Chapter 1

Introduction

Continuous cropping of grain cereals has been common practice in northern New South Wales (NSW). This has resulted in the depletion of soil organic carbon and nitrogen levels, and has reduced crop yields, grain protein contents and financial returns to producers (Horn *et al.* 1996). Pulse crops have often been incorporated into a rotation to reduce these losses while providing a disease and pest break.

Chickpea is one of the pulses suited to northern NSW; it is grown on a wide range of soil types, but prefers the medium to heavy clays (Knights 1991). The use of chickpea in rotations has been widely promoted after it was shown that their inclusion could in some cases double subsequent wheat yields (Knights 1991). However, there are some difficulties associated with growing chickpea in the grains region of north eastern Australia. Traditionally, lucerne has been grown in the region, but many pathogens and pests which are associated with lucerne production have also been found to affect chickpea (Knights 1991).

Phytophthora root rot is an important disease of chickpea in eastern Australia and has been a major impediment to the widespread acceptance of the crop in northern NSW. However, recent breeding and selection work has identified heritable resistance, so future releases of resistant material should be more suited to the region. A second problem is the susceptibility of chickpea to a number of aphid-transmitted luteoviruses (Rummery *et al.* 1996), many of which originate or are associated with lucerne (Schwinghamer *et al.* 1995). Chickpea is also susceptible to the foliar fungal diseases, *Botrytis* spp. and *Sclerotinia* spp.; seed borne diseases, *Botrytis* and *Ascochyta rabiei* (phoma blight); and insect attack by *Helicoverpa armigera* and *H. punctigera* (Knights 1991, Schwinghamer *et al.* 1995, Rummery *et al.* 1996).

One of the major obstacles in growing chickpea successfully is its poor ability to compete with weeds. Crop losses of 90% are possible in weedy situations (Knights 1991), and the lack of registered post-emergence herbicides to control broad-leaved weeds reduces the options for weed management.

To address some of the problems of weed management in the northern grains region (northern NSW and southern Queensland), a Grains Research and Development Corporation (GRDC) project, DAN262, was established. A component of this project (Module 4) focused on the development of an integrated weed management package for the production of chickpea and consisted of four areas of research. Firstly, there was a screening of herbicides for broad-leaved weed control in chickpea and early post emergence herbicide tolerance. Secondly, the research involved a survey of chickpea crops and growers to obtain information on the diversity and abundance of weed species in chickpea crops, in order to assess the level of weed control following herbicide application. The third area investigated the use of novel herbicide application techniques for inter-row spraying of chickpea, and the fourth research area (this project) involved an assessment of competitive interactions between chickpea and weeds, and the agronomic practices that could improve the competitive ability of chickpea.

Understanding competition between crop and weeds is the foundation for an integrated weed management system. This knowledge underpins decisions concerning what control measures to apply and when to apply them. The project objectives were:

- a quantification of competitive effects of weeds on chickpea;
- the establishment of a sound basis for the timing of weed control; and
- the identification of cultural management practices and breeding objectives for chickpea which increase competitive ability of the crop.

The experiments undertaken to meet these objectives examined the effects of wide and narrow crop row spacing, weed density and weed position on the competitive ability of chickpea. In addition, the optimum time to control weeds and the manipulation of chickpea competitive ability through breeding were examined.

Each experimental chapter contains an introduction that examines the relevant literature. To avoid repetition the literature review in Chapter 2 concentrates on the background information of chickpea production in the northern grains region of eastern Australia and the dominant weed species involved. Some reference is made to integrated weed management, but it was felt that the topic of integrated weed management *per se* has been adequately reviewed in recent years by many authors (e.g. Swanton & Weise 1991, Akobundu 1992, Bhan & Singh 1993, Bhowmik 1993, Chester 1993, Powles 1993, Singh 1993, Else *et al.* 1995, Sindel 1995, Swanton & Murphy 1996, Jones & Medd 1997).

The experiments for this research were conducted at two sites in the grains region of northern NSW over two years. The Methods sections of the experimental chapters, the sites and climatic conditions for 1996 and 1997 are comprehensively described in Chapter 3. Chapters 4 to 9 describe the experimental work that was designed to satisfy the original research objectives and meet the project aims. Chapter 10 draws the results from the individual experiments together to provide an understanding of weed competition in chickpea as the basis for enhancing the crop's overall competitive ability.

Chapter 2

Background review

2.1 History of cropping practices in the northern grains region

To understand the difficulties of weed control in chickpea grown in the northern grains region of eastern Australia, it is necessary to understand the development of dryland cropping in sub-tropical areas. The northern grains region of eastern Australia extends from 25°S to 32°S and lies between the 500 mm and 700 mm isohyets of average annual rainfall (Holland *et al.* 1987). The soils include the black and grey cracking clays found in the north western plains of NSW and the Darling Downs region of southern Queensland; the red-brown earths of the NSW slopes and plains; and to some extent, non-calcic brown soils and prairie soils (Hubble & Isbell 1983). Initially, the soil types and the available tillage machinery limited the area sown to crops. The first wheat crops were sown in the Tamworth area around 1870, and by 1900, some grain was grown throughout the present wheat belt (Hallsworth *et al.* 1954). However, cropping was restricted to the lighter soils by the difficulty of cultivation on the heavy clays (Hallsworth *et al.* 1954, Holland *et al.* 1987). By the 1950s, improvements in farm machinery enabled sowing on the heavy clay soils, and the northern grains region was expanded westward to the plains (Hallsworth *et al.* 1954).

The management practices associated with grain production up to the 1950s did not identify weeds or disease as major constraints; they concentrated on crop rotation, methods of treating stubble, types of cultivation, and fertiliser treatment. This selection of management practices is still the core of current management; however, the importance and understanding of each management practice has changed. Prior to 1950, the crop rotations used in the grains region of northern NSW could be divided into four types: continuous wheat with a short fallow between the wheat crops; continuous wheat with a short fallow, but with occasional long spells of lucerne; continuous wheat with a short fallow, but with occasional years of oats, long fallow and sorghum; and alternate wheat and oat crops for grazing, or wheat and long fallow (Hallsworth *et al.* 1954).

Stubble management up to the 1950s predominantly involved some form of stubble removal. Stubble was grazed, burned and cultivated; burned and cultivated; or heavily grazed and cultivated (Hallsworth *et al.* 1954). At this time, it was recognised that cropping the lighter soils of the slopes was causing erosion, so alternatives to stubble burning were examined. Crop residues on the heavy black soils, however, were still being burnt with around 80% of farmers burning their stubble in 1954 (Holland *et al.* 1987). From the early 1950s stubble burning was generally considered a poor practice, and although it was recognised that residue maintenance helped prevent soil erosion, the management and sowing of crops through residues caused considerable problems. These difficulties of sowing through stubble meant the adoption of stubble conservation practices was slow (Holland *et al.* 1987).

Tillage practices were changing with machinery development and improved knowledge of the soils within the area. Initial tillage involved deep mouldboard ploughing, which was not generally successful, especially on the heavier soils, and was soon replaced by disc ploughs (Hallsworth *et al.* 1954, Holland *et al.* 1987). In the 1950s, tined implements were appearing, especially on the western chernozemic soils (Hallsworth *et al.* 1954). The adoption of tined implements is considered a major reason for the western expansion of the northern grains region (Holland *et al.* 1987).

Soil fertility problems were beginning to be recognised in the 1950s; however, soil erosion was perceived to be a greater threat. The inclusion of lucerne in the rotation and the use of a regular long fallow (improving available nitrogen (N) through mineralization, not total N) was the first attempt to maintain soil nutritional status and delay the observed decline in soil nitrogen levels (Holland *et al.* 1987).

In 1983 and 1984, Martin *et al.* (1988) conducted a survey to identify changes in the farming systems of the northern grains region. The main change between the survey of Hallsworth *et al.* (1954) and Martin *et al.* (1988) was the western expansion of cropping onto the grey clays west of Moree and Narrabri. The expansion westward also moved the centre of the grain region as less continual cropping occurred on the western slopes or New England regions. In the 36 years between the recording of these surveys herbicides and better trash handling tillage equipment were developed. In 1984, northern farmers were still burning stubble predominantly on the western plains, and not for the sole purpose of easier sowing. The reasons given for stubble burning as reported by Martin *et al.* (1988) were: trash removal; disease control; machinery handling (ease of sowing); weed control; and soil fertility.

The use of rotations, and the inclusion of other crops in the rotation, also differed between the survey dates of 1948 and 1984. Wheat rotations on the inner slopes had changed little from 1948, maintaining a lucerne grazing phase and a sorghum summer crop. Continuous winter cereal cropping was most prevalent in the central and western plains regions in 1984. However, Martin *et al.* (1988) found that the rotation of cereals and summer sorghum crops occurred on a third of the properties surveyed. They also noted that other crops included in individual farmer's rotations were: sunflower; forage crops; cowpeas; soybean; chickpea; mungbean; lupins; rapeseed; dryland cotton; triticale; linseed and safflower. In 1948, the main reason provided for rotating wheat and fallow, or wheat and lucerne, was reduced returns from lowered nutritional status and soil erosion (Hallsworth *et al.* 1954). In 1984, the reasons for fallowing, in decreasing order of importance, were: weed control; moisture conservation; disease avoidance; soil fertility (available N); and seasonal conditions (opportunity cropping due to climate). The reasons provided for rotation with another crop were similar to those for fallowing i.e. weed control, disease control, fertility (from legumes), and moisture conservation.

Despite the advent of herbicides and improvements in farm machinery during the period between the two surveys, the control of weeds, cereal diseases and the ongoing problem of soil erosion had emerged as the major factors forcing change to the farming system. These factors are not independent, but their emergence as limitations to grain production in the northern grains region forced the re-examination of the whole farming system.

There are several important considerations relating to the production of high quality wheat in the northern grains region of eastern Australia: the effects of rotations on soil nutrition; erosion and moisture status; sowing times; weed control; and plant diseases. Different agronomic practices can influence these production constraints, and the best options for each individual farming system must be developed. The difficulty with the selection of individual agronomic practices is that they are not independent and one cultural practice may have a positive and/or negative effect on different production constraints. Production constraints are summarised in Table 2.1 and then discussed in relation to farming practice.

Table 2.1. The effect of different farming practices on the critical production constraints of cereal crops in the northern grains region of eastern Australia.

