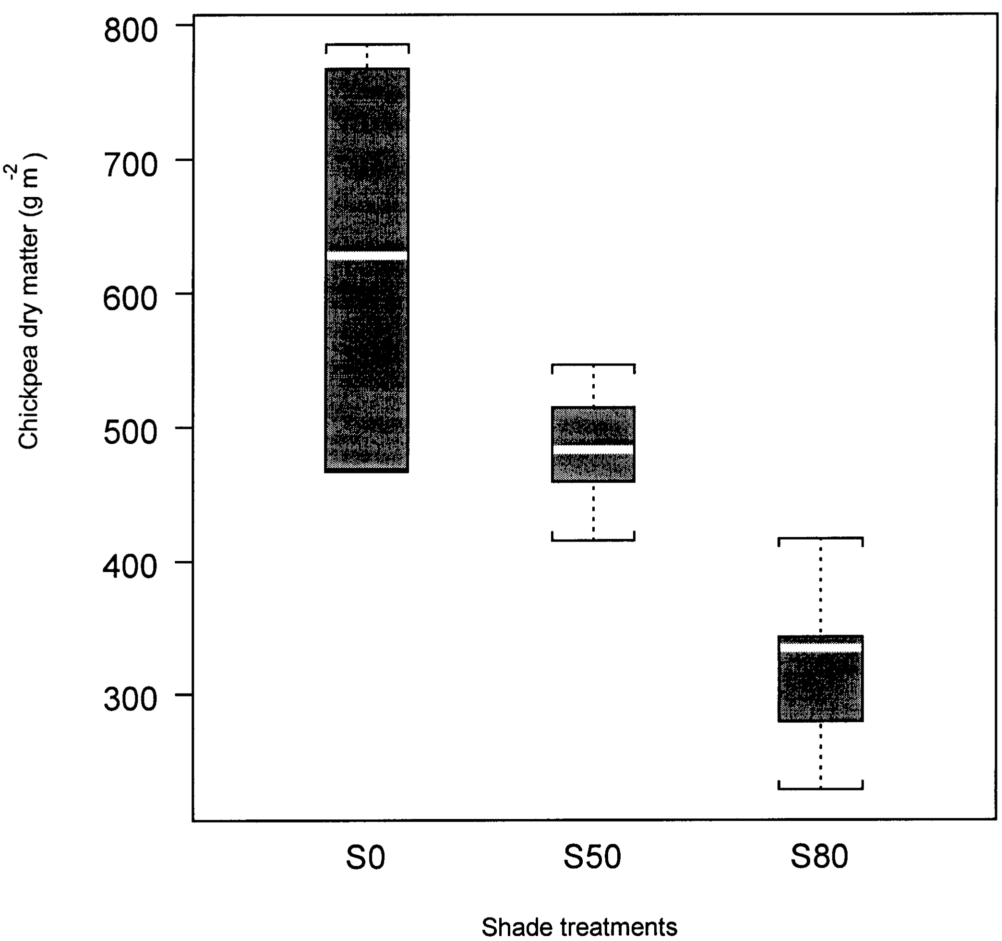


Fig. 8.2 The effect of different levels of shade on total dry matter production of chickpea grown at Warialda: S0 = no shade applied; S50 = 50% shade cloth applied; S80 = 80% shade cloth applied. White bars represent the median for each treatment. The box and whiskers show the range of the data. The box shows the inter-quartile range and the whiskers contain 95% of the data.

The application of 50% shade had no significant effect on the size of chickpea seed; however, 80% shade significantly reduced 100 seed weight (Fig. 8.3).

