BROAD-LEAVED WEED COMPETITION WITH SAUDI WHEAT *Triticum aestivum* cv. Yecora Rojo AND BARLEY *Hordeum vulgare* cv. Jasto.

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In the Name of Allah,

the Beneficent, the Merciful

(It is He Who sends down water (rain) from the sky, and with it We bring forth vegetation of all kinds, and out of it We bring forth green stalks, from which We bring forth thick clustered grain, and out of the date-palm and its spathe come forth clusters of dates hanging low and near, and gardens of grapes, olives and pomegranates, each similar (in kind) yet different (in variety and taste). Look at their fruits when they begin to bear, and the ripeness thereof. Verily! In these things there are signs for people who believe).

Qu'ran, Chapter 6 (Al-Anam) : verse 99.

DEDCATION

To my sweet heart Razan
To you my delicate butterfly
To you my blooming flower
I dedicate this work

I thought many times what if you lived to share this moment of triumph with me

......the moment of harvesting long years of effort and misfortunes

It would've given me lots of joy just to see the expressions of joy and happiness on your face after making this achievement eventually

Yet I say to my self there is a good chance that you might experience the same agony and grief with your own
.........And I don't wish that for you at all

Your biography is that lived by a tender blooming flower
,,,,,, that lived by a delicate astonishing butterfly.
Lived very short, yet their spirits and beauty will never be forgotten

Your memory will always live in my heart and sole,
And in the hearts and minds of all those who had the chance to know you well

And till we meet in a better place, in a better time
Good by my sweet heart

Author's Declaration

I declare that the work submitted in this thesis is the result of my own investigations, except for when the references are mentioned and assistance acknowledged. Therefore, no part of this thesis has been previously presented for any degree.

Ameera A. Aytah

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

SUMMARY

The present study investigated competitive interactions between two broadleaved weeds, *Chenopodium album* and *Amaranthus retroflexus*, and two Saudi Arabian cereal crops, wheat (*Triticum aestivum* cv. Yecora Rojo) and barley (*Hordeum vulgare* cv. Jasto), by looking at the effects on growth parameters such as plant height, whole-plant dry weight, shoot dry weight and root dry weight. The separation technique of roots and/or shoots was used allowing three types of interactions to be studied, root, shoot and root & shoot interactions, respectively occurring below-ground, above-ground, and at whole plant level.

The interference of weeds caused morphological changes in both crops, such as plant height, spike size, leaf chlorosis and root system. *Chenopodium* generally reduced all growth parameters of wheat under root interaction, and barley under all interactions, except for plant height. *Amaranthus* reduced dry matter accumulation in the shoots and roots of wheat plants under all three interactions. In the case of barley, *Amaranthus* reduced whole-plant dry weight under shoot interactions and root & shoot interaction.

The effects of wheat on *Chenopodium* plants were very limited and were only slightly significant when roots of both species interacted. Wheat also reduced all growth parameters of *Amaranthus* under root interaction, and plant height and whole-plant dry weight under shoot interaction. In contrast, barley was found to affect all growth parameters of *Amaranthus* regardless of the kind of interaction. In the case of *Chenopodium*, barley decreased all growth parameters related to dry matter accumulation.

Aggressivity indices were used to determine the competitive ability of each of the weeds and the crops. *Chenopodium* was aggressive towards wheat when only the roots of both species interacted and when both roots

and shoots interacted. In the case of barley, *Chenopodium* aggressivity was due to root interaction and both root & shoot interaction.

This suggests that *Chenopodium* aggressivity was mostly due to its roots' competitive ability. Under root interaction and based on all plant growth parameters, aggressivity was higher in *Amaranthus* towards wheat. Based on whole-plant or root dry weight, aggressively of *Amaranthus* against barley was null and barley was slightly more aggressive towards *Amaranthus*. This suggests dominance of barley over *Amaranthus*.

Allelopathy was also investigated by looking at the effects of different extract concentrations from the weed plant *Heliotropium europaeum* on the wheat and barley seed germination and root length. The extracts significantly reduced root growth and strongly inhibited the germination percentage of seeds in both crop plants. Allelopathy caused also some morphological changes in both crop seeds such as browning and deformation of roots and deformation of the plumule in the germinating seeds of wheat.

These results are discussed in the context of existing literature on the mechanisms of competition between crops and weeds.

CHAPTER 1

CHAPTER 1

INTRODUCTION & LITERATURE REVIEW

1-1 Preface

Crops and weeds are two major groups of plants of which some members are well known to everyone. Directly or indirectly, crops provide our food and many of the necessities of life. Weeds usually interfere with the growth of crops and are important because of the huge losses in yield, which they may cause to our crops if they are not controlled. For example; in the USA annual economic losses due to weeds stated by Aldrich (1984) exceed $8 billion, and there were losses in billions all over the world (Wayne & Stanley, 2002; Sinden *et al.,* 2004; Agricultural Information Services, 2005). However, weeds are also fascinating because of the many survival strategies they have adopted to adapt to their environment (Hill, 1977). Weed seeds are easily transported within and across international boundaries by natural factors such as wind, water and animals, and by human factors including transport within crop seed stocks, irrigation networks, and on farm machinery (Chaudhary & Akram, 1987).

To reduce dependence on herbicide use, and improve the efficiency of weed controls, there has long been an interest in developing the potential of allelopathic mechanisms which might allow crops to produce natural herbicides that can suppress their competitor weeds (Macias *et al.*, 2004; Lars, 2004).

1-2 The importance of cereals

Cereals can be defined as a grain or edible seed of the grass family, Gramineae (Bender & Bender, 1999). Some cereals have been staple foods both directly for human consumption and indirectly via livestock feed since the beginning of civilization (BNF, 1994). Cereals are the most important sources of food (FAO, 2002), and cereal-based foods are a major source of carbohydrates, proteins, vitamin B complex and minerals for the world population (McKevith, 2004). In terms of area sown and annual production, they occupy an important position in the world economy and trade as food, feed and industrial grain crops (Vasal, 2001).

The most important cereal crops are (in approximate order of popularity):

- **Wheat:** the basic food for more than one third of the world's population, and it is the primary cereal crop of temperate regions.
- **Rice:** the primary cereal of tropical regions.

- **Maize:** a staple food of people in Mexico, South America, and Africa. Also important worldwide for livestock.
- **Millet:** an important staple food in Asia and Africa.
- **Sorghum**: important staple food in Asia and Africa and it is a popular crop worldwide for livestock.
- **Rye:** important in cold climates.
- **Barley:** grown for malting and livestock on land, which is too poor for wheat.
- **Oats:** formerly the staple food of Scotland and popular worldwide for livestock.
- **Teff:** popular in Ethiopia but scarcely known elsewhere.
- **Wild rice:** unrelated to rice. It is the grain of a North American plant, *Zizania aquatica*, and, it is more expensive with higher protein content than rice (Bender & Bender, 1999).
- **Spelt:** closely related to common wheat, originating in the Middle East, and has been popular for decades in Eastern Europe. It is known to be higher in proteins than wheat (The Vegetarian Society, 2002).

1-3 Cereals in Saudi Arabia

The Kingdom of Saudi Arabia covers a large area of about 2, 000, 000 km^2, which is about 80 percent of the total area of the Arabian Peninsula. The country lies between 15.2° and 32.6° north and 34.1° and 55.5° east and the climate is generally mild in the winter and dry and hot in the summer. Rainfall occurs in the winter but never exceeds 100 mm per year in most regions except for the southwestern mountains of Asir, where it rains more often in the summer. Irrigation is mainly carried out from tube-wells, but in the Hofuf region water is derived from natural springs. The country is witnessing an unprecedented exploitation of its agricultural potential. As a result of government encouragement and financial aid, cultivated land has dramatically increased from about 435, 000 ha in 1980 to more than 1.8 million ha in 1992. Major crops include cereals (wheat, sorghum, barley and millet), vegetables (tomato, watermelon, eggplant, potato, cucumber and onions), and fruits (date-palm, citrus and grapes) and forage crops (alfalfa). Up to 60% of the cultivated lands are designated for cereal crop cultivation (FAO Country Report, 1996). The main cereal crops grown are wheat and barley. In 1992, the production of wheat and barley exceeded 4.07 Million tones and 406,000 tones respectively (FAO Country Report, 1996). However, as crop production increases, major agricultural problems are arising such as weeds, fungal diseases and nematode problems. The present work was carried out to gain knowledge of weed-crop competition and allopathic interactions for cereal cultivars grown in Saudi Arabia.

1-4 the importance of weeds

A weed may be defined as any plant out of place, growing where it is not wanted. By definition any plant can be a weed (Roberts, 1982). Weeds can reduce yields by competing with the crops for water, nutrients, space, and light (Roberts, 1982).

1-4-1 Weeds characteristics

Weed plants have many characteristics that make them competitive, adaptable and superior in terms of survival strategies compared to crop plants (Roberts, 1982). These characteristics are summarized by Hill (1977) as follows:

- High output of seeds in favourable conditions: Weeds produce at least some output of seeds even in very poor conditions.
- Seed production begins after only a short period of vegetative growth.
- Have ways to spread seeds over large distances.
- Variable seed dormancy and considerable longevity of seeds in soil.
- No special environmental requirements for germination.
- Rapid seedling growth and establishment.
- Wide tolerance of variations in physical environment.
- Adaptation for both long and short distance dispersal.
- Good powers of vegetative reproduction and ability to regenerate when divided into fragments.
- Self compatibility.
- High competitive ability.

The most important attributes of weeds are efficient reproduction combined with mechanisms that permit survival under temporarily unfavourable conditions (Roberts, 1982).

1-4-2 The different types of weeds

Weeds can be classified according to their life cycle. Three types of plant life cycle are recognized: annual, biennial and perennial:

ANNUAL: Plants that complete their life cycle in one year. They germinate from seeds, grow, mature, produce seeds, and die in one year or less, for example Velvetleaf (Fig 1).

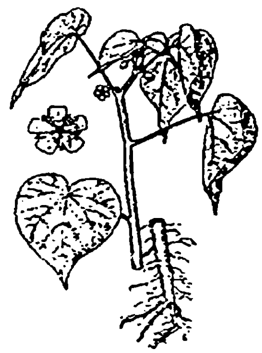


Fig (1) **Velvetleaf** (*Abutilon theophrasti*)

BIENNIAL: plants that complete their growth cycle in two years. They are easy to control in the seedling stage, for example Bull thistle (Fig 2).

Fig (2) **Bull thistle** (*Cirsium vulgare*)

PERENNIAL: plants live for two or more years. They can reproduce by seeds or vegetatively, for example Johnsongrass (Fig 3).

Fig (3) **Johnsongrass** (*Sorghum halepense*)

Annual, biennial and perennial weeds can all reproduce from seeds. Seeds are easily dispersed across a field by wind, rain, machinery, animals, and people. Many weed seeds can germinate after being dormant for long periods of time. They can also tolerate extreme climates such as temperature and moisture. To prevent seed dispersal, weeds should be controlled before they produce seed (Hines, 2002).

1-4-3 The harmful effects of weeds

Weeds do not only cause production losses due to competition. They may contain poisonous substances that make some crops unfit for human consumption. For example *Heliotropium* seeds harvested in wheat crops will contaminate flour made from the wheat with a poisonous alkaloid that causes liver disease (Haigh, 2001). *Agrostemmma githago* (Corncockle) and *Lolium temulentum* (Darnel) used to cause a similar problem in wheat production until effective control measures were developed (Haigh, 2001). The pollen of some weed species is believed to be a major cause of discomfort, illness and death for some people with respiratory problems. The main species responsible are *Ambrosia artemisiifolia* (Ragweed) and many grass species (Haigh, 2001).

Some weeds may contain substances that cause tainting of milk, such as *Arctotheca calendula* (Capeweed) (Haigh, 2001). Other weeds contain substances that cause contact dermatitis in humans, such as *Toxicodendron radicans* (Poison ivy), *Urtica dioica* (Stinging Nettle) and *Pastinaca sativa* (Wild Parsnip) (Haigh, 2001). Such weeds can also severely affect the hand harvesting of some vegetable crops (Haigh, 2001).

1-4-4 Weed aggression against crop plants

Weeds can sometimes invade farmland from elsewhere and disturb the growth of crop plants as they may have some physiological advantage over crop plants. This usually appears as a superior growth rate due to a high net photosynthetic rate. Weeds may also have a faster rate of development than crop plants or may have a shorter period of juvenility, thus being able to reproduce before the crop is harvested. Some weeds may have a reproductive advantage over crop plants because they can self fertilize, have large seed production or have an ability to propagate their seeds over large distances.

Weeds may reduce the quality of the crop produced in many ways. For example, Bazzaz (2001) reported that weed interference can reduce the quantity of crop yields due to the impact on the uptake of the resources in differing quantities and deploy them in different ways. However, little is known about the effect on the quality of crop yields. Zimdahl (1980) listed 600 publications proving economic losses in yields due to weeds growing with crops. Weed seeds of plants such as Wild Mustard, Sweet Clover, Mexican Poppy when threshed and ground with winter grains can result in serious consequences besides imparting an objectionable odour to the flour.

Crop losses that can result from the presence of weeds include complete crop loss in lettuce, where strong weed competition can prevent head formation, thus preventing the development of the harvestable product (Haigh, 2001). In pea crops, the presence of *Solanum nigrum* (Black Nightshade) fruit will cause rejection of the crop by processors as the immature fruit of nightshade and the seed of the pea are similar in size, shape and colour (Haigh, 2001).

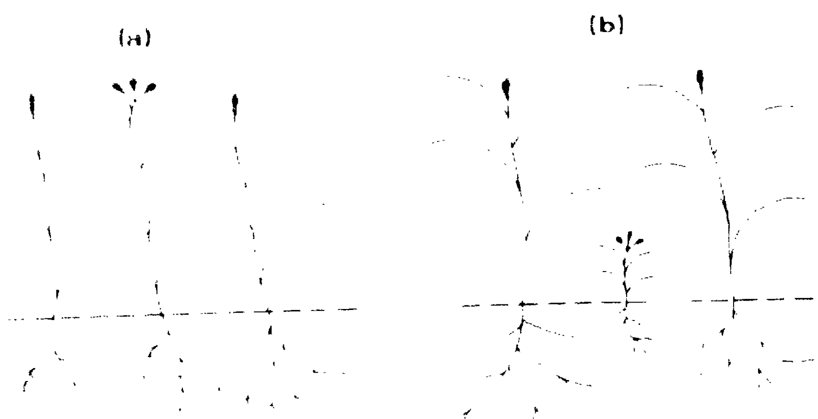


Fig 4: Diagrammatic illustration of different crop/weed situations:

(a) Weed (centre) plants resembling the crop plants in the general growth habit.

(b) Weed plants not resembling crop plants (Hill, 1977).

In Fig. 4 (a) the weed has a comparable structure to the crop and occupies a crop plant place. Both roots and leaves of the weed are distributed in a way similar to those of the crop plants which may create competition for light, nutrients and water. In Fig. 4 (b), although the weed is in the same position in relation to the crop it is less likely to be competing in the same way with the crop plants because it allows more space for crop plants to grow; unlike if the space was occupied by a fellow crop plant. This raises, an important concept that crop plants do compete very considerably with each other (Hill, 1977).

Another point relevant to Fig 4 (a) and (b) is that although interference with crops by weeds is likely to be particularly severe if there is a morphological similarity between the two, this similarity is by no means a condition for successful interference by the weed. The weed in Fig 4 (b) may, in the early stages of growth, have had an effect on the crop which will last until harvest, provided it is able to flower and set seeds when overtopped by the crop (Hill, 1977).

1-5 Competition definition and mechanism(s)

The term competition has been used for different meanings or to describe different forms of competition; this has created lot of confusion between ecologists. Muller (1969) was the first to differentiate between different forms of competition and Rice (1984) suggested the use of three forms of competition: Competition, Allelopathy and Interference.

1-5-1 Definition of Competition

Competition was defined by Rice (1984) as the removal or reduction of some factor from the environment that is required by some other plant sharing the habitat. Factors that may be reduced include mineral nutrients, water, space, and light:

Competition for mineral nutrients: All plants require the same basic nutrients but plants differ in the way they respond to nutrient availability. They differ in their ability to access nutrients because of differences in their root structure or mycorrhizal associations. They can also show differences in their ability to tolerate nutrient imbalances, or in their efficiency at converting nutrients into growth. Maintaining or improving soil fertility is thus an element of weed management. Crop competitiveness may improve with improved nutrient status; some weeds are more effective at utiliaqzing excess resources than some crops. Lower nutrient availability means less available nutrients for weed growth as well as for the crop growth. Higher nutrient levels stimulate the competitive ability of weeds; for example, Wild Oat (*Avena fatua*), Green Foxtail (*Setaria viridis*) and Barnyard Grass (*Echinochloa spp.*). Other weeds might be limited by nutrient levels that are adequate for crop growth (Frick & Johnson, 2002).

Some studies investigating growth and development and nutrient accumulation in the weeds *Chenopodium album* and *Senecio vulgaris*, showed that the two weeds were different in their growth (Qasem & Hill, 1994). It was suggested that this can be due to the rate in which weeds and crops utilize fertilizers. For example, Alkamper (1976) demonstrated that weeds absorb fertilizer faster in relatively larger amounts than crops which benefits the weed growth over the crop. Johnson & Hans (2002) reported that corn yield loss was due to Shattercane interference with the crop and this was due to the similarities of the two species in both growth characters and nutritional needs. Also, Hauggaard-Nielsen *et al* (2001) pointed out that N fertilization increased yield in pea-barley intercropping more than when each crop was grown alone.

On the other hand, Petersen (2003) showed that nitrogen supply affected plant biomass reduction and slurry banding improved crop competitiveness. Paolini *et al.* (1999) reported that late N_2 fertilization and early N_2 fertilization in the presence of *Sinapis arvensis* and *C. album*, respectively, favored competitive ability of two sugar beet cultivars.

Van Delden *et al*, (2002) indicated that nitrogen supply reduces the growth of the late-emerging weed *Stellaria media* in potato by enhancing canopy leaf area development and thereby reducing the availability of light for weed growth. However, in wheat, *S. media* total dry weight and seed number increased with soil N_2 supply despite reduced light availability.

Dotzenko *et al.* (1969) showed that rate and time of nitrogen fertilization affected weed population and the number of weeds; adding extra nitrogen stimulated growth of *C. album* more than sugar beets. Weed-free sugar beet yield was not affected by supplementary nitrogen whereas crop yield was depressed in the presence of weeds. According to Hoveland and Buchanan (1976), the effect of different levels of soil Potassium and Phosphorus varied widely among warm-season and cool season weeds. Generally, weeds were more sensitive to low soil Potassium than to low soil Phosphorus. In the contrary, crops were less sensitive to both low soil Potassium and Phosphorus.

Competition for water: Water is an essential factor in the growth and function of plants (Zimdahl, 1980). Water availability restricts the growth of many crops. Weeds like other plants, consume large quantities of water, and most of it is lost by transpiration to the atmosphere. The roots of some weeds develop much faster than roots of the crop with which it is competing. This allows the faster developing weeds to reach deeper soil moisture first (Aldrich & Kremer 1984). Low intensity of transpiration in some weeds can result in higher water use efficiency of net photosynthesis. For example, Szente *et al.* (1993) reported low transpiration intensity in the weed *Amaranthus chlorostachys* when competing with the crop sunflower (*Helianthus annuus* L.); this resulted in a better water use efficiency in the weed and consequently higher total plant dry weight. Such finding, suggests the ability of weed plants to tolerate drought conditions.

Moreshet *et al.* (1996) examined the effect of water deficit stress on competitive interaction of peanut (*Arachis hypogaea*) and sicklepod (*Senna obtusifolia*). They found that a response occurred even though the fraction of fine root length density in the bottom half was more than 45% of the total fine root length density in the DRY treatment of sicklepod and both species mixed. Significant osmotic adjustment was detected in both species following water deficit stress. At full turgor, leaf osmotic potential of all WET treatments reached -0.99 MPa; at zero turgor, it reached -1.12 MPa. For the DRY treatments, leaf osmotic potential at full turgor dropped significantly in both sicklepod and peanut; at zero turgor, it dropped in both species, but the differences were not significant. As the soil dried, water use by peanut mixed was significantly higher than sicklepod mixed. It was concluded that peanut can use more water under water deficit stress and can recover faster than sicklepod when it is grown with the other species

Water seemed to be the primary factor in below-ground competition between *Amaranthus retroflexus* and tomato. *Amaranthus retroflexus* dry matter production decreased as moisture stress increased (Mohammed & Sweet, 1978). Weise and Vandiver (1970; Cited in Zimdahl,1980) demonstrated that interaction between different species and soil moisture level was significant, indicating that all plants did not respond the same way when subjected to competition under different levels of soil moisture. They also observed that species producing the greatest growth under wet soil moisture conditions were most adversely affected by the combination of competition and a shortage of water.

Competition for Solar Energy: Light intensity plays an important role as the key driver of photosynthetic rate in plants (www.indiaagronet.com, 2002). Competition for light is one of the most common forms of competition in the plant community. In fact light intensity plays an important role as a key external variable of the photosynthetic process of the plant. Several investigators have stressed the importance of plant competition for light. Barbour *et al.* (1994) confirmed laboratory results, indicating that shade- accumulated peanut had greater efficiency at low light levels. Shaded plants accumulated less dry weight and produced fewer roots.

Competition for space: Weeds compete for space both in the rhizosphere and atmosphere. In the presence of weeds, crop plants also have limited space to develop their shoots, which leads to reduced photosynthetic productivity (indiaagronet.com, 2002; Farahbakhsh *et al.*, 1987; Nurse *et al.* 2003; Appleby *et al.* 1976).

1-5-2 Definition of Allelopathy

Quite apart from competition, plants may affect one another as a result of the production of chemical compounds that escape into the environment. There is ample evidence that some plants release chemicals which, when applied to other plants, inhibit germination or later growth. Such chemicals may be volatile or be released from the aerial parts of plants or their roots by active exudation or as a result of leaching by rain or soil water, or by decomposing. Allelopathy is clearly of interest in relation to interactions between crops and weeds; it could be a component of the process by which weeds suppress crop growth, and equally might assist crop plants to combat weed interference. It seems at least likely that allelopathy plays a role as one of several compounds in a competitive situation (Roberts, 1982).

The phenomenon of plant allelopathy was observed for centuries. De Candolle (1832; cited in Khanh *et al.*, 2005) indicated that weeds may be suppressed by crop rotation that releases exudates; material such material released from crop plants cause soil sickness and this can be minimized by crop rotation. However, Molisch (1937) was the first to define allelopathy as the biochemical interactions between all types of plants including microorganisms covering both inhibitory and stimulatory effects. Unlike competition, the effect of allelopathy depends on a chemical compound being added to the environment (Rice, 1984). According to Wardle *et al.* (1998), allelopathy was defined as the mechanism of interference between a plant that produces chemical compounds exerting an effect, generally negative, on associated plants. Khanh *et al.* (2005) defined allelopathy as an interaction among plants by chemical pathways. Both inhibition and promotion were included in this interaction.

The liberation of such compounds to the neighboring environment can be through root exudation, volatilisation and/or decomposition of plant residues, in both agricultural and natural systems (Pérez & Ormeno-Nunez, 1991; Tsuanuo *et al.*, 2003).

Many compounds that have allelopathic effects have been identified ranging from simple water-soluble organic acids, unsaturated lactones, phenols to flavonoids, tannins, terpenoids steroids (Rice, 1984). Allelopathic compounds affect many physiological processes in associated plants. For example, Einhellig (2004) reported that the different phenolic acids such as cinnamic and benzoic acids have similar mechanisms of action, inhibiting plant growth through multiple physiological effects that confer a generalized cytotoxicity. Their initial actions were on cell membranes, resulting in non-specific permeability changes that alter ion fluxes and hydraulic conductivity of roots, consequently affecting plant water relations, photosynthesis, respiration and flow of carbon. Polyphenols such as coumarins (e.g. scopoletin, umbelliferone and esculetin) and tannins (e.g. gallotannin) were also found to affect synthesis and action of some growth regulators (e.g. indole acetic acid and ethylene) and both free-living and nodulating nitrogen-fixing bacteria. He also reported that some of the allelopathic flavonoids are potent inhibitors of energy metabolism, blocking mitochondrial and chloroplast functions.

1-5-3 Definition of Interference

The term interference was used by Muller (1969) to refer to the overall influence of one plant on another, encompassing both allelopathy and competition. Due to the fact that it is difficult to separate between the two forms of competition in an experiment, Rice (1984) suggested the use of the term interference instead of competition.

1-6 Effects of weeds on cereals

1-6-1 Effect of weeds on wheat

It has been observed that the interference of weeds with wheat significantly reduced several growth parameters causing a loss in yield of wheat (Appleby *et al.,* 1976; Farahbakhsh *et al.*, 1987; Korres & Froud-Williams, 2002; Bazzaz, 2001). Stone *et al.* (1998) confirmed that wheat growth in the aboveground interaction only reduced wheat height, leaf number, tillering and leaf area. Wheat in full and belowground interaction only did not differ from one another in growth. No allelopathic response of wheat to Italian ryegrass (*Lolium multiflorum*) occurred. While the tallness of semi dwarf wheat minimized aboveground interference by ryegrass, the root growth of the thinner and more fibrous root of ryegrass greatly enhanced its belowground competitiveness. In contrast, more recent work of Iqbal & Wright (1997) showed that *C. album* was more competitive than wheat when N was added.

On the other hand Tanji *et al.* (1997) showed that wheat was the dominant competitor with either rigid ryegrass (*Lolium rigidum*) and cowcockle (*Vaccaria hispanica*; analyses of growth parameters demonstrated that wheat had the highest growth compared to that of the two weeds. Cousens & Mokhtari (1998) reported on the variability in the tolerance by wheat cultivars of interference from *Lolium rigidum*; in most of the cultivars examined there was little correlation between competitiveness at different sites within a year or in different years within a location. However, only one cultivar was shown to be clearly a good competitor and two cultivars were shown to be poor competitors

Blackshaw *et al.* (2002) examined the effect of added nitrogen on weed-wheat interaction and demonstrated weed growth was suppressed due to an increased nitrogen uptake by wheat that increased competitiveness of the latter. In contrast, Acciaresi *et al.* (2001) reported a progressively higher aggressivity of the weed *Lolium multiflorum* with increasing nitrogen rates in competition with wheat.

Lemerle *et al.* (2001) examined the ability of wheat varieties to compete with *Lolium rigidum* through a combination of short-term agronomic manipulations and longer-term breeding efforts with the use of herbicide resistant weeds; this increased wheat competitiveness.

Numerous other studies have shown the impact of weed interference on wheat yield when grown under different densities e.g (Appleby *et al.,* 1976; Medd *et al.,* 1985; Farahbakhsh *et al.*, 1987; Korres & Froud-Williams, 2002; Bazzaz, 2001) showed the effects of different densities of weeds on growth parameters (leaf area, height and yield of maize). Morgan *et al.* (2001) confirmed that cotton yields decreased under different densities of *Amaranthus palmeri.*

Other studies investigated the effects of nutrients on competition between wheat plants and weed plants. For example, Iqbal & Wright (1997) investigated the effects of nitrogen supply on the competition between spring wheat and three weed species (*Phalaris minor*, *Chenopodium album* and *Sinapis arvensis*). The results showed that low N supply decreased net photosynthetic rate (Pn), leaf N content, plant dry weight and N uptake of both wheat and weed species and grain dry weight of wheat. The authors also observed that when N supply was high, wheat was less competitive than *C. album* but more competitive than *P. minor.*

1-6-2 Effect of weeds on barley

Barley is considered to be the fourth greatest of the cereal crops in the world (Didon, 2002). Therefore, it is very important to study barley-weeds competition in order to understand how barley is affected or affect weeds and also to determine if barley varieties have any level of tolerance to weeds or any allelopathic qualities. For this reason, many studies have investigated the effects of weeds on growth and development of barley crops. The relative competitiveness of broadleaved weeds (eg. *C. album*, and *A. retroflexus)* with barley was observed to significantly reduce the growth parameters of barley plants (Hauggaard-Nielsen *et al.*, 2001). Martin & Snaydon (1982) observed that when barley and field beans were intercropped, barley was more competitive than field beans. This greater competitive ability was due almost to its greater root competitive ability. In addition, the application of nutrients did not determine any significant variation in the competition between barley and field beans.

Didon & Bostrom (2003) reported that *Sinapis alba* reduced the above-ground biomass of two barley cultivars (Etna and Blenheim) with low competitive ability. However, cv. Etna showed high grain yield in the presence of the weed compared to other cultivars. In two field experiments that were conducted in 1996 and 1997 respectively at a site SE of Uppsala, Sweden. The two cultivars, Etna and Blenheim allowed the highest weed biomass and the lowest crop biomass in competition. Although the biomass of cv. Etna was low, the grain yield was higher than that of the other cultivars when grown in competition with weeds. In 1997, cv. Svani with good competitive ability against weed, transmitted least light and had greater grain yields than most of the other cultivars. The absence of a relationship between high grain yield and low weed suppressive ability in this study indicated that it should be possible for plant breeders to combine high grain yielding capacity with approved weed-competitive ability. Similar results were reported by Dhima *et al.* (2000). They found that barley cultivars with low suppressive ability against *Avena sterilis* and *Phalaris minor* also had a lower crop biomass in competition with the weeds than more competitive cultivars. Didon (2002) investigated barley traits that are important for high competitive ability and demonstrated that high initial relative growth rate, large length of the two first internodes, long main shoot in the tillering stage; small leaf angle and early stem elongation were related to high competitive ability of barley cultivars.

1-7 Competition Indices

The interpretation of the outcome of competition can depend critically on the way competition is measured (Freckleton & Watkinson 1999). For this reason, researchers throughout the time formulated indices that can be used to measure and quantify competition parameters such as relative yield and competition abilities (De Wit *et al.* 1965; McGilchrist & Trenbath, 1971). According to (Weigelt & Joliffe, 2003), competition indices can help researchers in many ways:

a- Facilitating the presentation of results.

b- Help to express and quantify different composite ideas that characterise competition.

c- Help researchers interpret complex data.

d- The use of the same competition indices may help results from different researchers to be compared.

However, competition indices like any other mathematical indices may have possible shortcomings, and they can be misapplied (Weigelt & Joliffe, 2003).

Many Competition indices were used to quantify or compare competition and were summarized by Weigelt & Joliffe (2003). Some indices were designed to quantify the intensity of competition such as *Relative Competition Intensity* (Campbell & Grime, 1992) and *Aggressivity* (McGilchrist & Trenbath, 1971). Other indices were designed to quantify the effect of competition such as *Relative Yield Total* (De Wit & Van den Bergh, 1965). Lastly, some indices were designed to quantify Relative *Reproductive Rate* (De Wit & Van den Bergh, 1965). *Relative Yield, Relative Yield Total* (RYT) and *Aggressivity* were used extensively in studying weed-crop interaction by Snaydon and his colleagues (e,g. Snaydon, 1982; Snaydon & Satorre, 1989; Snaydon, 1991). In his studies, Snaydon (1991) clarified the confusion regarding the use of the most used indices with different experimental designs. Relative Yield Total was assigned to replacement design and Aggressivity or Competitive Ability was assigned to additive design.

1-8 Justification for the study

It is well known that the Arabian Peninsula including the land of Saudi Arabia is almost a desert with an exception of small areas that are used to grow crops. Numerous plant species of the Saudi Flora are weeds. Agriculture in Saudi is facing many problems including, plant diseases, high level of salts in soils and also weed infestations. One of the major problems to agriculture in these areas is weed plants that are particularly well adapted to the Saudi climate. Three weed species (*Heliotropium europaeum* L., *Chenopodium album* L. and *Amaranthus retroflexus* L.) particularly are amongst the most harmful weeds in the country (Chaudhary &

Akram, 1987; Al-Huqail, 1999). However, very little work has been carried out to investigate and evaluate the real problem caused by such weeds to cereal cultivars commonly used in Saudi. For the above reasons, the present work was undertaken, with the objective of increasing scientific knowledge of weed interference problems caused to Saudi crop.

1-9 Aims of the project

The aims of the project were:

- To determine the competitive ability of weed-species commonly occurring in Saudi Arabia with reference to Saudi cultivars of wheat and barley crop plants.
- To identify the interaction effects on the morphology of cereal plants
- To understand the behaviour of weeds and their dynamic interactions with cereal crop cultivars.
- To investigate, under experimental glasshouse conditions the effects of environmental factors upon the interaction of the target wheat and barley cultivars and weed species.
- To provide the knowledge gained from the study to inform the database required by weed management agencies and farmers attempting to minimize weed problems in Saudi Arabia.

CHAPTER 2

CHAPTER 2

COMPETITION EXPERIMENTS: MATERIALS AND METHODS

2-1 Cereal crops used in this study

2-1-1 Wheat (*Triticum aestivum*)

This is the most familiar cereal used in Britain today; more people eat wheat than any other cereal grain making it the single most important cereal crop grown in the world (The Vegetarian Society, 2002). All present varieties of wheat seem to be derived from the hybrid wild wheat that grew in the Middle East 10,000 years ago. Over 30,000 varieties are said to be cultivated (Alaoudat et al, 1984). Wheat can be grown in a very wide range of climatic conditions but is most successful in temperate zones including the UK, North America, Southern Russia and South West Australia (The Vegetarian Society, 2002).

2-1-2 Barley (*Hordeum vulgare*)

Barley grows in a wider variety of climatic conditions than any other cereal and on lands too poor for wheat. It used to be a very important source of direct human food, but its use has diminished over the last 250 years, replaced by wheat. It contains gluten, so barley flour can be made into bread (The Vegetarian Society, 2002). It is a major world crop and ranks as the most important cereal after rice, wheat and maize (Bengtsson, 1992). In Britain, barley has been the crop with the largest land acreage for a considerable period and still represents today, together with wheat, one of the major crops. It has been suggested that cultivated barley originated from the wild barley *Hordeum spontaneum* C Koch, which has its centre of origin in the Fertile Crescent of the Middle East (Zohary, 1969).

2-2 Plant material used in this study

2-2-1 Saudi Arabian Wheat

Samples of *Triticum aestivum* cv. Yecora Rojo were obtained from the Saudi Grain Silos & Flour Mills Organization (Kingdom of Saudi Arabia, 1989). This wheat cultivar is used for making bread and it is rich in proteins; it is adapted to rain fed conditions and it was also chosen in the USA amongst wheat varieties that are tolerant to wheat stripe diseases (Munier *et al.*, 2004). Many experiments have been carried out in Saudi Arabia and their results were applied to the basic crops. Despite harsh climatic conditions, the Kingdom succeeded and was able to achieve food security, and reaching the self-sufficiency and export stage (Saudi Grain silos & Flour mills Organization).

The Kingdom's efforts were not limited to the quantitative increase in the wheat harvest, but also to the quality of the products to reach high international standards; emphasizing cultivars of both *Triticum durum* Desf. and *Triticum aestivum* L. (Alaoudat *et al.*, 1984).

These primary qualities sought were:

- Full size grain which raises the flour in milling.
- Reduced humidity which gives it longer storage life.
- High protein rate which gives the product a higher nutrition value.
- Low percent of impurities which makes it cleaner and more useful.

Due to these specifications that distinguish Saudi wheat, many countries have started to make import agreements with the kingdom. Also many of the wheat producing countries have started to import Saudi wheat to mix it with locally produced wheat.

It was reported that EEC imported more than 100,000 million tones of Saudi wheat to England, Italy, Portugal and Germany during the 1980s (Times-dated 7/8/87).

Saudi agriculture had prepared short and long term plans to improve the planted brands of wheat by using modern technology, built Grain Silos in production areas, and exported to more than 45 countries in Asia, Europe and Africa as well as China and USSR (Business World Dec 1988).

2-2-2 Saudi Arabian Barley

Samples of *Hordeum vulgare* cv. Jasto (a variety that is adapted to rain fed conditions) were obtained from Saudi grain silos & flour mills organization. Barley grows well in some parts of the kingdom of Saudi Arabia, which are too poor for wheat (The Vegetarian Society, 2002), and barley tolerates low humidity better than wheat. Barley is also used for human consumption and cattle grazing (Alaoudat *et al.*, 1984). The kingdom of Saudi Arabia aims to vary the sources of national income to avoid being dependent on only one source.

2-3 Broadleaved weeds used in this study;

2-3-1 *Amaranthus retroflexus* L.

Amaranthus retroflexus (Fig. 5) belongs to the family Amaranthaceae. It is an annual or perennial herb. The plant is odourless lower leaves alternate, simple, lamina variable, acute; inflorescence spike-like cymes-like or distant glomerulus (Migahid, 1978). Spikes mostly leafless-looking. Flowers very small in dense clusters on terminal and axillaries simple, bisexual. Perianth of 3-5segments, green. Seeds are round, smooth-glossy and black (Mandaville, 1990); this species propagates by seeds, with distribution mainly via animal consumption vectors (Chaudhary & Akram, 1987). *A. retroflexus* is amongst the worst weeds of the world, occurring, in many regions including the Arabian Peninsula (Chaudhary & Akram, 1987, Mandaville, 1990).

Samples of *A. retroflexus* seed were obtained from HERBISEED (Herbiseed, New Farm, Mire Lane, West End, Twyford, RG10 0NJ, England, UK).

Fig. 5: *Amaranthus retroflexus* (Migahid, 1978)

2-3-2 *Chenopodium album* L.