	Production constraints						
Farming practices	Soil nutrition	Soil erosion	Soil moisture	Time of sowing	Crop sowing	Weed control	Plant disease
Early stubble burn		✗				✓	✓✓
Late stubble burn		✓				✓	✓✓
Continuous cultivation`		✗	✓			✓	✓✓
Minimal tillage late cultivation	✗	✓	✓✓	✓	✓	✓	✗
Minimal tillage early cultivation		✗	✓		✓	✓	✓
No- tillage	✗	✓✓	✓	✓	✗	✓	✗
Short fallow + stubble	✗	✓	✓	✓	✗	✗	✗
Short fallow – stubble		✗	✓	✗	✓	✓	✓
Long fallow + stubble		✓✓	✓	✓	✗	✓	✓
Long fallow – stubble		✗	✓	✗	✓	✓	✓
Rotate with summer crops	✗					✓✓	✓✓
Rotate with legumes	✓✓	✗			✓	✓	✓✓
Rotate with other cereals						✓	✗
Rotate cereals summer crops legumes.	✓	✓				✓✓	✓✓
Fertilisers	✓	✗	✗	✗	✗	✗	✗

✓ = positive effect, ✓✓= highly positive effect, ✗= negligible or negative effect, blank cells = no reported effect in the literature.

2.2 Soil nutrition

In 1948, the accepted practice of production in the northern grains region was continuous wheat punctuated by a short cultivated fallow; and superphosphate was the predominate fertiliser, but was generally applied in the wetter parts of the region (Hallsworth *et al.* 1954). By 1985, around 55% of farmers were applying nitrogenous fertiliser at sowing, but the rates of phosphorous (P) and N applied were inadequate to correct deficiencies (Martin *et al.* 1988).

The problem of soil erosion as a result of over-tillage and reduced ground cover caused nutrient losses and soil degradation, but this could be dramatically reduced by the use of no-till farming and chemical fallowing (Felton *et al.* 1994). The adoption of no-till farming has been slow, resulting from the initial difficulty of sowing crops into stubble, and the potential to suffer from nitrogen immobilisation in the early stages of crop growth (Holland *et al.* 1987).

Rotating production seasons and crops, and applying nitrogen at sowing can prevent nitrogen immobilisation and the plant disease problems associated with stubble (Holland *et al.* 1987). The rotation of pulse crops with wheat has been shown to greatly improve soil fertility (Herridge *et al.* 1995) and benefit subsequent cereal crops (Marcellos 1984).

2.3 Soil erosion

Historically, soil erosion has been a major problem in the northern grains region and management practices have been developed to reduce the losses (Holland *et al.* 1987). The adoption of management techniques such as stubble retention has been slow, and it is still not accepted practice. The difficulty with the implementation of methods such as stubble retention is the conflict between maintaining stubble to prevent erosion, and its removal to prevent disease. The practices of tillage to stimulate weed emergence, and the difficulty of changing to successfully sow through stubble, also conflict with a stubble retention system. These conflicts necessitate compromise so, in order to prevent erosion the removal of stubble early in the rotation should not be considered (Felton *et al.* 1994). Rotating cereal crops with legumes can prevent some of the conflicts associated with cereal crops and cereal stubble; however, the high nitrogen content of the legume stubble means that it is broken down quickly and can leave the soil exposed.

2.4 Soil moisture

To ensure successful winter crops, a full profile of moisture should be in the soil at sowing. The management of the fallow is critical in maximising the volume of water stored. Tillage removes weeds to prevent water loss; however, it can accelerate drying of the soil surface, and change soil structure, which decreases infiltration. Comparisons between tilled and no-tilled black earth, in the northern grains region, showed an improvement in soil structure after 3 years of no-till (Hamblin 1980, Holland *et al.* 1987). Harte (1984) showed that continuous cultivation of red brown earths substantially reduced the water holding capacity, increased bulk density, and reduced water infiltration.

The aim of reducing erosion and maximising the water holding capacity of the soil fostered the practice of no-till farming. Provided weeds were controlled, the practice of maintaining stubble and avoiding cultivation could improve the water stored in the soil on average by 20 mm (Holland & Felton 1983).

2.5 Sowing date

Sowing winter crops at the optimum time benefits final yields. It has been estimated that, for each week past the optimum sowing time, a 6% yield penalty is incurred in wheat crops (Doyle & Marcellos 1974, McDonald *et al.* 1983). A no-till fallow maintains soil moisture closer to the surface when compared with a cultivated fallow (Fawcett 1975, cited by Holland *et al.* 1987); this means a smaller rainfall event is required to enable sowing, and sowing at optimum time is more likely (Radford & Nielsen 1983).

Tillage during a fallow can cause erosion and rilling of the soil surface, which usually requires a tillage operation for removal (Felton *et al.* 1994). The need for additional tillage after heavy rainfall events can also delay sowing, and prevent the establishment of a crop at an optimal time.

2.6 Plant disease

Disease carry-over on stubble is the main drawback with stubble retention systems. The conflict between the maintenance of soil cover to prevent erosion and the problem of disease carry-over on stubble has prevented greater adoption of no-till farming techniques. In the farm survey completed by Martin *et al.* (1988), 55% of farmers cited disease prevention as their primary reason for burning stubble. However, in a truly integrated farming system, the carry-over of diseased residues can be prevented with late season burning, crop rotation, long fallow, and rotation between summer and winter crops (Table 2.1).

2.7 Weed control

In the 36 years between the data collection of the surveys of Hallsworth *et al.* (1954) and Martin *et al.* (1988), control of weeds became a major concern in northern farming systems. The primary reason, given by farmers in 1985 and 1986 for the rotation of crops and the use of long fallows, was weed control (Martin *et al.* 1988). Their 1985-86 survey showed that wild oats and turnip weed were the most prolific weed species ranked by producers. Wild oats was the most important weed in an on-farm survey (Martin *et al.* 1988) with turnip weed ranked after paradoxa grass, wireweed, common sowthistle, and prickly lettuce. This difference in the ranking of turnip weed may have been a result of control with chlorsulfuron and atrazine at this time. However, herbicide resistant turnip weed has now been found throughout the northern grains region (Adkins *et al.* 1997). A recent (1996) survey of weed species in this region (Storrie pers.comm.) again ranked wild oat and turnip weed as the most prolific weeds in the northern grains region.

2.7.1 Turnip weed

Rapistrum rugosum (turnip weed, giant mustard, bastard cabbage) is a native of Europe; it is adapted to most soils and is drought and frost tolerant (Bodkin 1990). As well as being common in the northern grains region, it is also a weed in parts of South Australia (Cousens *et al.* 1996) and in disturbed soils of Victoria and Tasmania (Fig. 2.1).

Fig. 2.1 Distribution of *Rapistrum rugosum* in 1982 (Hewson 1982).

Western Australia has experienced some small outbreaks of turnip weed in recent years, and considerable potential exists for it to spread throughout the Western Australian wheat belt (Hussey *et al.* 1997).

The accepted control measures for turnip weed in the northern grains region have been herbicide applications of MCPA, chlorsulfuron or atrazine; however, recent work has shown that resistance to chlorsulfuron and atrazine has occurred (Adkins *et al.* 1997), and that it is widespread throughout the region (Wills *et al.* 1996). Overall control in the region is considered poor owing to seed banks on roadsides, along water courses, and in reserves not being controlled.

Turnip weed seeds are dimorphic. The upper distal seed is ovoid and about 2mm in diameter and is tightly enclosed by a thick wall. The lower proximal seeds are smaller and have a thinner wall. Proximal seeds remain on the plant longer and may tend to be dispersed as individual seed. Proximal seeds appear to be less dormant than the distal seeds. Distal seed dormancy is also increased by the fruit wall of the pod. Low temperatures (< 5° C) could induce dormancy, which is subsequently released with higher temperatures (Cousens *et al.* 1994). About 50% of seed produced from a healthy plant will be proximal, whereas stressed plants produce mainly distal seed (Cousens *et al.* 1994). The optimal temperature range for turnip weed germination is between 10°C and 25°C with a base germination temperature of 5°C (Cousens *et al.* 1994). Flowering in turnip weed appears to be stimulated by photoperiod and temperature, with plants that emerge in summer reaching maturity in half the time of plants emerging in winter (Wilson 1981). However, the plants that emerged in winter carried significantly greater quantities of seed than the summer emerging plants (Wilson 1981).

The Brassicaceae as a family have the potential to colonise a range of environments, but *R. rugosum* and *Brassica tournefortii* have the ability to exist in hot and dry climates which gives them the potential for even greater spread (Cousens *et al.* 1996).

2.7.2 Wild oats

Two species of wild oats predominantly occur in the grains regions of Australia. These are *Avena fatua* and *A. sterilis* ssp. *ludoviciana* (sometimes still referred to as *A. ludoviciana* Dur.). *A. fatua* tends to dominate the southern and western grains regions, while *A. sterilis* ssp. *ludoviciana* dominates the northern grains region. Despite this separation, both types generally can be found in all Australian grain regions. A national survey of grain producers by the chemical company Hoechst Australia (now AgrEvo), as reported by Nugent (in press), found that wild oats occurs on two out of three farms in the winter cereal grains regions.

Wild oat is one of the most important weed species in the Australian grains regions. It is a most prolific weed in the northern grains region (Martin *et al.* 1988, Felton 1995, Storrie pers. comm.) and is one of the most researched weeds in Australia.

Included in the literature on wild oats are studies and reviews describing: the ecology of wild oats (Medd & Pandey 1993, Medd 1996a, 1996b); competition with major crops (Haizel & Harper 1973, Martin, *et al.* 1987, Cousens *et al.* 1991); chemical weed control methods (Malik *et al.*

1993, Nietschke & Medd 1996, Medd *et al.* 1992, Medd *et al.* 1995); non-chemical weed control methods (Purvis 1990, Jones 1992, Martin & Felton 1993, Nietschke 1996); and the economics of management (Medd & Pandey 1990, Pandey & Medd 1990, Jones & Medd 1997). While this is not a complete list of wild oat research, it shows the depth of information available.

The key to the success of wild oat is its similar life cycle to the major cereal grain crops. This mimicry has enabled wild oat, a plant without elaborate dispersal mechanisms, to utilise farmer operations in order to be dispersed throughout every grain producing area of Australia as a grain contaminant.

