THE INTERFERENCE POTENTIAL OF NINE SELECTED SOUTH AFRICAN SPRING WHEAT CULTIVARS WITH SELECTED WEED SPECIES

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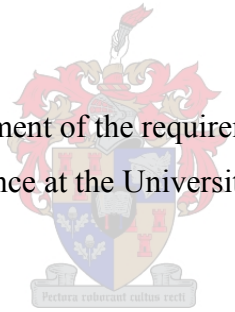

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DECLARATION

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Julia N. Nambili

To my family, their endless love and support was my strength.

ABSTRACT

The development of herbicide resistance in weeds is one of the major factors hampering profitable crop production worldwide. In South Africa resistance to herbicides in weeds is also a big problem, in particular in the Winter Rainfall Region of the country. The lack of sufficient different mode of action herbicide groups that can be rotated in these conditions necessitate the implementation of integrated weed management programmes to curb the development and spread of herbicide resistance. One of the alternative physical weed management strategies is to maximize crop competition to the weed population. One aspect of such a strategy is to plant crop cultivars that have greater interference potential than others.

The first experiment was done to investigate the interference potential of nine spring wheat cultivars, namely Baviaans, Kariege, PAN 3408, PAN 3492, SST 015, SST 027, SST 57, SST 88 and Tankwa with the objective of ranking them with regard to vigour and allelopathic potential. Firstly, seeds of the aforementioned spring wheat cultivars were planted in a temperature controlled glasshouse at 18/22°C night/ day temperatures and after the plants were fully established they were harversted every two weeks to determine plant growth parameters such as: plant height, LAI, number of leaves, number of tillers and total dry mass. Secondly, aqueous extracts of the nine spring wheat cultivars were prepared from the whole plant *i.e*. roots and shoots. These extracts were diluted as follows viz. 100% (undiluted), 75%, 50%, 25% and 0% (control = distilled water). Seeds of a commercial ryegrass cultivar (*Lolium multiflorum* cv Midmar) were germinated in petri dishes to which one of the different concentrations were added. The rate of germination and total final germination percentage were calculated after two weeks. Thirdly, seedlings of the same ryegrass cultivar were established in 8 cm x 8 cm square plastic pots. After the seedlings were well established, seedlings were watered with the aqueous solutions described above and harvested after two weeks to determine different vegetative growth parameters such as: plant height, number of leaves, number of tillers, root and shoot dry mass and total dry mass. The results obtained showed that different spring wheat cultivars differ in terms of growth pattern and allelopathy. Among the spring wheat cultivars, PAN 3492 were the fastest grower, SST 88 had the

strongest allelopathic action and Tankwa had the least allelopathic potential and also poor growth vigour. As a result, SST 88 was regarded as a competitive cultivar because of its moderate growth habit and higher allelopathic effects on ryegrass with Tankwa being the least competitive cultivar and PAN 3492 an intermediate competitive cultivar. Thus, these three cultivars were selected to perform allelopathic and competitive studies on when grown together with selected weed species.

The second experiment was done to determine the allelopathic effect of the three selected spring wheat cultivars, namely PAN 3492, SST 88 and Tankwa on germination and growth of selected weed species, namely *Lolium* species*, Raphanus raphanistrum, Oncosiphon suffruticosum, Stellaria media, Bromus diandrus* and *Avena fatua.* Aqueous extracts were prepared from the three spring wheat cultivars as described above and the same dilutions as described were prepared. The same procedure regarding the effect of the aqueous extracts on the germination and growth of the weed species were followed as described for the first experiment. The results obtained showed that aqueous extracts of spring wheat cultivars exhibited significant inhibition effects on seed germination and seedling growth of all weed species tested except that of *R. raphanistrum*. *Raphanus raphanistrum* germination was stimulated at lower extract concentrations but was inhibited as extract concentration increased. Overall the allelopathic potential of the wheat cultivars decreased in the order SST 88>PAN 3492>Tankwa.