Chenopodium album (Fig. 6), is a member of the family Chenopodiaceae; an annual weed; odourless, lower leaves alternate, some or all leaves dentate to lobed, leaves ovate-lanceolate (usually deltoid-ovoid with scattered obtuse teeth), etiolate, exstipulate, simple, lamina variable, acute; inflorescence spike-like or cyme-like (Migahid, 1978). Spikes are mostly leafless-looking. Flowers are very small in dense clusters on terminal and axillary's simple, bisexual perianth of 5 segments, green fleshy. Seeds are rough and dull up across; they propagate mainly via animal consumption vectors (Migahid, 1978). Like *A. retroflexus*, *C. album* is a weed of worldwide significance for example occurring widely in the UK (Williams, 1963; Cited in Al-Huqail, 1999) and in the Arabian Peninsula (Chaudhary & Akram, 1987).

Samples of *Chenopodium album* were also obtained from HERBISEED.

Fig. 6: *Chenopodium album* ((Chaudhary & Akram, 1987).

2-4 Competition Experiments

A series of glasshouse competition-partitioning experiments were undertaken to study the effect of *Chenopodium album* and *Amaranthus retroflexus* on the Saudi cultivars of *Triticum aestivum* L. cv. Yecora Rojo and *Hordeum vulgare* L. cv. Jasto.

In all experiments, plants grown in boxes were placed in standard glasshouse conditions. Illumination was provided by Kolorarc high-pressure mercury vapour lamps giving 150 μmol m^{-2} s^{-1} at plant level during a 16 h photoperiod. The temperature within the glasshouse was maintained at 20 ± 2° C with a relative humidity ranging between 65-80%.

The germination rate of seeds of several potential broadleaved species were first tested to determine speed and rate of germination: *Chenopodium album* and *Amaranthus retroflexus* proved to be relatively fast germinating and were hence selected for these experiments in preference to other possible species (e.g. *Hyoscyamus niger*). Weed seeds were germinated in seedling compost; that had been contained in special plastic bags and watered for a period of time approx. from 10 to 13 days. Cereal seeds were allowed to germinate on triple layer of filter paper (9 cm diameter) wetted with distilled water, and placed in plastic Petri-dishes covered with aluminum foil, and incubated at room temperature (around 23 °C). The percentage germination was determined when the radicle attained a length of approximately 1 cm.

In the above procedure simultaneous growth to the seedling appearance with respect to time was taken into account for both cereal and weed seeds, the time taken for this stage was about 24 to 48 hours

At first; seedlings of cereals were transplanted with care into partitioned wooden boxes (44×44×20 cm) the time consumed to do this was from 7:00 AM till 9:00 PM. The same was done for weeds seedlings next day; again the same time was consumed. To ensure that seedlings are damage free, each plastic bag was cut in the bottom using scissors, and then seedlings were transplanted in their compost into the wooden boxes.

Watering of the experiments was carried out every three days during winter and daily in summer; the next step was carried out 2 weeks later when fertilizer solution was added weekly to the soil in each box. The solution was made up by adding 9.5 mg of commercial fertilizer to 1.5 litre of water for each box.

Wooden boxes were designed with the following dimension(44×44×20 cm), divided into 6x6 parts (each 9×9cm) making column and rows to simulate normal farm land. Boxes contain compost, soil and sand mixture (3:1:1 ratio), and divided into above and below-ground compartments, using plywood partitions. Aerial partitions were covered by aluminum foil to enhance light penetration between the partitions. Each cell in the box contains either 7 crop plants or 5 weed plants. The experimental methodology used followed Snaydon (1979) which was developed from that of Donald (1958) and similar to that of Schreiber (1967). Cereal and weed plants were grown in alternate rows, between the partitions, with four arrangements of partitions providing differing combinations of above-ground, below-ground and above-below ground interactions between the weed and crop plants (Fig. 7).

The standard experimental design used in the competition experiments consisted of a randomized block design with three replicates and four levels of competition factors using the separation of roots and shoots technique (Martin & Snaydon, 1982):

1- **Root interaction**: where shoots of wheat or barley and *Chenopodium* or *Amaranthus* were separated.

2- **Shoot interaction**: where roots of wheat or barley and *Chenopodium* or *Amaranthus* were separated.

3- **Full interaction**: where roots and shoots of wheat or barely and *Chenopodium* or *Amaranthus* were allowed to interact.

Also, two nutrient treatments (fertilizer added; no fertilizer) were used, giving a total of 24 experimental units (boxes). The Miracle-Gro (NPK fertilizer 15-30-15 with trace elements) was obtained from The Scotts Company (UK) and used as a supplement nutrient to investigate the effect of the fertilizer on weed-crop interactions.

In the preliminary study (Chapter 3), the separation of roots and shoots technique was used to investigate physical competition between wheat (*Triticum aestivum*) and the weed *Chenopodium album* (Experiment 1). The experiment was started in September 2002 and harvested 2 months later.

In Chapter 4, competition between wheat (*Triticum aestivum*) and the two weeds *Chenopodium album* (Experiment 2) and *Amaranthus retroflexus* (Experiment 3) were investigated. The 2nd experiment was started in May 2003, and the 3rd was started in October 2003. In all cases, plants were harvested 6 weeks from sowing date.

Similarly, barley competition with *Chenopodium album* (Experiment 4) and *Amaranthus retroflexus* (Experiment 5) was investigated in Chapter 5. The 4th experiment was started in March 2004, while the 5th experiment was started in Jun 2004. The harvesting date for each experiment was in general 6 weeks from sowing date. In all the above experiments, the effect of the three interactions on the plant growth parameters such as plant height, whole-plant dry weight, shoot dry weight and root dry weight, were examined and data was recorded and subjected to analysis of variance.

The plants were monitored on a daily basis, and photographs were taken whenever an important change was observed; after 6 weeks, plant height was measured from the soil surface up to the shoot top end, and for statistical purposes, three readings were taken from different plants in each treatment. The plants harvested were selected randomly for each treatment.

During the harvesting process, plants were carefully removed to ensure that all roots were separated from soil; the roots were water washed gently with a fine brush to remove any leftover of soil particles, then dried with paper tissues; each 10 samples from a particular box were maintained in a separate aluminum container, the same arrangement for each plant sample groups were followed e.g. root parts, shoot parts, and whole plant, where all data regarding the box from which they were removed are written on the container using heat proof color pens.

In the next step all containers were placed in a drying oven, at 60° C for 72 hours.

2-5 Statistical Analysis

Means and standard errors of the means (standard deviation divided by the square root of the number of replicates) were calculated using Excel (version 2000). Standard errors were calculated over the means of the three replicates. ANOVA Analysis of variance was performed using a general linear model in Minitab (Version 13). Analysis of variance of the yield of the species was carried out as required to normalize the data. ANOVA results are summarised in tables and can be found in the Appendix at the end of this thesis.

2-6 Measurement of Competition Indices

Relative yield, relative yield total and aggressivity were calculated: These statistics describe how species interact with each other and whether or not they impose competitive effects on each other. **Relative Yield RY*i*** and **RY*j*** of species ***i*** and ***j*** respectively, are calculated as follows:

Relative Yield of species i: $RY_i = Y_{ij} / Y_{ii}$

Relative Yield of species j: $RY_j = Y_{ji} / Y_{jj}$

Where:

* Y_{ij} = yield of species ***i*** per plant when grown in one to one mixture with species ***j***.
* Y_{ii} = yield of species ***i*** per plant when grown only with other individuals of the same species.
* Y_{ji} = yield of species ***j*** per plant when grown in one to one mixture with species ***i***.
* Y_{jj} = yield of species ***j*** per plant when grown only with other individuals of the same species.

If Relative Yield >1, then the species shows an increase in yield in response to growing in mixture compared with the growing alone if <1, then the yield of the species ***i*** is reduced by interaction with species ***j*** compared to its yield when growing alone.

The performance of species ***i*** grown in the presence of species ***j*** can then be expressed as **Relative Yield Total (R Y T)** used by De Wit & Van den Burgh (1965) and calculated as:

$$\mathbf{R\,Y\,T = (RY}_i + \mathbf{RY}_j) = 1/2\,(Y_{ij} / Y_{ii} + Y_{ji} / Y_{jj})$$

This equation was used by many authors as yield per plant (De Wit *et al.*, 1965; McGilchrist & Trenbath, 1971; Martin & Snaydon, 1982 and Roush & Radosevich, 1985). A value for R Y T >1 suggests that the plants perform overall better in mixture than when growing alone, and R Y T < 1 indicates a mutual depression of performance in mixture culture.

The competitive relationship between pairs of competing species can also be described by the Aggressivity Score (McGilchrist & Trenbath, 1971) of one species relative to the other:

$$\textbf{Aggressivity of species } i \textbf{ relative to species } j = (Y_{ij} / Y_{ii} - Y_{ji}/Y_{jj})$$

$$\textbf{Aggressivity of species } j \textbf{ relative to species } i = (Y_{ji} / Y_{jj} - Y_{ij}/Y_{ii})$$

Like RYT, the aggressivity equation was also used by the same authors as yield per plant (De Wit *et al.*, 1965; McGilchrist & Trenbath, 1971; Snaydon, 1982 and Roush & Radosevich, 1985).

If the aggressivity score is positive, the yield of species ***i***, is either being reduced less or increased more than species ***j***, when the two are mixed, compared to when they are not. It can therefore be considered more aggressive in the competitive interaction as it is being more successful than the species ***j*** at either increasing its yield above what would be expected in pure culture or minimizing a reduction in yield due to mixed culture. A negative value implies the converse.

In the result tables, which follow in Chapter 3 for significant treatment effects (ANOVA, $P< 0.05$), mean values having superscript letters in common are not significant ($P> 0.05$); * = significant at $P< 0.05$; ** = significant at $P<0.01$; *** = significant at $P<0.001$, using the Tukey test procedure.

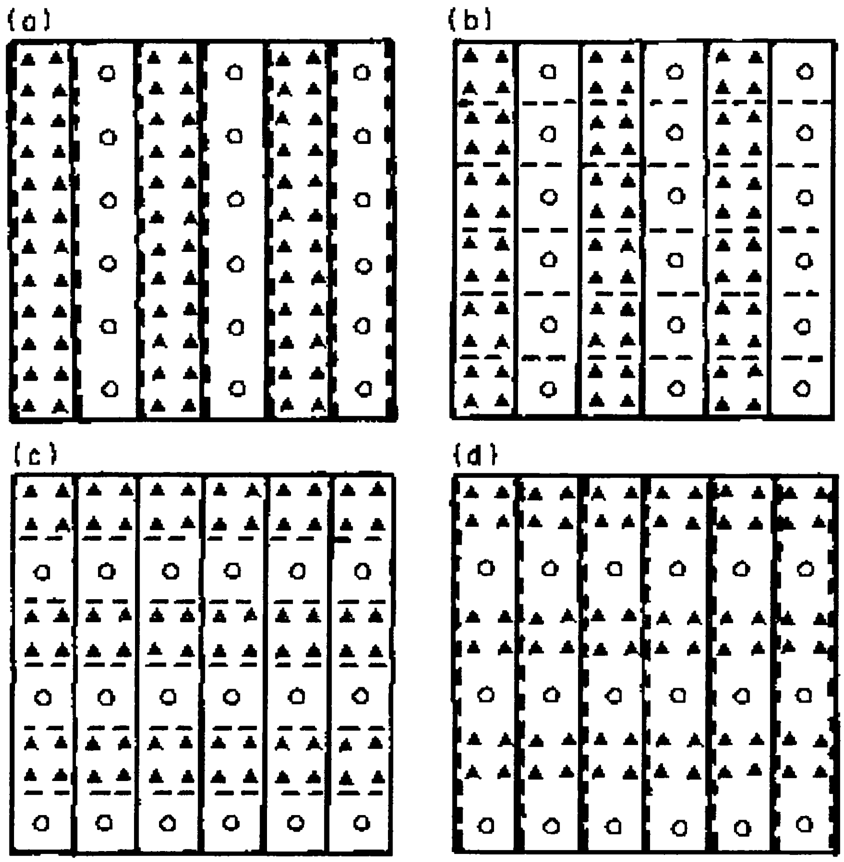


Fig. 7: Partitions were arranged according to Martin & Snaydon (1982) as follows:

(▲): Crop.

(○): Weed.

a. No interaction between species.
b. Root interaction only.
c. Shoot interaction only.
d. Both root and shoot interaction.

Solid lines: above–ground partition (Root interaction)

Dashed lines: below-ground partition (Shoot interaction)

However, Martin & Snaydon (1982) used a plant density of 4 crop plants : 1 weed plant and in the present study, density was: 7 crop plants : 5 weed plants per cell (each box is divided to 36 cells).

Figs. 8-9: General view of experiment

CHAPTER 3

CHAPTER 3

RESULTS OF PRELIMINARY EXPERIMENT

3-1 Experiment 1: Wheat *Triticum aestivum* cv. Yocora Rojo versus *Chenopodium album*

3-1-1 Plant Height (wheat)

The experimental results of the effect of *Chenopodium* on wheat plant height are recorded in Table 1 and Fig. 10. A slight significant differences were shown between blocks ($P< 0.05$), but no significant differences between fertilizer treatments were observed. In contrast, competition of the two species at the root level only or both root and shoot level significantly decreased ($P<0.001$) the height of wheat plants whether fertilizer was added or not which indicates that there was no interaction between competition and fertilizer.

Table 1:

Effects of *Chenopodium* interference on mean wheat plants height

WHEAT PLANT HEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	66.33	66.33	60.20	50.66	58.33	68.66	57.66	58.00
2	62.33	64.66	39.33	40.00	56.00	51.00	54.50	52.00
3	67.66	63.66	52.83	43.66	57.33	60.00	58.00	61.66
Mean	**65.44**	**65.50**	**50.79**	**44.66**	**57.22**	**59.89**	**56.72**	**57.12**
S.E.	**1.062**	**0.936**	**6.111**	**3.213**	**0.675**	**5.098**	**1.114**	**2.636**

+N: adding fertilizer

-N: not adding fertilizer

S.E: standard error

.

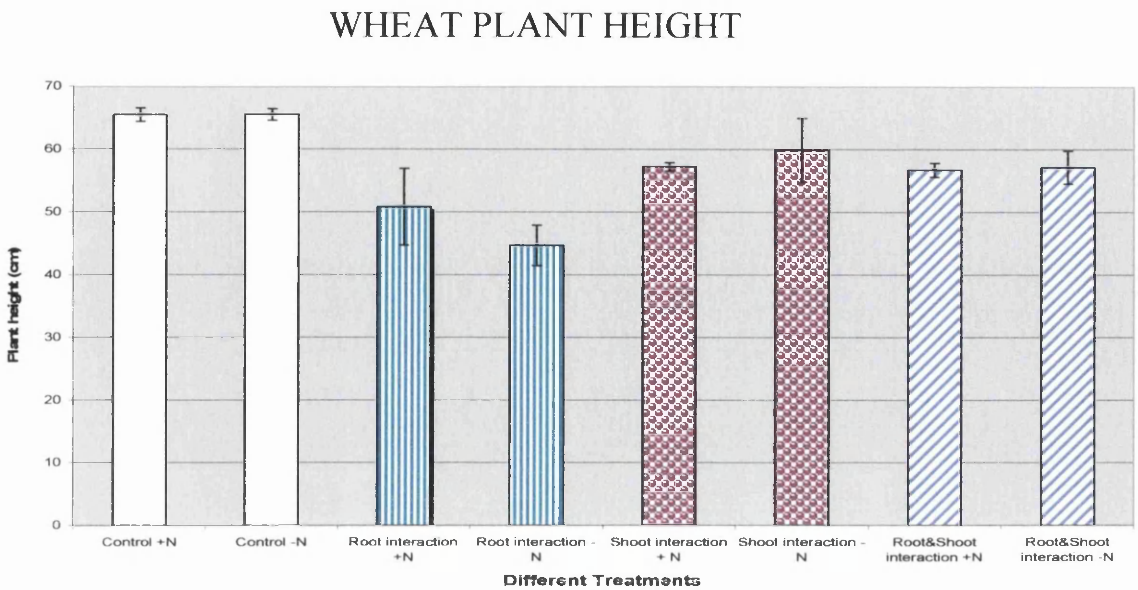


Fig. 10: Effect of *Chenopodium* interference on mean wheat plant height.
Error bars represent: Standard Errors

3-1-2 Whole-plant dry weight (wheat)

The effects of *Chenopodium* on wheat whole-plant dry weight are summarized in Table 2 and Fig. 11 which indicate that neither the blocks nor fertilizer treatments showed any significant differences ($P > 0.05$). Also competition of *Chenopodium* had no significant effect ($P>0.05$) on whole-plant dry weight of wheat in both absence and presence of fertilizer indicating no significant interaction between fertilizer and competition treatments.

Table 2:

Effects of *Chenopodium* interference on mean wheat whole-plant dry weight

WHEAT WHOLE PLANT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.544	0.687	0.449	0.322	0.460	0.290	0.372	0.396
2	0.314	0.389	0.296	0.570	0.433	0.575	0.315	0.265
3	0.459	0.404	0.319	0.305	0.394	0.575	0.386	0.381
Mean	0.439	0.493	0.3546	0.399	0.429	0.48	0.358	0.347
S.E.	0.067	0.097	0.048	0.086	0.019	0.095	0.022	0.041

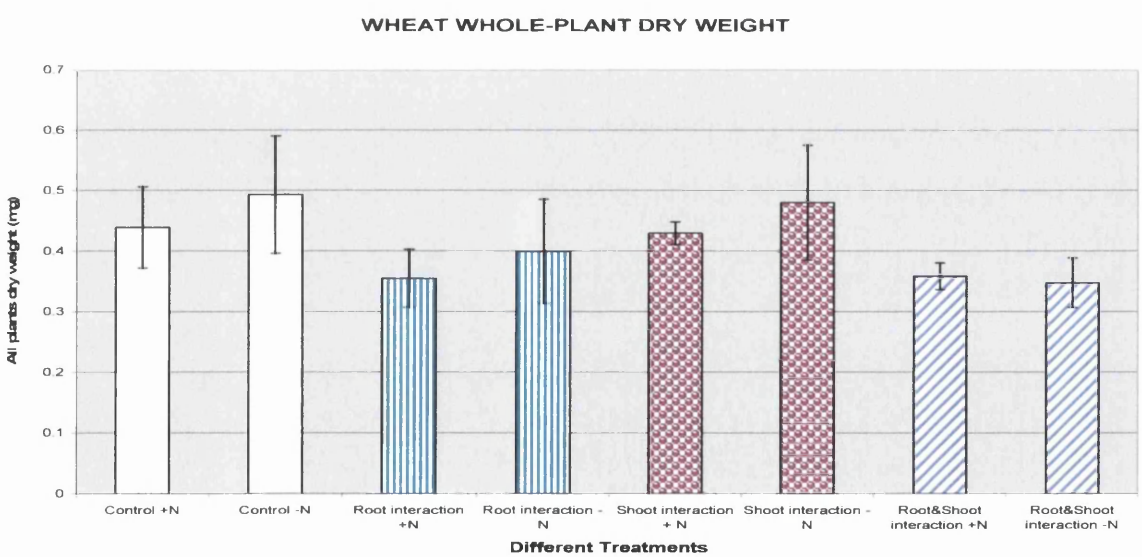


Fig. 11: Effect of *Chenopodium* interference on mean of wheat whole-plant dry weight

3-1-3 Shoot dry weight (wheat)

The results of the effect of *Chenopodium* competition on shoot dry weight of wheat plants are shown in Table 3 and Fig. 12. Analysis of variance ANOVA showed no significant effects ($P > 0.05$) due to either block or fertilizer treatment. However, the growth of wheat in the presence of *Chenopodium* was affected in that shoot dry weight of wheat plants was significantly ($P < 0.05$) reduced when roots interacted and fertilizer was added. In the absence of added fertilizer, wheat shoot dry weight was reduced significantly when only the shoots interacted. When fertilizer was added shoot interaction showed no significant differences in wheat shoot dry weight. ANOVA showed a significant ($P < 0.01$) interaction between fertilizer and competition treatments.

Table 3:

Effects of *Chenopodium* interference on mean shoot dry weight of wheat plants

WHEAT SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.475	0.43	0.354	0.513	0.416	0.288	0.374	0.411
2	0.301	0.324	0.126	0.264	0.36	0.25	0.28	0.144
3	0.419	0.472	0.127	0.355	0.349	0.195	0.344	0.344
Mean	**0.398**	**0.409**	**0.202**	**0.377**	**0.375**	**0.244**	**0.333**	**0.299**
S.E.	**0.051**	**0.044**	**0.076**	**0.073**	**0.021**	**0.027**	**0.028**	**0.080**

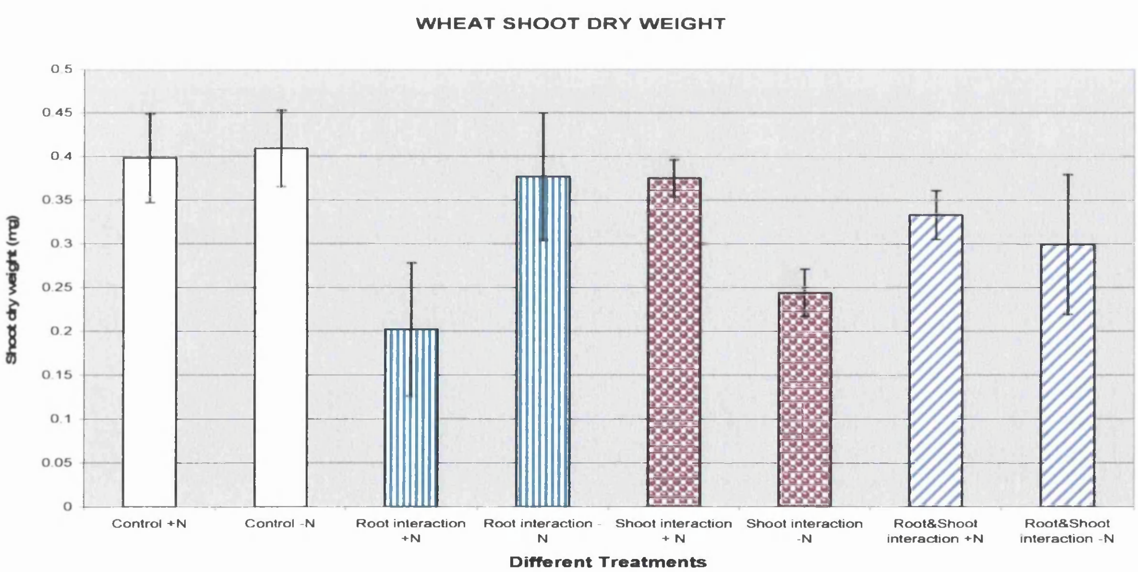


Fig. 12: Effect of *Chenopodium* interference on mean of wheat shoot dry weight

3-1-4 Root dry weight (Wheat)

The results of the effect of *Chenopodium* competition on root dry weight of wheat plants are shown in Table 4 and Fig. 13. ANOVA showed that there was no significant effect of adding the fertilizer on root dry weight of wheat plants. Competition of *Chenopodium* decreased root dry weight in wheat but this decease was not significant (P> 0.05). Also, no significant (P> 0.05) interactions between different competition treatments and fertilizer treatment were observed.

Table 4:

Effects of *Chenopodium* interference on mean root dry weight of wheat plants

WHEAT ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.296	0.242	0.122	0.123	0.154	0.141	0.120	0.143
2	0.080	0.080	0.020	0.030	0.060	0.040	0.040	0.040
3	0.050	0.011	0.090	0.050	0.105	0.090	0.090	0.070
Mean	**0.142**	**0.111**	**0.077**	**0.068**	**0.105**	**0.090**	**0.083**	**0.084**
S.E.	**0.077**	**0.069**	**0.030**	**0.028**	**0.027**	**0.029**	**0.023**	**0.030**

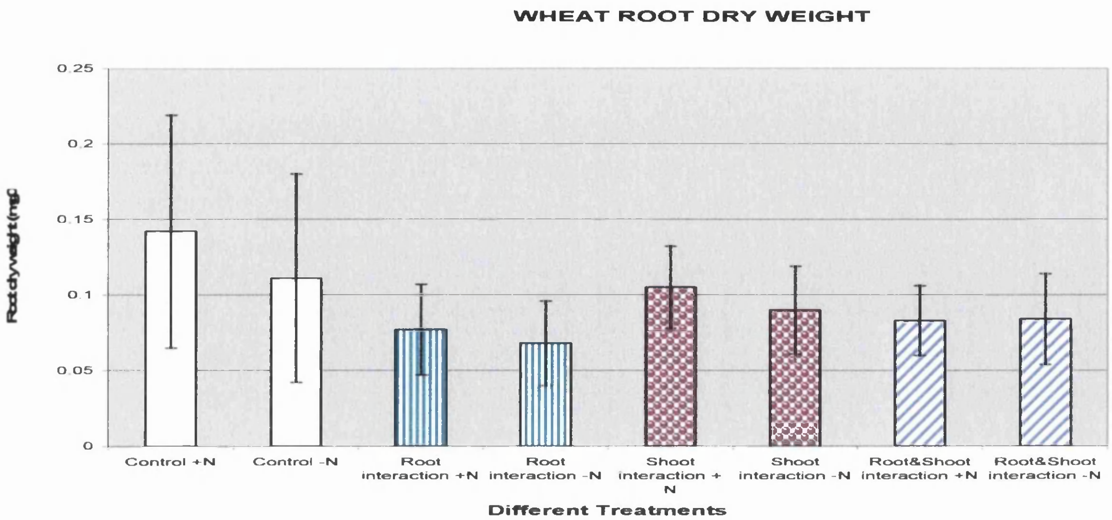


Fig. 13: Effect of *Chenopodium* interference on mean of wheat root dry weight

3-1-5 Summarized effects of *Chenopodium* on wheat

Effects of *Chenopodium* on wheat growth parameters when fertilizer was added are summarized in Table 5. Plant height of wheat plants grown in the presence of *Chenopodium* was reduced significantly in root interaction and both root and shoot interaction. Whole-plant dry weight showed no change with competition or adding the fertilizer. However, shoot dry weight was only significantly ($P < 0.05$) reduced in root interaction or both root-shoot interaction and there was a very significant ($P< 0.01$) interaction between fertilizer and competition treatments. Wheat root dry weight was statistically unchanged when grown with *Chenopodium*.

Type of interaction				
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **65.44**	b **50.79**	c **57.22**	c **56.72**
Whole- plant dry weight	a **0.44**	a **0.36**	a **0.43**	a **0.36**
Shoot dry weight	a **0.40**	b **0.20**	a **0.38**	a b **0.33**
Root dry weight	a **0.14**	a **0.08**	a **0.11**	a **0.08**

Table 5: Effect of *Chenopodium* interference on the means of wheat plant growth parameters, for significant treatment effects (ANOVA, P < 0.05). Mean values having superscript letters in common are not significant (P> 0.05). Plants Height (cm), Whole-plant dry weight (mg), Shoot dry weight (mg) and Root dry weight (mg). Data in this Table are originated from Table 1, 2, 3 and 4 and show the means of values representing different interactions with added fertilizer only.

CHAPTER 4

CHAPTER 4

RESULTS OF COMPETITION EXPERIMENTS: WHEAT

4-1 Experiment 2: Wheat *Triticum aestivum* L. Yecora Rojo versus *Chenopodium album*

4-1-1 Wheat Plant Height

The effects of *Chenopodium* interference on the height of wheat plants are recorded in Table 6 and Fig. 14. Analysis of Variance ANOVA showed that there were no significant differences ($P > 0.05$) in the wheat plant height between blocks. *Chenopodium* plants slightly decreased the height of wheat plants in all competition treatments when no fertilizer was added. However, ANOVA showed that none of the differences were significant ($P > 0.05$). The fertilizer treatment also had no significant effect ($P > 0.05$) on the height of wheat plants, although there was a slight but insignificant increase ($P > 0.05$) in plant height when the fertilizer was added in all treatments (except for root-interaction treatment, that showed a slight but insignificant decrease ($P > 0.05$) in plant height). However, ANOVA showed significant levels of wheat sensitivity to the presence of *Chenopodium* which suggests that wheat plants are less competitive compared to the weed *Chenopodium*. This wheat sensitivity was shown to be significant ($P < 0.05$) in all three treatments (root-interaction, shoot-interaction and root & shoot-interaction). As ANOVA showed no significant ($P > 0.05$, see appendix) interaction between the added fertilizer and the different types of interactions we can suggest that adding the fertilizer did not help wheat to tolerate competition with *Chenopodium*. This could be due to the fact that *Chenopodium* benefits from the extra resources more than wheat which makes the former grow well and in the mean time suppress growth of wheat either by producing chemicals that suppress directly wheat height or indirectly by stopping wheat using the extra recourses.

Table 6:
Effects of *Chenopodium* interference on wheat plant height

WHEAT PLANT HEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	36.00	35.66	31.33	30.00	34.33	35.00	35.00	36.33
2	37.30	35.66	30.00	32.00	30.00	35.31	26.00	31.00
3	38.00	36.00	30.00	33.66	39.33	35.33	35.33	36.66
Mean	**37.10**	**35.77**	**30.44**	**31.89**	**34.55**	**35.21**	**32.11**	**34.66**
S.E.	**0.59**	**0.11**	**0.44**	**1.06**	**2.70**	**0.11**	**3.06**	**1.83**

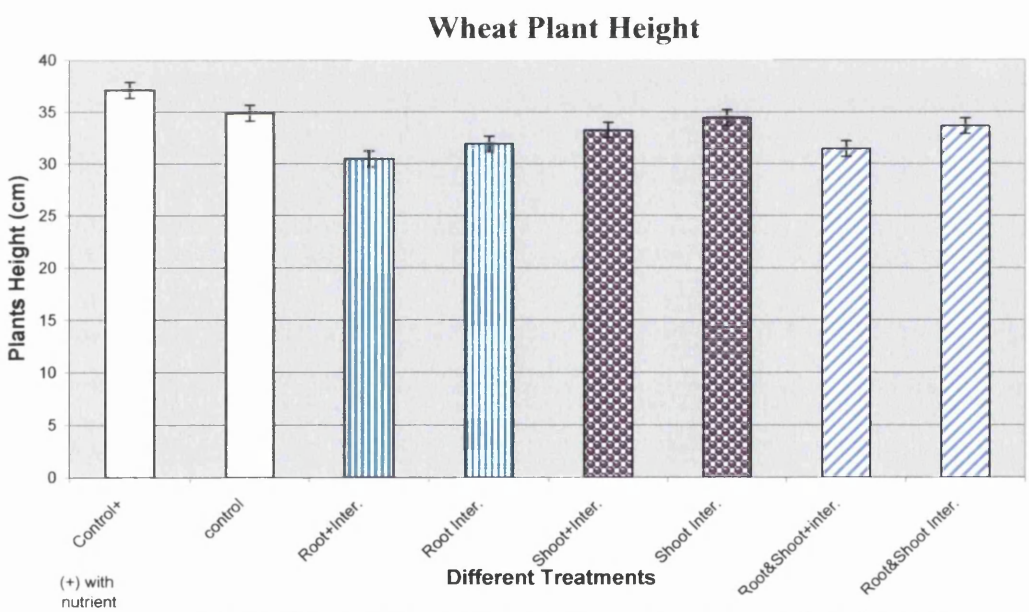


Fig. 14: Effect of *Chenopodium* interference on mean wheat plant height

4-1-2 *Chenopodium* Plant Height

The effects of wheat interference on the height of *Chenopodium* plants are recorded in Table 7 and Fig. 15. The results showed that there were no significant differences (P> 0.05) in the height of *Chenopodium* plants grown in different blocks. When grown with wheat plants, *Chenopodium* were slightly increased in height in the root-interaction treatment. In contrast, *Chenopodium* plants were decreased in height in both shoot-interaction and root & shoot-interaction treatments. ANOVA showed that different competition treatments affected *Chenopodium* significantly (P< 0.001) in plant height. This suggests that *Chenopodium* was also sensitive to the presence of wheat plants in both shoot-interaction and root & shoot-interaction but was dominant when interaction with wheat was occurring at the root system. Interaction between the fertilizer and the type of competition was not significant (P> 0.05) in any of the species when grown together.

Table 7:
Effects of wheat plant interference on *Chenopodium* plant height

Chenopodium PLANT HEIGHT(cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	57.00	58.00	67.00	71.66	59.66	54.00	55.00	56.66
2	62.33	59.00	73.00	69.00	49.00	46.00	54.00	49.66
3	58.00	53.00	71.00	72.00	51.00	49.00	47.00	53.66
Mean	**59.11**	**56.67**	**70.33**	**71.21**	**53.55**	**49.89**	**52.00**	**53.33**
S.E.	**1.64**	**1.86**	**1.76**	**1.98**	**3.13**	**2.23**	**2.52**	**2.03**

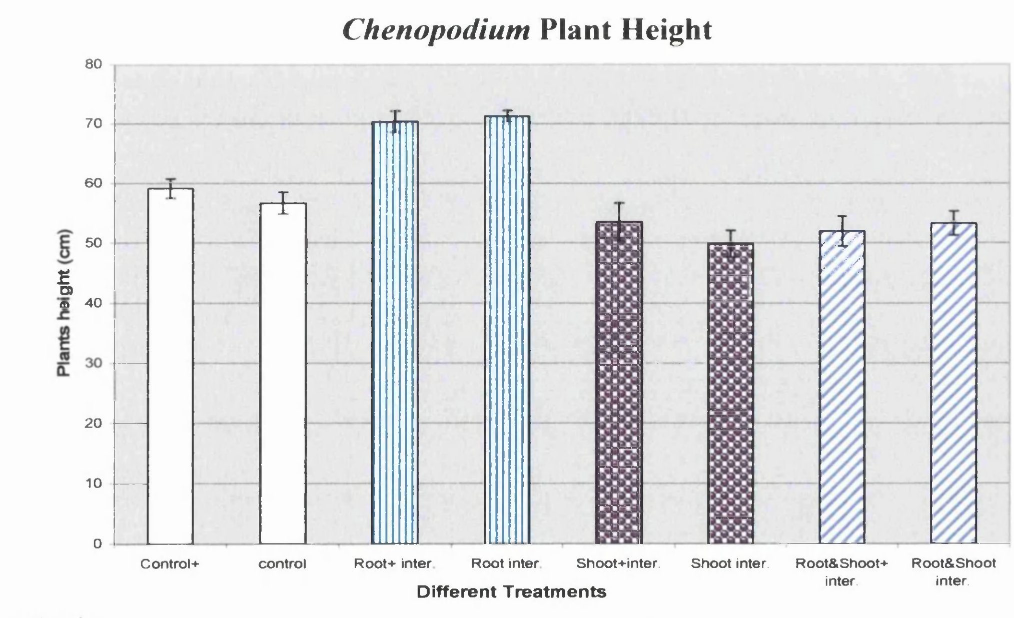
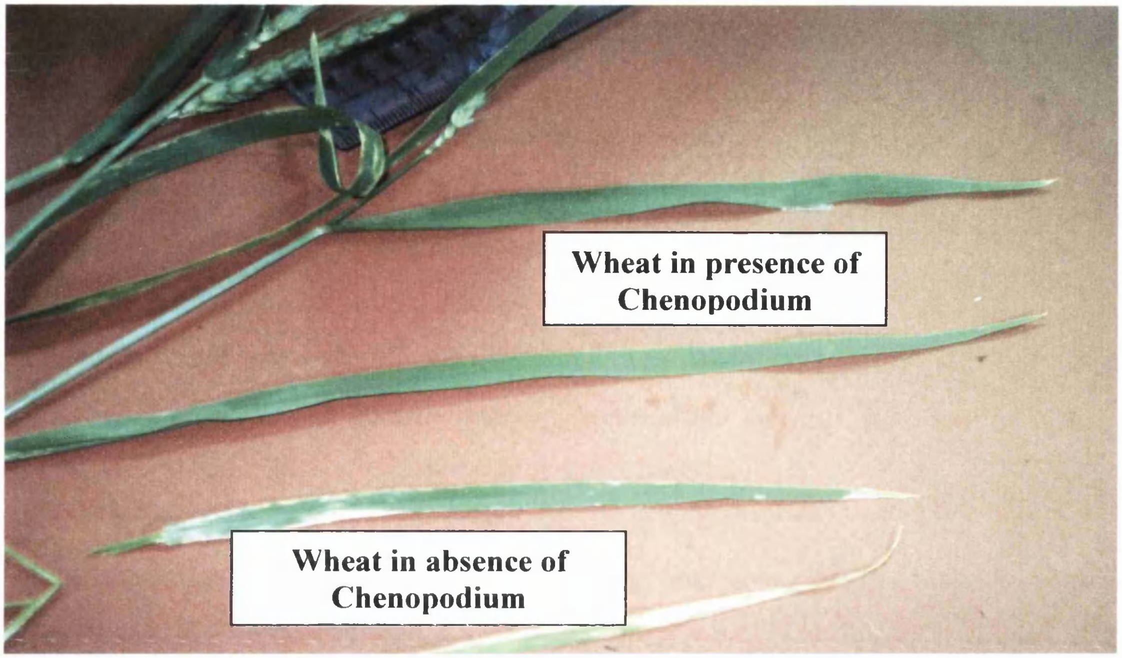


Fig. 15: Effect of wheat interference on mean *Chenopodium* plant height

Fig. 16: Effect of weed plant (*Chenopodium*) interference on wheat spike size (as compared with the control)

Fig. 17: Effect of weeds *Chenopodium* on plant height and spike size of wheat (as compared with the control)



Figs. 18-19: Leaf chlorosis due possibly to weed interference with wheat plant leaves (as compared with the control)

4-1-3 Whole-plant dry weight (Wheat)

The effects of *Chenopodium* interference on the whole-plant dry weight of wheat plants are recorded in Table 8 and Fig. 20. The results showed that no significant differences ($P > 0.05$) between blocks were detected. The fertilizer treatment had also no significant effect on the whole-plant dry weight of wheat when control was considered. However, there were significant differences ($P < 0.001$) between the controls and the different competition treatments due to *Chenopodium* interference especially at the root level as a significant level of reduction was observed at the whole-plant dry weight of wheat where *Chenopodium* interferes with wheat at under-ground level. ANOVA showed that interaction between fertilizer treatments and competition treatments were not significant ($P > 0.05$).