In the northern grains region, control of wild oat has involved crop rotation and the application of selective chemicals. The chemical approach, especially in pulse crops, has specifically utilised Group A herbicides (Group A refers to the Australian herbicide resistance classification system, group A, which includes the Aryloxyphenoxy propionates "Fops" and Cyclohexanediones "Dims"). Crop rotation with summer crops like sorghum has been a successful approach to reducing wild oat populations (Jones 1992, Martin & Felton 1993); however, new approaches, which focus on seed kill offer an alternative (Pandey & Medd 1990, Medd *et al.* 1995). The use of chemical weed control as the sole management option is unsustainable, since herbicide resistant wild oat have been identified in isolated patches within the northern grains region (Wills pers. comm.).

2.7.3 Cultural weed management

Weed control by cultural farming practices in the northern grains region involves a degree of conflict with other practices. Farmers often view burning as a means of killing weed seed (Martin *et al.* 1988), but if done early in the fallow, burning exposes the soil to erosion. Cultivation can cause similar consequences; however, a cultivation prior to sowing can stimulate weed emergence and help reduce the seed bank size, prior to sowing. The different forms of cultivation also affect the seed bank: some bury seed deep in the soil; and others bring seed to the surface stimulating germination. In no-till farming systems, the weed seed is maintained on the soil surface which in Canadian trials has reduced the seed bank by exposing the seed to fluctuating temperatures, disease and insect predation (Blackshaw 1998). There has been little evidence of no-till having a similar effect in the northern grains region (Felton pers. comm.); however, there is evidence that the adoption of reduced-tillage has led to the emergence of new problem weed species, for example barley grass (*Hordeum leporinum* ssp. *glaucum)* and silvergrass (*Vulpia* spp.) in southern

Australia. Aerially dispersed weeds such as common sowthistle (*Sonchus oleraceus*), prickly lettuce (*Lactuca serriola*), and fleabane (*Conyza albida*) have also become abundant where stubble is retained (Wicks *et al.* 1994).

The use of rotations offers the best cultural method for weed control. The main reason, reported by Felton *et al.* (1994) for the use of grain sorghum in the rotation, was wild oat control (by 77% of farmers surveyed). The emergence pattern of wild oat seedlings following a summer crop of sorghum was shown to be 72% less than that of a clean fallow (Purvis 1990). The rotation of crops and cropping seasons also enables herbicide rotation, which can help prevent the development of herbicide resistance in common weeds (Malik & Singh 1993, Medd 1995, Sindel 1995).

The surveys of farming practices in the northern grains region of eastern Australia over the last 60 years have presented a picture of grain production problems in this area, and identified some solutions to prevent or repair the damage of previous management. Crop rotations offer the greatest benefit in the immediate future for improving the management of weeds, reducing disease, allowing stubble retention, maintaining soil nutrition, and maintaining farm profitability.

It has been shown that the inclusion of grain legumes in rotations significantly improves cereal yields in the following year (Doughton *et al.* 1981, Reeves *et al.* 1984, Marcellos 1984, Strong *et al.* 1986, Doyle *et al.* 1988, Hossain *et al.* 1996). Chickpea, fababeans, and lupins are all grown in the northern grains region and generally all produce the same beneficial effects on following cereal crops (Marcellos 1984). Continual cropping, repeated tillage, and burning of stubble residues have depleted much of the original high soil fertility of the northern grains region (Holland *et al.* 1987). The results of this decline are degraded soils and a decline in cereal grain yield and quality. The addition of fertiliser is one method to reverse this trend; however, survey results show that farmers within the region have been reluctant to apply fertilisers in adequate amounts (Martin *et al.* 1988). Conservation farming using rotations with legumes is another method to slow the fertility decline in these soils. The use of legumes in a rotation alone will not restore lost soil fertility. Under ideal conditions the legume will fix sufficient nitrogen to replace that nitrogen lost in grain removal, but it will not replace the nitrogen lost through cereal grain removal (Marcellos *et al.* 1998, Herridge, *et al.* 1998). To restore the fertility of a soil and to replace nitrogen lost through cereal grain production, additions of nitrogen are required. The benefits of growing legumes in a rotation compared with continual cereal productions stem from the increase in available nitrogen following a legume crop and the reduced occurrence of cereal diseses following legumes (Felton *et al.* 1998).

Chickpea is well suited to the northern grains region. Its slow early growth means that its initial water usage of the stored soil water is low compared with that of barley (Thomas *et al.* 1995). However, the increased time to canopy closure means evaporation from the exposed soil reduces the water use efficiency of the crop (Thomas & Fukai 1995b). Chickpea crops have a slow initial growth rate, an open canopy, and a low stature; which reduce the crop's competitive ability when grown in the presence of weeds (Knights 1991). The physiological deficiencies of chickpeas competing with weeds has been discussed by many authors and these will be reviewed in the introductions for the relevant chapters within this thesis.

2.8 Conclusion

Wild oats and turnip weed are the most significant winter weeds in the northern grains region of eastern Australia. A successful integrated weed management (IWM) solution for winter crops of the northern grains region would require strategic management solutions for these two weeds. Integrated weed management is described as a strategy that combines all appropriate chemical and non-chemical weed control methods within a particular farming system (Sindel 1995). This is correct. However, if the weed management methods are the sole consideration, the system has the potential to become unsustainable. In order to achieve sustainability, there must be an understanding of how the weed control methods of the IWM system interact with other farming components, such as erosion control, because until the components of each management system are complementary, farm management is unlikely to be improved.

Chapter 3

Site descriptions and climate

3.1 Introduction

Fieldwork for this thesis was conducted at two sites within the northern grains region of eastern Australia. Site one, referred to as Tamworth, is situated on the New South Wales Department of Agriculture's Tamworth Centre for Crop Improvement, Calala Lane, Tamworth. Site two, referred to as Warialda, is situated on the University of New England's Douglas McMaster Research Farm approximately 200 km northwest of Tamworth. Each site will be described separately with details of the specific paddocks used each year.

3.2 Tamworth

The Tamworth Centre for Crop Improvement is located in the New England Region of northern New South Wales, 10 km southeast of the city of Tamworth. The Centre is about 450 m above sea level at latitude 31° 08' 55" South and longitude 150° 59' 05" East (Riddler 1989). The general terrain is moderately undulating with low hills and wide valleys.

The area has moderately steeply dipping interbedded sedimentary rock formations of variable thickness and resistance to weathering. Under the Centre, the underlying rocks are of Devonian and Carboniferous origin and are made up of interbedded mudstones, sandstone cherts and limestones (Riddler 1989). The soils developed from these parent materials are predominantly red brown earths and red, brown and grey clays, many of which are seasonally cracking while others are self-mulching.

Tamworth has been described as part of the semi-arid zone (Riddler 1989). The annual average rainfall is 675 mm (rainfall averaged over 107 years between 1876-1988, 5 years missing data) with almost two-thirds falling in the 6 months from October to March (Fig. 3.1). The potential evapotranspiration is 1750 mm, and the annual temperature ranges from – 4°C in July to 42°C in December. The mean monthly minimum and maximum temperatures for July are 1.5 and 15°C and for January are 19 and 36°C (Fig. 3.1).

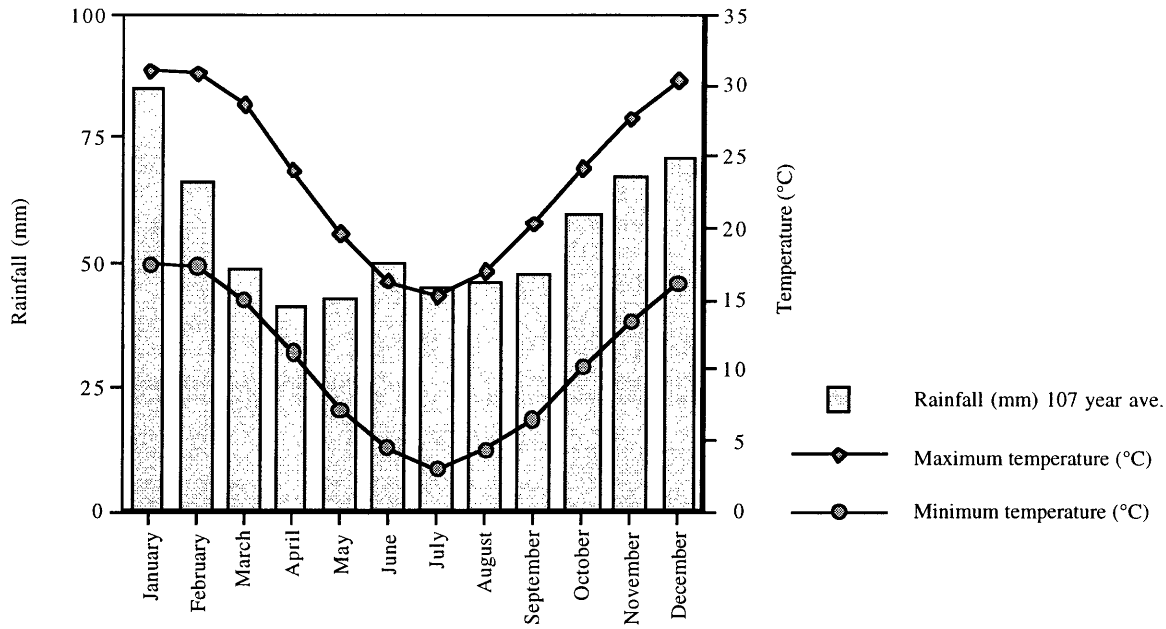

Fig. 3.1 Mean monthly rainfall and temperature at the Tamworth Centre for Crop Improvement (107 year rainfall average 1876–1988, and 22 year temperature average 1966-1988).

3.2.1 Tamworth research areas 1996/97

Soil

In 1996, the soil was a grey clay, calcaric phaeozem classified as a Uf6.42 with an "A" horizon pH of 8.0 (1:5, soil/water). A full description of the soil profile is presented in Table 3.1.