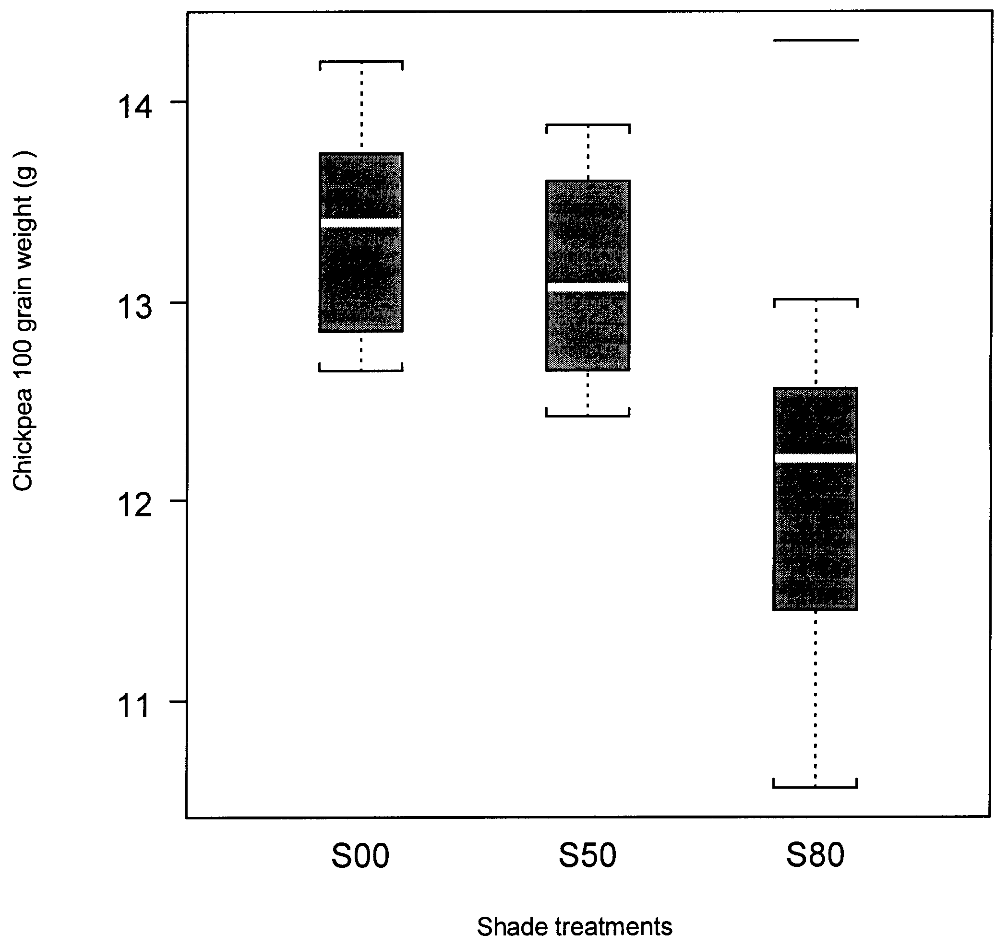


Fig. 8.3 The effect of different levels of shade on 100 seed weight of chickpea produced at Warialda: S0 = no shade applied; S50 = 50% shade cloth applied; S80 = 80% shade cloth applied. White bars represent the median for each treatment. The box and whiskers show the range of the data. The box shows the inter-quartile range and the whiskers contain 95% of the data. Points outside this are displayed as single horizontal bars. The standard error of the means was 0.34.

8.4 Discussion

The results show that shading from flowering to harvest significantly reduced chickpea yield (Fig. 8.1), dry matter (Fig. 8.2), and 100 seed weight at 80% shade, (Fig. 8.3). The initial aim of this experiment had been to compare the relative yield losses from the shade treatments with those of the turnip weed density treatments, to identify the proportion of yield loss that could be attributed to shade. The level of shade was measured in the turnip weed plots in 1997, but a fault in the light meter prevented comparisons with the levels of light under the shade cloth. A second trial was sown in 1998 with the objective of imposing a series of shade levels for different durations to enable yield loss curves to be fitted against relative levels of shade. Unfortunately, unseasonally high rainfall caused flooding of the experimental sites at both Tamworth and Warialda, resulting in all 1998 trials being abandoned.

The results of this experiment are consistent with the work of Saxena and Krishnamurthy (1979) who found 80% shade to generate similar effects. The 50% shade treatment also reduced the grain yield and dry matter of chickpea. Some inconsistency had been observed with the application of 50% shade in India (Saxena & Krishnamurthy 1979). However, the reduction in yield and dry matter observed in this experiment as a result of applying 50% shade at 50% flowering is similar to that found in three other pulse crops (Munier-Jolain *et al.* 1998).

Ney *et al.* (1993) showed that once the seed water concentration of field pea (*Pisum sativum* L.) at a given morphological position on the plant decreased below 0.85 g g^{-1}, seeds were unlikely to abort no matter what the level of intra-plant competition for assimilate allocation. As with field pea the indeterminate flowering of chickpea could lead to the application of stress during flowering causing seeds and flowers near the apex of the shoot to abort, while lower seeds remained unaffected. The application of shade decreases assimilate availability by manipulating the source-sink ratio by limiting assimilate production (Munier-Jolain *et al.* 1998). This would reduce the accumulation of dry matter and stop flowering.

The shade applied during this experiment was from flowering until harvest; however, observations of the turnip weed plants show that the shade lasted only until after turnip weed plants flowered (23 weeks after sowing) at which time the turnip weeds dropped their leaves. The indeterminate nature of chickpea flowering would enable the shoots to recommence flowering and produce seed after the turnip weeds dropped their leaves.

The results presented in this chapter show that the level of chickpea yield loss observed in Chapter 5 could be partly explained as an effect of shade. However, the data on shading is limited and further work under different environmental conditions is necessary to better determine the importance of shading in chickpea/turnip weed competition. If shading is a major part of chickpea/turnip weed competition then chemical and cultural practices could be designed to achieve chickpea flowering before turnip weeds could shade the plants, or weed management systems that reduce the height of the turnip weed could be used. Yield loss caused from the shade cloth and that caused from turnip weeds suggest that the 50% shade was equivalent to a turnip weed density of 30 plants m^{-2}. The abandoned 1998 trial would have provided answers to this question by allowing hyperbolic curves to model the effect of shade.