Table 8:
Effects of *Chenopodium* interference on wheat whole-plant dry weight

WHEAT WHOLE PLANTS DRY WEIGHT(mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.438	0.432	0.324	0.332	0.413	0.332	0.365	0.384
2	0.405	0.439	0.347	0.318	0.373	0.318	0.308	0.306
3	0.402	0.447	0.335	0.307	0.379	0.381	0.312	0.317
Mean	0.415	0.439	0.335	0.319	0.388	0.344	0.328	0.339
S.E.	**0.012**	**0.004**	**0.007**	**0.007**	**0.012**	**0.019**	**0.018**	**0.028**

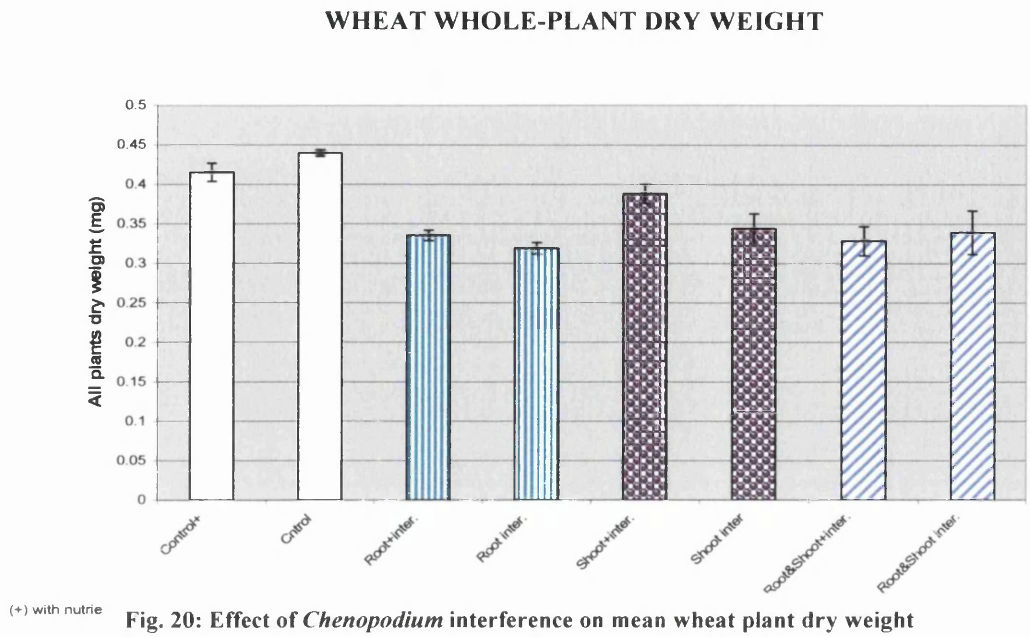
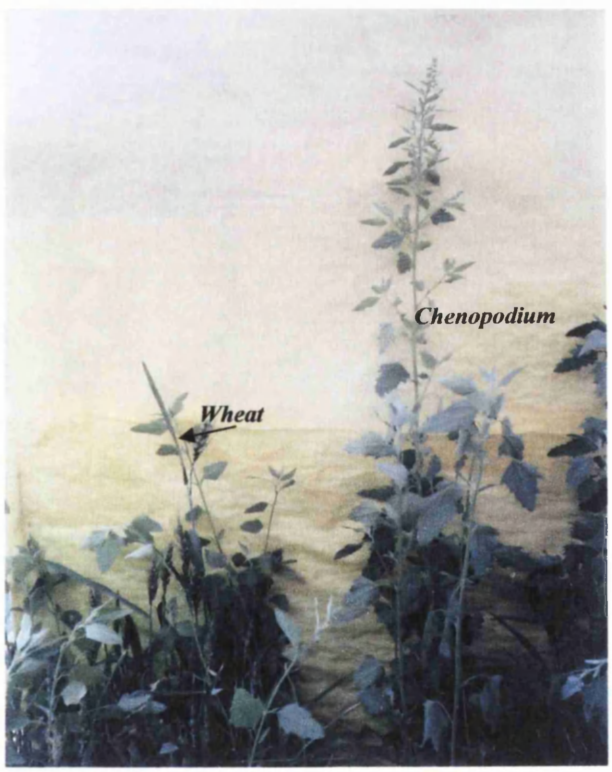


Fig. 20: Effect of *Chenopodium* interference on mean wheat plant dry weight

Figs. 21-22: Domination of *Chenopodium* plants over wheat plants



4-1-4 Whole-plant dry weight (*Chenopodium*)

The effects of wheat interference on the whole-plant dry weight of *Chenopodium* are recorded in Table 9 and Fig. 23. The results showed that no significant differences (P> 0.05) between blocks were detected. The fertilizer treatment had also no significant (P> 0.05) effect on the whole-plant dry weight of *Chenopodium* in any competition treatment as shown in the appendix (page 149).

Table 9:
Effects of wheat interference on *Chenopodium* whole-plant dry weight

***Chenopodium* WHOLE PLANT DRY WEIGHT (mg)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.685	0.645	0.843	0.997	0.657	0.697	0.856	0.749
2	0.698	0.791	0.962	0.989	0.758	0.855	0.793	0.631
3	0.692	0.621	0.983	0.949	0.669	0.715	0.704	0.633
Mean	**0.691**	**0.686**	**0.929**	**0.945**	**0.695**	**0.756**	**0.784**	**0.671**
S.E.	**0.004**	**0.044**	**0.044**	**0.048**	**0.032**	**0.049**	**0.044**	**0.039**

CHENOPODIUM WHOLE-PLANT DRY WEIGHT

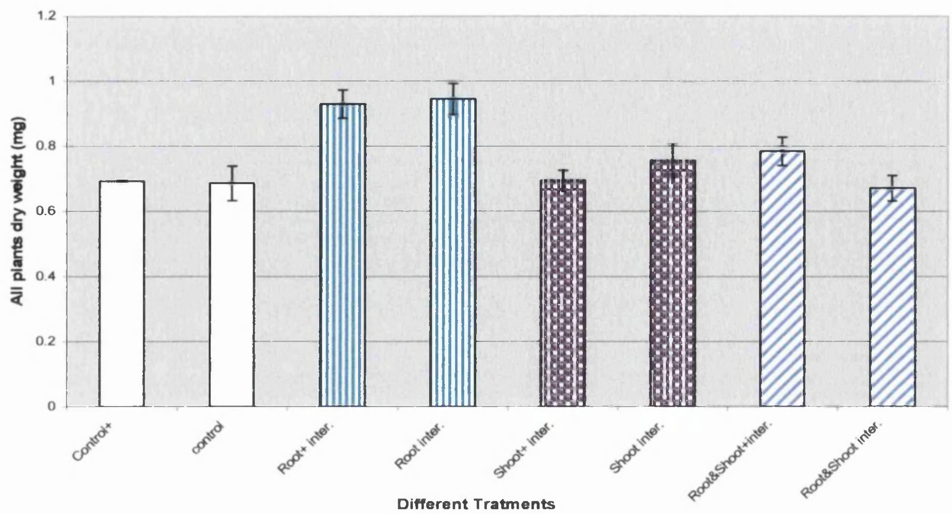


Fig. 23: Effect of Wheat interference on mean of *Chenopodium* whole-plant dry weight

4-1-5 Shoot dry weight (Wheat)

The experimental results of wheat shoot dry weight are recorded in Table 10 and Fig. 24. There were no significant differences ($P > 0.05$) between blocks, and the fertilizer treatment had also no significant effect ($P > 0.05$) on shoot dry weight of wheat. However, ANOVA showed that *Chenopodium* interference with wheat was highly significant ($P < 0.001$) especially when roots interacted. There were no significant ($P > 0.05$) differences between fertilizer treatments and any of the competition interactions.

Table 10:
Effects of *Chenopodium* interference on wheat shoot dry weight

WHEAT SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.354	0.361	0.222	0.202	0.292	0.293	0.251	0.259
2	0.323	0.352	0.232	0.243	0.287	0.273	0.221	0.253
3	0.306	0.393	0.241	0.251	0.279	0.261	0.297	0.232
Mean	0.328	0.366	0.231	0.232	0.286	0.276	0.256	0.248
S.E.	0.014	0.012	0.005	0.015	0.004	0.009	0.022	0.008

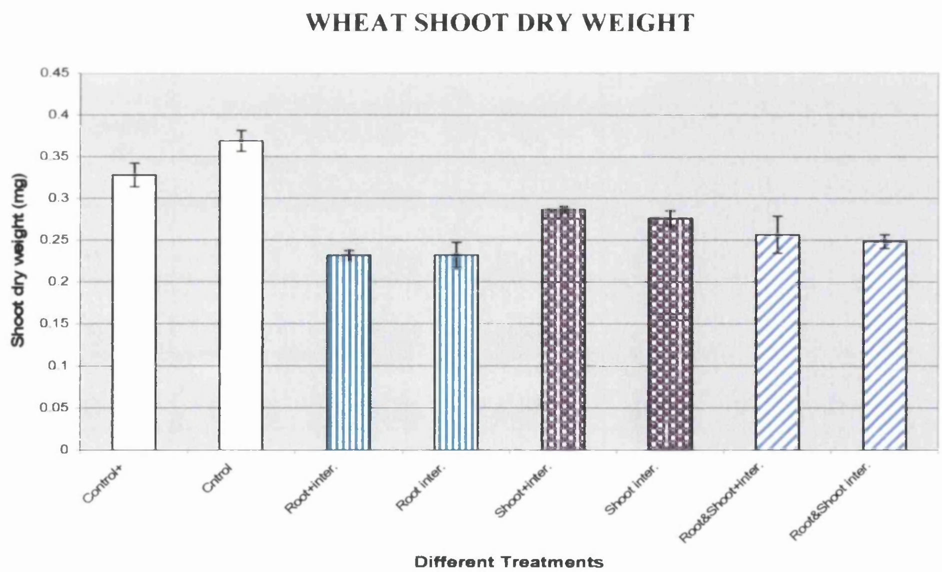


Fig. 24: Effect of *Chenopodium* interference on mean wheat shoot dry weight

4-1-6 Shoot dry weight (*Chenopodium*)

The experimental results of *Chenopodium* plants shoot dry weight are recorded in Table 11 and Fig. 25. ANOVA showed no significant differences (P> 0.05) between blocks. When control is considered, the fertilizer treatment had a highly significant (P< 0.001) effect on shoot dry weight of *Chenopodium*. Also, high significant differences (P< 0.001) due to competition treatments were observed. Root-interaction treatment was shown to significantly increase (P< 0.05) shoot dry weight in *Chenopodium*. Statistical analysis showed that the interaction between competition treatments and fertilizer treatments was insignificant (P> 0.05).

Table 11:

Effects of wheat interference on *Chenopodium* shoot dry weight

***CHENOPODIUM* SHOOT DRY WEIGHT (mg)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.498	0.473	0.693	0.645	0.495	0.453	0.687	0.463
2	0.557	0.561	0.79	0.682	0.634	0.532	0.603	0.491
3	0.589	0.491	0.756	0.626	0.465	0.422	0.595	0.529
Mean	**0.548**	**0.508**	**0.746**	**0.651**	**0.531**	**0.469**	**0.628**	**0.494**
S.E.	**0.027**	**0.027**	**0.028**	**0.016**	**0.052**	**0.032**	**0.029**	**0.019**

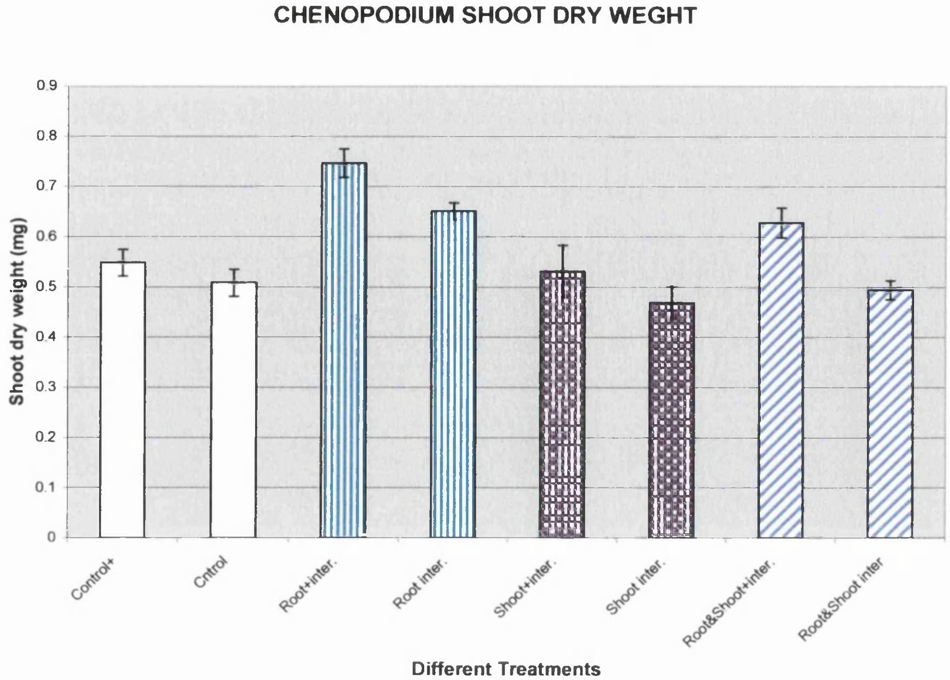


Fig. 25: Effect of wheat interference on mean *Chenopodium* shoot dry weight

4-1-7 Root dry weight (Wheat)

The effects of *Chenopodium* interference on the root dry weight of wheat plants are recorded in Table 12 and Fig. 26. The results showed no significant differences ($P > 0.05$) between blocks, and the fertilizer treatment had also no significant effect on root dry weight. However, significant differences ($P < 0.05$) due to competition with *Chenopodium* were shown by ANOVA. Root-interaction treatment had the most effect on wheat root dry weight as it was reduced dramatically whether the fertilizer was added or not. Statistical analysis showed a slight significant ($P \approx 0.06$) interaction between competition and fertilizer treatments.

Table 12:
Effects of *Chenopodium* interference on wheat root dry Weight

WHEAT ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.18	0.19	0.097	0.089	0.15	0.196	0.15	0.109
2	0.24	0.189	0.11	0.111	0.17	0.206	0.17	0.116
3	0.198	0.213	0.123	0.091	0.171	0.207	0.095	0.119
Mean	**0.206**	**0.197**	**0.11**	**0.097**	**0.164**	**0.201**	**0.138**	**0.115**
S.E.	**0.018**	**0.007**	**0.008**	**0.007**	**0.007**	**0.003**	**0.022**	**0.003**

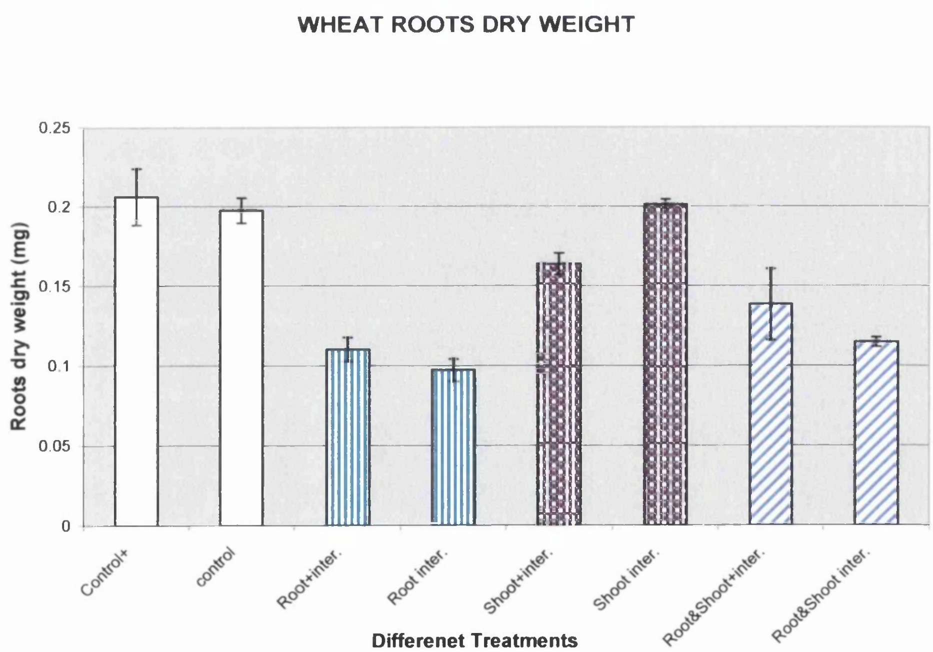


Fig. 26: Effect of *Chenopodium* interference on mean wheat root dry weight

4-1-8 Root dry weight (*Chenopodium*)

The effects of wheat interference on the root dry weight of *Chenopodium* plants are recorded in Table 13 and Fig. 27. The results showed no significant differences (P> 0.05) between blocks, and the fertilizer treatment had also no significant effect on root dry weight. However, some differences were observed due to competition with wheat plants especially at root level but ANOVA demonstrated a slight significance (P< 0.05). Interaction between competition and fertilizer was not significant (P> 0.05).

Table 13:
Effects of wheat interference on *Chenopodium* root dry Weight

***CHENOPODIUM* ROOT DRY WEIGHT (mg)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.273	0.235	0.269	0.295	0.293	0.247	0.295	0.245
2	0.249	0.278	0.297	0.298	0.281	0.292	0.238	0.243
3	0.259	0.249	0.291	0.291	0.256	0.261	0.269	0.261
Mean	0.260	0.254	0.285	0.295	0.277	0.267	0.267	0.250
S.E.	0.007	0.013	0.009	0.002	0.011	0.013	0.016	0.006

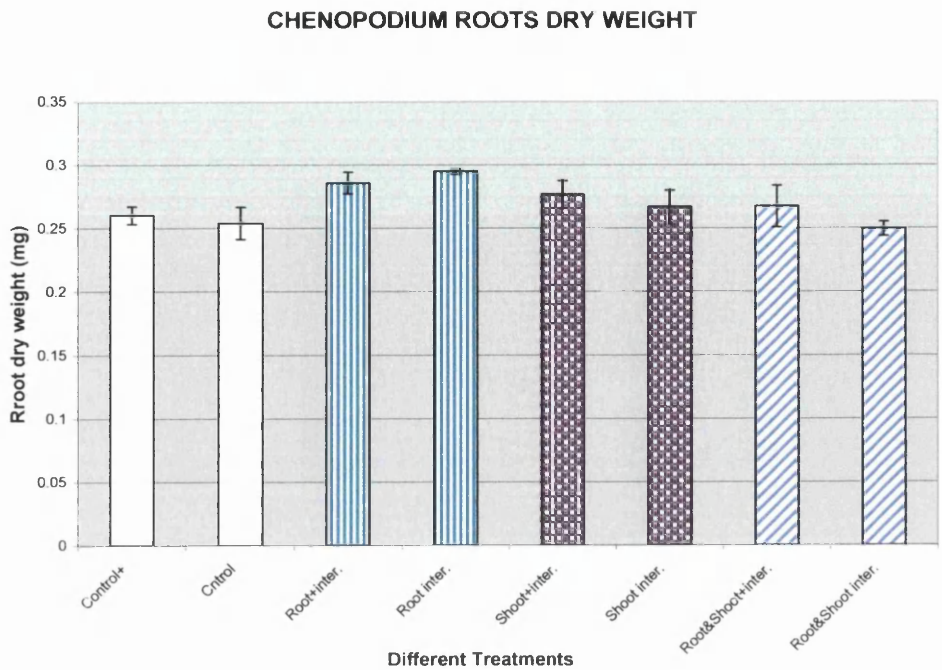


Fig. 27: Effect of wheat interference on mean *Chenopodium* root dry weight

4-1-9 Summarized effects of *Chenopodium* on wheat

Both effects of *Chenopodium* on wheat growth parameters and wheat on *Chenopodium* growth parameters are summarized in Tables 14 and 15 respectively.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **37.10**	b **30.44**	c **34.55**	bc **32.11**
Whole- plant dry weight	a **0.42**	b **0.34**	ab **0.39**	b **0.33**
Shoot dry weight	a **0.33**	b **0.23**	a **0.29**	a b **0.26**
Root dry weight	a **0.21**	b **0.11**	c **0.16**	b **0.14**

Table 14: Effect of *Chenopodium* interference on mean wheat plant growth parameters, for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); plant height (cm), whole-plant (mg), shoot dry weight (mg) and root dry weight (mg). Data in this Table are originated from

Table 6, 8, 10 and 12 and show the means of values representing different interactions with added fertilizer only.

Type of interaction				
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	^{a} **59.11**	^{b} **70.33**	^{c} **53.55**	^{ac} **52.00**
Whole- plant dry weight	^{a} **0.69**	^{b} **0.93**	^{a} **0.70**	^{ab} **0.78**
Shoot dry weight	^{a} **0.55**	^{b} **0.75**	^{a} **0.53**	^{ab} **0.63**
Root dry weight	^{a} **0.26**	^{b} **0.29**	^{ab} **0.28**	^{a} **0.27**

Table 15: Effect of wheat interference on mean *Chenopodium* plant Growth Parameters, for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); Plants height (cm), Whole-plant (mg), shoot dry weight (mg) and root dry weight (mg). Data in this Table are originated from Table 7, 9, 11 and 13 and show the means of values representing different interactions with added fertilizer only.

4-1-10 Competitive ability (aggressivity) of *Chenopodium*

Results are recorded in Table 16 and in Figs. 28, 29, 30, and 31. There were some significant differences (P< 0.05) between competition treatments indicating that plants showed higher aggressivity under root-interaction condition than under shoot-interaction and both root & shoot-interaction.

A- Aggressivity based on plant height

Chenopodium and wheat had similar competitive abilities (agressivity ≈ 0) when only shoot or both root and shoot systems interacted (Table 16 and Fig. 28), but *Chenopodium* was more competitive than wheat (P< 0.05) when the root systems interacted.

B- Aggressivity based on whole-plant dry weight

Chenopodium had a significantly higher competitive ability (P= 0.001) than wheat when only roots interacted or both shoots and roots interacted. When just the shoots interacted, *Chenopodium* showed no significant aggressivity against wheat (Table 16 and Fig. 29).

Table 16:
***Chenopodium* aggressivity against wheat plants**

Growth Parameters	Type of interaction	S.E.	Mean	Aggressivity block 1	2	3
Plant height	Root- interaction	0.019	0.18	0.15	0.18	0.22
	Shoot- interaction	0.036	-0.01	0.05	-0.01	-0.08
	Full – interaction	0.040	0.01	0.00	0.08	-0.06
Whole-plant dry weight	Root- interaction	0.014	0.27	0.25	0.26	0.29
	Shoot- interaction	0.024	0.03	0.01	0.08	0.01
	Full – interaction	0.026	0.17	0.21	0.19	0.12
Shoot dry weight	Root- interaction	0.039	0.33	0.38	0.35	0.25
	Shoot- interaction	0.055	0.05	0.08	0.12	-0.06
	Full – interaction	0.091	0.18	0.34	0.20	0.02
Root dry weight	Root- interaction	0.044	0.28	0.22	0.37	0.25
	Shoot- interaction	0.042	0.13	0.12	0.21	0.06
	Full – interaction	0.055	0.18	0.12	0.12	0.28

Chenopodium aggressivity on wheat plant height

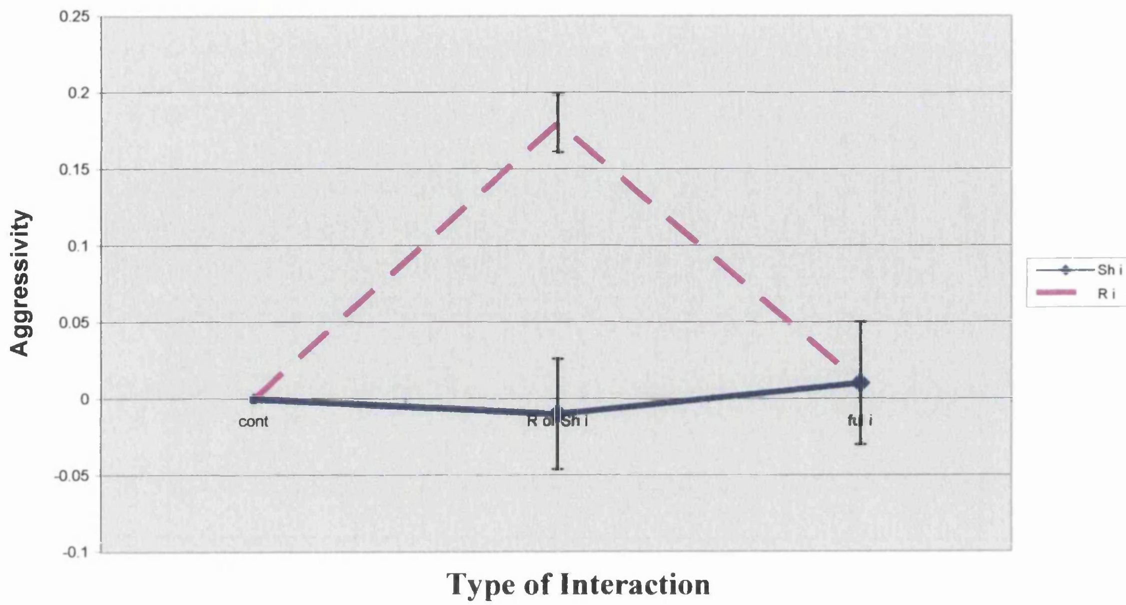


Fig. 28: *Chenopodium* aggressivity on wheat plant height

Chenopodium aggressivity on wheat whole-plant dry weight

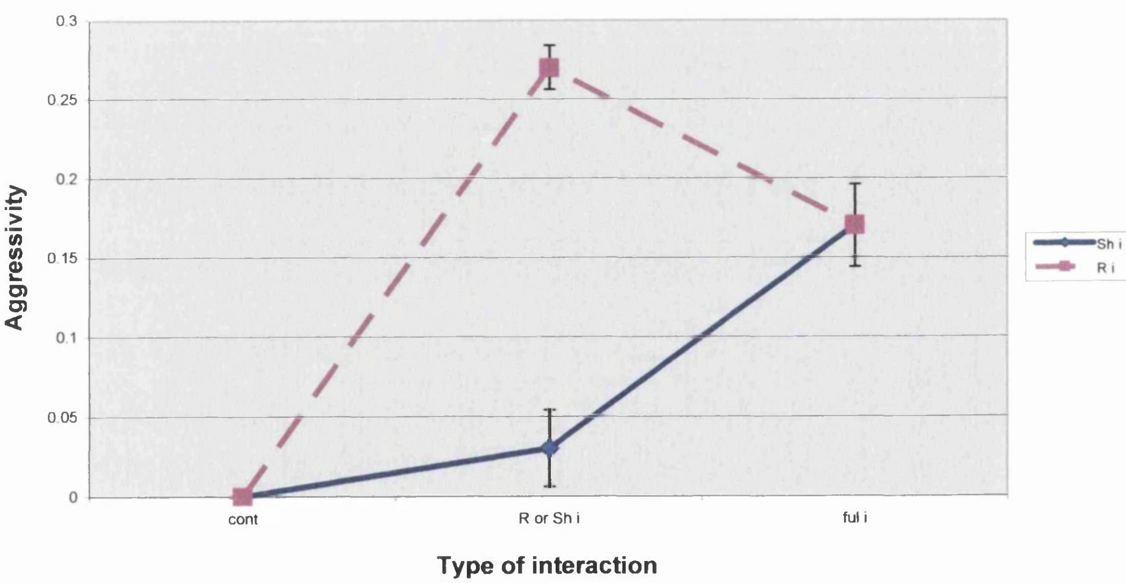


Fig. 29: *Chenopodium* aggressivity on wheat whole-plant dry weight

C- Aggressivity based on shoot dry weight

Chenopodium had a higher competitive ability than wheat in all three interactions but more when just the root systems interacted (Table 16 and Fig. 30). However, ANOVA showed no significant aggressivity ($P > 0.05$) when only the shoots or the shoots and roots interacted. In contrast, when the root systems of both *Chenopodium* and wheat interacted, *Chenopodium* was highly and significantly ($P < 0.001$) aggressive against wheat.

D- Aggressivity based on root dry weight

Chenopodium had a higher competitive ability than wheat in all three interactions but more when just the root systems or both root and shoot systems interacted (Table 16 and Fig. 31). ANOVA, showed that *Chenopodium* was significantly aggressive against wheat in all interactions but especially when roots of both *Chenopodium* and wheat interacted.

***Chenopodium* aggressivity on wheat shoot dry weight**

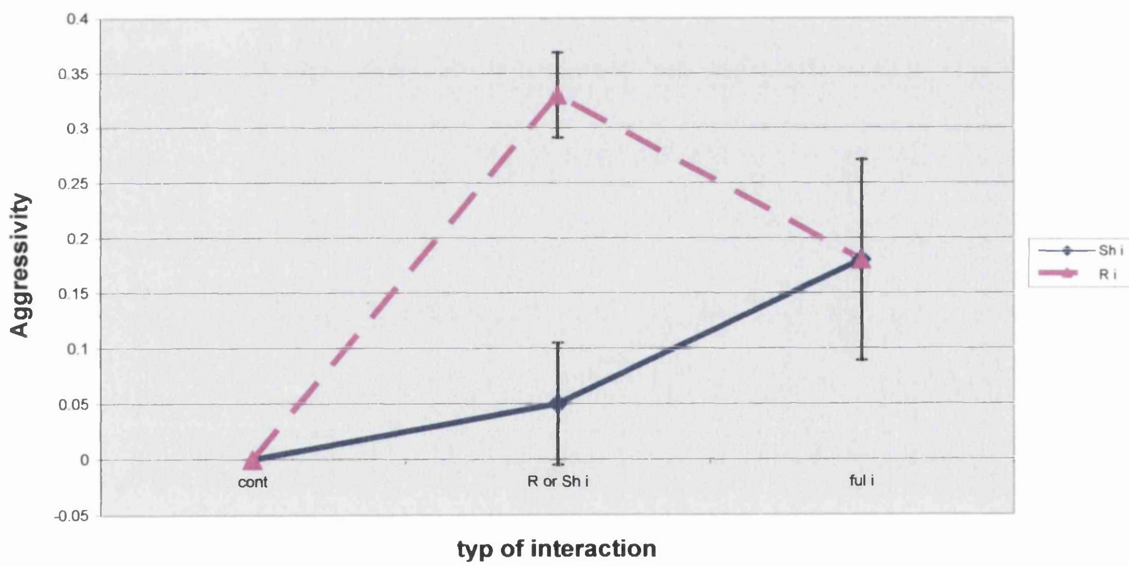


Fig. 30: *Chenopodium* aggressivity on wheat shoot dry weight

***Chenopodium* aggressivity on wheat root dry weight**

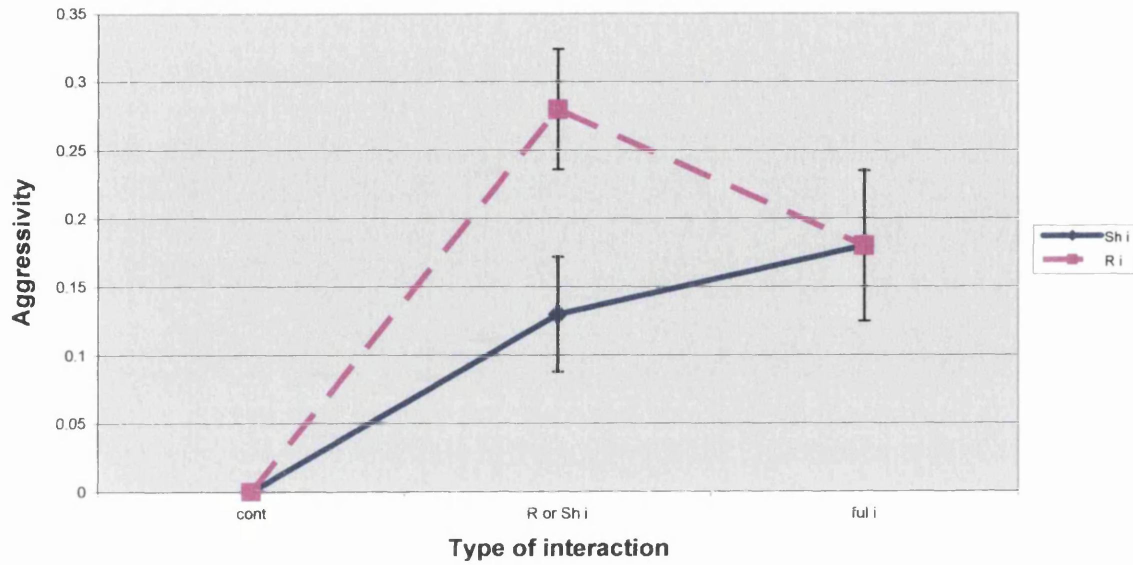


Fig. 31: *Chenopodium* aggressivity on wheat root dry weight

4-2-Experiment 3 Results: Wheat *Triticum aestivum* L. Yecora Rojo versus *Amaranthus retroflexus*

4-2-1 Plant Height (Wheat)

The effects of *Amaranthus* on wheat plant height are recorded in Table 17 and Fig. 32. The results showed no significant differences ($P > 0.05$) between blocks, and plant height did not change whether fertilizer was added or not. However, ANOVA showed that competition treatments were significantly different ($P < 0.05$). The competition of *Amaranthus* and wheat plants especially at the root system level reduced significantly ($P < 0.01$) wheat plant height in either the presence or absence of added fertilizer. However, ANOVA showed no significant ($P > 0.05$) differences between competition type and fertilizer treatments.

Table 17:
Effects of *Amaranthus* interference on wheat plant height

WHEAT PLANT HEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	67.50	69.00	65.66	66.00	67.00	69.00	68.50	68.00
2	68.00	68.50	65.00	64.50	67.50	65.50	68.00	67.00
3	69.00	68.00	66.00	65.50	68.00	67.00	68.00	67.50
Mean	68.16	68.50	65.55	65.33	67.50	67.17	68.17	67.50
S.E.	**0.44**	**0.289**	**0.294**	**0.441**	**0.289**	**1.017**	**0.167**	**0.289**

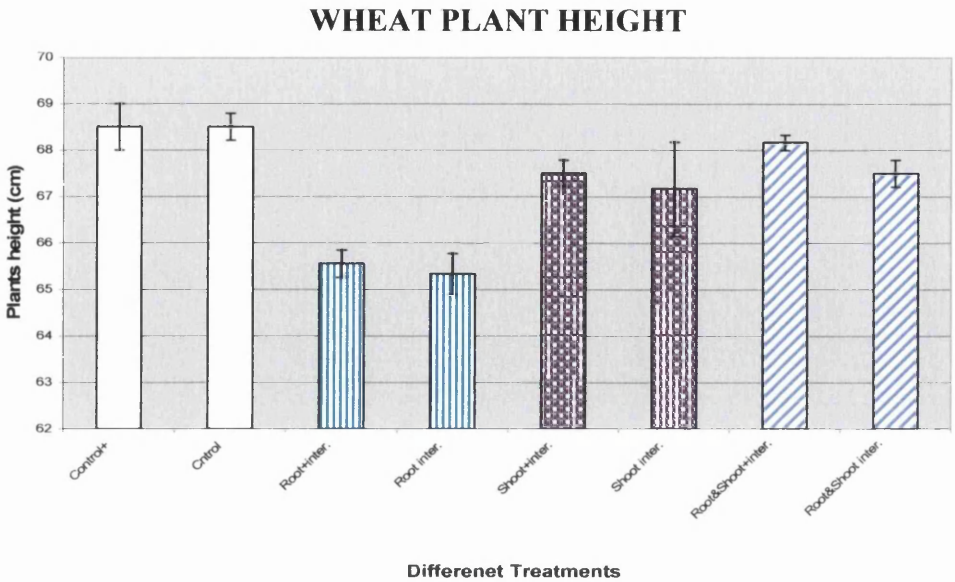


Fig. 32: Effect of *Amaranthus* interference on mean wheat plant height

4-2-2 *Amaranthus* Plant Height

The experimental results of the effect of wheat on *Amaranthus* plant height are recorded in Table 18 and Fig. 33. As in wheat, *Amaranthus* showed no significant changes ($P > 0.05$) in plant height between blocks or by adding fertilizer. However, competing with wheat in shoot-interaction or root & shoot-interaction decreased *Amaranthus* plant height slightly but significantly ($P < 0.05$). Furthermore, there were significant ($P < 0.01$) interactions between fertilizer and competition treatments. This suggests that wheat is more competitive than Amaranthus when height was used to measure competition effects.