Table 3.1 Soil description of research area, Tamworth 1996 (Riddler, 1989)

Horizon	Depth	Description
A_{p1}	0 cm	Dark grey (10YR4/2, dry; 10YR3/2 moist) light clay, with a massive structure and pH of 8.0
A_1	5 cm	As above
B_{21}	6 cm	Grey, dark grey (10YR3/3, 10YR3/2) light to medium clay, sub-angular blocky (3 cm) to angular blocky (1 cm) structure, with a pH of 8.0
B_{22}	94 cm	Yellowish grey, dark brown (10YR4/3, 10YR3/2) heavy clay, sub-angular blocky (2 cm) to angular blocky structure (1 cm), with a pH of 8.5
B_3	119 cm	Greyish brown, dark grey (7.5YR4/4, 10YR3/2) medium clay, angular blocky structure (3 cm), with a pH of 8.5
$2B_{21}$	137 cm	Olive brown, grey (7.5YR4/4, 10YR4/2) medium clay, angular blocky structure (2 cm) – (4 cm), with a pH of 9
$2B_{22}$	171 cm	Yellowish brown (7.5YR4/4) medium clay, angular blocky structure (2 cm), with a pH of 9.0
$2B_{23}$	185 cm	Yellowish brown (7.5YR4/4) medium clay, angular blocky structure (2 cm), with a pH of 9.0
$2B_3$	190 cm	Maximum, not penetrable: dense, hard, massive clays

The soil at Tamworth in 1997 was a brown clay, modified red brown earth (Uf6.32) calcaric phaeozem with an "A" horizon pH of 7.5. A full description of the soil profile is presented in Table 3.2.

Table 3.2 Soil description of research area, Tamworth 1997 (Riddler 1989)

Horizon	Depth	Description
A_0	0 cm	Brown (7.5YR4/4 dry, 5YR3/3 moist) light clay with an apedal, massive structure and a pH of 7.5
B_1	12 cm	Dark brown (5YR3/2) light clay with a pH of 7.5
B_2	20 cm	Reddish brown (2.5YR3/4, 7.5YR5/6) medium clay, angular blocky structure (3 cm) and a pH of 8.0
BC	54 cm	Brown, yellowish brown (2.5YR3/4,7.5YR5/6) medium clay with a pH of 8
C_1	68 cm	Yellowish brown (7.5YR6/4, 2.5Y6/2) light medium clay with gravel, sub angular blocky structure with a pH of 9
C_2	114 cm	Grey, red brown (2.5Y6/2, 2.5YR3/6) light medium clay with gravel (pH 9)
D	132 cm	Maximum, not penetrable: weathered gravel

History

The 1996 Tamworth research area had been sown to wheat in 1995. During the following summer fallow, weeds were controlled with cultivation. A month before sowing, 60 kg ha^{-1} of triple superphosphate was spread and incorporated with a light working of the soil. The 1997 research area had also been sown to wheat the previous season; however, the summer fallow was treated as a no-till situation and the weeds were controlled with periodic applications of glyphosate at 675 g a.i. ha^{-1} (as Roundup CT). Prior to sowing, the area was again sprayed with glyphosate, and the chickpea and fertiliser (60 kg ha^{-1} of triple superphosphate) were drilled directly through the previous wheat stubble. In both years following sowing the weeds were managed as determined by the experimental aims.

Weeds

In 1996 and 1997, broad-leaved weeds were controlled by hand-chipping, while grass weeds were removed with fluazifop-p at 106 g a.i. ha^{-1} (as Fusilade). The dominant weeds during the 1996 season were wild oats (*Avena ludoviciana* Durieu), sowthistle (*Sonchus oleraceus* L.), and black bindweed (*Fallopia convolvulus* L.); and in 1997 the weeds were paradoxa grass (*Phalaris paradoxa* L.), wild oats, and sowthistle. Variegated thistle (*Silybum marianum* [L.] Gaertner), Mexican poppy (*Argemone ochroleuca* Sweet. ssp. *ochroleuca*), spear thistle (*Cirsium vulgare*

[Savi.] Ten.), turnip weed (*Rapistrum rugosum* [L.] All.), Indian hedge mustard (*Sisymbrium orientale* [L.] Scop.), wild radish (*Raphanus raphanistrum* L.), deadnettle (*Lamium amplexicaule* L.), and wireweed (*Polygonum aviculare* L.) were also present at varying densities.

Climate

Climatic data for the year 1996 show that the site experienced above-average rainfall. The bulk of this rain fell in the summer months of January and December. However, above-average rain fell in all but two of the chickpea-growing months from May to December (Fig. 3.2).

Temperatures during 1996 were generally average. The warm temperatures and high moisture levels during the chickpea-growing season enabled both chickpeas and weeds to grow without experiencing water stress.

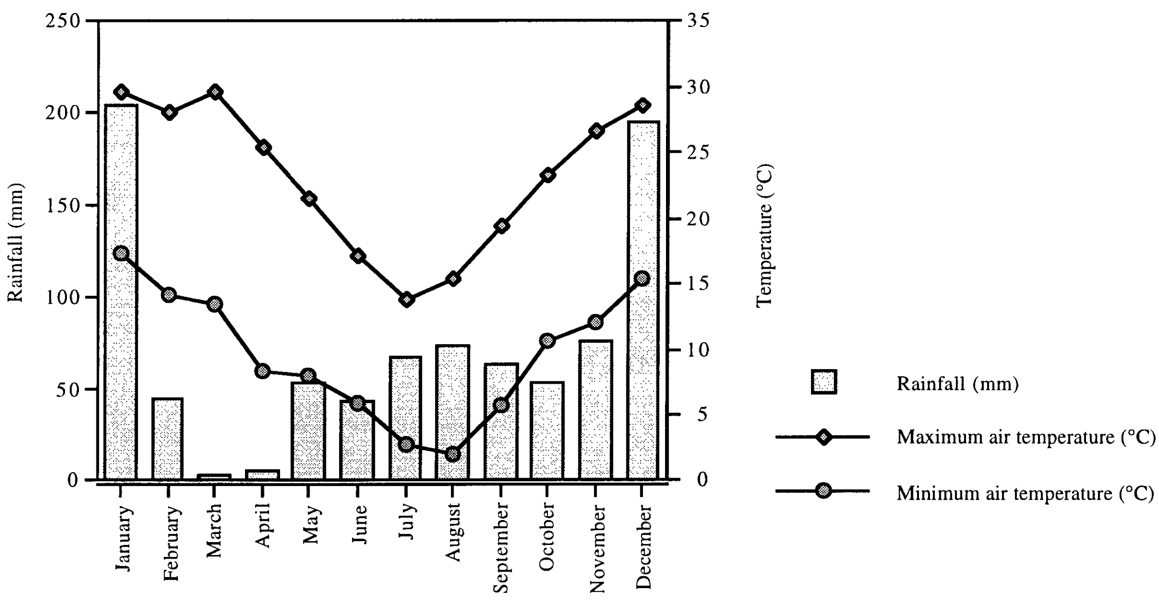

Fig. 3.2 Monthly rainfall and mean monthly temperatures at the Tamworth Centre for Crop Improvement, 1996

Rainfall during 1997 was close to average, with 674.1 mm (the 107-year average was 671 mm). Unlike 1996, the rainfall in 1997 was fragmented with a few very wet months interspersed with dry months (Fig. 3.3). The chickpea growing season of late May to December experienced good sowing rains in early June; however, the initial growing months of July and August were dry. The dry period between June and September reduced the above-ground population of weeds, and contained their emergence to a single cohort synchronous with the crop, not the usual succession of flushes throughout the season. Despite this dry period chickpea and emerged weed growth was not inhibited due to the adequate moisture store within the soil. Temperatures during 1997, were generally average. The climatic data described for each site was logged using electronic weather stations situated within 500m of the experimental sites.

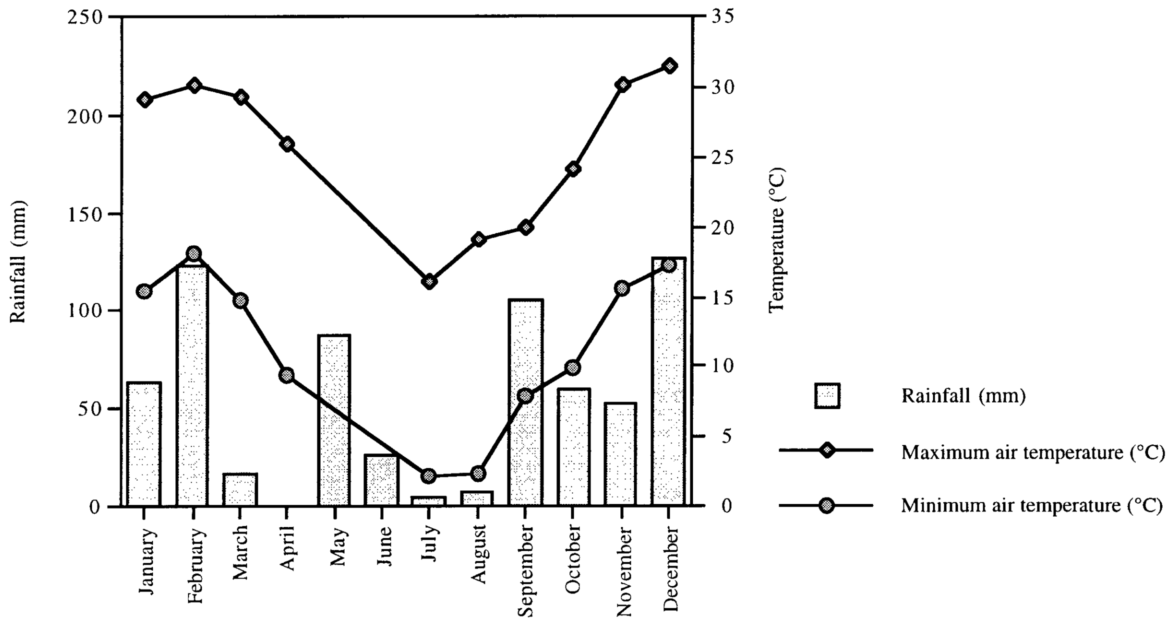

Fig. 3.3 Monthly rainfall and mean monthly temperatures at the Tamworth Centre for Crop Improvement, 1997.

3.3 Warialda

Douglas McMaster Research Farm is located on the North West Slopes and Plains region of northern New South Wales. The research farm is located about 36 km northwest of Warialda, at latitude 29° 18' 19.4" South and longitude 150° 36' 01.5" East. The general terrain is undulating with large flat alluvial floodplains.

Rainfall records for the research farm are limited, but a 15-year recording period from 1980 to 1997 (1994 and 1995 were unavailable) shows an average annual rainfall of 738 mm. No temperature data exist for this period; however, temperatures recorded during this project show little difference between the two years of experimentation, 1996 and 1997.

The Douglas McMaster Research Farm has a large uniform area of alluvial soil available for research. This area is divided into several paddocks that are used for both research and commercial farming.

3.3.1 Warialda research areas 1996/97

Soil

The soil of this area was uniform and could be classified under the Australian soil classification system as a self-mulching black Vertosol (Isbell 1996). The parent material was a colluvium sandstone/lithic, fine basic. There was no evidence of salting and the erodibility of the topsoil was moderate. The high fertility and favourable physical attributes of this soil make it most suitable for the production of winter cereals or summer crops. It is suited to summer fallowing to conserve moisture although soil profiles that are fully charged may pose an erosion hazard. A full description of the soil profile is presented in Table 3.3. There was no difference between the soil used in 1996 and 1997.

Table 3.3 Soil description for Douglas McMaster Research Farm, Warialda (Harte 1990)

Horizon	Depth	Description
A	10 cm	Black medium clay, blocky peds, earthy fabric, pH 8.5
B	40 cm	Black heavy clay, strong blocky peds, to massive, cracks 5-10 mm, pH 8.5
C	100cm	Black heavy clay, strong blocky peds with lenticular patterns, cracks 5-10 mm, pH 8.5
D	250 cm	Dark brown heavy clay, very strong blocky peds, cracks 5-10 mm, pH 9.0

History

During 1994 and 1995, the 1996 experimental area had been sown to wheat. Over the following summer fallow, weeds were controlled with glyphosate at 675 g a.i. ha^{-1} (as Roundup CT). Seed was drilled directly through the wheat stubble, and a band of fertiliser placed below the seed in the row spacing experiment (Chapter 5) as triple superphosphate at 120 kg ha^{-1}.

The 1997 experimental area had been cropped with sorghum during the 1995/96 summer and then fallowed until 1997. During the long fallow, the sorghum stubble was grazed by cattle until December 1996. The remaining stubble was then incorporated and weeds controlled by cultivation. Prior to sowing, the area was sprayed with glyphosate at 675 g a.i. ha^{-1} (as Roundup CT). Fertiliser was banded with the seed at the time of sowing at a rate of 60 kg ha^{-1} of triple superphosphate. Following sowing, weeds were controlled as determined by the experimental aims.

Weeds

During the experiments at Warialda, weeds were generally controlled by hand chipping; however, in 1997 the grass weeds were removed with fluazifop-p at 106 g a.i. ha^{-1} (as Fusilade).

The dominant grass weed during 1996/97 was wild oats, and the dominant broad-leaved weeds were deadnettle and sowthistle. Other weeds that occurred at various levels during this period were: variegated thistle; Mexican poppy; spear thistle; turnip weed; Indian hedge mustard; wild radish; black bindweed; European bindweed (*Convolulus arvensis* L.); and wireweed. Despite wild oats being the dominant grass weed in both years, there were less background wild oat plants in 1997.

Climate

During 1996, Warialda experienced above average rainfall, with a yearly total of 1174.5 mm. A summer dominance can be seen in the 1996 rainfall pattern (Fig. 3.4); however, each month experienced good falls of rain. The high and even distribution of rainfall during 1996 would have reduced competition for moisture.

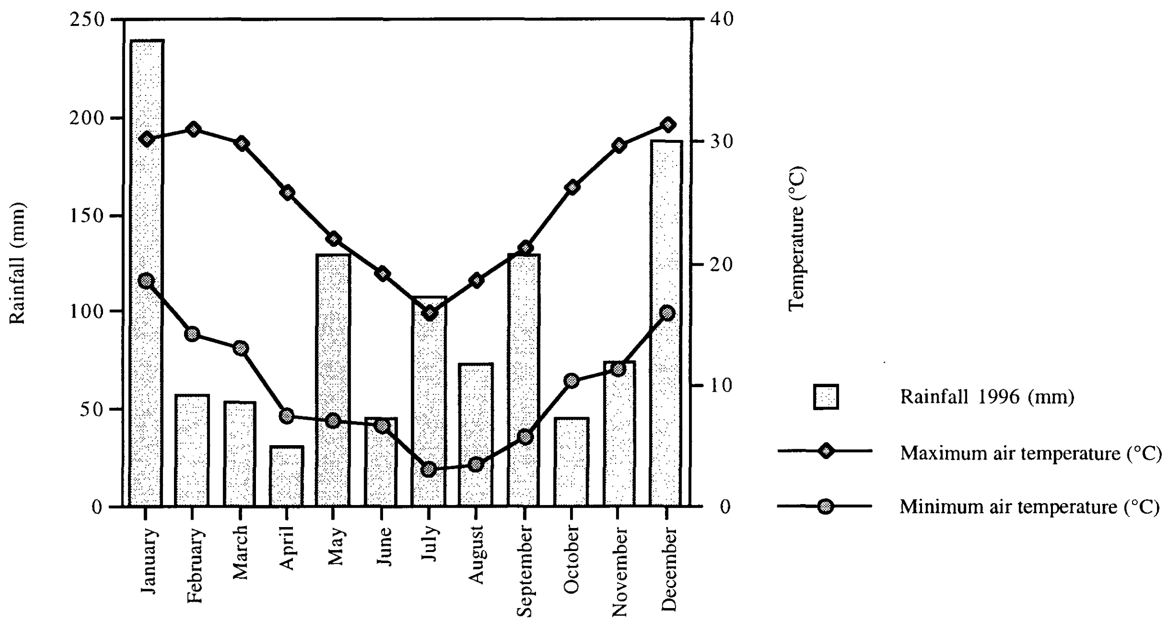

Fig. 3.4 Monthly rainfall and mean monthly temperature for Douglas McMaster Research Farm, Warialda, 1996.

Warialda's 1997 rainfall (see Fig. 3.5) was also above the 15-year average with 928.5 mm being recorded. Comparing this year with 1996 (Fig. 3.4) shows some differences in the distribution of rainfall. Prior to the 1997 sowing month of May, very little rain fell. After sowing, the first three months were relatively dry. This dry period may have influenced the weed population, limiting it to a single emergence time, similar to the crop.

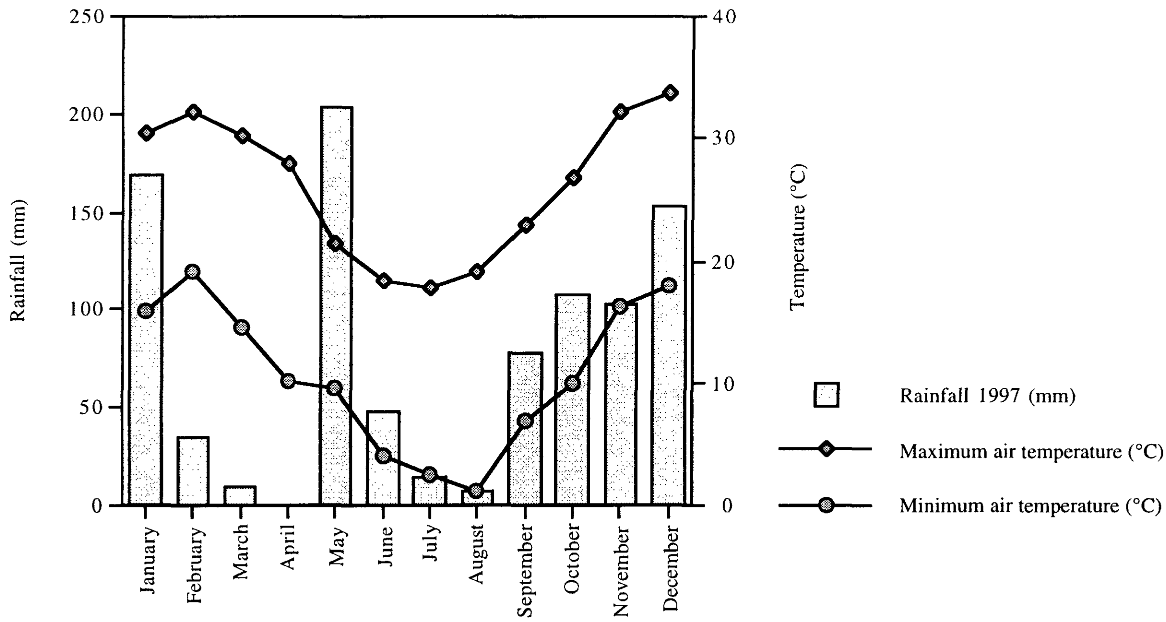

Fig. 3.5 Monthly rainfall and mean monthly temperatures for Douglas McMaster Research Farm, Warialda, 1997.

3.4 Conclusion

Warialda and Tamworth were selected as sites for this research because they represent two different areas in the northern grains region of eastern Australia, and because they have the conditions to ensure successful field experiments. Tamworth has the possibility of irrigation should excessively dry conditions have occurred. Warialda does not have irrigation, but for the last 20 years, 9 out of 10 crops sown have successfully reached maturity. The weather conditions experienced during 1996 and 1997 did not require irrigation. However, experiencing one wet season and one season that was dry for the vegetative stage of the crop has helped determine the influence of weather on the competitive ability of chickpea.

Chapter 4

Determining the competitive ability of desi chickpea varieties

4.1 Introduction

Plants have to compete with other plants for resources; the intrinsic mechanisms developed to maximise this competition enables plants to occupy a particular niche in an ecological system. In crop species, these mechanisms can be used to help compete against weeds, while minimising yield loss.

Crop species have been selected and bred over the centuries to have characteristics that make them desirable to human-kind. Initially, these traits may have been as rudimentary as reliable germination, good plant growth, little seed shattering, and palatability. In modern agriculture, specific areas are targeted with plants being bred to resist disease, maximise harvest index, resist insect attack, and make harvesting easier and more reliable. Throughout this domestication process, weeds continue to compete with crops and reduce yield. Over time, the plants that have been selected are those that gave the best yields, and in the past this has simultaneously been those plants with the greatest competitive ability. However, over the last two decades plant breeding has progressed under weed free situations, thus reducing the inadvertent selection for more competitive plants.