Table 18:
Effects of wheat interference on *Amaranthus* plant height

***Amaranthus* PLANT HEIGHT (cm)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	24.66	23.33	27.66	28.66	19.66	22.66	23	17
2	27.33	21.13	25	26	20.33	23	20.33	20
3	25.66	22	26	24	18.33	21	22.66	18.5
Mean	25.88	22.15	26.22	26.22	19.44	22.22	21.997	18.5
S. E.	0.779	0.640	0.776	1.350	0.588	0.618	0.167	0.866

***AMARANTHUS* PLANT HEIGHT**

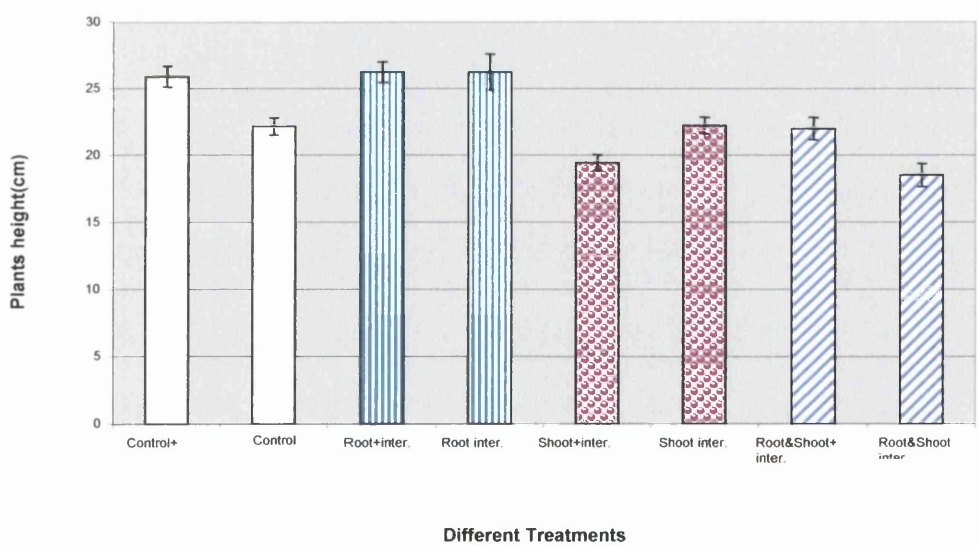


Fig. 33: Effect of wheat interference on mean *Amaranthus* plant height

4-2-3 Whole-plant dry weight (Wheat)

Results of the effects of *Amaranthus* on wheat whole-plant dry weight are shown in Table 19 and Fig. 34. Plants grown in different blocks showed no significant differences (P> 0.05) in whole-plant dry weight and added fertilizer also had no effect. In contrast, competition with *Amaranthus* significantly decreased (P< 0.001) whole-plant dry weight in wheat plants whether the interaction was below or above-ground. However, competition at root level was slightly more aggressive. There were no significant (P> 0.05) interactions between fertilizer treatments and competition treatments.

Table 19:
Effects of *Amaranthus* interference on wheat whole-plant dry weight

WHEAT WHOLE PLANT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.587	0.585	0.383	0.382	0.467	0.366	0.417	0.416
2	0.502	0.507	0.391	0.371	0.409	0.455	0.409	0.389
3	0.589	0.584	0.351	0.329	0.452	0.489	0.495	0.431
Mean	**0.560**	**0.559**	**0.375**	**0.361**	**0.443**	**0.436**	**0.440**	**0.412**
S. E.	**0.029**	**0.025**	**0.012**	**0.016**	**0.017**	**0.037**	**0.027**	**0.012**

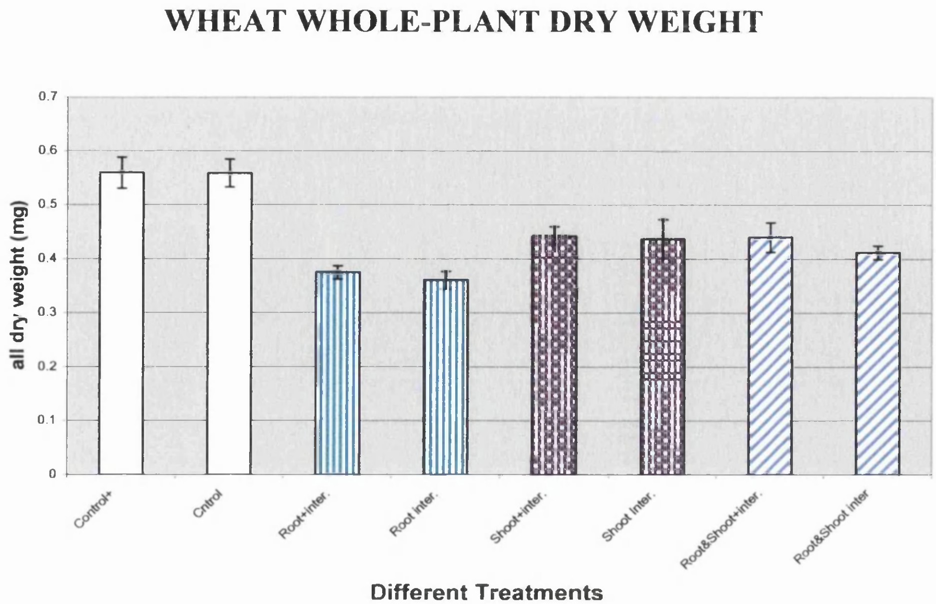


Fig. 34: Effect of *Amaranthus* interference on mean wheat whole-plant dry weight

4-2-4 Whole-plant dry weight (*Amaranthus*)

The effects of wheat on *Amaranthus* whole-plant dry weight are summarized in Table 20 and Fig. 35. No significant differences ($P > 0.05$) were observed between blocks or between the presence and absence of added fertilizer. In contrast, competing with wheat at the root system level or together at root and shoot levels significantly increased or decreased ($P < 0.001$) *Amaranthus* whole-plant dry weight respectively. The latter suggests the dominance of wheat over *Amaranthus* when competition is occurring both above and below-ground. This dominance of wheat is clearly shown in Fig 36. Statistical analyses showed no significant ($P > 0.05$) interactions between fertilizer treatments and competition treatments.

Table 20:
Effects of wheat interference on *Amaranthus* whole-plant dry weight

***Amaranthus* WHOLE-PLANT DRY WEIGHT (mg)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.314	0.325	0.364	0.359	0.292	0.295	0.261	0.269
2	0.286	0.331	0.341	0.388	0.265	0.282	0.254	0.228
3	0.304	0.314	0.391	0.396	0.274	0.277	0.262	0.302
Mean	**0.301**	**0.323**	**0.365**	**0.381**	**0.277**	**0.284**	**0.259**	**0.266**
S.E	**0.01**	**0.005**	**0.014**	**0.011**	**0.008**	**0.005**	**0.003**	**0.021**

AMARANTHUS WHOLE-PLANT DRY WEIGHT

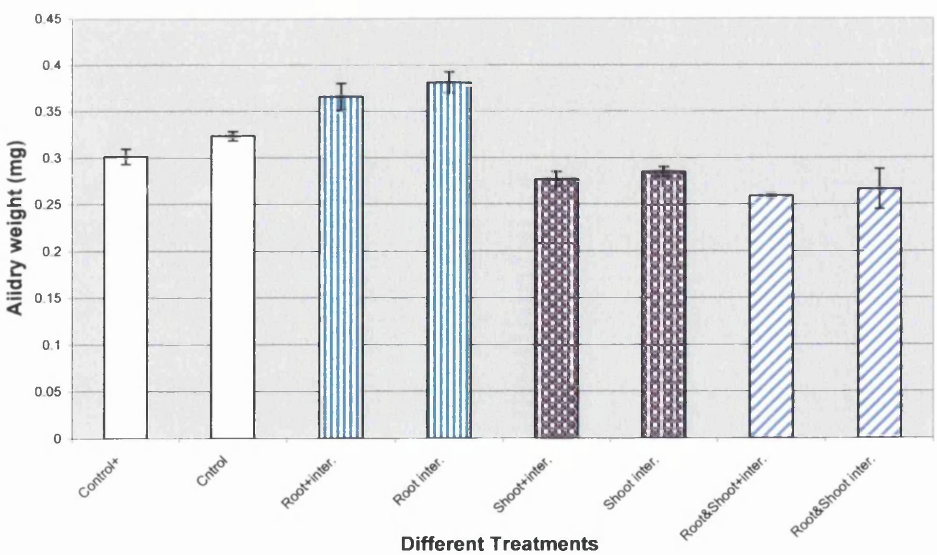


Fig. 35: Effect of wheat interference on mean *Amaranthus* whole-plant dry weight

Fig. 36: Domination of wheat plants over *Amaranthus* plants

4-2-5 Shoots Dry weight (Wheat)

Results of wheat shoot dry weight are summarized in Table 21 and Fig. 37. No significant differences (P> 0.05) were due to blocks or fertilizer treatment. However, competition with *Amaranthus* decreased significantly (P< 0.05) shoot dry weight of wheat plants in root, shoot and roots & shoot interactions. This suggests that wheat above-ground parts are sensitive to all interactions with *Amaranthus*. There were no significant (P> 0.05) interactions between fertilizer treatments and competition treatments.

Table 21:

Effects of *Amaranthus* interference on wheat shoot dry weight

WHEAT SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.395	0.397	0.298	0.286	0.318	0.321	0.293	0.297
2	0.393	0.387	0.281	0.273	0.291	0.282	0.295	0.292
3	0.398	0.397	0.296	0.295	0.306	0.301	0.285	0.309
Mean	**0.395**	**0.394**	**0.292**	**0.285**	**0.305**	**0.301**	**0.291**	**0.289**
S.E.	**0.001**	**0.003**	**0.005**	**0.006**	**0.008**	**0.011**	**0.003**	**0.012**

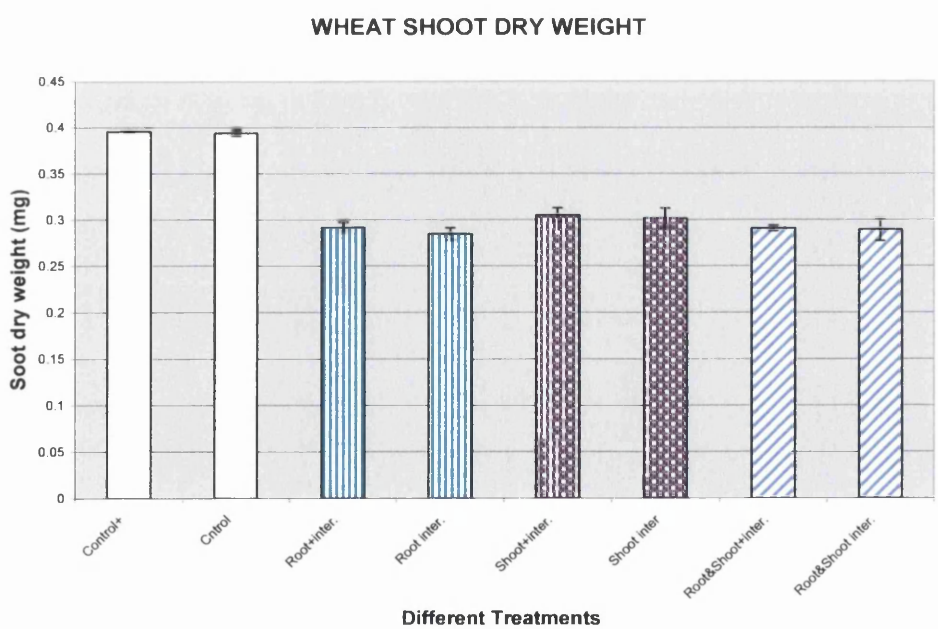


Fig. 37: Effect of *Amaranthus* interference on mean wheat shoot dry weight of

4-2-6 Shoot dry weight (*Amaranthus*)

The experimental results are recorded in Table 22, and Fig. 38. In contrast to wheat, slight unusual significant differences (P< 0.05) were observed between blocks. However, no differences were observed between fertilizer treatments. The competition treatments with wheat had significant (P< 0.01) effects on *Amaranthus* shoot dry weight. At root system level, *Amaranthus* showed an increase in shoot dry weight suggesting some level of dominance over wheat. ANOVA showed no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 22:
Effects of wheat interference on *Amaranthus* shoot dry weight

Amaranthus SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.216	0.204	0.293	0.285	0.226	0.205	0.242	0.244
2	0.212	0.205	0.282	0.258	0.183	0.202	0.256	0.183
3	0.209	0.198	0.188	0.263	0.164	0.208	0.205	0.205
Mean	**0.204**	**0.202**	**0.254**	**0.269**	**0.191**	**0.205**	**0.234**	**0.211**
S. E.	**0.004**	**0.002**	**0.033**	**0.008**	**0.018**	**0.001**	**0.015**	**0.017**

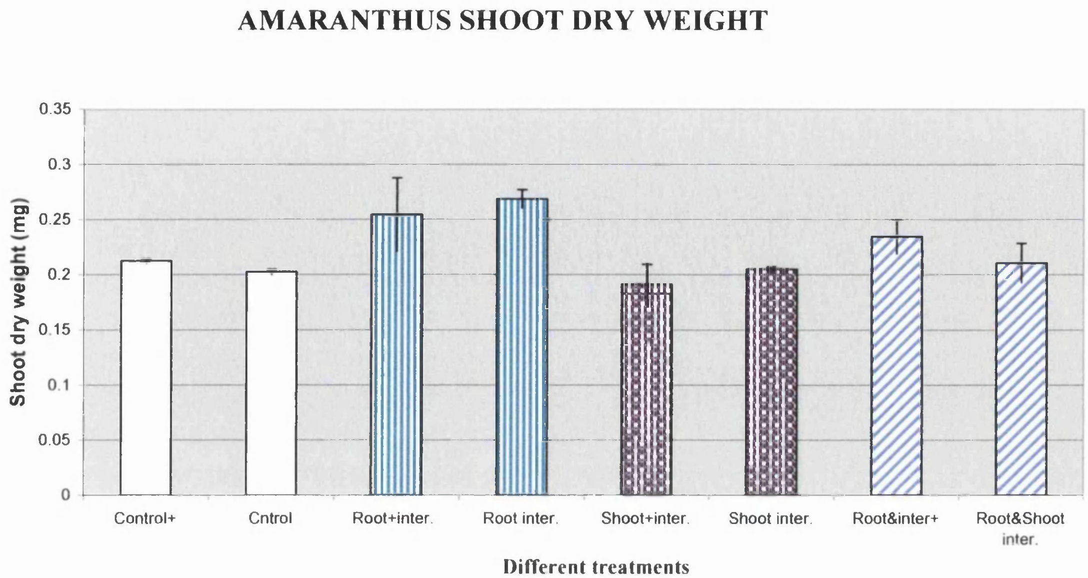


Fig. 38: Effect of wheat plant interference on mean shoot dry weight of *Amaranthus*

4-2-7 Root dry weight (Wheat)

Table 23 and Fig. 39 show the effects of *Amaranthus* on wheat root dry weight. No significant differences (P> 0.05) were observed between blocks or fertilizer treatments. Competition of *Amaranthus* with wheat in both above and below-ground interactions significantly decreased (P< 0.05) root dry weight in wheat plants. This decrease was more pronounced when root systems interacted. However, statistical analyses showed no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 23:

Effects of *Amaranthus* interference on wheat root dry weight

WHEAT ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.193	0.193	0.144	0.152	0.177	0.167	0.182	0.179
2	0.205	0.213	0.153	0.156	0.156	0.161	0.177	0.177
3	0.198	0.192	0.162	0.147	0.183	0.175	0.185	0.181
Mean	**0.199**	**0.199**	**0.153**	**0.152**	**0.172**	**0.168**	**0.181**	**0.179**
S. E.	**0.003**	**0.007**	**0.005**	**0.002**	**0.008**	**0.004**	**0.002**	**0.001**

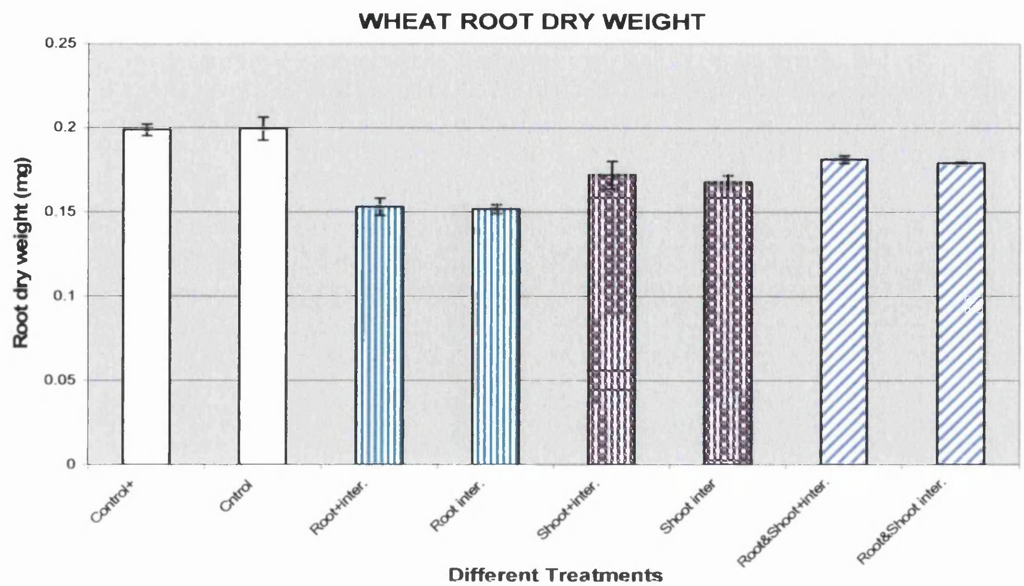


Fig. 39: Effect of Amaranthus interference on mean wheat root dry weight

4-2-8 Root dry weight (*Amaranthus*)

Table 24 and Fig. 40 summarize the effects of wheat on *Amaranthus* root dry weight. The different blocks showed unusual significant differences ($P < 0.05$). However, fertilizer treatments had no significant ($P > 0.05$) effect on root dry weight. Wheat competition had no negative effect on *Amaranthus* root dry weight. Instead, a significant increase ($P < 0.001$) was observed especially at root interaction. However, statistical analyses showed no significant ($P > 0.05$) interactions between fertilizer and competition treatments.

Table 24:
Effects of wheat interference on *Amaranthus* root dry weight

ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.124	0.124	0.174	0.172	0.151	0.151	0.153	0.151
2	0.121	0.125	0.168	0.178	0.124	0.145	0.114	0.125
3	0.122	0.118	0.168	0.163	0.151	0.115	0.115	0.104
Mean	**0.122**	**0.122**	**0.170**	**0.171**	**0.142**	**0.137**	**0.127**	**0.127**
S.E.	**0.001**	**0.002**	**0.002**	**0.004**	**0.009**	**0.011**	**0.013**	**0.014**

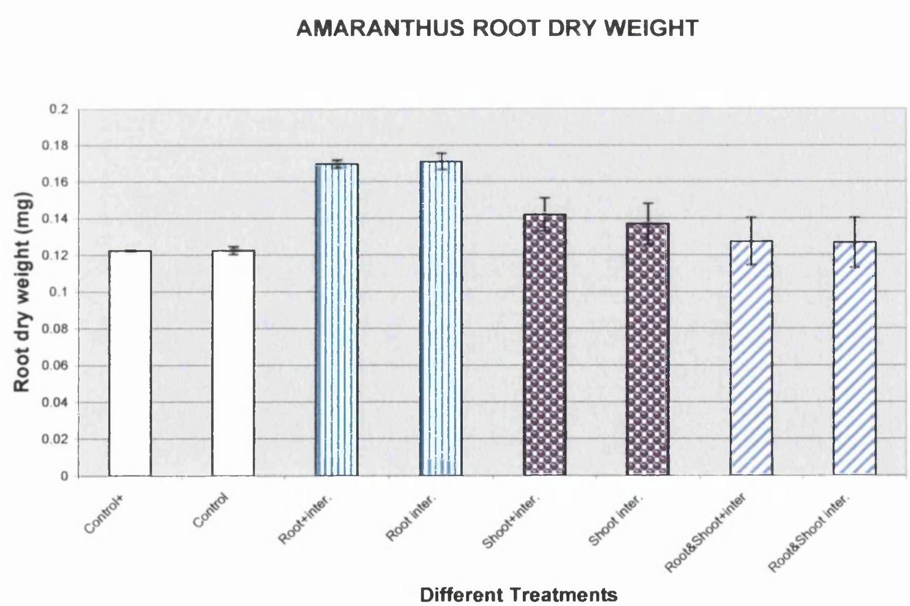


Fig. 40: Effect of Wheat interference on mean *Amaranthus* root dry weight

4-2-9 Summarized effects of wheat on *Amaranthus*

Both effects of *Amaranthus* on wheat growth parameters and wheat on *Amaranthus* growth parameters are summarized in Tables 25 and 26 respectively.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **68.2**	b **65.6**	a **67.5**	a **68.2**
Whole-plant dry weight	a **0.56**	b **0.38**	c **0.44**	bc **0.44**
Shoot dry weight	a **0.40**	b **0.29**	b **0.31**	b **0.29**
Root dry weight	a **0.20**	c **0.15**	b **0.17**	b **0.18**

Table 25: Effect of *Amaranthus* interference on mean wheat plant growth parameters, for significant treatment effects (ANOVA, $P< 0.05$) mean values having superscript letters in common are not significant ($P> 0.05$; height plants (cm), Whole-plant dry weight (mg), Shoot dry weight (mg) and Root dry weight (mg). Data in this Table are originated from Table 17, 19, 21 and 23 and show the means of values representing different interactions with added fertilizer only.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **25.88**	b **26.22**	c **19.44**	ac **22.00**
Whole- plant dry weight	a **0.30**	b **0.37**	c **0.28**	ac **0.26**
Shoot dry weight	a **0.20**	b **0.25**	a **0.19**	ab **0.23**
Root dry weight	a **0.12**	b **0.17**	ab **0.14**	a **0.13**

Table 26: Effect of wheat interference on mean *Amaranthus* plant growth parameters, for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); Plants height (cm), Whole-plant dry weight (mg), Shoot dry weight (mg) and Root dry weight (mg). Data in this Table are originated from Table 18, 20, 22 and 24 and show the means of values representing different interactions with added fertilizer only.

4-2-10 Competitive ability (agressivity) of *Amaranthus*

The results of the Competitive ability of *Amaranthus* are recorded in Table 27, and Figs (41, 42, 43 and 44). *Amaranthus* showed a significantly high aggressivity (P< 0.05) when roots of both *Amaranthus* and wheat interacted more than when shoots or both and roots + shoots interacted.

A- Aggressivity based on plants height

Amaranthus had a slightly increased competitive ability when only root systems interacted with that of wheat (Table 27 and Fig. 41). However, ANOVA showed no significant differences (P> 0.05). In contrast shoot systems interaction and both shoot & root interaction decreased significantly (P< 0.05) the competitive abilities of *Amaranthus* against wheat when the height of wheat plants were used.

B- Aggressivity based on whole-plant dry weight

Amaranthus had a significantly (P = 0.001) higher competitive ability than wheat when root or shoot systems interacted but this competitive ability was more prominent when root systems interacted (Table 27 and Fig. 42).

Table 27:

***Amaranthus* aggressivity against wheat plant**

Growth barameters	Type of interaction	S.E.	Mean	Aggressivity block 1	2	3
Plant height	Root- interaction	0.027	0.03	0.07	-0.02	0.03
	Shoot- interaction	0.011	-0.12	-0.10	-0.12	-0.14
	Full – interaction	0.027	-0.07	-0.04	- 0.13	-0.05
Whole-plant dry weight	Root- interaction	0.041	0.27	0.25	0.21	0.35
	Shoot- interaction	0.004	0.06	0.07	0.06	0.07
	Full – interaction	0.014	0.04	0.06	0.04	0.01
Shoot dry weight	Root- interaction	0.075	0.23	0.30	0.31	0.08
	Shoot- interaction	0.033	0.06	0.12	0.06	0.01
	Full – interaction	0.028	0.18	0.19	0.23	0.19
Root dry weight	Root- interaction	0.028	0.30	0.32	0.34	0.25
	Shoot- interaction	0.001	0.14	0.14	0.15	0.14
	Full – interaction	0.045	0.06	0.14	0.06	-0.06

AMARANTHUS AGGRESSIVITY ON WHEAT PLANT HEIGHT

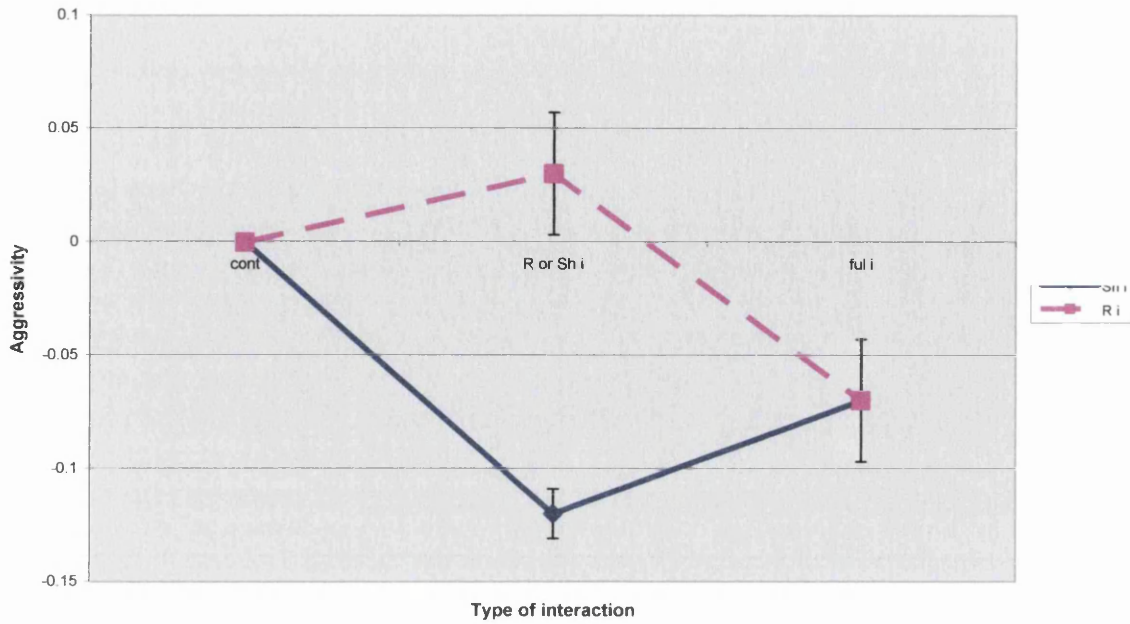


Fig. 41: *Amaranthus* aggressivity on wheat plant height

AMARANTHUS AGGRESSIVITY ON WHEAT WHOLE-PLANT DRY WEIGHT

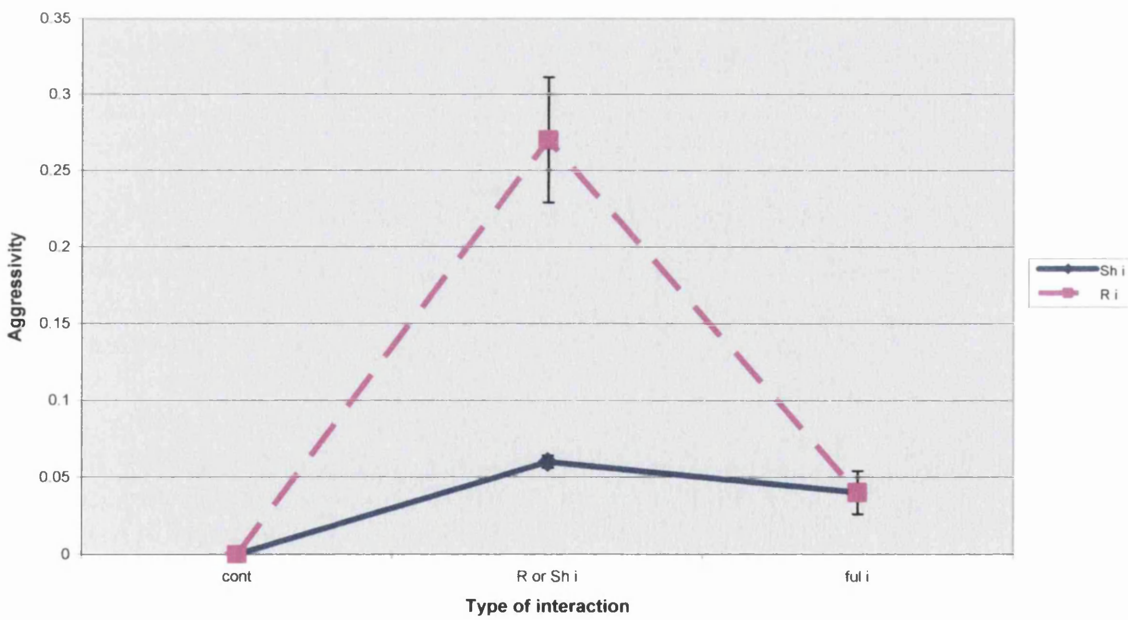


Fig. 42: *Amaranthus* aggressivity on wheat whole-plant dry weight

C- Aggressivity based on shoot dry weight

Amaranthus had generally a higher competitive ability than wheat in all three interactions but more when both shoot & root systems interacted (Table 27 and Fig. 43). However, only root systems interaction and shoot & root interaction where statistically significant ($P< 0.05$) compared to no interaction.

D- Aggressivity based on root dry weight

Amaranthus had a significantly ($P< 0.005$) higher competitive ability than wheat when only the shoot systems or root systems interacted (Table 27 and Fig. 44). Shoot competitive ability of *Amaranthus* increased dramatically in shoot or root interaction, while root competitive ability showed no significant changes ($P> 0.05$) when both shoot & root systems interacted.

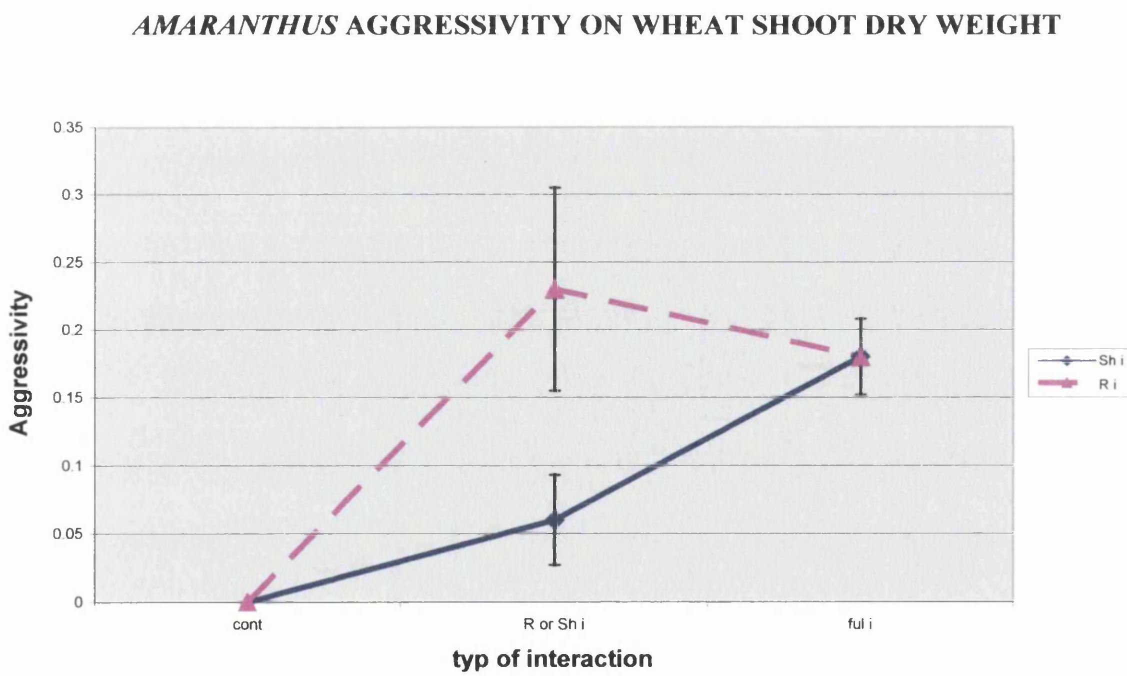


Fig. 43: *Amaranthus* aggressivity on wheat shoot dry weight

AMARANTHUS **AGGRESSIVITY ON WHEAT ROOT DRY WEIGHT**

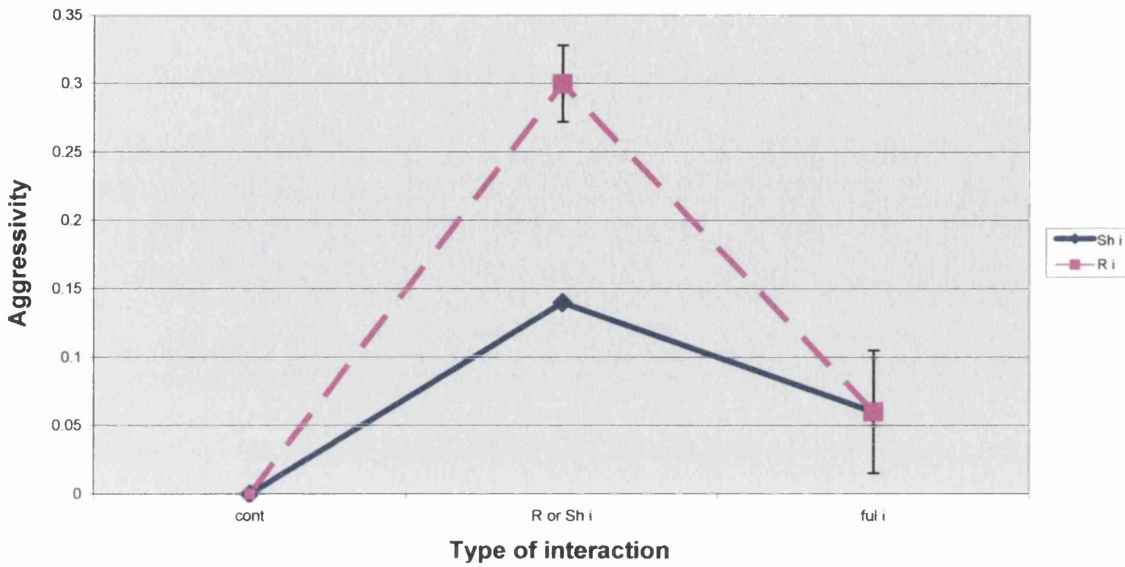


Fig. 44: *Amaranthus* aggressivity on wheat root dry weight

CHAPTER 5

CHAPTER 5

RESULTS OF COMPETITION EXPERIMENTS: BARLEY

5-1 Experiment 4: Barley *Hordeum vulgare* L. cv. Jasto versus *Amaranthus retroflexus*

5-1-1 Plant Height (barley)

The experimental results of the effects of *Amaranthus* on barley plant height are shown in Table 28 and Fig. 45. ANOVA showed no significant differences (P> 0.05) between either blocks or fertilizer treatments. However, there were some slight significant differences (P< 0.05) due to competition with *Amaranthus* in above, below-ground or both interactions. ANOVA showed that interaction between competition and adding the fertilizer produced significant differences (P< 0.05) in barley plant height.

Table 28:
Effects of *Amaranthus* interference on barley plant height

BARLEY PLANT HEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	63.00	63.00	56.00	56.00	58.00	55.00	55.00	55.00
2	60.00	61.00	57.00	57.00	59.00	54.00	56.00	56.00
3	61.00	62.00	59.00	56.00	57.00	53.00	53.00	57.00
Mean	61.33	62.00	57.33	56.33	58.00	54.00	54.66	56.00
S. E.	0.881	0.577	0.881	0.333	0.577	0.577	0.881	0.577

BARLEY PLANT HEIGHT

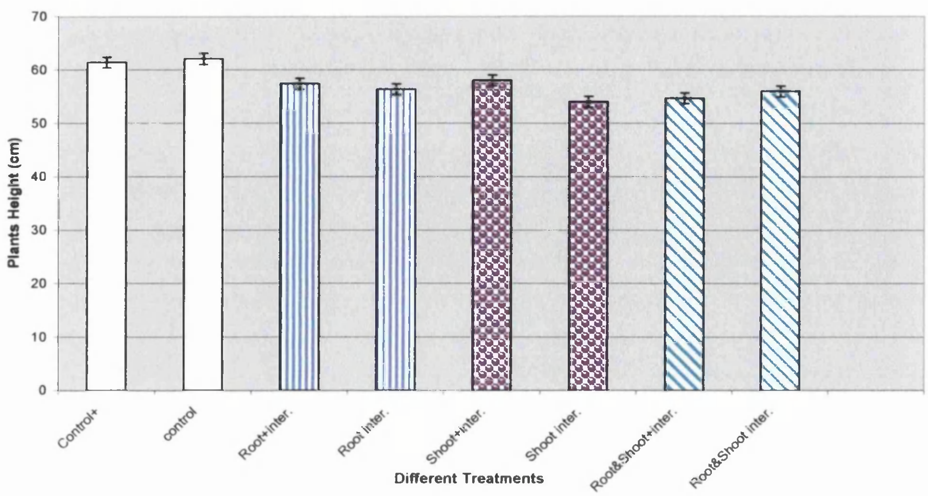


Fig. 45: Effect of *Amaranthus* interference on mean barley plant height

5-1-2 Plant Height (*Amaranthus*)

The experimental results of the effects of barley on *Amaranthus* plant height are recorded in Table 29 and Fig. 46. ANOVA showed no significant differences ($P > 0.05$) between either blocks or fertilizer treatments. However, when barley competed with *Amaranthus*, plant height of *Amaranthus* plants decreased significantly ($P < 0.01$) in all competition interactions when the fertilizer was added. Interaction between competition treatments and adding the fertilizer was not significant ($P > 0.05$).