The use of herbicides in crops has greatly improved agricultural production. However, economics (Wicks *et al.* 1986), environmental concerns (Christensen 1995, Cosser *et al.* 1997) and herbicide resistance (Lemerle *et al.* 1995) have led to re-examination of the widespread use of herbicides. The selection and re-introduction of competitive crop varieties is one mechanism that will aid weed control in agricultural systems (Ramsel & Wicks 1988, Cosser *et al.* 1997). To select competitive plants, the varietal traits that confer competitiveness must be identified (Christensen 1994). These traits vary between plant species, but can be described as the morphological and physiological characters contributing to competitiveness. They include: the relative rate of emergence (Wicks *et al.* 1986); growth (Wortmann 1993, Blackshaw 1994, Lemerle, Verbeek &

Coombes 1996, Lemerle *et al.* 1996); ground cover (Richards 1992); phenological development (Cousens *et al.* 1991); size and shape of the leaves (Richards 1992, Wortmann 1993, Blackshaw 1994, Lemerle, Verbeek & Coombes 1996, Lemerle *et al.* 1996); degree of light interception (Cudney *et al.* 1991, Heath *et al.* 1992, Wortmann 1993, Christensen 1995); and degree of nutrient uptake (Konesky *et al.* 1989).

Competitiveness will develop independently so that morphological and physiological characters differ between plant species. Pavlychenko and Harrington (1934) ranked relative crop competitiveness against wild oats (*Avena fatua* L.) as barley > rye > wheat > flax. Lemerle *et al.* (1995) ranked crop competitiveness against annual ryegrass (*Lolium rigidum* Gaud.) as oats (*Avena sativa* L.), cereal rye (*Secale cereale* L.), and triticale (X *Triticosecale*) > oilseed rape, (*Brassica napus* L.) > spring wheat (*Triticum aestivum* L.) > spring barley (*Hordeum vulgare* L.) > field pea (*Pisum sativum* L.) and lupin (*Lupinus angustifolius* L.). In assessing crops in this manner, two things became apparent: (1) wheat and barely showed great variation within the species; and (2) some within-species variation can be explained by environmental influences (genotype by environment interactions, Lutman *et al.* 1994, Lemerle *et al.* 1995, Van Acker *et al.* 1995, Lemerle *et al.* 1996). Considerable debate occurs over the identification of crop features that provide superior competitive ability. Height in wheat cultivars is considered a more competitive adaptation than tillering and dry matter production (Balyan *et al.* 1991, Lemerle *et al.* 1995, Cosser *et al.* 1997), yet in other situations and for other crops, height is considered unimportant (Wicks *et al.* 1986). This difference demonstrates the importance of understanding how specific environments influence the expression of a plant's competitive traits.

Pulse crops generally rank poorly when compared with cereals and oilseed crops for competitive ability (Pavlychenko & Harrington 1934, Lutman *et al.* 1994, Lemerle *et al.* 1995). Little is known about how pulses specifically compete with weeds. Heath *et al.* (1992) reviewed the literature of pulses with respect to their plant architecture, competitive ability, and productivity. This review highlights the difference in growth, form, and structure of pulse crops, and outlines the importance of canopy structure and radiation interception.

Chickpea ranks as one of the least competitive of the major pulse crops. Its low height and open canopy architecture are two factors that contribute to its poor ability to compete with weeds. In the northern grain area of eastern Australia, the slow growth of chickpea during its vegetative phase is recognised as the dominant non-competitive trait (Knights 1991). In this region, the chickpea variety, Amethyst, is recommended at sites which have a low risk of virus (Knights 1998). Amethyst was the first chickpea variety to be derived from an Australian hybridisation program, and exhibits a tall lodging-resistant gene which is a major objective of this breeding program (Knights 1991). Unlike modern wheat breeders who select dwarf material (Richards 1992), Australian chickpea breeders are trying to increase crop height, which will promote better air movement, thus reducing the risk of disease (Knights 1991).

Competition studies in the literature predominantly refer to competition between cereal crops and grass weeds. A few studies include pulse or broad-leaved crops, but very few examined broad-leaved crops competing with broad-leaved weeds. Within chickpea crops in northern NSW, broad-leaved weeds and specifically turnip weed (*Rapistrum rugosum*) are the main weed problems (Storrie pers. comm.). Chemical control of grass weeds is currently well catered for with both pre-emergence herbicides i.e. trifluralin, tri-allate, and pendimethalin; and post-emergence herbicides i.e. fluazifop-P, haloxyfop, sethoxydim, quizalofop-p-ethyl, and clethodim being available. To date there is only one post-emergent herbicide registered for broad-leaved weed control in chickpea, i.e. pyridate, and this chemical controls only a narrow weed spectrum (capeweed [QLD]; Fumitory [NSW, VIC]; mouse-eared chickweed; sheepweed; toadrush [SA,WA only]; amsinckia [QLD]; deadnettle NSW,VIC]; common sowthistle and prickly lettuce [WA only] (Whish *et al.* 1996).

This chapter describes an experiment designed to investigate the relative competitive abilities of six chickpea lines grown in the presence of a selected Indian mustard (*Brassica juncea* cv. JE13*2) pseudo weed species. To relate this work to existing competition experiments, cultivars of wheat and canola were also included. The wheat and canola were sown at the same density and row spacing as the chickpea to remove external variation related to sowing pattern. The results of this experiment will give some insight into the competitive ability of chickpea, and help determine if the current chickpea breeding objectives are altering crop competitiveness.

4.2 Methods

Two sites within the northern grains region of eastern Australia were selected as trial sites for this experiment. They were the University of New England's Douglas McMaster Research Farm at Warialda (referred to as Warialda) and the NSW Department of Agriculture's Tamworth Centre for Crop Improvement (referred to as Tamworth) (see Chapter 3, sections 3.2 and 3.3 for detailed descriptions).

4.2.1 Plant material

Six chickpea lines plus wheat and canola were sown in this experiment, the selection of cultivars being done in consultation with Ted Knights (Senior chickpea breeder, Tamworth Centre for Crop Improvement). Lines were selected for a range of vigour (low, medium or high) and growth habits (semi-erect or erect, see Table 4.1). Ted Knights made the assessments of vigour and habit by observation and in comparison to a standard line. All three crops were sown in 50 cm rows at a rate which would give an establishment density of 40 plants m $^{-2}$ (Table 4.2).

Table 4.1 Characteristics of selected chickpea varieties taken from 1995 desi core trial results (Knights unpub.)

Crop line	Ranking Vigour	Vigour 1= poor 5=good	Habit Erectness	Virus 0=free 5=severe	* DTF days	Height cm	Lodging 1=erect 5=prostrate	♣100SW
† N° sites	6	6	6	6	1	6	7	6
Tyson	Low	2.0	semi	3.8	108	36	2.6	13.2
Amethyst	Low	2.3	erect	3.7	105	46	1.9	14.5
Barwon	Medium	2.8	semi	3.5	109	42	3.4	17.9
8818-26	Medium	2.8	erect	3.3	111	48	2.3	16.5
904-105	High	3.3	semi	3.3	103	40	4.1	25.5
8813-7	High	3.2	erect	3.3	113	52	2.0	16.5

† *Number of trial sites from which the results were averaged. All trial sites were in the grains region of eastern Australia.*

* *DTF = Days to 50% Flowering*

♣ *100SW = 100 seed weight*

Rankings of vigour were as determined by Ted Knights chickpea breeder Tamworth centre for crop improvement.

Table 4.2 Sowing densities of experimental crops

Crop line	*100SW g	N° seeds required per plot	% Germination	Weight of seed sown /plot g
Tyson	15.5	480	80	75
Amethyst	20	480	80	95
Barwon	24	480	80	115
8818-26	17.5	480	80	84
904-105	30	480	80	144
8813-7	19	480	80	91
Wheat var. Hartog	3.92	480	80	19
Canola var. Hyola 44	0.52	550	60	2.9
Mustard JE13*2	0.25	75	30	0.6

* *100SW = 100 seed weight*

An Indian mustard research line was used as a pseudo weed to compete against the crop species. Indian mustard was selected because of its perceived similarity to turnip weed (following consultation with Mustard breeder). A cultivated crop variety was used as the weed to reduce the natural variation found in a non-selected weed population and to obtain a more uniform germination.

4.2.2 Experimental design

A split-plot experimental design was used with five replicates. The main plots were 8 m x 2 m and contained 4 crop rows; each main plot corresponded to one of the eight crop varieties, while the sub-plots (4 m x 2 m) were designated weed or weed-free. The same cone seeder fitted with narrow-pointed tines and coulters was used to sow both sites, which had been sown to wheat in the previous season. The Warialda experiment was direct-drilled into a no-till seedbed on 27/5/96.

The Tamworth experiment was direct-drilled into a cultivated seedbed 13/6/96. At both sites on their respective sowing dates, pseudo weeds were mixed with sand and broadcast over each sub-plot at a rate which would give an emergence of 15 plants m^{-2}. At Tamworth the plots were given a light raking to help incorporate the weed seeds, while at Warialda an afternoon storm helped to incorporate the seed. Crop establishment was recorded 8 weeks after sowing by counting plant numbers along two randomly selected 1m sections of row in each sub-plot.

4.2.3 Maintenance

During the season, volunteer broad-leaved weeds were removed by hand, and grass weeds were controlled with a single application of fenoxaprop-ethyl at 90 g a.i. ha^{-1} (as Puma) at Warialda on 15/8/96, and at Tamworth on 22/8/96.

4.2.4 Non-destructive measurements

During the growing season, non-destructive measurements of the plant canopy were made using surface photographs taken at a set distance above the crop. The method used was a combination of the methods described by Siddique *et al.* (1989) and Lutman (1992). Canopy cover was measured by taking one photograph per sub-plot. The photographs were taken from a custom-made tripod (David Creed, Rural Science Workshop, UNE) that held the camera parallel to the ground at a height of 1.5 m. A 50 mm Olympus® lens was used with Kodak 35 mm print film, ISO 100. The field of vision covered a ground area of 84 by 58 cm. Photographs were taken at Tamworth on 12/8/96 and Warialda on 15/8/96. Only a single set of images was taken during this trial, because the height of the pseudo weed (mustard) prevented focusing from the selected 1.5 m in the second half of the growing season. The photographs were interpreted by placing a sheet of glass, etched with a 6 mm square grid (425 grid points per 15 by 10 cm print), over the photograph and counting the number of intersection points covering crop or weed. The photographic ground cover measurements recorded during this trial were used solely to estimate relative cover, and not to estimate the relative damage coefficient of Kropff and Spitters (1991).