Table 29:
Effects of barley interference on *Amaranthus* plant height

***AMARANTHUS* PLANT HEIGHT (cm)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	42.00	39.00	39.00	40.00	41.00	41.00	40.00	35.00
2	43.00	41.00	44.00	41.00	42.00	39.00	39.00	39.00
3	45.00	40.00	39.00	39.00	39.00	37.00	33.00	37.00
Mean	**43.33**	**40.00**	**40.66**	**40.00**	**40.66**	**39.00**	**37.33**	**37.00**
S. E.	**0.881**	**0.577**	**1.666**	**1.577**	**0.881**	**1.154**	**2.185**	**1.154**

***AMARANTHUS* PLANT HEIGHT**

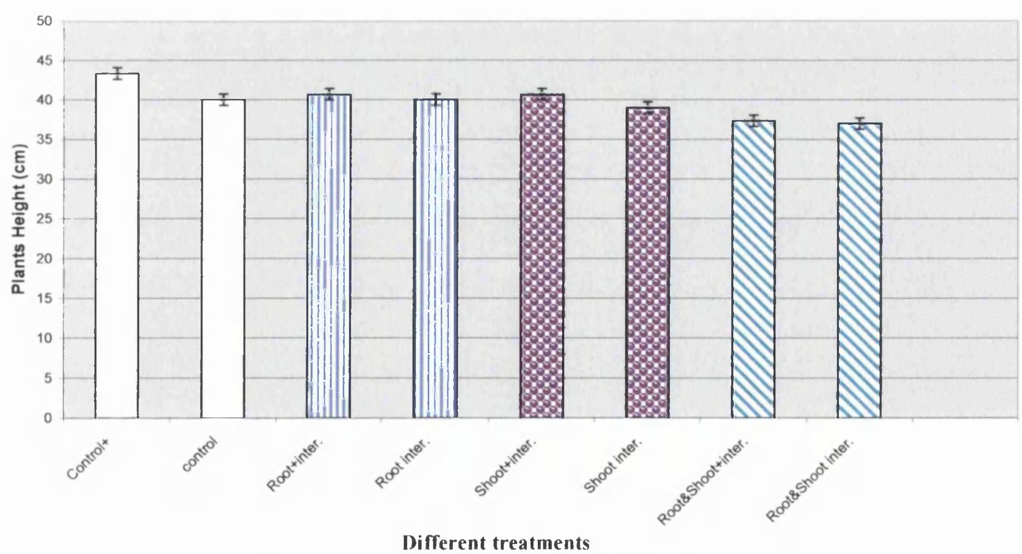


Fig. 46: Effect of barley interference on mean *Amaranthus* plant height

5-1-3 Whole-plant dry weights (Barley)

The experimental results for the effects of *Amaranthus* on barley whole-plant dry weight are recorded in Table 30 and Fig. 47. ANOVA showed no significant differences (P> 0.05) between blocks or fertilizer treatments. When barley was grown with *Amaranthus*, no significant decrease (P> 0.05) in barley whole-plant dry weight was observed whether the fertilizer was added or not. Furthermore, there were no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 30:

Effects of *Amaranthus* interference on barley whole-plant dry weight

BARLEY WHOLE PLANTS DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.8957	0.8966	0.8813	0.7601	0.9113	0.7005	0.7805	0.6508
2	0.9875	0.9735	0.9312	0.8157	0.7204	0.6729	0.6975	0.7981
3	0.7756	0.9857	0.8127	0.7932	0.8933	0.9785	0.9753	0.7911
Mean	**0.886**	**0.951**	**0.8751**	**0.7897**	**0.8417**	**0.7839**	**0.8178**	**0.7467**
S. E.	**0.061**	**0.027**	**0.034**	**0.016**	**0.060**	**0.097**	**0.082**	**0.047**

BARLEY WHOLE-PLANT DRY WEIGHT

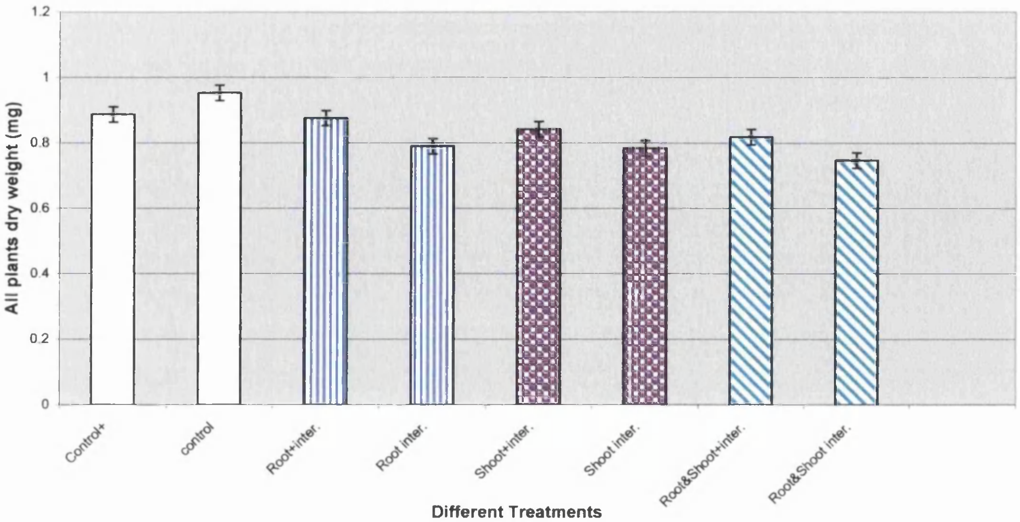


Fig. 47: Effect of *Amaranthus* interference on mean barley whole-plant dry weight

5-1-4 Whole-plant dry weight (*Amaranthus*)

Amaranthus whole-plant dry weights are shown in Table 31 and Fig. 48. ANOVA showed no significant differences (P> 0.05) between blocks or fertilizer treatments. Competition with barley lowered *Amaranthus* whole-plant dry weight in all interactions. This effect was more pronounced when both shoot and root systems interacted and especially when no fertilizer was added. However, all differences were not statistically different (P> 0.05). Interaction between competition and fertilizer treatments slightly but significantly (P= 0.05) lowered whole-plant dry weight.

Table 31:
Effects of barley interference on *Amaranthus* whole-plant dry weight

AMARANTHUS WHOLE-PLANT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.5973	0.4759	0.5478	0.3389	04537	0.3691	0.3693	0.2997
2	0.4885	0.3985	0.3023	0.5021	0.4491	0.3721	0.2991	0.325
3	0.3987	0.5037	0.4217	0.3521	0.3977	0.4112	0.5113	0.3079
Mean	**0.494**	**0.459**	**0.4239**	**0.3977**	**0.4335**	**0.3841**	**0.3932**	**0.3199**
S. E.	**0.057**	**0.031**	**0.070**	**0.052**	**0.017**	**0.013**	**0.062**	**0.162**

***AMARANTHUS* WHOLE-PLANT DRY WEIGHT**

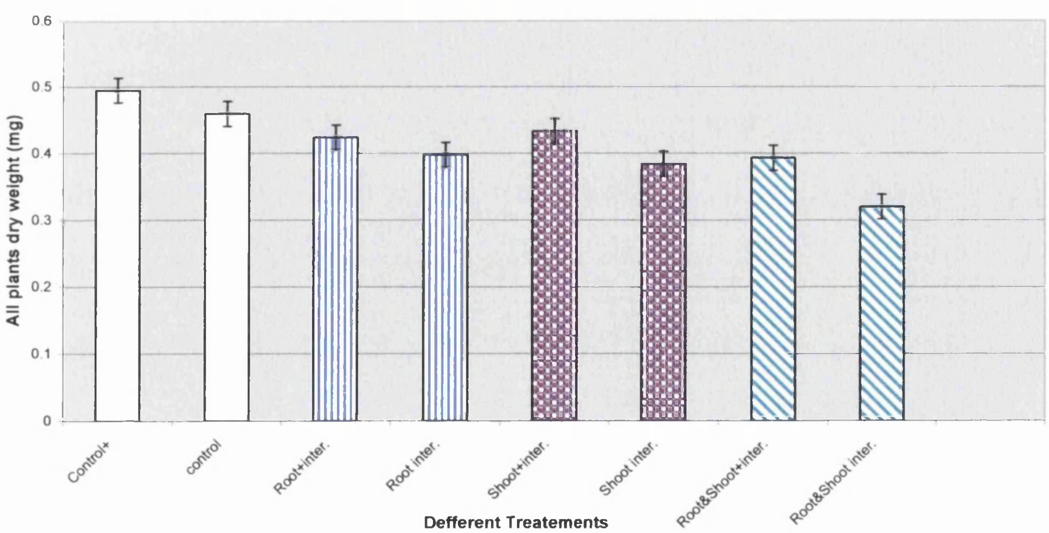


Fig. 48: Effect of barley interference on mean *Amaranthus* whole-plant dry weight

5-1-5 Shoot dry weight (Barley)

The effects of *Amaranthus* on barley shoot dry weight are recorded in Table 32 and Fig. 49. No significant differences (P> 0.05) were found between blocks or fertilizer treatments. However, different competition treatments by *Amaranthus* decreased barley shoot dry weight significantly (P= 0.01). When both shoots and roots interacted, the effect of *Amaranthus* was greater on barley shoot dry weight. There were no significant (P> 0.05) interactions between fertilizer and competition treatments.

It was also observed that *Amaranthus* competition, caused chlorosis of barley leaves as shown in Fig 50, likely have had an impact on dry matter accumulation.

Table 32:
Effects of *Amaranthus* interference on barley shoot dry weight

BARLEY SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.378	0.457	0.3739	0.2987	0.328	0.3451	0.3162	0.3245
2	0.453	0.387	0.3517	0.4795	0.3278	0.3220	0.2985	0.2798
3	0.396	0.402	0.3357	0.3303	0.3751	0.2970	0.3357	0.3117
Mean	0.409	0.415	0.3544	0.3695	0.3452	0.3214	0.3166	0.3053
S. E.	0.022	0.021	0.011	0.055	0.015	0.013	0.010	0.0130

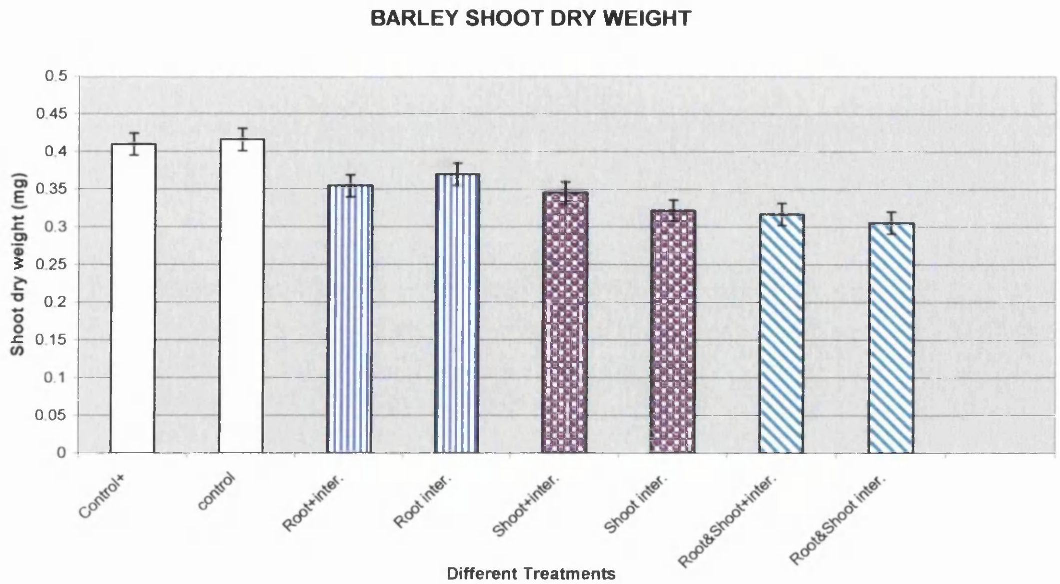


Fig. 49: Effect of *Amaranthus* on mean barley shoot dry weight

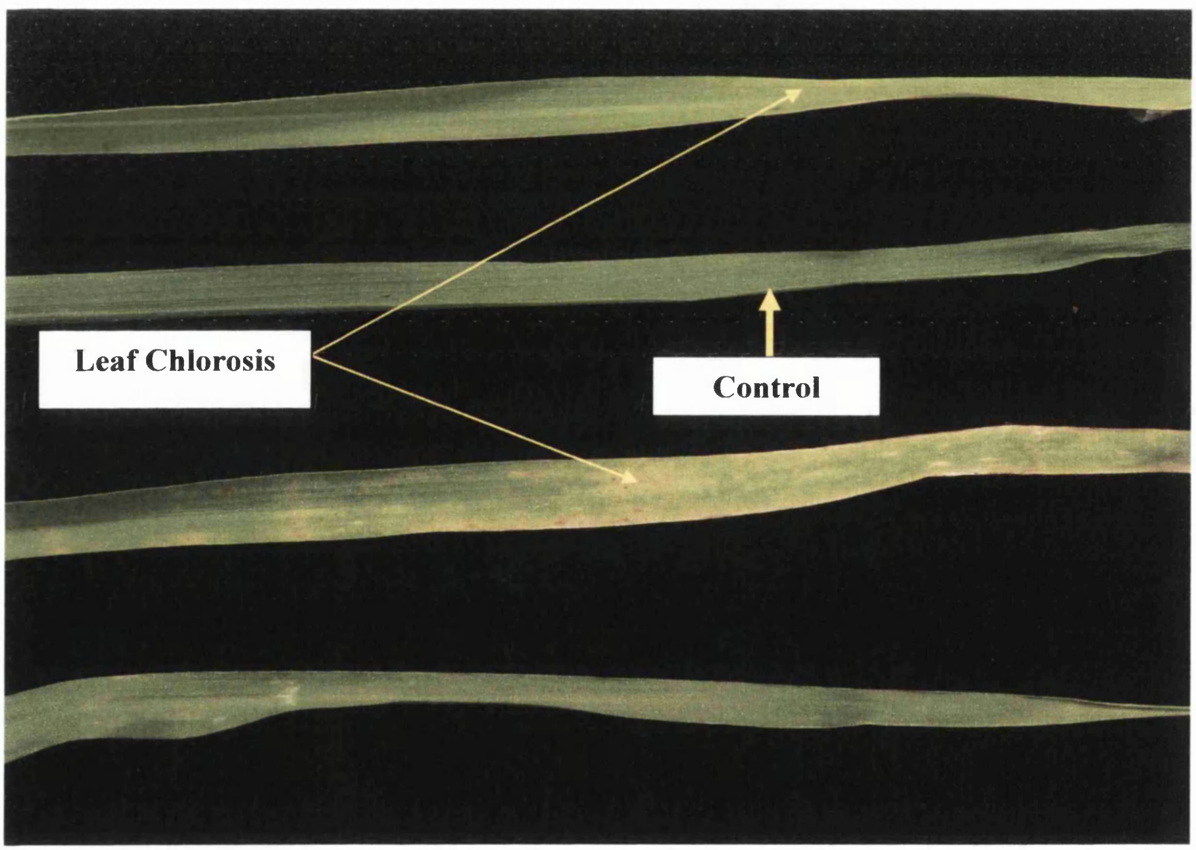


Fig. 50: Leaf chlorosis due to weed interference on barley plant leaves (as compared with control)

5-1-6 Shoot dry weight (*Amaranthus*)

The experimental results of the effects of barley on *Amaranthus* shoot dry weights are recorded in Table 33 and Fig. 51. ANOVA showed no significant differences (P> 0.05) between blocks or fertilizer treatments. Also, no significant differences (P> 0.05) due to competition were found. There were no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 33:
Effects of barley interference on *Amaranthus* shoot dry weight

Amaranthus SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.3459	0.2952	0.3148	0.3021	0.2925	0.3012	0.2637	0.2486
2	0.2748	0.3752	0.2983	0.2793	0.2842	0.2791	0.2985	0.3312
3	0.3962	0.3103	0.3021	0.2935	0.3002	0.2353	0.3662	0.2246
Mean	0.3390	0.3269	0.3050	0.2916	0.2923	0.2719	0.3095	0.2681
S. E.	0.035	0.024	0.004	0.006	0.004	0.030	0.030	0.032

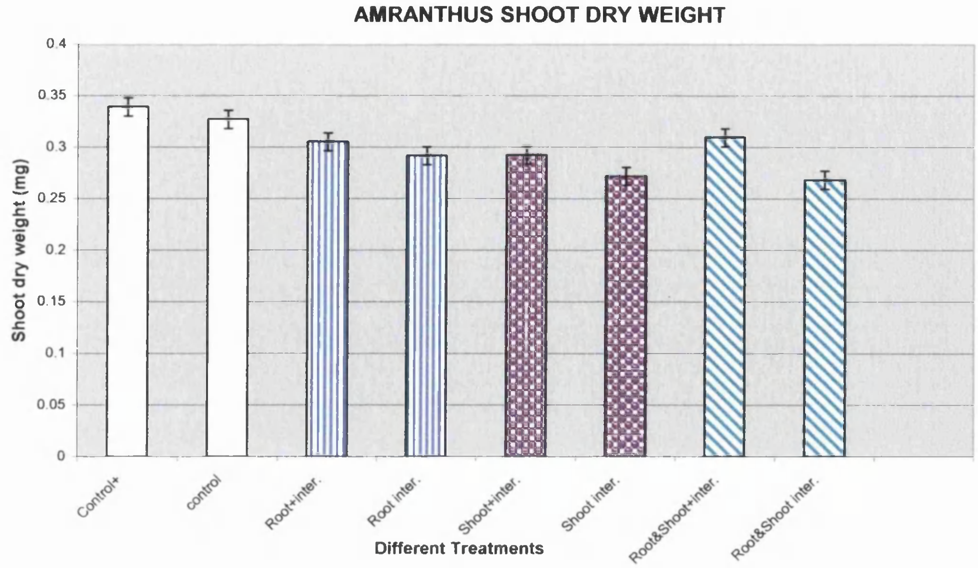


Fig. 51: Effect of barley on mean *Amaranthus* shoot dry weight

5-1-7 Root dry weight (Barley)

Table 34 and Fig. 52a show the effect of *Amaranthus* on barley root dry weight. No significant differences (P> 0.05) between blocks or fertilizer treatments were observed. However, *Amaranthus* was found to lower significantly (P< 0.01) barley root dry weight when both *Amaranthus* and barley competed at the root system level. Also Figs. 52b and 52c demonstrate how the root system is affected when both *Amaranthus* and barley competitively grow together. There were no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 34:
Effects of *Amaranthus* interference on barley root dry weight

BARLEY ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.1977	0.1875	0.1533	0.1761	0.1895	0.2105	0.1489	0.1977
2	0.2001	0.2791	0.1379	0.1531	0.2173	0.1874	0.1765	0.1832
3	0.2395	0.2014	0.1758	0.1642	0.2073	0.2003	0.1987	0.2013
Mean	**0.2124**	**0.2226**	**0.1556**	**0.1644**	**0.2047**	**0.1994**	**0.1747**	**0.1940**
S .E.	**0.013**	**0.028**	**0.011**	**0.006**	**0.008**	**0.006**	**0.014**	**0.005**

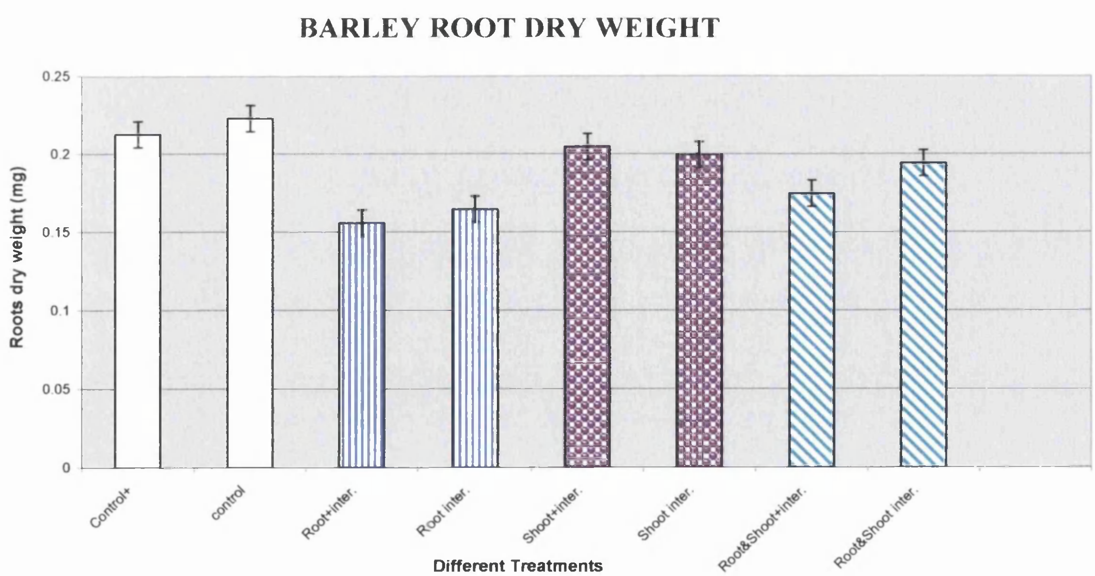
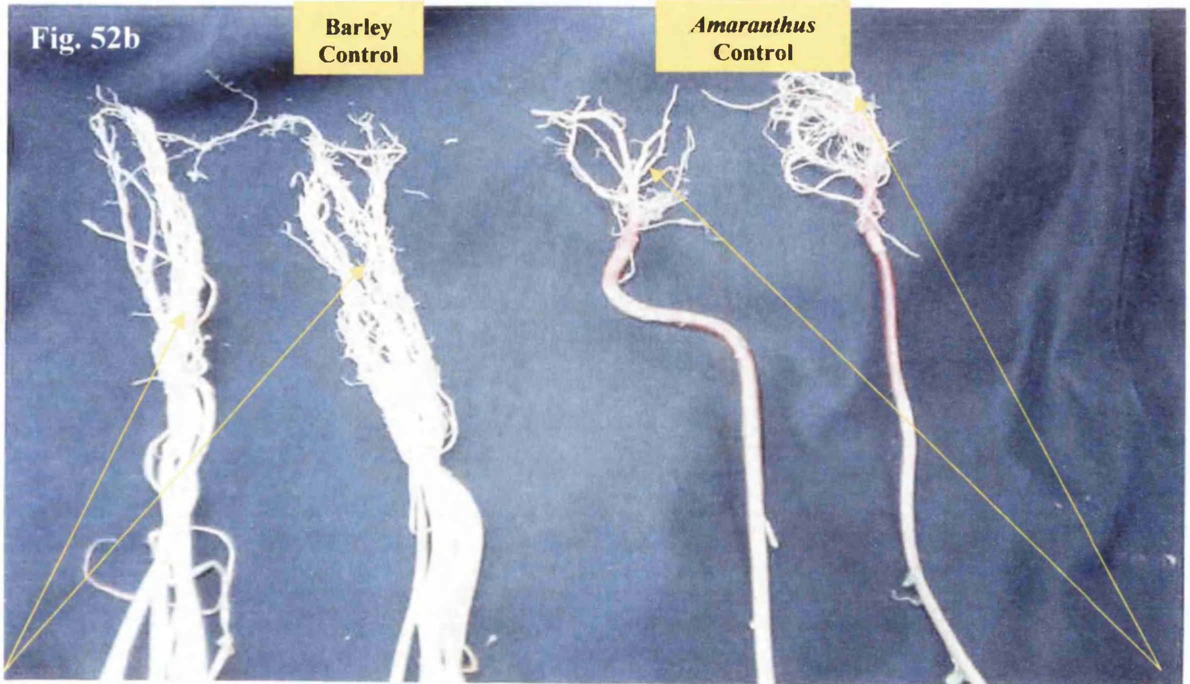
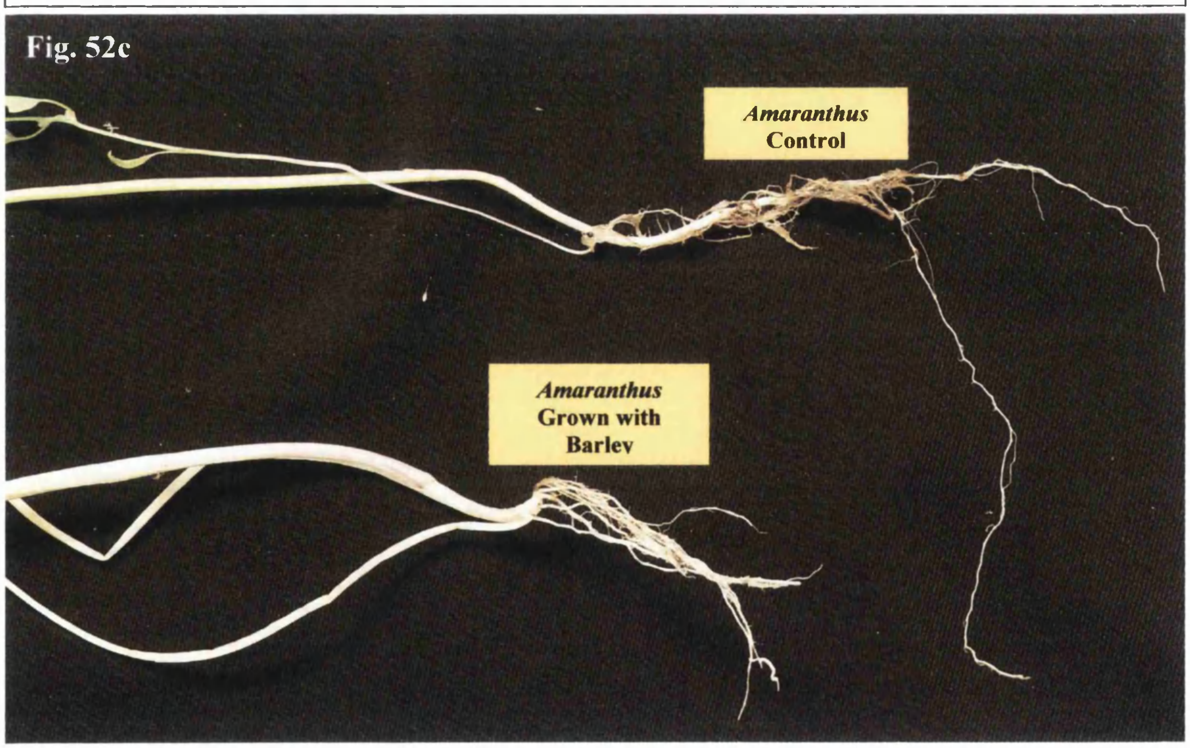


Fig. 52a: Effect of *Amaranthus* on mean barley root dry weight



Figs. 52b-52c: Effect of the interference (barley-*Amaranthus*) on root system (as compared with control



5-1-8 Root dry weight (*Amaranthus*)

Table 35 and Fig. 53 show the effect of barley interference with *Amaranthus*. The ANOVA showed that there were no significant differences (P> 0.05) between blocks or fertilizer treatments. Competition interactions between *Amaranthus* and barley decreased significantly root dry weight in the former. This effect was greater when no fertilizer was added. Statistical analyses showed no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 35:
Effects of barley interference on *Amaranthus* root dry Weight

AMARANTHUS ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.201	0.2071	0.1798	0.1758	0.1642	0.1508	0.1759	0.1601
2	0.197	0.1885	0.2101	0.1459	0.1842	0.1446	0.1842	0.1242
3	0.200	0.1997	0.1579	0.1597	0.1579	0.1398	0.1284	0.1621
Mean	0.199	0.198	0.1826	0.1605	0.1668	0.1450	0.1628	0.1488
S .E.	0.001	0.005	0.001	0.008	0.007	0.003	0.017	0.012

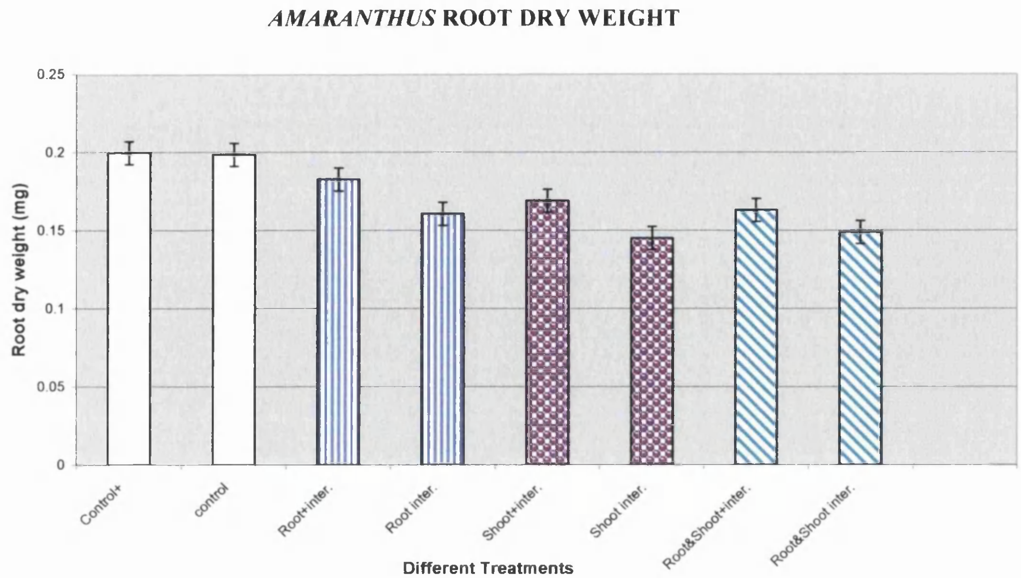


Fig. 53: Effect of barley on mean *Amaranthus* root dry weight

5-1-9 Summarized effects of *Amaranthus* on barley

Both effects of *Amaranthus* on barley growth parameters and barley on *Amaranthus* growth parameters are summarized in Tables 36 and 37 respectively.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **61.33**	b **57.33**	b **58.00**	c **54.66**
Whole-plant dry weight	a **0.89**	a **0.88**	**b** **0.84**	**c** **0.82**
Shoot dry weight	a **0.41**	b **0.35**	b **0.35**	c **0.32**
Root dry weight	a **0.21**	b **0.16**	a **0.21**	ab **0.18**

Table 36: Effect of *Amaranthus* interference on the means of barley plant growth parameters; for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); * = significant at P< 0.05; **

= significant at P< 0.01; *** = significant at P< 0.001. Plants height (cm), Whole-plant dry weight (mg), Shoot dry weight (mg) and Root dry weight (mg). Data in this Table are originated from Table 28, 30, 32 and 34 and show the means of values representing different interactions with added fertilizer only.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **43.33**	b **40.66**	b **40.66**	c **37.33**
Whole- plant	a **0.49**	b **0.42**	b **0.44**	c **0.39**
Shoot dry weight	a **0.34**	b **0.31**	c **0.29**	a **0.31**
Root dry weight	a **0.20**	b **0.18**	c **0.17**	c **0.16**

Table 37: Effect of barley interference on the means of *Amaranthus* plant growth parameters; for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); plants height (cm), Whole-plant dry weight (mg), shoot dry weight (mg) and root dry weight (mg). Data in this Table are originated from Table 29, 31, 33 and 35 and show the means of values representing different interactions with added fertilizer only.

5-1-10 Competitive ability (aggressivity) of *Amaranthus*

As the fourth experiment is recorded in Table 38 and Figs. 54, 55, 56 and 57, there were some significant differences (P< 0.05) indicated that the root interaction was more aggressive than shoot interaction and both root & shoot interaction.

A- Aggressivity based on plant height

Amaranthus had an increased competitive ability when root and shoot systems interacted (Table 38 and Fig. 54). However, none of the differences were significant (P> 0.05) according to ANOVA.

B- Aggressivity based on whole-plant dry weight

Amaranthus had no significant (P> 0.05) competitive ability against barley in any of the interaction (Table 38 and Fig. 55).

Table 38:

***Amaranthus* aggressivity on barley plant**

Growth Parameters	Type of interaction	S.E.	Mean	Aggressivity block 1	2	3
Plant height	Root- interaction	0.027	0.00	0.02	0.04	-0.05
	Shoot- interaction	0.018	0.00	0.03	0.00	-0.03
	Full – interaction	0.031	-0.01	0.04	-0.01	-0.07
Whole-plant dry weight	Root- interaction	0.051	-0.06	-0.03	- 0.16	0.00
	Shoot- interaction	0.065	-0.04	-0.13	0.09	- 0.08
	Full – interaction	0.042	-0.06	-0.13	- 0.05	0.01
Shoot dry weight	Root- interaction	0.065	0.02	-0.03	0.15	-0.05
	Shoot- interaction	0.075	0.01	-0.01	0.15	-0.10
	Full – interaction	0.074	0.07	-0.04	0.21	0.03
Root dry weight	Root- interaction	0.049	0.09	0.06	0.19	0.03
	Shoot- interaction	0.014	-0.06	-0.07	-0.09	-0.04
	Full – interaction	0.015	0.01	0.03	0.02	- 0.02

AMARANTHUS AGGRESSIVITY ON BARLEY PLANT HEIGHT

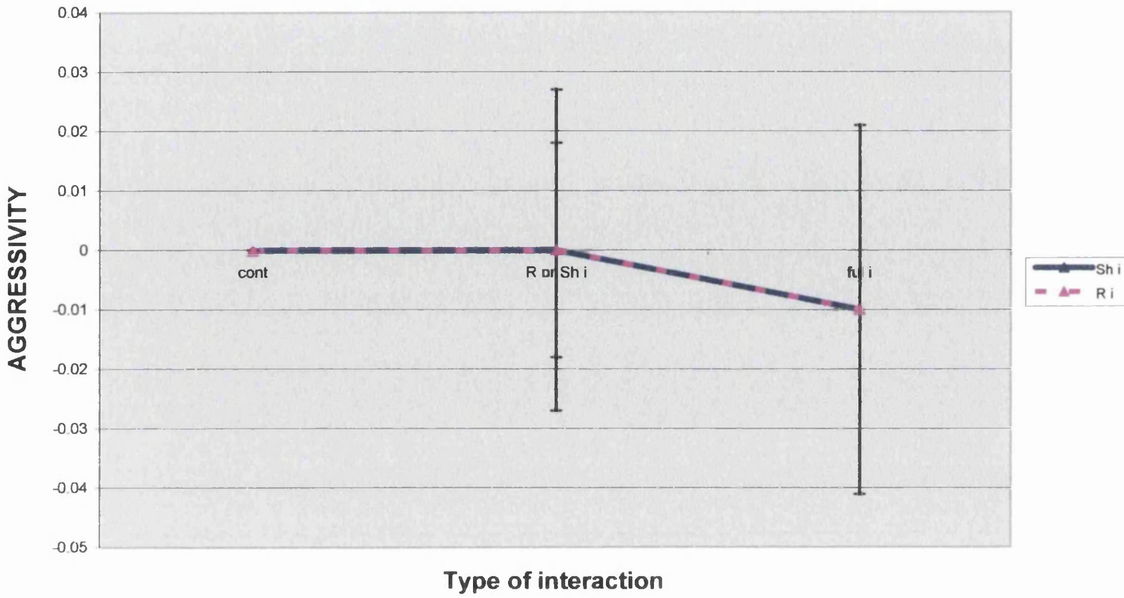


Fig. 54 ***Amaranthus aggressivity*** **on barley plant height**

AMARANTHUS AGGRESSIVITY ON BARLEY WHOLE-PLANT DRY WEIGHT

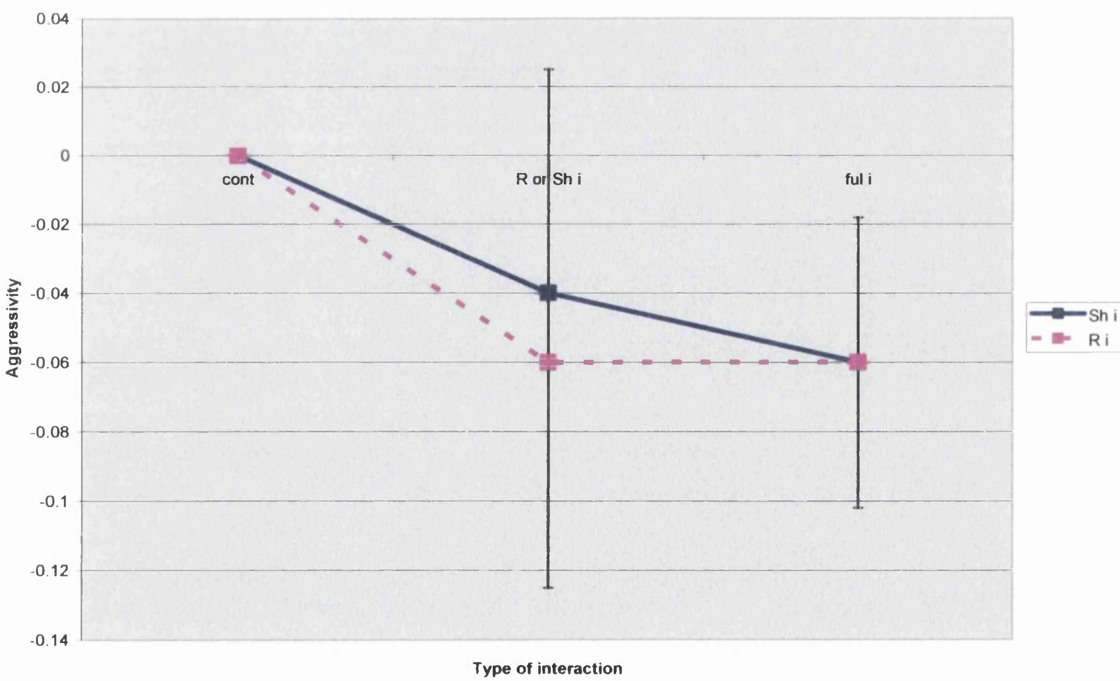


Fig. 55 ***Amaranthus*** **aggressivity on barley whole-plant dry weight**

C- Aggressivity based on shoot dry weight

Similarly, *Amaranthus* was not significantly (P> 0.05) aggressive to barley in any of the interactions (Table 38 and Fig. 56).

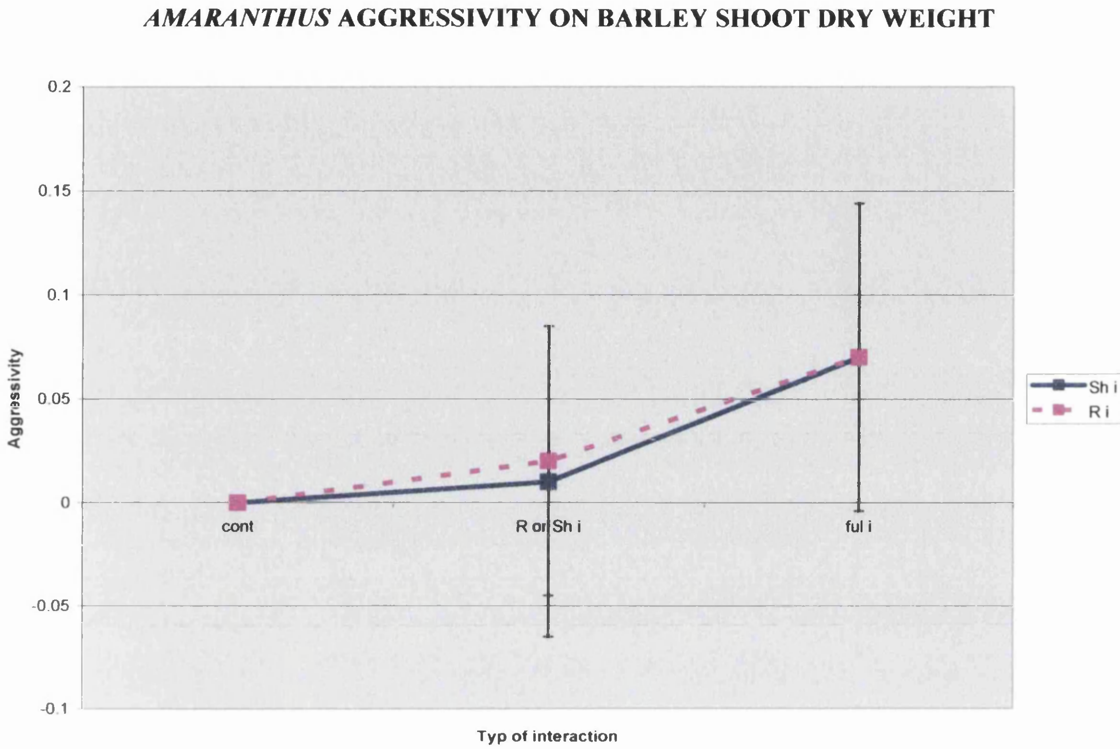


Fig. 56 ***Amaranthus aggressivity*on barley shoot dry weight**

D- Aggressivity based on root dry weight

Amaranthus had a significantly higher (P< 0.05) competitive ability than barley when only the shoot systems interacted (Table 38 and Fig. 57). Root interaction also appears to increase *Amaranthus* aggressivity against barley. However, ANOVA showed no significance (P> 0.05).

AMARANTHUS AGGRESSIVITY ON BARLEY ROOT DRY WEIGHT

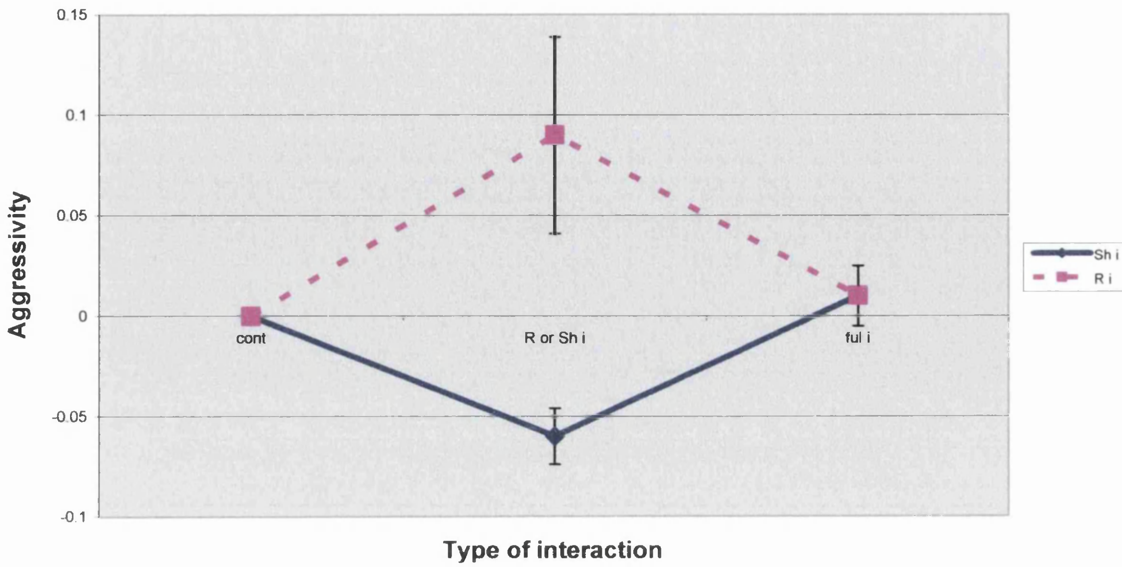


Fig. 57 ***Amaranthus aggressivity*** **on barley root dry weight**

5-2 Experiment 5 Results: Barley *Hordeum vulgare* L. Jasto versus *Chenopodium album*

In this experiment, the effects of *Chenopodium* on barley and the effect of barley on *Chenopodium* were investigated.

5-2-1 Plant Height (Barley)

Table 39 and Fig. 58 summarize the effect of *Chenopodium* on barley plant height. No significant differences (P> 0.05) were found between blocks or fertilizer treatments. Competition with *Amaranthus* significantly decreased (P< 0.05) the height of barley plants, especially when both roots and shoots of barley and *Amaranthus* interacted. There were no significant (P> 0.05) interactions between fertilizer and competition treatments.

Table 39:
Effects of *Chenopodium* interference on barley plant height

BARLEY PLANT HEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	63.00	63.00	53.00	53.00	54.00	55.00	50.00	52.00
2	60.00	61.00	55.00	54.00	56.00	54.00	53.00	53.00
3	65.00	65.00	56.00	56.00	55.00	53.00	51.33	50.00
Mean	**62.67**	**63.00**	**54.67**	**54.33**	**55.00**	**54.00**	**51.33**	**51.67**
S. E.	**1.451**	**1.155**	**0.882**	**0.882**	**0.577**	**0.577**	**0.882**	**0.882**

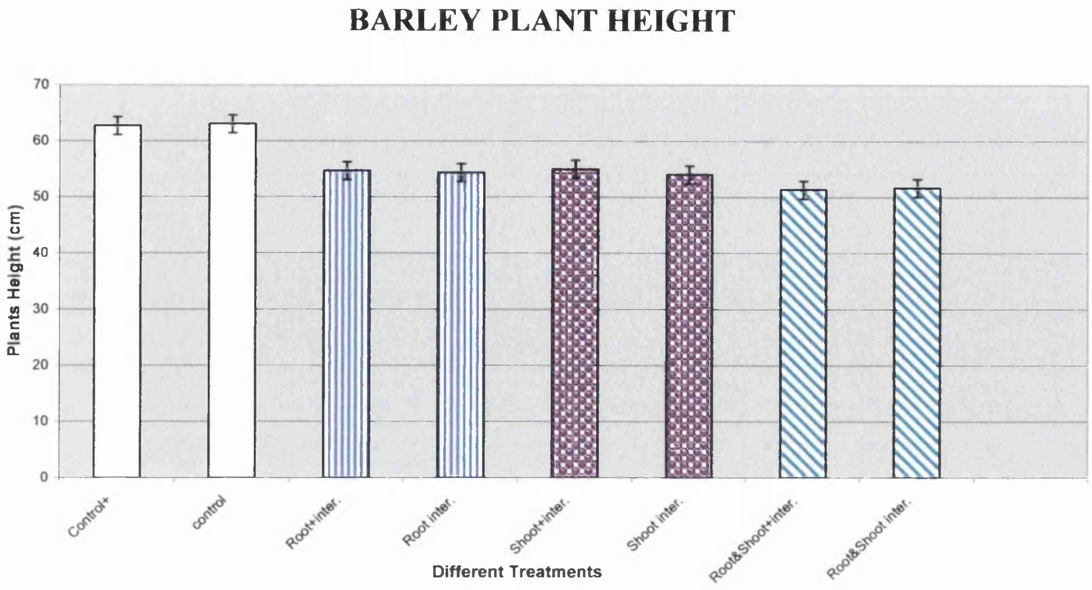


Fig. 58: Effect of *Chenopodium* on mean barley plant height

5-2-2 Plant Height (*Chenopodium*)

Chenopodium plant height is shown in Table 40 and Fig. 59. Different blocks or fertilizer treatments had no significant effect (P> 0.05) on *Chenopodium* plant height. Competition treatments had significant effect (P< 0.05) on *Chenopodium* plant height except when both roots and shoots interacted in the presence of the fertilizer. Interactions between fertilizer and competition treatments were not significant (P> 0.05).

Table 40:
Effects of barley interference on *Chenopodium* plant height

CHENOPODIUM PLANT HEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	57.00	60.00	59.00	54.00	55.00	52.00	43.00	55.00
2	61.00	55.00	54.00	58.00	52.00	56.00	49.00	52.00
3	57.00	59.00	62.00	59.00	59.00	49.00	44.00	47.00
Mean	**58.33**	**58.00**	**58.33**	**57.00**	**55.33**	**52.00**	**45.33**	**51.33**
S. E.	**1.33**	**1.53**	**2.33**	**1.53**	**2.03**	**2.27**	**1.86**	**2.33**

***CHENOPODIUM* PLANT HEIGHT**

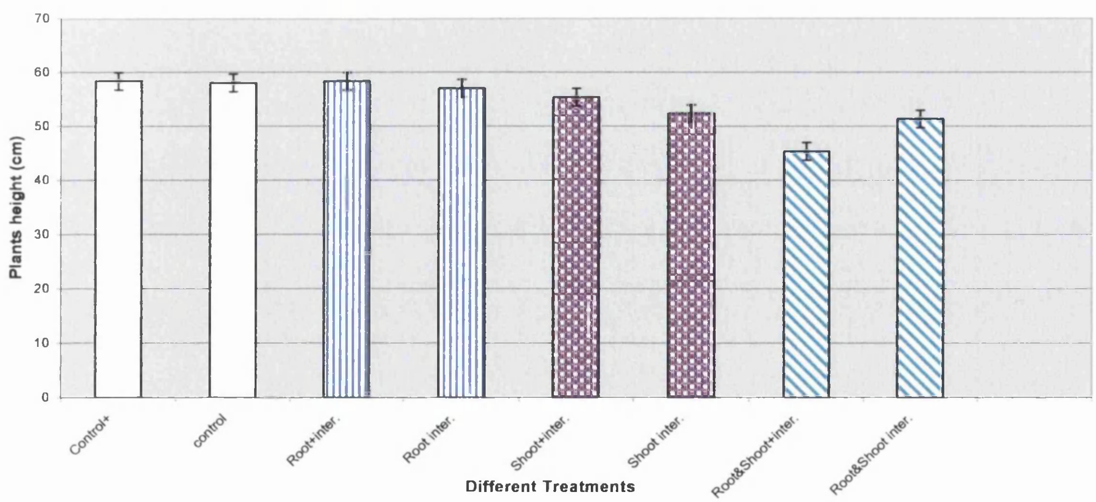


Fig. 59: Effect of barley on mean *Chenopodium* plant height

5-2-3 Whole-plant dry weights (barley)

The effect of *Chenopodium* on barley whole-plant dry weight is shown in Table 41 and Fig. 60. No significant differences (P> 0.05) between blocks or fertilizer treatments were observed. The only significant differences (P< 0.05) observed, are those of competition treatments especially when barley and *Chenopodium* interacted at only at the roots level or at both roots and shoots level. These interactions significantly decreased the whole-plant dry weight in barley. However, interactions between fertilizer and competition treatments were not significant (P> 0.05).

Table 41:
Effects of *Chenopodium* interference on barley whole-plant dry weight

BARLEY WHOLE-PLANT DRY WEIGHT (cm)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	1.326	1.075	0.763	0.498	0.732	0.695	0.596	0.610
2	0.987	0.882	0.599	0.662	0.892	0.659	0.499	0.543
3	1.063	0.964	0.605	0.683	0.764	0.776	0.601	0.504
Mean	**1.125**	**0.974**	**0.656**	**0.614**	**0.796**	**0.710**	**0.565**	**0.553**
S. E.	**0.102**	**0.056**	**0.054**	**0.058**	**0.049**	**0.034**	**0.033**	**0.031**

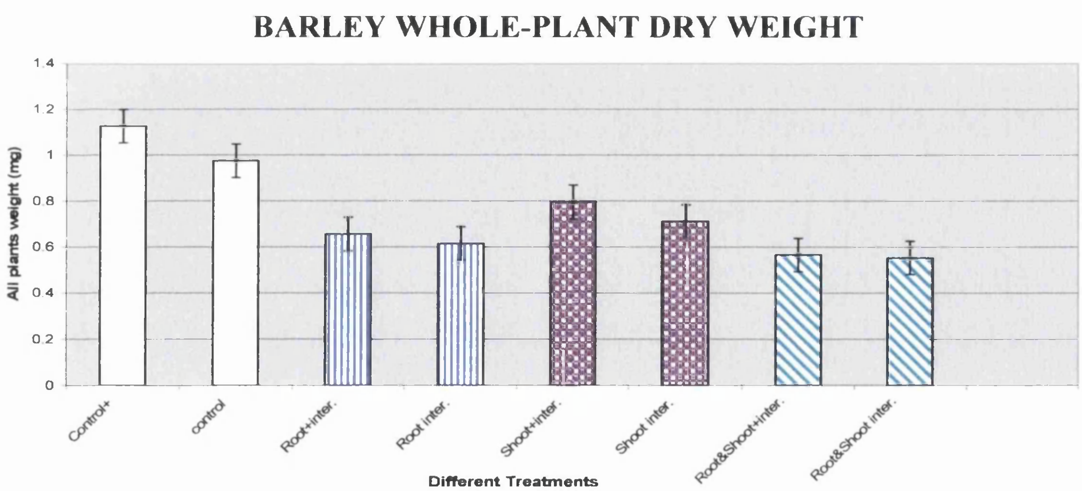


Fig. 60: Effect of *Chenopodium* interference on mean barley whole-plant dry weight

5-2-4 Whole-plant dry weights (*Chenopodium*)

Barley effect on *Chenopodium* whole-plant dry weight is shown in Table 42 and Fig. 61. Neither blocks nor fertilizer treatments had a significant effect ($P > 0.05$) on whole-plant dry weight. ANOVA showed that barley competition with *Chenopodium* had a significant effect ($P < 0.01$) on *Chenopodium* whole-plant dry weight especially when both roots and shoots interacted.

Table 42:
Effects of barley interference on *Chenopodium* whole-plant dry weight

Chenopodium WHOLE PLANTS DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.379	0.457	0.376	0.299	0.333	0.345	0.316	0.324
2	0.453	0.388	0.352	0.479	0.328	0.322	0.298	0.280
3	0.397	0.402	0.336	0.330	0.375	0.297	0.336	0.312
Mean	**0.409**	**0.416**	**0.354**	**0.369**	**0.345**	**0.321**	**0.317**	**0.305**
S.E.	**0.022**	**0.021**	**0.017**	**0.056**	**0.015**	**0.014**	**0.011**	**0.013**

***CHENOPODIUM* WHOLE-PLANT DRY WEIGHT**

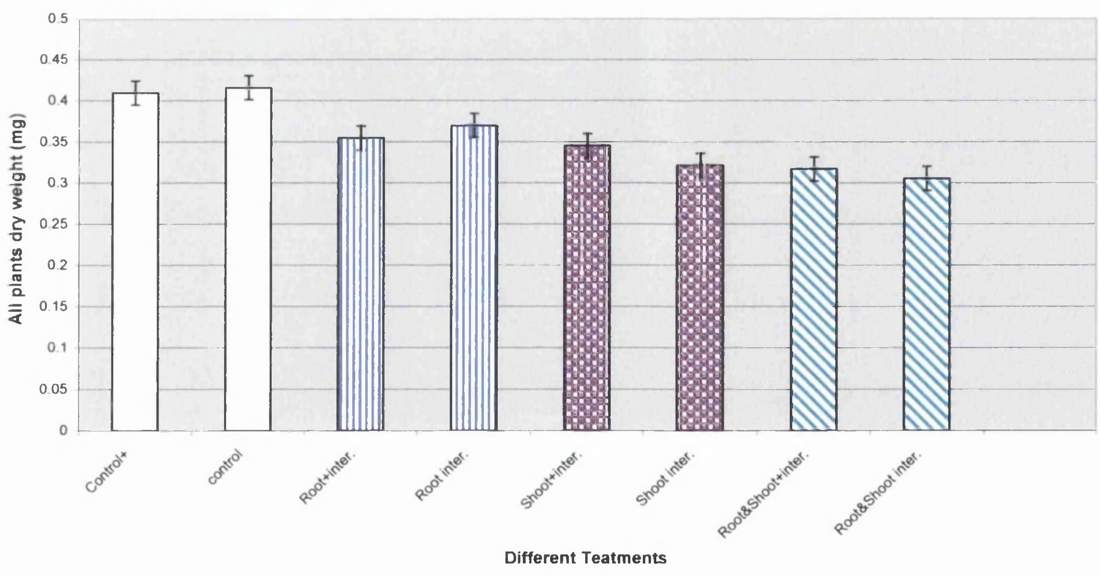


Fig. 61: Effect of barley on mean *Chenopodium* whole-plant dry weight

5-2-5 Shoot dry weight (Barley)

The experimental results for the effect of *Chenopodium* on barley shoot dry weight are summarized in Table 43 and Fig. 62. ANOVA showed no significant differences ($P > 0.05$) between blocks or fertilizer treatments. *Chenopodium* competition had a serious effect on barley growth in that barley shoot dry weight was dramatically lowered whether the interaction was at roots level only, shoots level only or both roots and shoots level. Interactions between fertilizer and competition treatments were not significant ($P > 0.05$).

Table 43:
Effects of *Chenopodium* interference on barley shoot dry weight

BARLEY SHOOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.579	0.457	0.306	0.219	0.234	0.302	0.215	0.224
2	0.453	0.588	0.292	0.279	0.328	0.226	0.258	0.236
3	0.497	0.502	0.326	0.300	0.272	0.330	0.236	0.216
Mean	**0.509**	**0.516**	**0.308**	**0.266**	**0.278**	**0.286**	**0.236**	**0.225**
S.E.	**0.037**	**0.038**	**0.010**	**0.024**	**0.027**	**0.031**	**0.012**	**0.006**

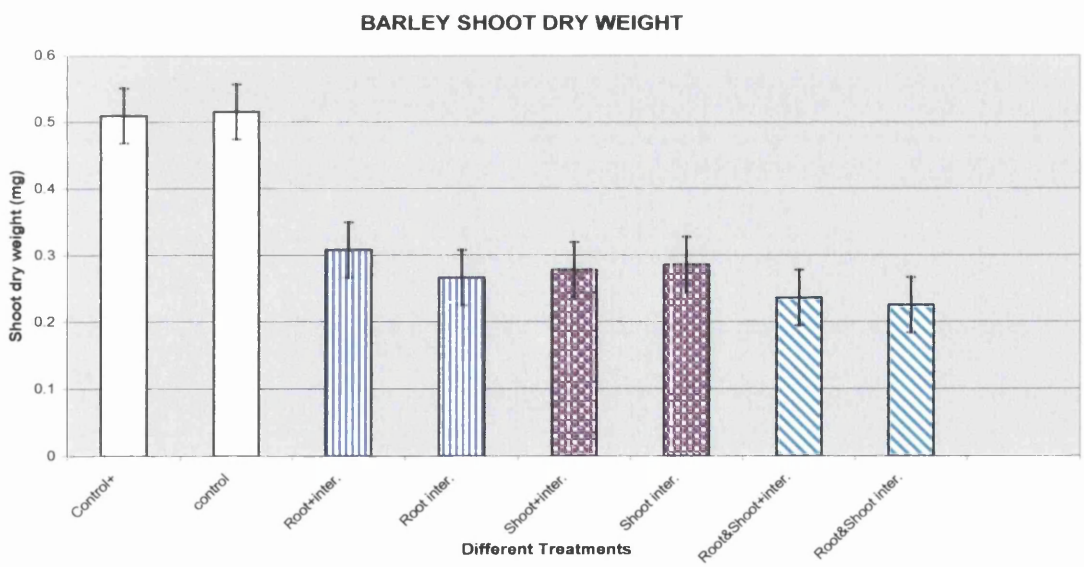


Fig. 62: Effect of *Chenopodium* on mean barley shoot dry weight

5-2-6 Shoot dry weight (*Chenopodium*)

The shoot dry weight of *Chenopodium* was recorded in Table 44 and Fig. 63. ANOVA showed no significant (P> 0.05) effects of blocks, fertilizer treatments or barley competition interactions on *Chenopodium* shoot dry weight. Statistical analyses showed that interactions between fertilizer and competition treatments were not significant (P> 0.05).

Table 44:
Effects of Barley interference on *Chenopodium* shoot dry weight

***CHENOPODIUM* SHOOT DRY WEIGHT (mg)**								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.4059	0.3752	0.3877	0.2702	0.2995	0.2992	0.2933	0.3108
2	0.3033	0.2880	0.3098	0.3703	0.3842	0.3033	0.2885	0.3066
3	0.3852	0.3907	0.3112	0.2933	0.3101	0.7266	0.3066	0.2966
Mean	**0.3648**	**0.3513**	**0.3362**	**0.3113**	**0.3312**	**0.2930**	**0.2961**	**0.3047**
S.E.	**0.0313**	**0.0319**	**0.0257**	**0.0302**	**0.0266**	**0.0083**	**0.0054**	**0.0042**

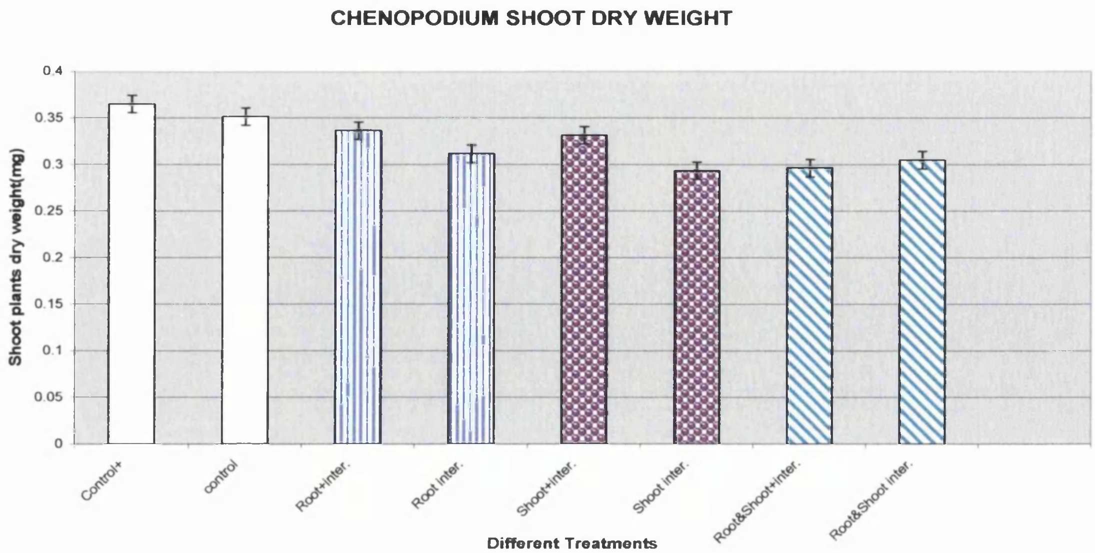


Fig. 63: Effect of barley on mean *Chenopodium* shoot dry weight

5-2-7 Root dry weight (barley)

Table 45 and Fig. 64 summarize the experimental results of the effect of *Chenopodium* on barley root dry weight. The results showed no significant differences (P> 0.05) between blocks or fertilizer treatments. *Chenopodium* competition had a very significant effect (P< 0.01) on barley root system in that root dry weight was dramatically lowered in root-interaction, shoot-interaction and root & shoot-interaction. However, interactions between fertilizer and competition treatments were not significant (P> 0.05).

Table 45:
Effects of *Chenopodium* interference on barley root dry weight

BARLEY ROOT DRY WEIGHT(mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.2937	0.2875	0.1103	0.1003	0.0961	0.1075	0.1033	0.0948
2	0.1702	0.2991	0.0874	0.0979	0.1501	0.1077	0.0821	0.1033
3	0.2313	0.2014	0.1703	0.1758	0.1032	0.0973	0.0701	0.0985
Mean	**0.2317**	**0.2626**	**0.1227**	**0.1247**	**0.1165**	**0.1042**	**0.0851**	**0.0987**
S.E.	**0.0356**	**0.0308**	**0.0247**	**0.0255**	**0.0169**	**0.0034**	**0.0097**	**0.0024**

BARLEY ROOT DRY WEIGHT

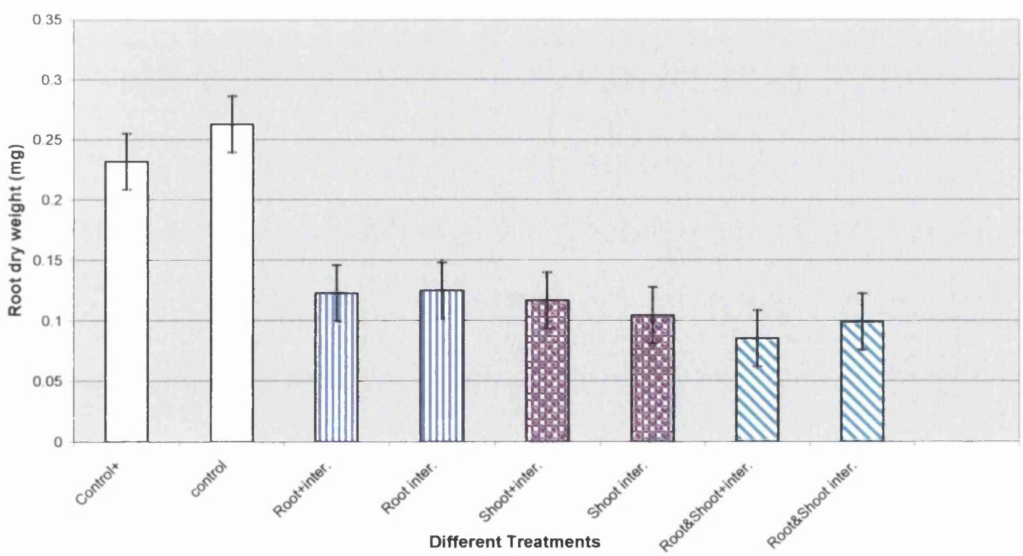


Fig. 64: Effect of *Chenopodium* on mean barley root dry weight

5-2-8 Root dry weight (*Chenopodium*)

The effects of barley on *Chenopodium* root dry weight are recorded in Table 46 and Fig. 65. No significant differences (P> 0.05) were observed between blocks or fertilizer treatments. However, competition with barley significantly lowered (P< 0.01) *Chenopodium* root dry weight in all competition interactions when no fertilizer was added. ANOVA showed that interactions between fertilizer and competition treatments were not significant (P> 0.05).

Table 46:
Effects of barley interference on *Chenopodium* root dry Weight

CHENOPODIUM ROOT DRY WEIGHT (mg)								
Block	Control +N	Control -N	Root +N interaction	Root -N interaction	Shoot +N interaction	Shoot -N interaction	Root&Shoot +N interaction	Root&Shoot -N interaction
1	0.1998	0.2773	0.1933	0.1977	0.1744	0.1688	0.1855	0.1703
2	0.2233	0.1988	0.2502	0.1713	0.1992	0.1766	0.1897	0.1366
3	0.2266	0.2097	0.1776	0.1566	0.1733	0.1433	0.1773	0.1688
Mean	**0.2166**	**0.2286**	**0.2070**	**0.1752**	**0.1823**	**0.1629**	**0.1842**	**0.1586**
S. E.	**0.0084**	**0.0245**	**0.0220**	**0.0120**	**0.0084**	**0.0100**	**0.0036**	**0.0109**

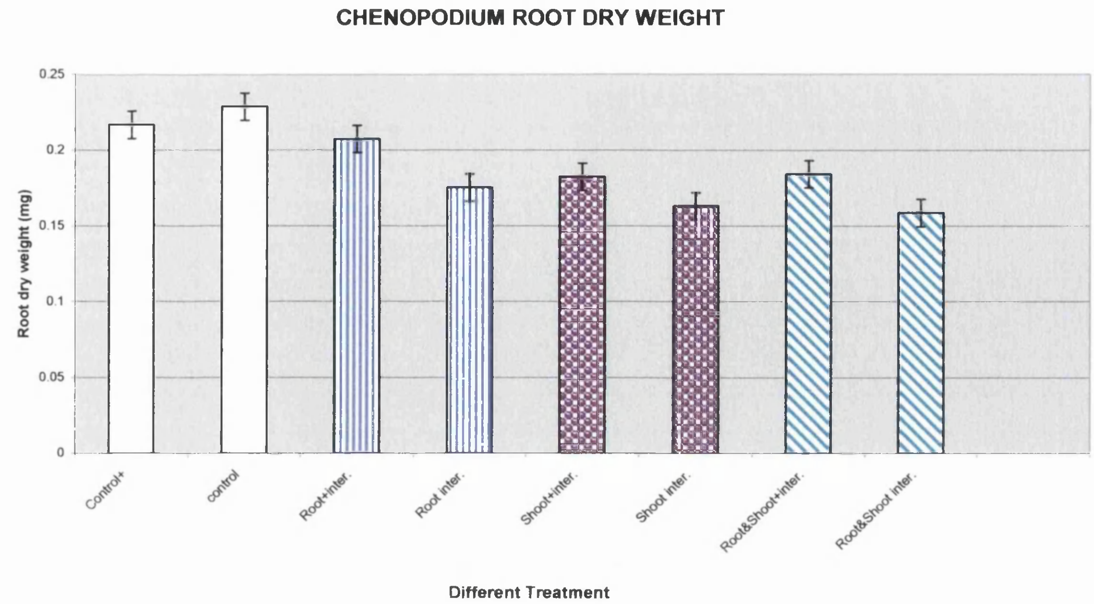


Fig. 65: Effect of barley on mean *Chenopodium* root dry weight

5-2-9 Summarized effects of *Chenopodium* on barley

Both effects of *Chenopodium* on barley growth parameters and barley on *Chenopodium* growth parameters are summarized in Tables 47 and 48 respectively.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **62.67**	b **54.67**	ab **55.00**	ab **51.33**
Whole- plant dry weight	a **1.12**	b **0.66**	d **0.80**	**c** **0.57**
Shoot dry weight	a **0.51**	b **0.31**	c **0.28**	d **0.24**
Root dry weight	a **0.23**	b **0.13**	c **0.10**	c **0.09**

Table 47: Effect of *Chenopodium* interference on barley plant growth parameters, for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); plants height (cm), Whole- plant (mg), shoot dry

weight (mg) and root dry weight (mg). Data in this Table are originated from Table 39, 41, 43 and 45 and show the means of values representing different interactions with added fertilizer only.

	Type of interaction			
Growth Parameters	Control	Root interaction	Shoot interaction	Root&Shoot interaction
Plant height	a **58.33**	a **58.33**	b **55.33**	c **45.33**
Whole- plant dry weight	a **0.41**	b **0.35**	**b** **0.35**	**c** **0.32**
Shoot dry weight	a **0.37**	b **0.34**	b **0.33**	c **0.30**
Root dry weight	a **0.22**	a **0.21**	b **0.18**	b **0.18**

Table 48: Effect of Barley interference on *Chenopodium* plant growth parameters, for significant treatment effects (ANOVA, P< 0.05) mean values having superscript letters in common are not significant (P> 0.05); Plants height (cm), Whole- plant (mg), Shoot dry weight (mg) and root dry weight (mg). Data in this Table are originated from Table 40, 42, 44 and 46 and show the means of values representing different interactions with added fertilizer only.

5-2-10 Competitive ability (aggressivity) of *Chenopodium*

The results are shown in Table 49 and Figs. 66, 67, 68 and 69. There were some significant differences (P> 0.05) indicating that root interaction was more aggressive than shoot or both root & shoot interactions.

A- Aggressivity based on Plant height

Chenopodium had an increased competitive ability when only root or shoot systems interacted (Table 49 and Fig. 66). In contrast, both shoot and root interaction decreased the competitive ability of Chenopodium against barley. However, ANOVA showed that the effects were not statistically significant (P> 0.05).

B- Aggressivity based on whole-Plant dry weight

The competitive ability of shoot and root systems were similar in *Chenopodium* grown with barley (Table 49 and Fig. 67). When both shoot and root interactions were exerted, the effects were not additive; this demonstrates that when whole plant dry weight is used the aggressivity level is the same in all interactions. All differences were significant ($P< 0.05$) according to ANOVA.