4.2.5 Harvest

At maturity (December 1996), grain yield was measured by cutting a 1 m section of crop row from each of the centre two rows at ground level. Plant material was 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 of bulk material, samples were passed through a stationary thrasher to obtain grain yields. One hundred seeds were randomly selected from each plot and weighed to give a 100 seed weight. Mustard plants growing in and between the two centre crop rows were counted and harvested; these were also dried, weighed and thrashed. Seed yields from the mustard plants showed a degree of variation due to the difference in time of maturity between mustard and chickpea. The mustard plants ripened 2 weeks before the chickpeas and some seed was lost waiting for a single harvest time.

A univariate analysis utilising the statistical procedure ASREML which estimates variance components under a general mixed model by restricted maximum likelihood [REML] (Gilmour *et al.* 1998), was used to examine the effect of the pseudo weed and determine the competitive ability of the crops. Linear regression was used to relate grain yield and the other crop parameters to weed growth, using the statistical software package S-Plus 4 (Mathsoft 1997).

4.3 Results

4.3.1 Crop and weed establishment

The three winter crops and the mustard pseudo weed emerged within 3 weeks of sowing. The crop density for both experimental sites was approximately 40 plants m^{-2}, and the mustard density was between 10 and 14 plants m^{-2}.

4.3.2 Crop grain yields

Crop grain yields from the weed-free plots were similar for both sites, wheat being the only exception with a higher yield at Tamworth. The yields in the presence of weeds were more variable and displayed a greater reduction at Tamworth. At both sites, canola had the smallest yield loss, suggesting that it was the most competitive of the three crops (Table 4.3).

The wheat yields were not consistent between the two sites. Wheat at Warialda was clearly the second most competitive plant type; however, the competitive ability of wheat was similar to the better chickpea lines (Table 4.3).

Chickpea yields were 2.5 and 3 t ha^{-1} at Tamworth and Warialda respectively and there was little difference between the competitive abilities of the six chickpea lines. The most competitive line at Warialda was 8813-7 and at Tamworth was 904-105 (Table 4.3).

Table 4.3 Grain yields of winter crops grown with and without a pseudo weed (Mustard cv. JE13*2)

	Warialda			Tamworth		
Crop lines	Grain yield Weed-free (kg ha^{-1})	Yield loss (%)	Std Error †	Grain yield Weed-free (kg ha^{-1})	Yield loss (%)	Std Error †
Tyson	2,677	49.2	±5.0	2,046	86.0	±5.5
Amethyst	2,944	53.8	±4.8	2,271	80.6	±5.1
Barwon	2,876	60.0	±4.8	2,852	77.2	±4.6
8818-26	2,501	54.1	±5.2	2,488	71.3	±4.8
904-105	2,148	48.6	±5.5	2,773	65.3	±4.5
8813-7	3,413	46.7	±4.4	2,590	73.8	±4.8
Wheat var. Hartog	2,176	26.3	±5.4	4,190	80.6	±3.8
Canola var. Hyola 44	1,362	9.4	±6.8	1,690	54.2	±5.8

† *Standard Error of % yield loss*

4.3.3 Dry matter production

Dry matter production showed a high correlation with grain yield (Fig. 4.1). Signs of this close correlation can also be seen in Table 4.4 where the loss of dry matter as a result of weeds is similar to the grain yield loss (Table 4.3). Examination of the results from both sites in Table 4.4 show that the most competitive chickpea lines for dry matter production were the research lines 8818-26, 904-105 and 8813-7.

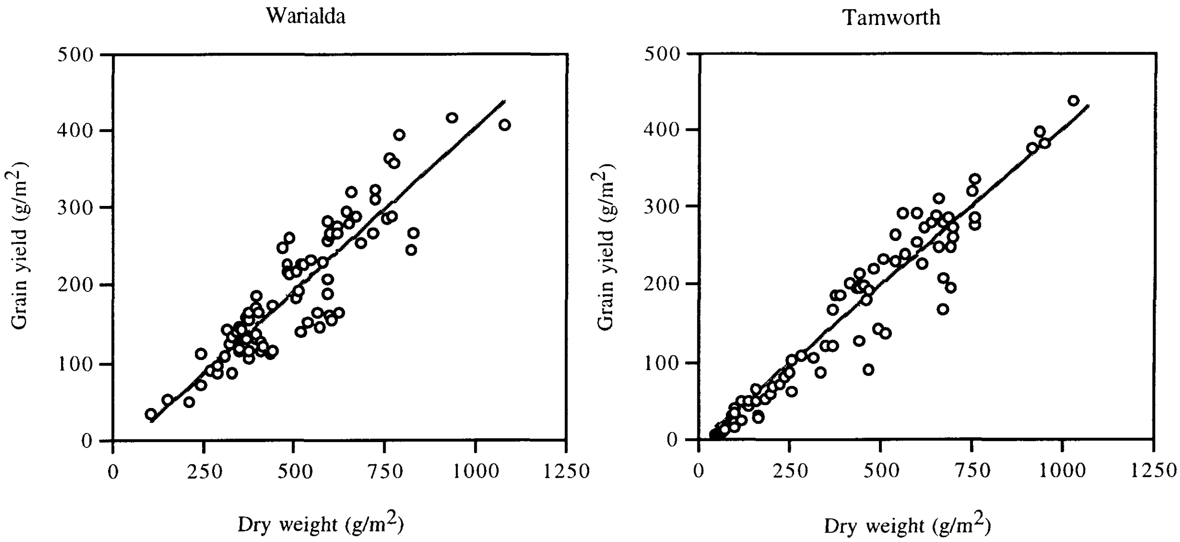

Fig. 4.1. Correlation between total crop dry weight at maturity and grain yield for Warialda and Tamworth. The regression equations were Warialda: y=0.4234x-18.86; R^2=0.80 and Tamworth: y=0.407x –3.98; R^2=0.84.

Table 4.4 Above-ground dry matter weights at harvest of winter crops grown with and without a pseudo weed (Mustard research line JE13*2)

Crop lines	Warialda			Tamworth		
	Dry matter weed-free (kg ha^{-1})	Dry matter with weeds (% dry matter loss)	Std Error †	Dry matter weed-free (kg ha^{-1})	Dry matter with weeds (% dry matter loss)	Std Error †
Tyson	5,672	43.2	±5.6	4,262	74.6	±4.7
Amethyst	6,327	47.9	±5.3	4,932	72.8	±5.3
Barwon	6,857	52.1	±5.2	6,997	73.6	±4.5
8818-26	6,387	44.9	±5.3	6,210	61.2	±4.7
904-105	6,485	49.4	±5.3	6,798	61.0	±4.5
8813-7	7,782	34.4	±4.8	5,834	69.3	±4.9
Wheat var. Hartog	5,032	25.0	±5.9	9,765	75.1	±3.8
Canola var. Hyola 44	5,141	7.7	±5.8	6,068	45.4	±4.7

† *Standard Error of % yield loss*

4.3.4 Canopy development and relative cover

The measurements of relative cover were different between the two sites. At Warialda the crop lines were more advanced than at Tamworth, with larger canopies and a more uniform response to competition with weeds (Table 4.5). The relative area covered by the crop canopy at Tamworth showed no significant difference between the plant lines growing under weed-free conditions. However, significant variation existed between the varieties when cover loss ([relative canopy cover weed-free] – [relative canopy cover with weeds] / [relative canopy cover weed-free]) was examined. The Warialda site shows significant variation between the plant lines in the weed-free and the with-weed situations. Warialda also shows a consistency across measurements in that canola and the experimental line 8813-7 have the least relative cover loss (Table 4.5), dry matter loss (Table 4.4), and yield loss (Table 4.3).

Table 4.5 Relative canopy loss of winter crops grown with a pseudo weed (Mustard cv. JE13*2)

	WARIALDA			TAMWORTH		
Crop lines	Relative cover weed-free * Counts	Relative cover with weeds (% cover loss)	Std Error †	Relative cover weed-free * Counts	Relative cover with weeds (% cover loss)	Std Error †
Tyson	151	24.0	5.6	55	45.1	5.9
Amethyst	213	31.6	4.8	59	22.9	5.7
Barwon	241	47.0	4.5	50	14.7	6.1
8818-26	234	34.1	4.5	41	-12.9	6.7
904-105	210	30.5	4.8	59	25.8	5.6
8813-7	167	15.1	5.3	46	13.4	6.5
Wheat var. Hartog	174	30.1	5.2	44	-10.2	6.5
Canola var. Hyola 44	319	-0.5	3.8	66	6.2	5.3

† *Standard Error of % cover loss*

* *Counts = the number of grid points covered by the crop, 100% cover = 425 counts (see section 5.2.4)*

Negative values occur when relative cover in the weed sub-plots is larger than the weed-free sub-plots.

4.3.5 Indian mustard dry-weight and seed production

The dry weights of the pseudo weed mustard ranged from 100 to 1500 g m^{-2} at Tamworth and 100 to 1200 g m^{-2} at Warialda. No linear relationship existed between the weed dry matter and crop yield loss for either site (Fig. 4.2). Examination of the yield loss by dry matter regression (Fig. 4.3) at Warialda shows three separate groups of points. These groups correspond to the yield losses of the different plant types. These were canola with the lowest yield loss followed by wheat and finally the larger group of chickpea lines. These plots also show the uniformity of the weed dry matter, with an average of 400 g m^{-2}. Although canola was able to yield well in the presence of weeds, the canola plants had very little effect on the dry matter (Fig. 4.2) and seed yield (Fig. 4.3) of the mustard.

Seed yield of the mustard plants showed little variation despite having different crop lines growing in competition with it (Fig. 4.3). The size of mustard plants varied (Fig. 4.2); however, this range was not repeated in the seed yields. There was no correlation between the seed yields of the mustard and the yield losses of the crops (Fig. 4.3).