Table 49:

***Chenopodium* aggressivity on Barley plants**

Growth Parameters	Type of interaction	S.E.	Mean	Aggressivity block 1	2	3
Plant height	Root- interaction	0.014	0.06	0.10	- 0.02	0.11
	Shoot- interaction	0.040	0.04	0.05	-0.04	0.09
	Full – interaction	0.009	-0.02	-0.02	-0.04	-0.01
Whole-plant dry weight	Root- interaction	0.030	0.14	0.21	0.09	0.14
	Shoot- interaction	0.015	0.14	0.16	0.14	0.11
	Full – interaction	0.019	0.18	0.19	0.21	0.14
Shoot dry weight	Root- interaction	0.042	0.16	0.21	0.19	0.08
	Shoot- interaction	0.043	0.19	0.17	0.27	0.13
	Full – interaction	0.009	0.17	0.16	0.19	0.16
Root dry weight	Root- interaction	0.092	0.021	0.30	0.30	0.02
	Shoot- interaction	0.078	0.15	0.27	0.01	0.16
	Full – interaction	0.030	0.24	0.29	0.18	0.24

CHENOPODIUM **AGGRESSIVITY ON BARLEY PLANT HEIGHT**

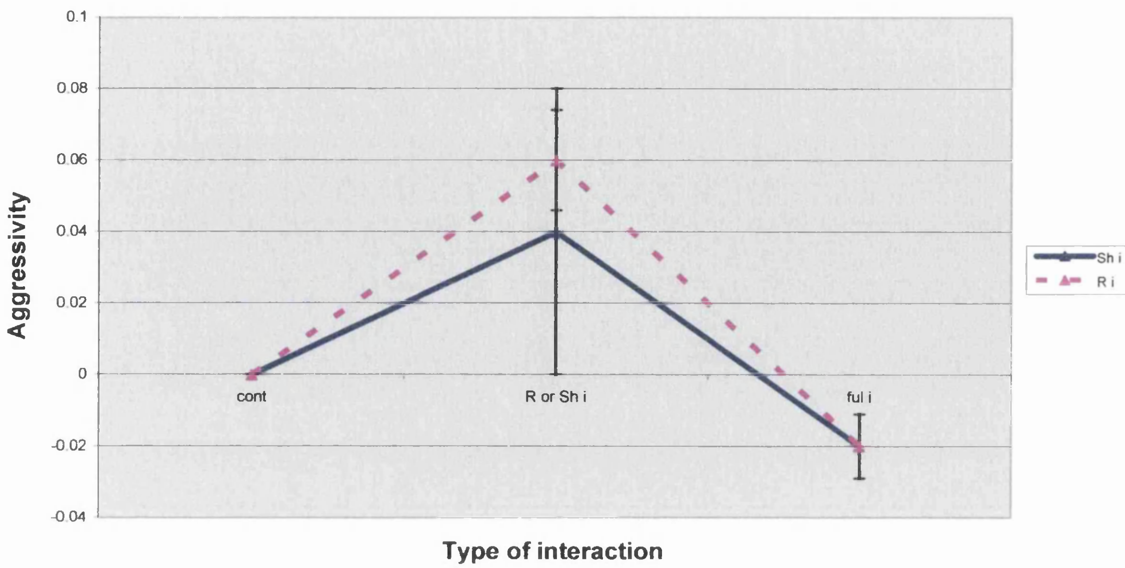


Fig. 66 *Chenopodium* aggressivity on barley plant height

CHENOPODIUM **AGGRESSIVITY ON BARLEY WHOLE-PLANT DRY WEIGHT**

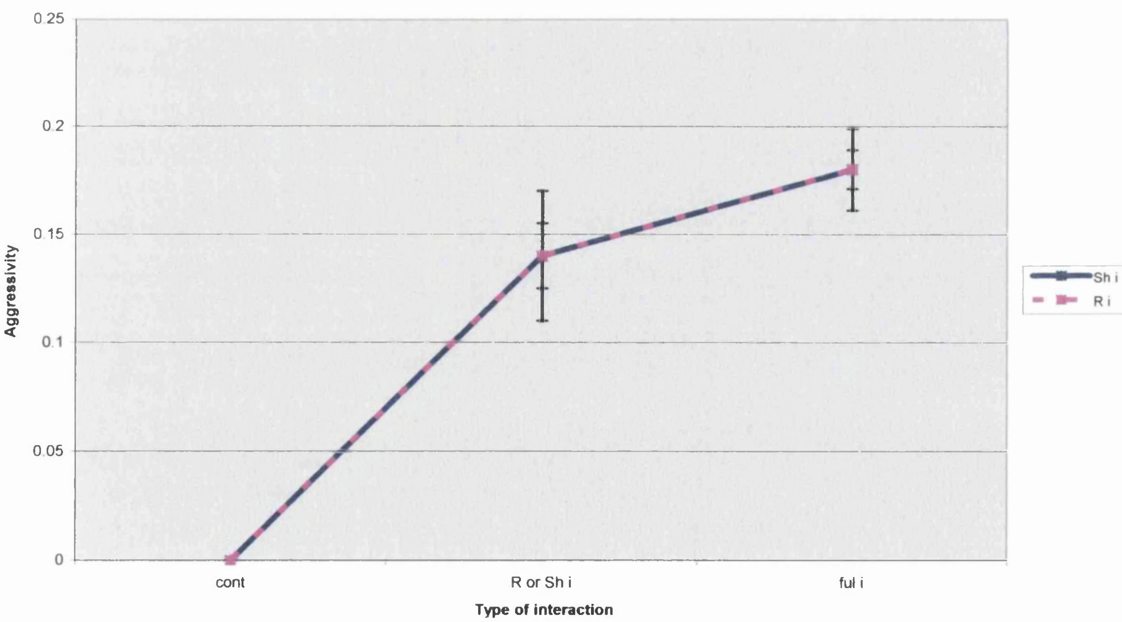


Fig. 67 *Chenopodium* aggressivity on barley whole-plant dry weight

C- Aggressivity based on shoot dry weight

Chenopodium had a significantly (P< 0.01) higher competitive ability than barley in root interaction and both root and shoot interaction (Table 49 and Fig. 68). The shoot interaction showed also a significantly (P< 0.05) higher level of *Chenopodium* aggressivity against wheat.

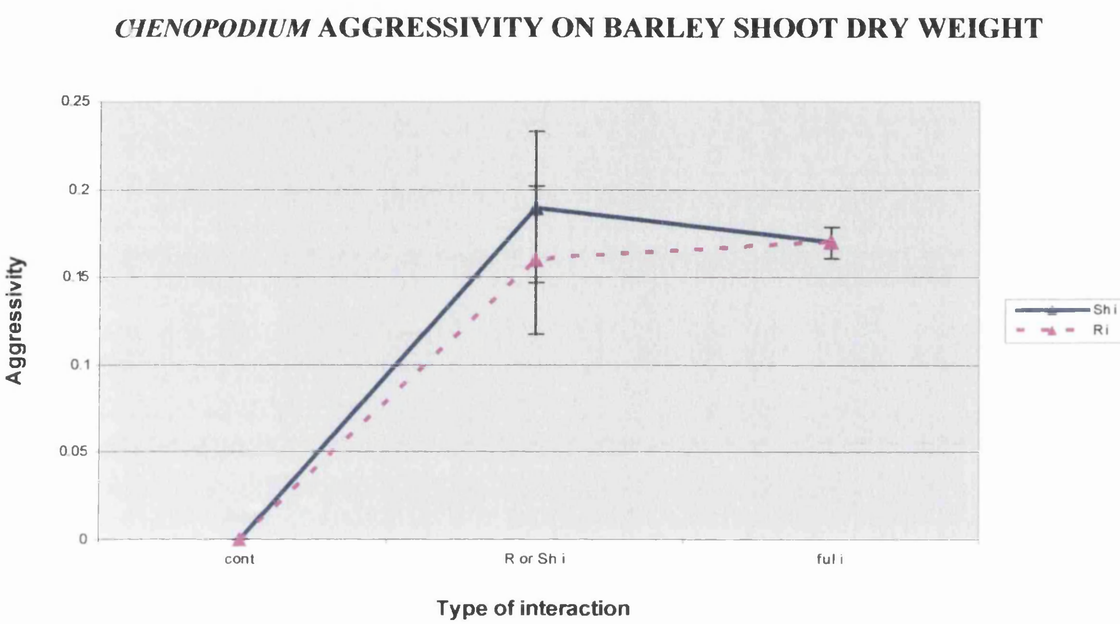


Fig. 68 *Chenopodium* aggressivity on barley shoot dry weight

D- Aggressivity based on root dry weight

Chenopodium had a higher competitive ability than barley when in all interactions (Table 49 and Fig. 69). However, only when both shoot and root systems interacted the aggressivity was significant (P< 0.01).

CHENOPODIUM AGGRESSIVITY ON BARLEY ROOT DRY WEIGHT

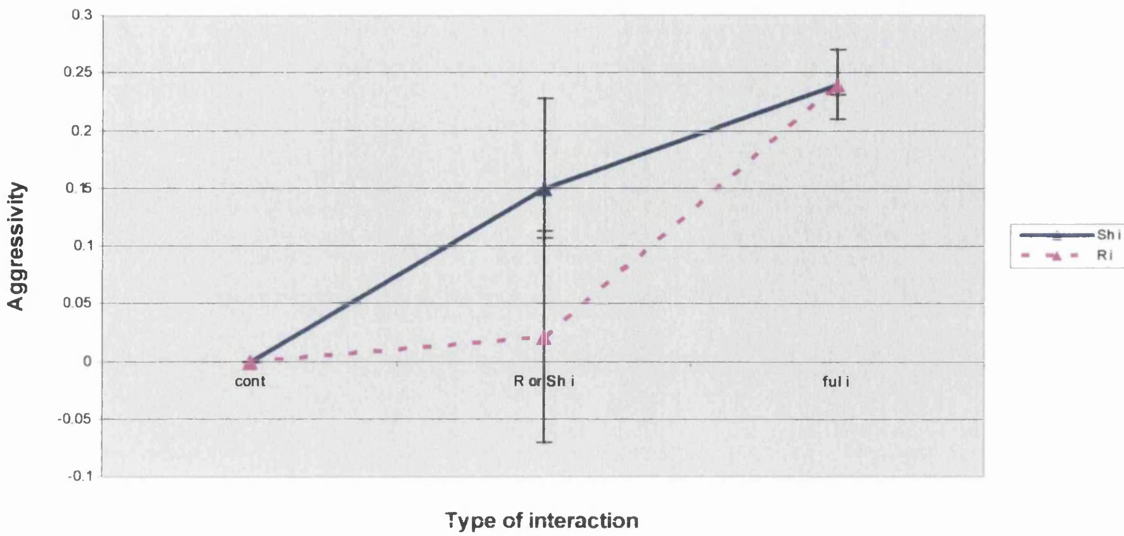


Fig. 69 *Chenopodium* aggressivity on barley root dry weight

CHAPTER 6

CHAPTER 6

6-1 introduction Materials and Methods:

After examining the physical competition of weed plants with crop plants for space and resources in the previous chapters, the objective of the experiments in this chapter is to investigate another kind of interference between plant species which is through releasing chemicals by some weed plants to the environment to limit the growth and development of neighboring crop plants. This phenomenon is called allelopathy and defined as the effect of chemical interactions between plants (Olofsdotter *et al.*, 2002). As discussed in the introduction to this thesis, allelopathic interactions can have important effects on germination of crop plants; for this reason, the present study was conducted to evaluate the effects of different plant extract concentrations from the weed plant *Heliotropium europaeum* L. on the crop plant *Triticum aestivum* L. (wheat) and *Hordeum vulgare* L. (barley) seeds germination and root length.

6-2 Materials and Methods

6-2-1 Plant material

6-2-1-1 Crop Plants

In the next Chapter, seeds of Saudi Arabian wheat *Triticum aestivum* L. cv. Yecora Rojo and barley *Hordeum vulgare* L. cv. Jasto were used to study the effect of weed extracts on crop seed germination.

In preliminary experiments, the study investigated the effect of *Chenopodium album and Amaranthus retroflexus* extracts on crop seed germination but no effect were observed. For this reason, another important Saudi Arabian weed (*Heliotropium europaeum* L.) was used.

6-2-1-2 Weed Plants

The weed plant used in this study is the broadleaved weed *Heliotropium europaeum* L. (Boraginaceae). *Heliotropium* is represented by the largest number of species of this family of 41-51 species. These are commonly known as Heliotropes in English and Ramram in Arabic (Fig. 70). *H. europaeum L.* is a common weed of

Saudi Arabia. It propagates mainly through seeds (Chaudhary & Akram, 1987). Animals avoid eating this weed due to the toxic alkaloid content that is harmful to the liver (Chaudhary & Al-Jowaid, 1999). Moreover, *Heliotropium* seeds when harvested with wheat crops can contaminate flour made from wheat for human consumption and this can be a health hazard (Haigh, 2001).

Fig. 70: *Heliotropium europaeum*

6-3 Plant sampling

H. europaeum shoots were collected from Alkhulayal agricultural area in the north region of Al Madinah Al-Munawwarah city in Saudi Arabia (Fig. 71-72).

6-4 Preparation of plant extracts

Fresh leaves and stems of *H. europaeum* were rinsed in distilled water then blended in distilled water using a Moulinex blender at room temperature. The yielded extract was considered as 100% concentration. Other diluted concentrations (10, 20, 30 and 40%) were obtained by adding distilled water. Pure distilled water was used as a control (0% sap).

6-5 Germination bio-assays

In preliminary experiment the study investigated the effect of each of the concentrations 1, 2, 3, 4 and 5% but no effect was observed, and 50, 60, 70 % totally inhibited germination.

Germination tests were conducted for each of the concentrations 0, 10, 20, 30 and 40%. Barley or wheat seeds were evenly placed on filter paper in sterilized 9 cm Petri dishes. Ten ml of the extract solution from each concentration was added to each Petri dish and distilled water was used as a control. All Petri dishes were kept at 24°C and included 10 seeds in every Petri dish.

Treatments were arranged in a completely randomized design with 3 replications. Germination was determined by counting the number of germinated seeds at 24 hours intervals over a 4-day period, and expressed as total percent germinated.

6-6 Experimental design and statistical analyses

Germination bioassays were conducted in a randomized design with 3 replicates. Analysis of variance ANOVA was performed using a general linear model in Minitab (version 13). The means and standard errors were calculated using Excel (version 2003).

Fig. 71: AlKhulayl agriculture locations from the study area which extends to the north region of Al-Madinah Al-Munawwarah.

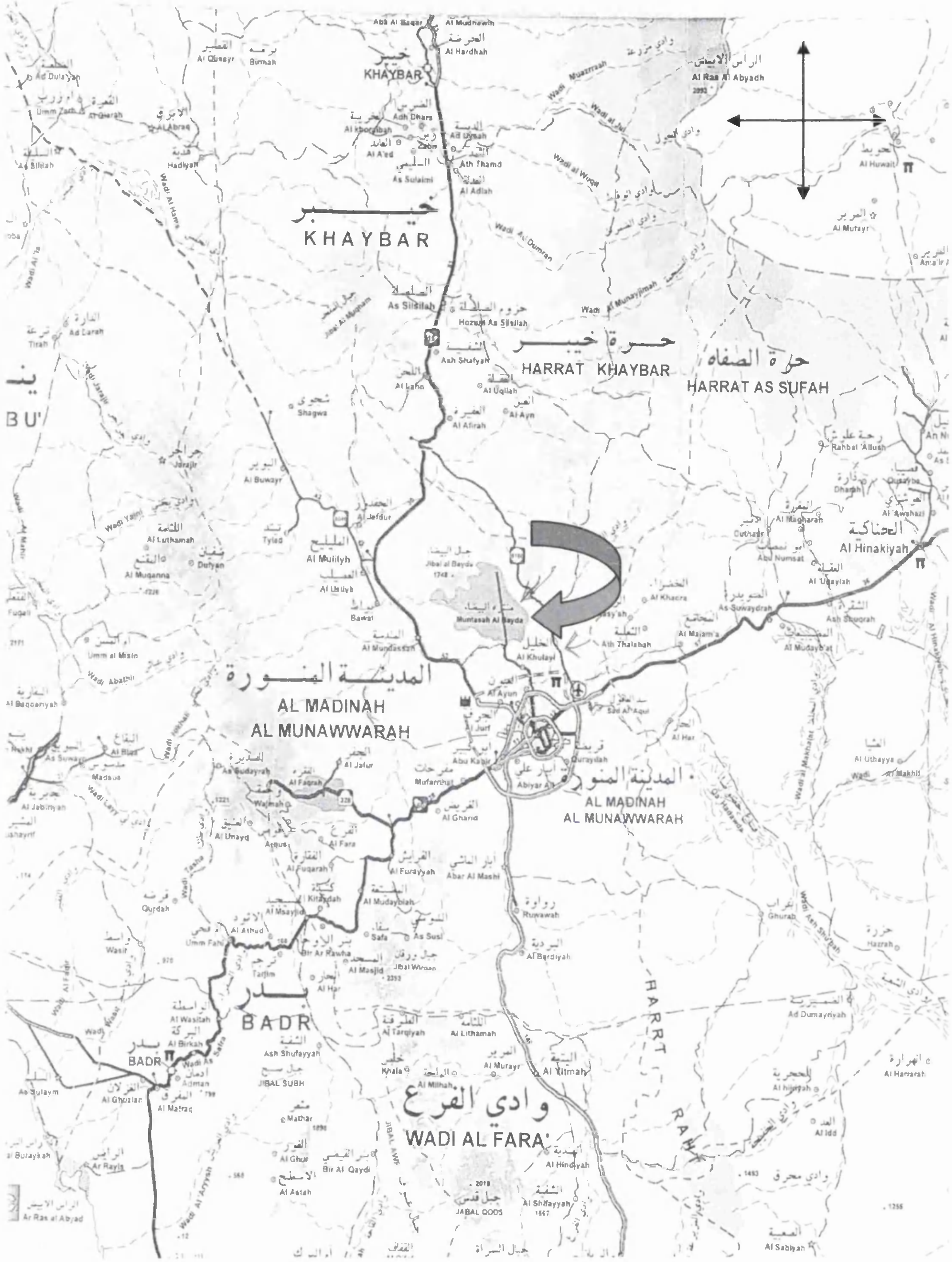


Fig. 72: Map of the study area (Alkhullayl) which extends the north of Al-Madinah Al-Munawwarah

CHAPTER 7

CHAPTER 7

RESULTS OF ALLELOPATHY EXPERIMENTS

7.1 Experiment 6: Wheat *Triticum aestivum* L. cv. Yecora Rojo and *Heliotropium europaeum* L.

The ability of wheat seeds to germinate in the presence of *Heliotropium* plants extract was investigated and the root length was measured. In all assays, no significant effects (P> 0.05) of blocks on germination or root length were observed.

7-1-1 Germination percentage (wheat)

The effects of different extract concentrations on wheat seed germination are summarized in Table 50 and Fig. 73. As shown by ANOVA TEST, Wheat seeds germination was inhibited significantly (P< 0.001) by all the 4 extract concentrations. As the extract concentration increased, the inhibition of germination also increased causing almost 53% of the seeds not to germinate at 40% extract concentration after 3-4 days of incubation compared to the control.

Table 50:
Effects of different concentration of *Heliotropium* extracts on the mean of wheat seed germination.

WHEAT SEED GERMINATION PERCENTAGE MEANS after treatment with *H. europaeum* extracts					
Time (days)	**Control**	**10%**	**20%**	**30%**	**40%**
1-2 days	100±4.0	80±5.2	70±1.7	40±5.3	30±0.9
2-3 days	100±6.0	90±4.2	90±1.0	70±3.8	50±4.1
3-4 days	100±1.0	100±0.6	90±5.5	90±1.7	53±2.6

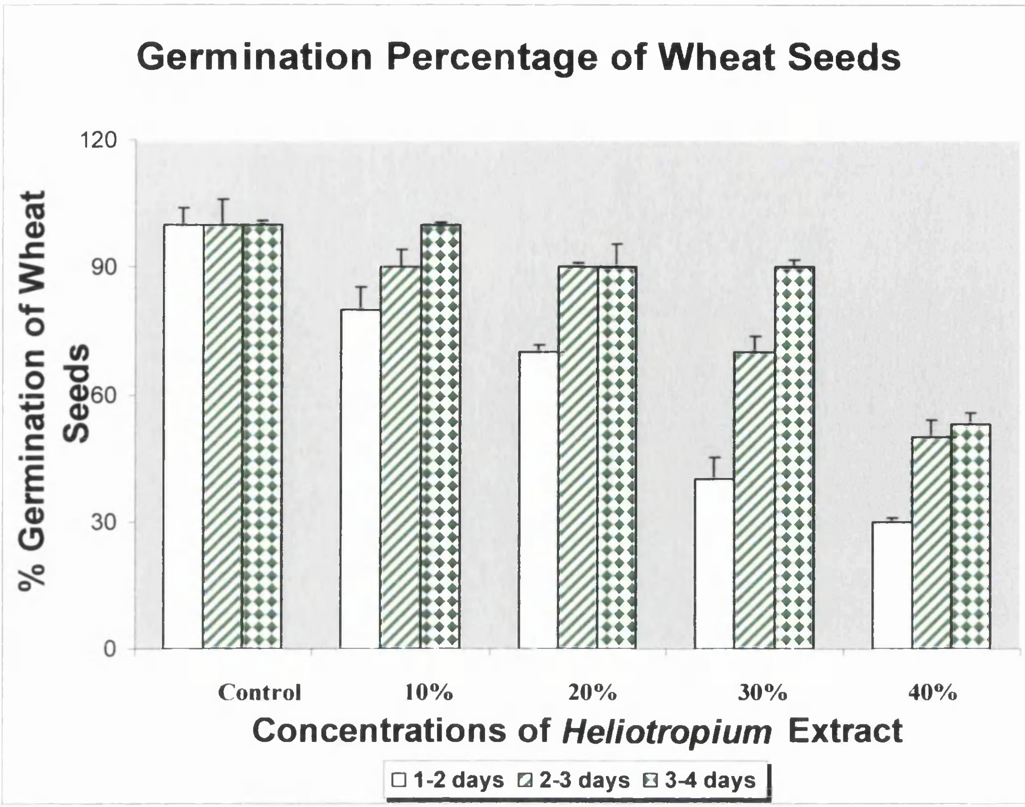


Fig. 73: Effect of different concentration of *Heliotropium* extract on mean germination percentage of wheat

7-1-2 Root Length (wheat)

Table 51 and Fig. 74 summarize the effects of *H. europaeum* extracts on wheat growth measured as root length over time. Increasing concentration of the extract significantly reduced ($P < 0.001$) root length to about half that of the control at 10% extract. The 40% extract reduced root length 3-4 days after treatment by about 90% compared to the control. Statistical analysis also showed that the interaction between root length and time were significant ($P < 0.001$) which indicates different rates of changes in root length over time between the different treatments.

Table 51:
Effects of different concentrations of *Heliotropium* extracts on wheat root length.

ROOT LENGTH MEANS (mm) OF WHEAT after treatment with *H. europaeum* extracts					
Time (days)	**Control**	**10%**	**20%**	**30%**	**40%**
1-2 days	7.0±0.6	3.5±0.3	2.5±0.5	2.0±0.5	1.3±0.2
2-3 days	30.0±2.9	17.0±1.5	5.0±0.1	4.6±0.3	3.3±0.1
3-4 days	71.0±5.8	30.0±5.8	18.0±3.0	9.0±1.0	6.0±1.2

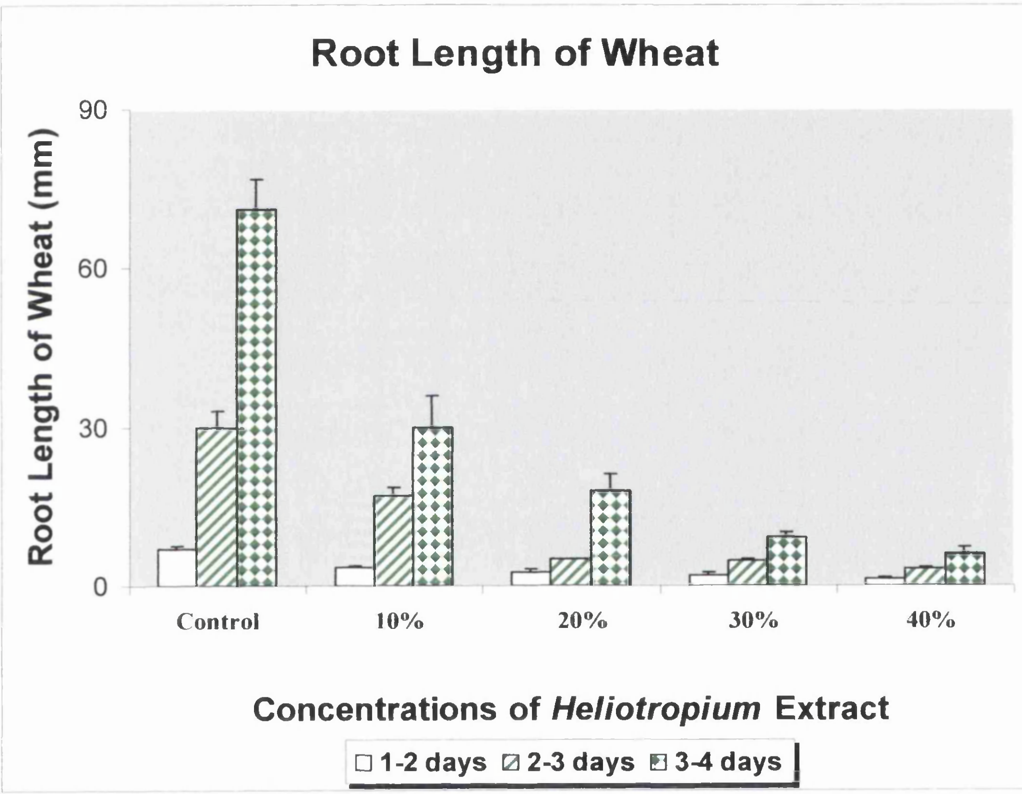


Fig. 74: Effect of different concentration of *Heliotropium* extracts on mean wheat root length

7-2 Experiment 7: Barley *Hordeum vulgare* L. Jasto and *Heliotropium europaeum.*

The ability of barley seeds to germinate in the presence of *Heliotropium* plant extracts was investigated and different growth parameters were measured.

7-2-1- Germination percentage (barley)

The experimental results of the effects of *H. europaeum* extracts on barley seed germination are recorded in Table 52 and Fig. 75. *H. europaeum* extracts reduced significantly (P< 0.001) barley germination rate in all concentrations with the 40% extract reaching up to 40% germination inhibition 3-4 days after treatment compared to the control.

Table 52:
Effects of different concentrations of *Heliotropium* extracts on the mean of barley seeds.

BARLEY SEED GERMINATION PERCENTAGE MEANS after treatment with *H. europaeum* extracts					
Time (days)	**Control**	**10%**	**20%**	**30%**	**40%**
1-2 days	100±2.0	70±2.9	50±2.3	30±3.2	10±1.5
2-3 days	100±3.0	80±1.2	70±0.6	60±1.5	20±2.1
3-4 days	100±1.0	90±1.7	80±5.2	70±0.6	60±3.6

7-2-2 Root length (barley)

Table 53 and Fig. 76 show the effects of *H. europaeum* extracts on barley root length. Increasing concentration of the extract reduced significantly (P< 0.001) root length to about half that of the control at 10% extract and the 40% extract reduced root length by about 20% at the last harvest compared to the control. Like wheat, statistical analysis also showed that the interaction between barley root length and time were significant (P< 0.001) which indicates different rates of changes in root length over time between the different treatments.

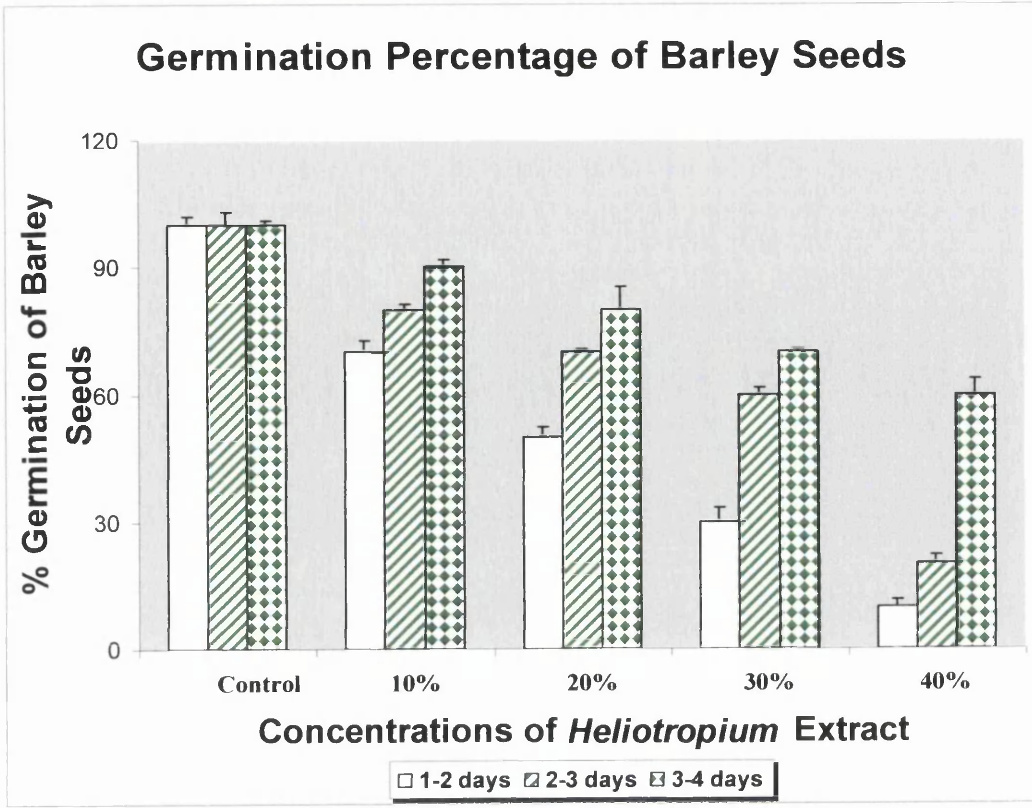


Fig. 75: Effect of different concentration of *Heliotropium* on mean germination percentage of barley.

Table 53:
Effects of different concentration of *Heliotropium* extracts on the mean of barley root length.

ROOT LENGTH MEANS (mm) OF BARLEY after treatment with *H. europaeum* extracts					
Time (days)	**Control**	**10%**	**20%**	**30%**	**40%**
1-2 days	7.0±0.6	5.0±0.6	2.5±0.1	3.0±0.6	2.0±0.2
2-3 days	37.0±2.3	23.0±2.1	16.0±1.5	8.0±0.6	6.0±0.6
3-4 days	54.0±1.2	24.0±1.5	18.0±1.5	13.0±0.6	9.0±0.6

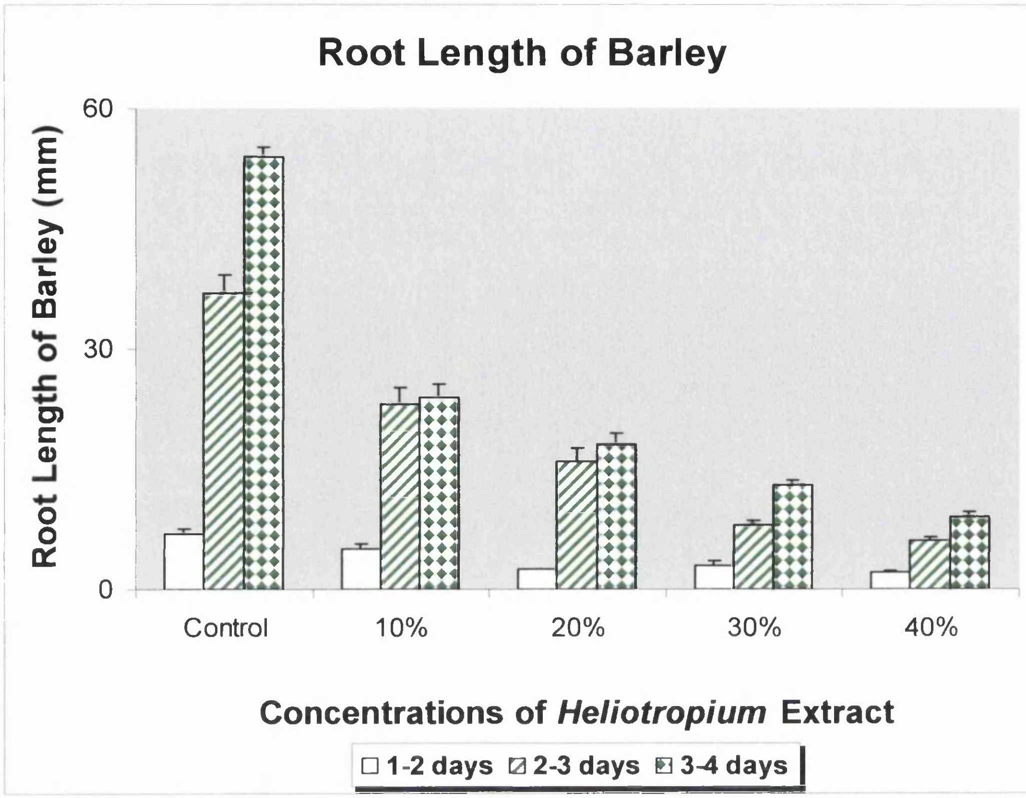


Fig. 76: Effect of different concentration of *Heliotropium* extract on mean barley root length

7-2-3 Effects on root morphology

Incubation of wheat seeds in *H. europaeum* extracts caused a brownish colour of the roots and deformation (Fig. 78). A spirillum was also found to be a consequence of the effect of the extracts on wheat seeds (Fig. 77). The deformation of the plumule of wheat seedlings was also observed (Fig. 79).

Barley emerging roots were found to be deformed and browned as a consequence of the extracts application (Fig. 80).

Fig. 77: Brownish colour and deformation of wheat roots due to weed extracts (as compared with control.

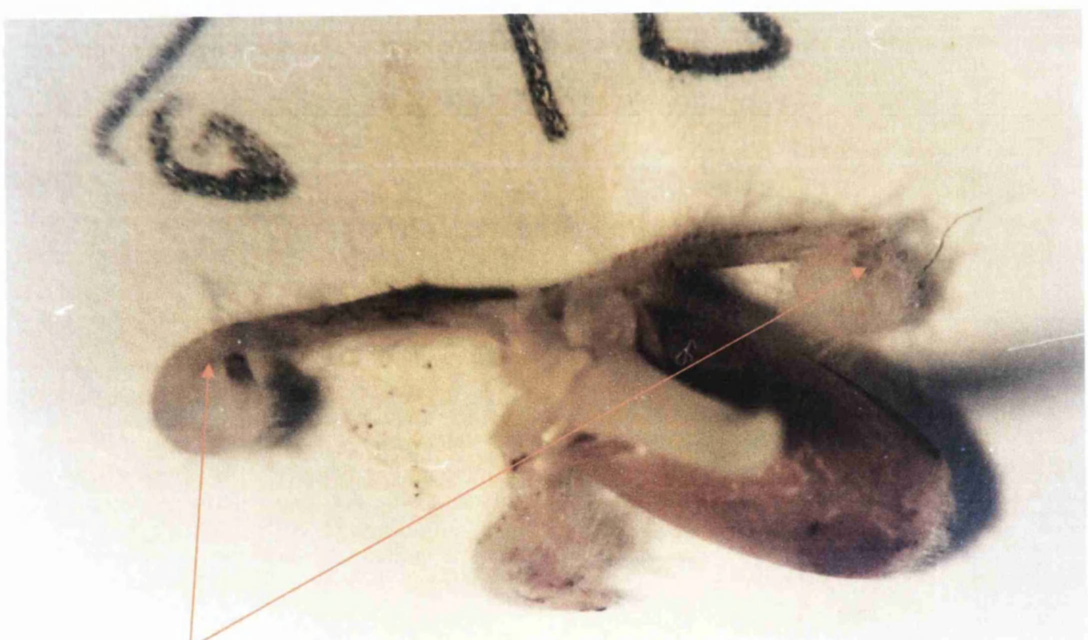


Fig. 78: Spirillum and brownish colour on wheat roots due to weed extract.

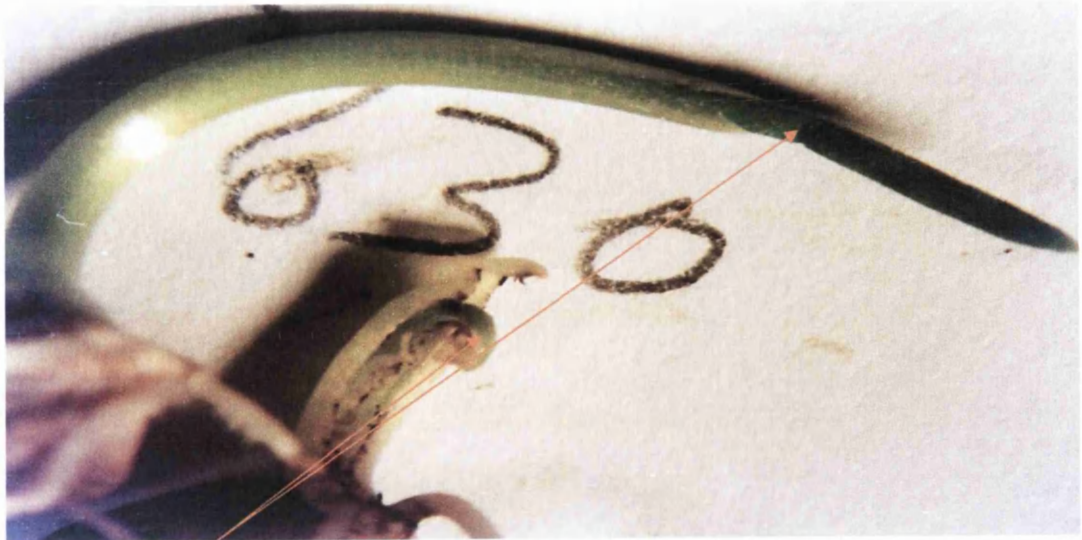


Fig. 79: Deformations appeared in plumule on wheat seedling stage (as compared with control).