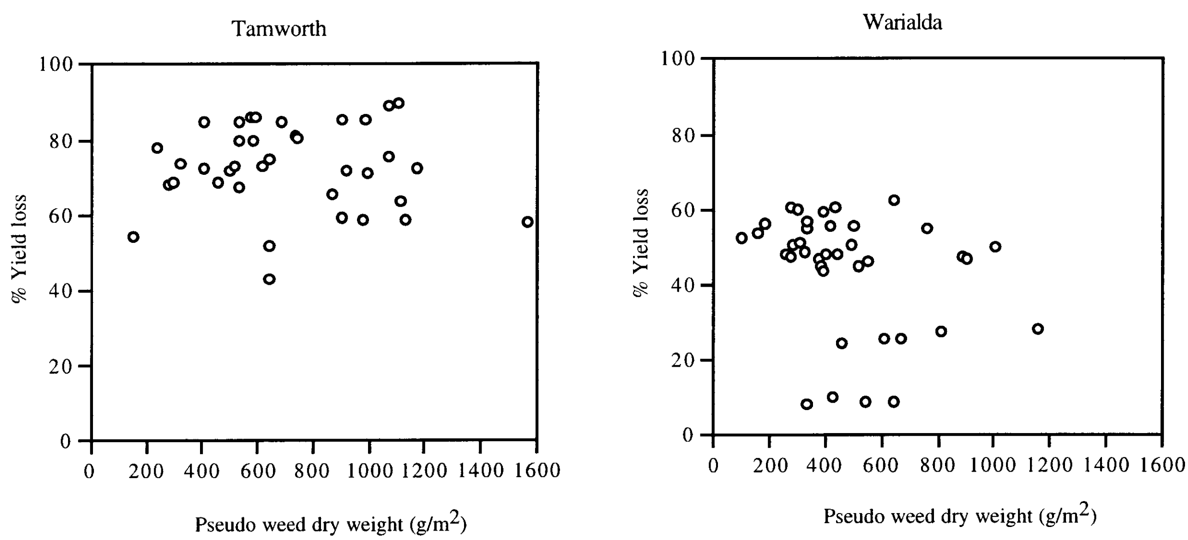

Fig. 4.2. Correlation between crop grain yield loss and the pseudo weed (Indian mustard) dry weight at the time of harvest; values are given for all crops, breeding lines, and replicates.

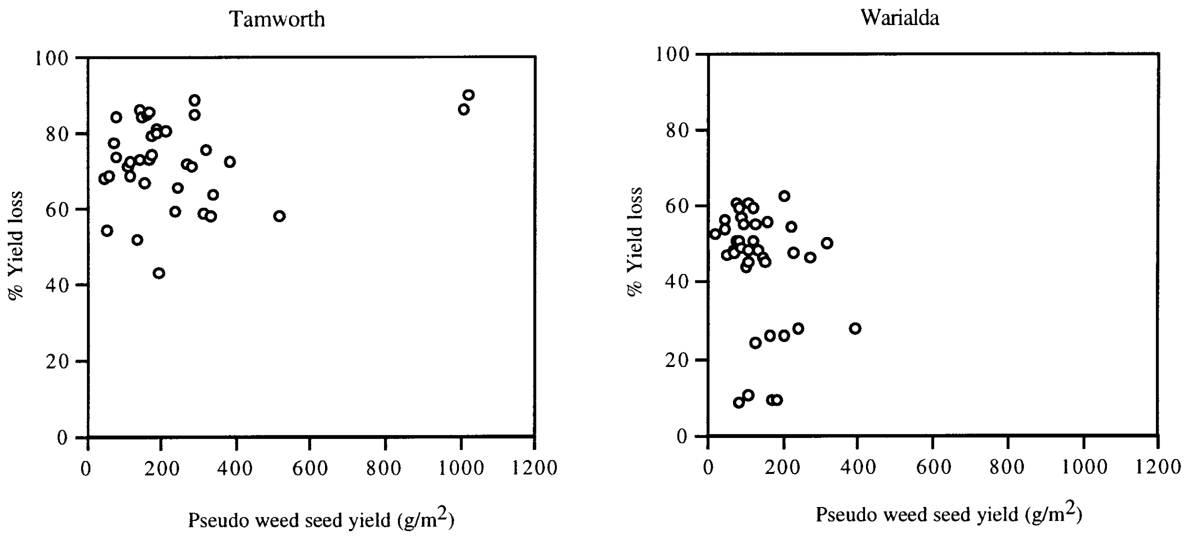

Fig. 4.3. Correlation between crop grain yield loss and the pseudo weed (Indian mustard) seed yield at the time of harvest; values are given for all crops, breeding lines, and replicates.

4.4 Discussion

This study identified differences in the competitive ability of three Australian winter crops when in competition with a uniform stand of Indian Mustard at 10-14 plants m^{-2}. The main difference between this experiment and those reported in the literature is that in the present experiment all crops were sown at a chickpea density and row spacing (40 plants m^{-2} and 50 cm between row centres), thus removing the effect of crop density and spatial pattern on competitive ability. The order of competitive ability was canola > wheat > chickpea. This series is very similar to that found in southern Australia by Lemerle *et al.* (1995) who identified the competitive abilities of winter crops with *Lolium rigidum*, and determined the order to be cereal rye = triticale > canola > spring wheat = spring barley > field pea = lupin. The differences between these two experiments were not only the weed types applying competition, but the focus of the experiments. Lemerle *et al.* (1995) compared competitive abilities when grown as commercial crops. This experiment examined the competitive abilities of the individual plants because the influence of seeding rate and row spacing was removed.

Another difference between the present experiment and that of Lemerle *et al.* (1995) was the use of a broad-leaved weed. The majority of reported weed competition experiments utilise grass-weeds. This raises the question as to whether a crop's competitive abilities against grass-weeds are the same as those against broad-leaved weeds. This experiment did not set out to answer this question, but it is interesting to note that the sequence of competitive abilities recorded by Lemerle *et al.* (1995) is the same as in this experiment. It is also interesting to see that the levels of yield loss that they found over two years are similar to those recorded in this experiment.

The experimental results show a distinct difference in yield loss between Tamworth and Warialda. The higher level of loss at Tamworth may be the result of, or combination of, three factors. Firstly, the above average rainfall recorded during the growing season (Chapter 3) may have prevented adequate hand weeding. The major weed was black bindweed, which appeared late in the season. Some bindweed did occur at Warialda, but the problem was far less than at Tamworth. Secondly, the warmer winter conditions at Warialda (Chapter 3) may have caused the pseudo weed mustard to ripen earlier than the other crops, thus reducing the level of competition late in the season. A reduction of late season competition may not have been of benefit to canola and wheat, but the indeterminate nature of chickpeas (Heath *et al.* 1992) may have benefited (the crop) in this situation. Thirdly, Tamworth is in the middle of a large lucerne growing area and many of the chickpeas showed symptoms of aphid transmitted luteoviruses. There were no signs of virus infection at Warialda.

4.4.1 Competitive ability of chickpea lines

The chickpea lines used in this experiment were selected to span the range of vigour and growth habit. The results in Fig. 4.3 appear to support these being important traits for weed competitive ability. The Tamworth results show a steady reduction in yield loss with increasing vigour. The only significant difference between the chickpea lines was when the most competitive and the least competitive were compared. This occurred for both Warialda and Tamworth where the most competitive chickpea varieties were those selected for having high vigour and an erect habit.

The dry matter production of the chickpea lines was closely correlated with the seed yield (Fig. 4.1), and as a result the research lines selected for vigour and erect habit were again the most competitive. The estimate of canopy loss using photographs taken after 2 months growth is a good measure of a plant's early vigour. Unfortunately, no other times were included due to weather conditions and the rapid growth of the mustard plants. The latter problem could have been overcome by increasing the height of the tripod.

The cover loss measurements show consistent differences in the more advanced Warialda data, but the degree of variation in the Tamworth data made it less consistent. Despite these limitations, it can be seen that those plants showing the lowest cover loss, (i.e. good early vigour) also had the lowest percentage yield loss and dry matter loss.

4.4.2 Competitive ability of Indian mustard

The Indian mustard research line, JE13*2, was selected as a pseudo weed because of its vigorous growth and similarity to the dominant northern weed, *Rapistrum rugosum* as determined by the mustard breeder. Figures 4.2 and 4.3 show the lack of any relationship between features of the weed and crop yield loss. This result is considered unusual; it may be that the wrong level of weed infestation was selected. Cousens (1985a, b) showed that weed density and crop yield loss could be represented by a rectangular hyperbolic curve. Lutman *et al.* (1996) showed this same curve could be used to describe weed dry matter and yield loss. In the relationship between *Lolium rigidum* and crop yield loss, the curve is linear (Lemerle *et al.* 1995) suggesting that the weed density was insufficient to place it in the non-linear second half of the rectangular hyperbolic equation. The weed density selection in the *L. rigidum* experiment (Lemerle *et al.* 1995) is ideal, because the weed numbers are insufficient to compete significantly against themselves, thus applying an even pressure on the crop without "swamping it". The results in the present experiment showed very little difference in crop yield loss between the lowest dry matter level and the highest. This suggests that a lower density of mustard would have been more appropriate, and may have improved the separation of the chickpea lines with respect to their competitive ability.

4.5 Conclusion

The results from this experiment, although influenced by the selected weed density, show that the more recently selected research lines have an improved competitive ability. The data support the chickpea breeding objectives of height and resistance to lodging, which inadvertently improves competitive ability of the crop against weeds.

The use of competitive varieties has been proposed as one method of reducing the level of reliance on herbicides in an integrated weed management system (Ramsel & Wicks 1988, Cosser *et al.* 1997). Despite some chickpeas being more competitive than others, as a whole the competitive ability of chickpea is well below that of other winter crops. An integrated weed management approach to weeds involves the combination of several weed management options. A successful approach will involve examining these options and ranking them to determine the most suitable for a particular crop in a particular area and at the particular stage of the crop's commercial development. The procedure for the selection of competitive chickpea varieties, could be assigned a low priority, because current breeding objectives are slowly creating more competitive varieties, and the chance of significantly improving the competitive ability of chickpeas, compared with other crops, is unlikely in the short term. At this stage of development in the chickpea industry in Australia one would have to conclude that manipulation of the agronomic environment, combined with strategic applications of herbicide offers the greatest potential in reducing the competitive ability of weeds in chickpea crops.