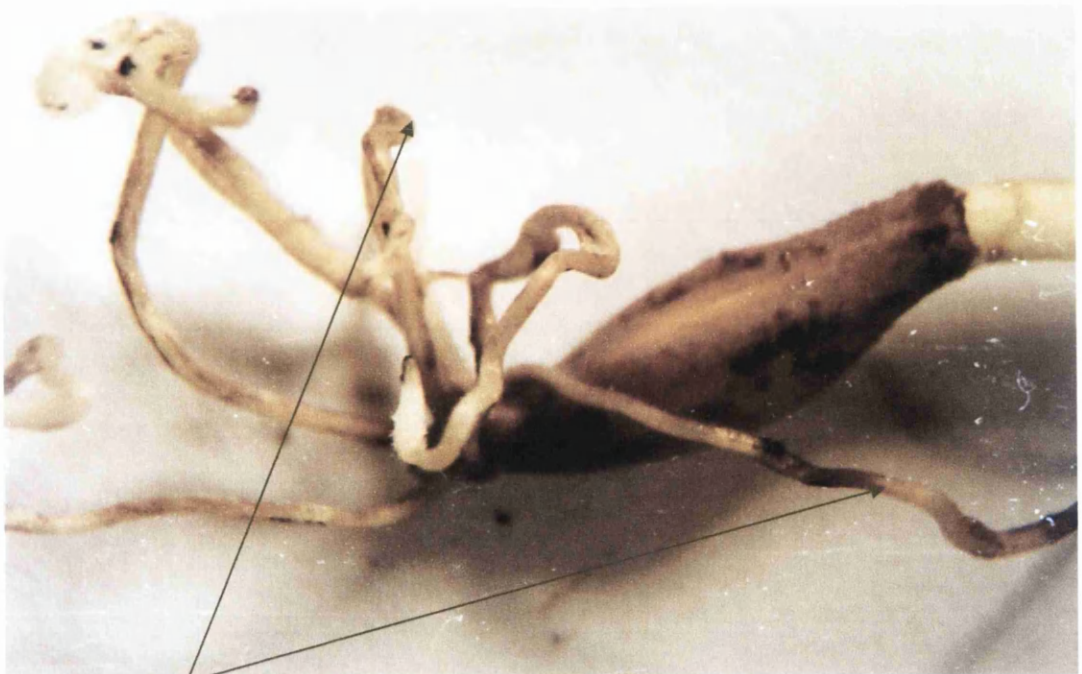


Fig. 80: Deformations and brownish colour on barley seeds and roots.

CHAPTER 8

CHAPTER 8

DISCUSSION

Inter-specific Competition

Many studies have shown significant effects of weed plants on crop plants such as wheat (e.g. Farahbaksh *et al.*, 1987; Korres & Froud-Williams, 2002) and barley (e.g. Dunan & Zimdahl, 1991; Didon., 200)). One of the most successful weeds that are known to compete for space and resources with crop plants are the broadleaved weeds such as *Chenopodium* and *Amaranthus* (Paolini *et al.*, 1999; Morgan *et al.*, 2001; Nurse *et al.*, 2003; Qasem & Hill, 1994). The present study investigated in detail the effects of the two weeds on Saudi Arabian wheat and barley varieties and vice versa.

The results showed that interference of the weeds (*Chenopodium* and *Amaranthus*) with wheat plants significantly reduced some growth parameters. Similar observations were made by Korres & Froud-Williams, (2002) Bazzaz, (2001) and Medd *et al.* (1985), who reported that wheat growth parameters and yield were reduced under stress caused by interference of weeds with wheat.

In the first experiment, the results showed that *Chenopodium* significantly reduced some growth parameters in wheat but did not affect others. This could be due to the ability of wheat to tolerate competition by compensating for the loss in growth and preserving some important growth parameters such as the overall plant dry weight. Like many cereals, it was reported that wheat has some level of competition ability in its own right (Tanji *et al.*, 1997; Cousens & Mokhtari, 1998) and this may in part explain the general lack of impact which *Chenopodium* had on wheat in this experiment.

Plant height and shoot dry weight were shown to be reduced by the presence of *Chenopodium* especially in the below-ground competition (root interaction treatment). This is in line with the finding of Martin & Snaydon (1982), who provided evidence that weeds, in plants root competition had a much greater effect on the relative performance of the crop plants of the field d beans than did shoot competition.

In this experiment, the application of nutrients produced slightly significant variation in the performance of wheat plants. In the absence of added fertilizer, only shoot interaction showed an effect on shoot dry weight of wheat plants. In contrast, when fertilizer was added shoot dry weight recovered when shoots interacted but decreased when roots interacted.

However, statistical analyses showed that the interaction between competition treatments and fertilizer treatments showed some significance, for this reason all competition experiments were run using fertilizer treatments. However, other problems were interfering with experiment 1 such as fungal infection, high direct sunlight due to summer season. For this reason experiment 1 was treated as a preliminary and re-run as experiment 2 after overcoming all the problems mentioned above.

In the second experiment, *Chenopodium* plants were dominant as illustrated in Figs. 22 & 21, due to its competitive ability over wheat. In the presence of *Chenopodium* plants, all growth parameters of wheat were reduced under the three interactions except whole-plant dry weight under shoot interaction and also shoot dry weight under shoot interaction or both root & shoot interaction. Root dry weight and plant height of wheat were the most affected as they were reduced under all three interactions (Chapter 4, Table 14). Under root interaction, *Chenopodium* reduced all growth parameters of wheat suggesting the high competitive ability of *Chenopodium* roots for nutrients and water more than shoots. This was also in line with the observation made by Martin & Snaydon (1982) who confirmed that when some crops have higher competitive ability over other crops, root competition had a much greater effect on the relative performance of the weak crop species than did shoot competition.

Unlike wheat, *Chenopodium* plants showed high competitive ability when grown in the presence of wheat. The only negative effects on *Chenopodium* were a reduction in height (when shoots interacted) and whole plant dry weight (when roots interacted). However, these effects were very limited compared to that of wheat. However, the results showed that some of Chenopodium growth parameters were increased instead in the presence of wheat plants. For example, plant height and shoot dry weights were increased when root systems interacted, suggesting that *Chenopodium* plants were more tolerant to competition than wheat plants.

Again, the interaction between fertilizer and competition treatments was not significant in any of the plant growth parameters of both species. Other authors such as Qasem & Hill (1994), and showed that the competitive ability and accumulation of nutrients by *Chenopodium album* were higher than in other plants. Also, Dotzenko *et al.* (1969) showed that extra nitrogen stimulated growth of *Chenopodium album* more than sugar beets. In contrast, wheat was found to be affected by supplementary nitrogen. Also, Iqbal & Wright (1997) found that low N supply decreased plant dry weight in both wheat and weed species and grain dry weight in wheat. Also found when fertilizer was added C. album was more competitive than wheat.

In the third experiment, *Amaranthus* reduced dry matter accumulation in the shoots and roots of wheat plants under all three interactions, and the only growth parameter not affected was plant height when shoots or both roots and shoots interacted. This suggests that wheat is a weak competitor. This was reported by other studies (Lemerle *at al.*, 1996) and wheat was classified as weaker competitor compared to barley, rye and flax. Wheat also reduced some growth parameters of *Amaranthus* such as plant height under shoot interaction, and whole-plant dry weight under shoot & root interaction. However, it had no effect on any of the growth parameters of *Amaranthus* under root interaction.

In contrast to the present study, wheat was observed to be dominant by many authors such as Tanji *et al.* (1997), Cousens & Mokhtari (1998) who showed wheat dominance over some weeds, and the growth parameters indicated that wheat had greater growth ability.

It was expected that under both shoot and root interaction the competitive ability of wheat would be high, but this was not the case for the Saudi variety used in this study.

Like *Chenopodium*, *Amaranthus* showed an increase of root, shoot and whole plant dry weights when root systems interacted with that of wheat. This suggests that some weeds may benefit from the presence of other species. This could be due to some compensatory mechanism which needs to be investigated.

When the effects of *Chenopodium* and *Amaranthus* competition on wheat plants were compared it was found that *Amaranthus* was a bit less competitive than *Chenopodium*. This may be related to the date of sowing. The most suitable time of vegetation activity for annual weeds is the summer season (Hill, 1977). On the other hand, winter is a suitable time for wheat plant growth. In the future we can avoid the competition of weeds when wheat is sown in winter. Also in this experiment, the application of nutrient did not produce any significant variation in the performance of wheat plants.

In the fourth experiment, the competition of barley and *Amaranthus* was studied. *Amaranthus* was found to decrease plant height and shoot dry weight of barley plants in all interactions. The whole-plant dry weight was affected under all interactions except under root interaction. Root dry weight was only affected under root interaction. This suggests that dominance of *Amaranthus* over barley was dependent on the kind of competition taking place: whether it is under or above-ground. This effect of weeds on barley was reported by many researchers. For example, Didon (2002) observed that the white mustard weed (*Sinapis alba* L.) decreased the whole-plant dry weight in three barley cultivars. However, the levels of response of the three barley cultivars to weed competition were different, suggesting a variation between barley cultivars to weed competition. Also in her studies, Didon (2002) observed that white mustard caused an early stem elongation in barley, but only in the most competitive barley cultivars. This effect was not observed in the present study; however, plant weight was reduced, probably because stem elongation of this Saudi Arabian barley cultivar is too sensitive to competition, or that *Amaranthus* weed simply exerts more effect on barley than the white mustard weed does. Similarly to the present study, plant height was also found to be reduced but not until tillering stage and not all cultivars showed the same level of response.

In the present study, whole plant dry weight and root dry weight were not affected in wheat grown in the presence of *Amaranthus*.

In the case of the effect of barley on *Amaranthus*, barley was also found to affect some growth parameters regardless of the kind of interaction. Barley plants reduced *Amaranthus* plant height and root dry weight in all interactions. These results suggest that barley has some level of competitive ability when grown with

Amaranthus. The ability to endure the presence of weeds in barley compared to the other cereals is a well documented phenomenon. For example, Lemerle *et al.* (1996) stated that barley is a more competitive crop than rye, wheat, oat and flax. Similarly to the present study, Izquierdo *et al.* (2003) observed that different barley cultivars reduced the whole-plant dry weight of the weed ryegrass (*Lolium rigidum*). Again in this experiment, added fertilizer was found to have no effect on the competition between barley and *Amaranthus*.

In the fifth experiment, barley was grown with the weed *Chenopodium* to study the effect of the stress exerted by the presence of one species with the other. *Chenopodium* decreased all growth parameters, related to dry matter accumulation, of barley in all interactions except the plant height that showed statistically an insignificant decrease under shoot interaction and root interaction. Similarly, barley had decreased all growth parameters, related to dry matter accumulation of *Chenopodium*, except plant height in shoot interaction and root interaction, and shoot dry weight in all interactions. These results suggest that both species had a negative effect on each other with barley being the most affected species. Barley tolerance of *Chenopodium* was not clear in this experiment either because the Saudi Arabian barley cultivar used in the present study is again a weak competitor or because of unknown factors related to the growth environment where the experiments were carried out.

Based on root, shoot or whole-plant dry weight, aggressivity analyses showed that *Chenopodium* was aggressive towards wheat when only the roots of both species interacted and slightly when both roots and shoots interacted. As aggressivity under shoot interaction was null, competitive ability of *Chenopodium* was due almost entirely to its greater root competitive ability.

Amaranthus against wheat was shown to be more aggressive against wheat when roots of both species interacted and when whole plant dry weight was used. However, plant height showed no sign of *Amaranthus* aggressivity in any interaction.

In the case of *Chenopodium* and barley, aggressivity of *Chenopodium* based on plant height was found to be slightly higher in both root and root & shoot interactions and also in root interaction when based on root dry weight. Whole plant dry weight showed no sign of *Chenopodium* aggressivity against barley.

Amaranthus showed no aggressivity against barley in any interaction except when root dry weight was used.

From the above results, it is clear that root interaction is behind most of the aggressivity of one species against another. Most previous studies (e.g. Snaydon, 1971; Eagles, 1972; Martin & Snaydon, 1982) have also shown that root competition has a greater effect on the relative performance of species than does shoot competition.

I thought that the competition treatment where root & shoot interactions are engaged in the process would be more effective and aggressive than root interactions only, however the experimental results proved that root treatment is dominant in terms of competition effectiveness and aggression than other treatment selected for this study. This behavior may be attributed to the survival phenomena, where it is assumed that compression on certain part of a plant would force it to adapt by raising the resistance potential of others. Adaptation process might take the form of additional elongation of stem or rise in leafs number to compensate for stress exerted on roots.

Allelopathy

Numerous studies have shown that allelopathic effect can exert moderate to strong competition pressure on crop growth parameters as recent studies suggested (Kocacalikan & Terzi, 2001; Migahid & Elkhazan, 2002; Kadio & Yanar, 2004; Macias *et al.*, 2004). Allelopathy may be one of the main factors which limit the distribution of numerous plants especially in the natural habitats (Gaynar & Jadhav, 1993; Qasem, 1993 & 1995). Many compounds that have allelopathic effects have been identified ranging from simple water-soluble organic acids, unsaturated lactones, phenols to flavonoids, tannins, terpenoids steroids (Rice, 1984; Einhellig, 2004). Many reports have proven that the aerial part of the plant contains many secondary products such as alkaloids, glycoside and tannins (Hassanean & El-Hamouly, 1993; Elgamal *et al.*, 1995).

The results of the sixth and seventh experiments supported the allelopathic effect of the weed *H. europaeum* on seed germination of both wheat and barley. The application of different concentrations of *H. europaeum* extracts on wheat and barley seeds significantly reduced root growth and strongly inhibited the germination percentage of seeds in both crop plants. The reductions were enlarged with the increase of the concentration of *H. europaeum* extracts. There was also a slight reduction in the emerging root growth of both crop species. This was observed by Macias *et al.* (2004) who confirmed that the radish radicles from treated seeds were much shorter and coarser compared to the control due to the inhibition effect of the extract on root cell expansion.

The treatments from different concentrations of *H. europaeum* extracts caused a very noticeable deformation in the growing roots as it was shown in Fig. 77 in this study and other studies such as that of Macias *et al.* (2004). A brownish colour of roots was also observed as in Fig. 78, and spirillum roots as in Figs. 77, 78, 80. Some deformations also appeared in the plumule of the seedling stage Fig. 79. The cause of this problem may be due to the allelopathic effect (chemical substances).

Allelopathic competition between the weed and the two crops wheat and barley revealed that the highest reduction (as compared with control) were in wheat roots length and wheat germination. This suggests that barley is a more tolerant crop than wheat. How do barley seeds tolerate the allelopathic effects of neighboring weed plants? This resistance of barley seeds to different concentrations of *H. europaeum* leaves extracts is probably due to the morphological and anatomical structures of barley seed cover and barley membrane as suggested by Migahid & Elkhazan (2002).

In addition, there is some evidence, that allelopathy effect might weaken plant immunity, thus making crop plants less resistant to insect pests and disease attack (e. g. for fungi attack); in this respect, the barley plants seem to have more tolerance and resistance to physical competition by weeds (Chapter 5) and chemical interference (allelopathy) by chemicals released by the weeds to the environment (Chapter 7).

The present result, suggest that *Heliotropium europaeum* might change plant communities when it is recycled in the soil due to its strong allelopathic effect on neighboring plants.

To reduce dependence on herbicide use, and improve the efficiency of the control of weeds, there is a growing interest in developing the potential of allelopathic mechanisms in crop plants which might allow them to produce better natural herbicides to suppress their competitor weeds (Macias *et al.*, 2004; Lars, 2004). This advantage of allelopathic effects in weeds is a good survival strategy that makes them more successful than crop plants. However, a recent study

(Olofsdotter *et al*., 2002) demonstrated that some crop plants may have a potential allelopathic effect that can be exploited to control weeds as an integrated weed control management (IWCM).

In a recent study, Olofsdotter *et al.* (2002) investigated the possibilities of using allelopathy to improve the overall competitive ability of crop plants against weeds using rice, *Oryza sativa.* She concluded that it is possible to improve allelopathy in crop plants such as rice using marker-assisted selection. Optimizing, allelopathy in combination with breeding for competitive plant types could result in crop cultivars with superior weed-suppressive ability.

GENERAL CONCLUSIONS

In this section, I will conclude my findings and discuss them according to the project aims in Chapter 1 (Introduction & Literature Review):

1. Determine the competitive ability of weeds with reference to Saudi cultivars of wheat and barley crop plants:

The present study showed clearly that *Chenopodium* plants were more dominant over wheat plants, due to its roots' competitive ability. In contrast, *Amaranthus* was found to be less competitive than *Chenopodium* towards wheat.

2. Identify the interaction effects on the morphology of crop plants.
3. Understand the behaviour of weeds and their dynamic interactions with crops:

The 2nd and 3rd project aims are concerned with the effects of weed-crop interactions on the morphology of plants. Experimental results showed that *Amaranthus and Chenopodium* interference with wheat plants significantly decreased cereal growth under each of three interaction conditions (root interaction, shoot interaction and root & shoot interaction). The interference of weeds caused morphological changes in wheat such as plant height, spike size and leaf chlorosis. *Amaranthus* reduced dry matter accumulation in shoots and roots of wheat plants under all three interactions.

In the case of barley, *Chenopodium* and *Amaranthus* interference decreased slightly all barley growth parameters in all interaction conditions. Weed interference caused morphological changes in barley such as root system size and leaf chlorosis.

It was concluded in this thesis that sowing crop plants in winter season is the key for crop to avoid weed plants whose vegetative active is higher during summer seasons.

Although this study contributed to the understanding of Saudi Arabian cereal cultivars reaction to weeds, more research is needed on crop cultivars commonly grown in Saudi Arabia. In particular, there is a need for further studies to investigate the behaviour and dynamic interactions of weeds with neighboring crop plants, or under varying soil and environmental conditions.

4. Investigate the various mechanisms of interactions between weeds and crop plants:

Some effects of weeds on crop plants were proven to be due to allelopathic. The application of different concentration of *Heliotropium* extracts on wheat and barley seed significantly reduced root length and strongly inhibited the germination percentage of seeds in both wheat and barley crops.

Heliotropium extracts caused some morphological changes such as deformation and browning of roots and deformation of the plumule in emerging wheat seedlings. More studies are needed to study allelopathic ability in Saudi Arabian crop cultivars that can be used in the fight against weeds without affecting the environment.

5. Examine the interaction effects of wheat and barley plants:

The effects of wheat on *Chenopodium* and *Amaranthus* plants were very limited and only slightly significant when roots of both species interacted. Barley decreased all growth parameters related to dry matter accumulation of *Amaranthus* suggesting that barley was more competitive than wheat towards this broadleaved weed.

6. Study the effects of environmental factors on the interaction process:

Only added fertilizer was studied in the present work. It was concluded that added fertilizer had no significant effect on any plant growth parameter. This was probably due to the nutrient-rich growth medium used for plant growth. More environmental factors such as light, CO_2 and water, should be studied using Saudi cultivars under Saudi Arabia environmental conditions.

7. Investigate the tolerance and resistance abilities of crop plants (wheat or barley) against weeds.

Barley plants were found to be more tolerant of weed interference than wheat plants. Weed-tolerant cultivars can be a powerful method that can be integrated in weed control management. More studies are needed to reveal all Saudi Arabian crop cultivars that are weed-tolerant.

8. Apply the knowledge gained from the study as a primary basis in application for finding ways to minimize weeds aggression in Saudi Arabia.

As mentioned above, more studies should be carried out to discover all Saudi crop cultivars that are weed-tolerant or have allelopathic ability so they can be integrated locally into the weed-control management system.

9. Establish a suitable solution as a primary basis for some agricultural problems in Saudi Arabia.

The present study is a step forward to address some Saudi Arabian agricultural problems caused by weeds. More weeds will be studied in Saudi Arabia to understand mechanisms of weed-crop interactions.

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APPENDIX

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Competition between weeds and wheat

Analysis of Variance (Balanced Designs)

Chapter 3 – experiment 1- *Chenopodium* competition with wheat

Effects of *Chenopodium* interference on wheat plants height

Source	DF	SS	MS	F	P
Nutrition	1	4.34	4.34	0.27	0.614
Competition	3	923.89	307.96	18.85	< 0.001
Nutrition* Competition	3	61.40	20.47	1.25	0.328
Block	2	286.76	143.38	8.78	0.005
Error	14	228.70	16.34		
Total	23	1505.09			

Effects of *Chenopodium* interference on wheat whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.00728	0.00728	0.51	0.488
Competition	3	0.05710	0.01903	1.32	0.306
Nutrition* Competition	3	0.00416	0.00139	0.10	0.961
Block	2	0.00935	0.00467	0.33	0.728
Error	14	0.20116	0.01437		
Total	23	0.27904			

Effects of *Chenopodium* interference on wheat on shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.000176	0.000176	0.05	0.830
Competition	3	0.045721	0.015240	4.12	0.027
Nutrition* Competition	3	0.073166	0.024389	6.59	0.005
Block	2	0.092017	0.046009	12.43	0.100
Error	14	0.051807	0.003710		
Total	23	0.262888			

Effects of *Chenopodium* interference on wheat root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.001162	0.001162	0.58	0.461
Competition	3	0.009804	0.003268	1.62	0.230
Nutrition* Competition	3	0.000805	0.000268	0.13	0.939
Block	2	0.064508	0.032254	15..97	0.08
Error	14	0.028274	0.002020		
Total	23	0.104553			

Competition between weeds and wheat

Analysis of Variance (Balanced Designs)

Chapter 4 – experiment 2- *Chenopodium* competition with wheat

Effects of *Chenopodium* interference on wheat plants height

Source	DF	SS	MS	F	P
Nutrition	1	2.653	2.653	0.69	0.421
Competition	3	75.774	25.258	6.55	0.005
Nutrition* Competition	3	17.408	5.803	1.50	0.257
Block	2	12.788	6.394	1.66	0.226
Error	14	54.011	3.858		
Total	23	162.634			

Effects of wheat interference on *Chenopodium* plants height

Source	DF	SS	MS	F	P
Nutrition	1	5.69	5.69	0.45	0.515
Competition	3	1385.28	461.76	36.21	< 0.001
Nutrition* Competition	3	27.20	9.07	0.71	0.561
Block	2	33.93	16.97	1.33	0.296
Error	14	178.55	12.75		
Total	23	1630.66			

Effects of *Chenopodium* interference on wheat whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0002535	0.0002535	0.43	0.520
Competition	3	0.0376190	0.0125397	21.49	< 0.001
Nutrition* Competition	3	0.0041982	0.0013994	2.40	0.112
Block	2	0.0030630	0.0015315	2.62	0.108
Error	14	0.0081683	0.0005835		
Total	23	0.0533020			

Effects of wheat interference on *Chenopodium* whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.000683	0.000683	0.16	0.697
Competition	3	0.230169	0.076723	17.72	0.177
Nutrition* Competition	3	0.024588	0.008196	1.89	0.101
Block	2	0.023483	0.011742	2.71	
Error	14	0.060633	0.004331		
Total	23	0.339555			

Effects of *Chenopodium* interference on wheat shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0001927	0.0001927	0.37	0.55
Competition	3	0.0463792	0.0154597	29.88	< 0.001
Nutrition* Competition	3	0.0025933	0.0008644	1.67	0.219
Block	2	0.0003730	0.0001865	0.36	0.704
Error'	14	0.0072443	0.0005175		
Total	23	0.0567825			

Effects of wheat interference on *Chenopodium* shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.041168	0.041168	18.68	< 0.001
Competition	3	0.139438	0.046479	21.09	< 0.001
Nutrition* Competition	3	0.007587	0.002529	1.15	0.364
Block	2	0.014281	0.007140	3.24	0.070
Error'	14	0.030855	0.002204		
Total	23	0.233328			

Effects of *Chenopodium* interference on wheat root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0000220	0.0000220	0.06	0.807
Competition	3	0.0383401	0.0127800	36.12	< 0.001
Nutrition* Competition	3	0.0033125	0.0011042	3.12	0.060
Block	2	0.0013563	0.0006782	1.92	0.184
Error'	14	0.0049530	0.0003538		
Total	23	0.0479840			

Effects of wheat interference on *Chenopodium* root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0002344	0.0002344	0.63	0.441
Competition	3	0.0042291	0.0014097	3.79	0.035
Nutrition* Competition	3	0.0005655	0.0001885	0.51	0.684
Block	2	0.0000968	0.0000484	0.13	0.879
Error'	14	0.0052119	0.0003723		
Total	23	0.0103376			

experiment 3- *Amaranthus* competition with wheat

Effects of *Amaranthus* interference on wheat plants height

Source	DF	SS	MS	F	P
Nutrition	1	0.5581	0.5581	0.88	0.365
Competition	3	31.0245	10.3415	16.27	< 0.001
Nutrition* Competition	3	0.3478	0.1159	0.18	0.907
Block	2	2.1163	1.0581	1.66	0.225
Error'	14	8.9008	0.6356		
Total	23	42.9475			

Effects of wheat interference on *Amaranthus* plants height

Source	DF	SS	MS	F	P
Nutrition	1	7.415	7.415	3.56	0.080
Competition	3	141.415	47.138	22.61	< 0.001
Nutrition* Competition	3	43.387	14.462	6.64	0.004
Block	2	4.539	2.269	1.09	0.364
Error'	14	29.184	2.085		
Total	23	225.940			

Effects of *Amaranthus* interference on wheat whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1 1	0.000913	0.000913	0.59	0.454
Competition	3 3	0.115762	0.038587	25.13	< .001
Nutrition* Competition	3 3	0.000654	0.000218	0.14	0.933
Block	2 2	0.005207	0.002603	1.70	0.219
Error’	1414	0.021493	0.001535		
Total	2323	0.144029			

Effects of wheat interference on *Amaranthus* whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0010402	0.0010402	3.23	0.094
Competition	3	0.0423382	0.0141127	43.88	< 0.001
Nutrition* Competition	3	0.0002228	0.0.0000743	0.23	0.873
Block	2	0.0013968	0.0006984	2.17	0.151
Error’	14	0.0045026	0.0003216		
Total	23	0.0495005			

Effects of *Amaranthus* interference on wheat shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0000735	0.0000735	0.53	0.478
Competition	3	0.463980	0.0154660	112.06	< 0.001
Nutrition* Competition	3	0.0000285	0.0000095	0.07	0.976
Block	2	0.0006398	0.0003199	2.32	0.135
Error'	14	0.0019323	0.0001380		
Total	23	0.0490720			

Effects of wheat interference on *Amaranthus* shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0000050	0.0000050	0.01	0.925
Competition	3	0.0142601	0.0047534	8.75	< 0.01
Nutrition* Competition	3	0.0015392	0.0005131	0.94	0.445
Block	2	0.0049029	0.0024515	4.51	0.031
Error'	14	0.0076028	0.0005431		
Total	23	0.0283099			

Effects of *Amaranthus* interference on wheat root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.00002017	0.00002017	0.28	0.606
Competition	3	0.00685633	0.00228544	31.61	< 0.001
Nutrition* Competition	3	0.00001950	0.00000650	0.09	0.964
Block	2	0.00008508	0.00004254	0.59	0.568
Error'	14	0.00101225	0.00007230		
Total	23	0.00799333			

Effects of wheat interference on *Amaranthus* root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0000070	0.0000070	0.05	0.833
Competition	3	0.0084078	0.0028026	18.45	< 0.001
Nutrition* Competition	3	0.0000338	0.0000113	0.07	0.973
Block	2	0.0013771	0.0006885	4.53	0.030
Error'	14	0.0021263	0.0001519		
Total	23	0.0119520			

Chapter 5 experiment 4- *Amaranthus* competition with barley

Effects of *Amaranthus* interference on barley plants height

Source	DF	SS	MS	F	P
Nutrition	1	3.375	3.375	2.14	0.66
Competition	3	148.458	49.486	31.37	< 0.001
Nutrition* Competition	3	25.458	8.486	5.38	0.011
Block	2	0.583	0.292	0.18	0.833
Error'	14	22.083	1.577		
Total	23	199.958			

Effects of barley interference on *Amaranthus* plants height

Source	DF	SS	MS	F	P
Nutrition	1	13.500	13.500	3.64	0.077
Competition	3	64.167	21.389	5.77	0.01
Nutrition* Competition	3	8.167	2.722	0.73	0.549
Block	2	22.750	11.375	3.07	0.079
Error'	14	51.917	3.708		
Total	23	160.500			

Effects of *Amaranthus* interference on barley whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.00827	0.00827	0.77	0.395
Competition	3	0.06208	0.02069	1.92	0.172
Nutrition* Competition	3	0.02171	0.00724	0.67	0.583
Block	2	0.01920	0.00960	0.89	0.432
Error'	14	0.15054	0.01075		
Total	23	0.26181			

Effects of barley interference on *Amaranthus* whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.071373	0.071373	11.02	0.005
Competition	3	0.211621	0.070540	10.89	< 0.001
Nutrition* Competition	3	0.065201	0.021734	3.36	0.050
Block	2	0.003650	0.001825	0.28	0.759
Error'	14	0.090675	0.006477		
Total	23	0.442520			

Effects of *Amaranthus* interference on barley shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.000075	0.000075	0.04	0.851
Competition	3	0.34625	0.011592	5.66	0.01
Nutrition* Competition	3	0.001374	0.000458	0.22	0.878
Block	2	0.000848	0.000424	0.21	0.815
Error'	14	0.0.28559	0.002040		
Total	23	0.065481			

Effects of barley interference on *Amaranthus* shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.002856	0.002856	1.58	0.229
Competition	3	0.009196	0.003065	1.70	0.212
Nutrition* Competition	3	0.000822	0.000274	0.15	0.927
Block	2	0.000309	0.000154	0.09	0.918
Error'	14	0.025226	0.001802		
Total	23	0.038408			

Effects of *Amaranthus* interference on barley root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0004109	0.0004109	0.72	0.412
Competition	3	0.0109659	0.0036553	6.37	< 0.01
Nutrition* Competition	3	0.0004671	0.0001557	0.27	0.845
Block	2	0.0010208	0.0005104	0.89	0.433
Error'	14	0.0080390	0.0005742		
Total	23	0.0209036			

Effects of barley interference on *Amaranthus* root dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.0013984	0.0013984	4.77	0.046
Competition	3	0.0072894	0.0024298	8.29	< 0.01
Nutrition* Competition	3	0.0004765	0.0001588	0.54	0.661
Block	2	0.0010620	0.0005310	1.81	0.200
Error'	14	0.0014036	0.0002931		
Total	23	0.0143300			

Experiment -5 *Chenopodium* competition with barley

Effects of *Chenopodium* interference on barley plants height

Source	DF	SS	MS	F	P
Nutrition	1	0.167	0.167	0.07	0.802
Competition	3	428.000	142.667	55.87	< 0.001
Nutrition* Competition	3	1.833	0.611	0.24	0.867
Block	2	7.583	3.792	1.48	0.260
Error'	14	35.750	2.554		
Total	23	473.333			

Effects of barley interference on *Chenopodium* plants height

Source	DF	SS	MS	F	P
Nutrition	1	0.67	0.67	0.05	0.820
Competition	3	371.67	123.89	9.98	< 0.001
Nutrition* Competition	3	69.67	23.22	1.87	0.181
Block	2	0.25	0.13	0.01	0.990
Error'	14	173.75	12.41		
Total	23	616.00			

Effects of *Chenopodium* interference on barley whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.03185	0.03185	3.36	0.088
Competition	3	0.0.83734	0.27911	29.43	< 0.001
Nutrition* Competition	3	0.01649	0.00550	0.58	0.638
Block	2	0.0.2065	0.01033	1.09	0.364
Error'	14	0/13279	0.00949		
Total	23	1.03913			

Effects of barley interference on *Chenopodium* whole- plants dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.000075	0.000075	0.04	0.851
Competition	3	0.034625	0.011542	5.66	0.01
Nutrition* Competition	3	0.001374	0.000458	0.22	0.878
Block	2	0.000848	0.000424	0.21	0.815
Error'	14	0.028559	0.002040		
Total	23	0.065481			

Effects of *Chenopodium* interference on barley shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.000566	0.000566	0.25	0.622
Competition	3	0.284044	0.094681	42.67	< 0.001
Nutrition* Competition	3	0.002377	0.000792	0.36	0.785
Block	2	0.001489	0.000744	0.34	0.721
Error'	14	0.031062	0.002219		
Total	23	0.319537			

Effects of barley interference on *Chenopodium* shoot dry weight

Source	DF	SS	MS	F	P
Nutrition	1	0.001743	0.001743	0.94	0.348
Competition	3	0.011137	0.003712	2.01	0.159
Nutrition* Competition	3	0.001768	0.000589	0.32	0.812
Block	2	0.000545	0.000273	0.15	0.864
Error'	14	0.025896	0.001850		
Total	23	0.41089			

Effects of *Chenopodium* interference on barley root dry weight

Source	DF	SS	MS	F	P
Nutrition	**1**	**0.000442**	**0.000442**	**0.27**	**0.610**
Competition	**3**	**0.089391**	**0.029797**	**18.35**	**< 0.001**
Nutrition* Competition	**3**	**0.001508**	**0.000503**	**0.31**	**0.818**
Block	**2**	**0.000573**	**0.000286**	**0.18**	**0.840**
Error'	**14**	**0.022736**	**0.001624**		
Total	**23**	**0.114650**			

Effects of barley interference on *Chenopodium* root dry weight

Source	DF	SS	MS	F	P
Nutrition	**1**	**0.0015746**	**0.0015746**	**2.63**	**0.127**
Competition	**3**	**0.0102691**	**0.0034230**	**5.72**	**0.01**
Nutrition* Competition	**3**	**0.001702**	**0.0005701**	**0.95**	**0.442**
Block	**2**	**0.0012935**	**0.0006467**	**1.08**	**0.366**
Error'	**14**	**0.0083765**	**0.0005983**		
Total	**23**	**0.0232239**			

Chapter 4:
***Amaranthus* aggressivity against Wheat**

Source	DF	SS	MS	F	P
Aggressivity based on Plant height	2	0.03369	0.01684	10.38	0.011
Error	6	0.00973	0.00162		
Total	8	0.04342			
Aggressivity based on Whole-plant dry weight	2	0.09669	0.04834	24.72	< 0.001
Error	6	0.01173	0.00196		
Total	8	0.10842			
Aggressively based on Shoot dry weight	2	0.04809	0.02404	3.52	0.097
Error	6	0.04093	0.00682		
Total	8	0.08902			
Aggressivity based on Root dry weight	2	0.10082	0.05041	12.20	0.008
Error	6	0.02480	0.00413		
Total	8	0.12562			

***Chenopodium* aggressivity against Wheat plant**

Source	DF	SS	MS	F	P
Aggressivity based on Plant height	2	0.070289	0.035144	10.14	0.012
Error	6	0.020800	0.003467		
Total	8	0.091089			
Weight Aggressivity based on Whole-plant dry	2	0.08276	0.04138	28.87	< 0.001
Error	6	0.00860	0.00143		
Total	8	0.09136			
Aggressivity based on Shoot dry weight	2	0.1176	0.0588	4.49	0.064
Error	6	0.0786	0.0131		
Total	8	0.1962			
Aggressivity based on Root dry weight	2	0.03576	0.01788	2.61	0.153
Error	6	0.04107	0.00684		
Total	8	0.07682			

Chapter 5:
***Amaranthus* aggressivity against Barley plant**

Source	DF	SS	MS	F	P
Aggressivity based on Plant height	2	0.00047	0.00023	0.11	0.895
Error	6	0.01233	0.00206		
Total	8	0.01280			
Aggressivity based on Whole-plant dry weight	2	0.00087	0.00043	0.5	0.951
Error	6	0.05093	0.00849		
Total	8	0.05180			
Aggressivity based on Shoot dry weight	2	0.0048	0.0024	0.16	0.854
Error	6	0.0896	0.0149		
Total	8	0.0944			
Aggressivity based on Root dry weight	2	0.03842	0.01921	6.73	0.029
Error	6	0.01713	0.00286		
Total	8	0.05556			

***Chenopodium* aggressivity against Barley plant**

Source	DF	SS	MS	F	P
Aggressivity based on Plant height	2	0.01162	0.00581	1.76	0.250
Error	6	0.01980	0.00330		
Total	8	0.03142			
Aggressivity based on Whole-plant dry weight	2	0.00309	0.00154	0.83	0.480
Error	6	0.01113	0.00186		
Total	8	0.01422			
Aggressivity based on Shoot dry weight	2	0.00140	0.00070	0.20	0.822
Error	6	0.02080	0.00347		
Total	8	0.02220			
Aggressivity based on Root dry weight	2	0.0126	0.0063	0.41	0.681
Error	6	0.0924	0.0154		
Total	8	0.1050			

Chapter 7 experiment -6 *Heliotropium* competition with wheat

One-Way analysis of Variance

Effects of different concentration of *Heliotropium* extracts on wheat seed germination

Source	DF	SS	MS	F	P
Block	2	11.0	5.5	0.17	0.841
Time	2	3885.6	1942.8	61.75	< 0.001
Treatment	4	16568.9	4142.2	131.65	< 0.001
Time* Treatment	8	2269.2	283.7	9.01	< 0.001
Error'	28	881.0	31.5		
Total	44	23615.8			

Effects of different concentration of *Heliotropium* extracts on Wheat root length

Source	DF	SS	MS	F	P
Block	2	11.8	5.9	0.53	0.597
Time	2	5056.2	2528.1	225.64	< 0.001
Treatment	4	7782.6	1945.7	173.66	< 0.001
Time* Treatment	8	5127.3	640.9	57.20	< 0.001
Error'	28	313.7	11.2		
Total	44	18291.6			

experiment -7 *Heliotropium* competition with barley
One-Way analysis of Variance

Effects of different concentration of *Heliotropium* extracts on barley seed germination

Source	DF	SS	MS	F	P
Block	2	12.1	6.1	0.37	0.692
Time	2	5880.0	2940.0	180.58	< 0.001
Treatment	4	25280.0	6320.0	388.18	< 0.001
Time* Treatment	8	2920.0	365.0	22.42	< 0.001
Error	28	455.9	16.3		
Total	44	34548.0			

Effects of different concentration of *Heliotropium* extracts on barley root length

Source	DF	SS	MS	F	P
Block	2	14.72	7.36	1.92	0.166
Time	2	2895.30	1447.65	376.65	< 0.001
Treatment	4	3746.80	936.70	243.71	< 0.001
Time* Treatment	8	1359.20	169.90	44,20	< 0.001
Error	28	107.62	3.84		
Total	44	8123.64			