The third experiment was conducted to determine the allelopathic potential of different weed species, namely *R. raphanistrum, O. suffruticosum, S. media, Lolium* spp*., A. fatua, B. diandrus, Phalaris minor* and *Cotula australis* on germination and growth of three selected spring wheat cultivars SST 88, PAN 3492 and Tankwa. The procedures regarding the preparation of the aqueous extracts and the effects thereof on germination and growth of the spring wheat cultivars were similar to the procedures followed in the first two experiments. The result obtained showed that weed species such as *Lolium* spp*., A. fatua, B. diandrus, O. suffruticosum* as well as *P. minor* exhibited significant inhibitory effects while *P. minor, C. australis* and *S. media* showed little effects on the growth parameters of the three spring wheat cultivars. Spring wheat cultivar SST 88 was comparatively more tolerant to the extract solutions of weed species than PAN 3492 and Tankwa.

The last experiment was conducted to determine the competitive ability of the abovementioned three spring wheat cultivars when grown together with three grass weed species (*Lolium* spp., *B. diandrus* and *A. fatua*) in order to confirm their competitiveness. Each spring wheat cultivar were established together with four varying densities (0 (control = no weed), 3, 6 and 9 plants) of weed species in 8 cm X 8 cm pots in a temperature controlled glasshouse. The result obtained showed that PAN 3492 was more competitive than SST 88 and Tankwa. Weed species affected the spring wheat cultivars differently with more effects observed from *B. diandrus* than *A. fatua* and *Lolium* spp. An increase in weed density significantly reduced the growth parameters of all spring wheat cultivars.

OPSOMMING

Die ontwikkeling van onkruiddoderweerstand deur onkruide is een van die belangrikste faktore wat winsgewende gewasverbouing wêreldwyd belemmer. In Suid-Afrika is onkruiddoderweerstand ook ’n groot probleem, veral in die winterreëngebied van die land. Die gebrek aan genoegsame verskillende metode van werking onkruiddodergroepe wat geroteer kan word in hierdie gebied noodsaak die implementering van geïntegreerde onkruidbeheer programme om die ontwikkeling en verspreiding van onkruiddoderweerstand te bekamp. Een van die alternatiewe fisiese onkruidbestuur strategiëe is om gewaskompetisie met die onkruidpopulasie te maksimeer. Een aspek van so ’n strategie is om gewaskultivars te plant wat oor beter kompeteringsvermoë as ander beskik.

Die eerste eksperiment is uitgevoer om die kompeteringsvermoë van nege lentekoring kultivars naamlik Baviaans, Kariege, PAN 3408, PAN 3492, SST 015, SST 027, SST 57, SST 88 en Tankwa te ondersoek met die doel om hulle te rangskik in terme van groeikragtigheid en allelopatiese potensiaal. Eerstens is saad van die reeds genoemde koringkultivars in ’n temperatuur beheerde glashuis by 18/22°C nag/dag temperature geplant en die plante is elke twee weke (14 dae) nadat dit goed gevestig was, ge-oes om plantegroei parameters soos planthoogte, blaaroppervlakindeks (BOI), aantal blare, aantal halms en totale droëmassa te bepaal. Tweedens is waterige aftreksels van die nege lentekoring kultivars berei vanaf die hele plant m.a.w. die loof en wortels en dit is verdun om vyf konsentrasies daar te stel nl. 100% (onverdund), 75%, 50%, 25% en 0% (kontrole = gedistilleerde water). Saad van ‘n kommersiële raaigras kultivar (*Lolium multiflorum* kv. Midmar) is in petribakkies waarin een van die verskillende aftreksel konsentrasies bygevoeg is, ontkiem. Die totale ontkiemingspersentasie asook die ontkiemingstempo is na twee weke bereken. Derdens is saailinge van dieselfde raaigraskultivar in 8 cm x 8 cm plastiekpotjies gevestig. Nadat die saailinge goed gevestig was, is dit benat met waterige aftreksels soos hierbo beskryf en na twee weke van toediening ge-oes om verskillende plantegroei parameters te meet. Die resultate wat verkry is het getoon dat die verskillende koringkultivars van mekaar verskil in terme van groeipatroon en allelopatiese potensiaal. Onder die koringkultivars het PAN 3492 die vinnigste gegroei, SST 88 het die sterkste allelopatiese potensiaal vertoon en Tankwa het die minste allelopatiese potensiaal getoon en ook die swakste gegroei. As gevolg hiervan is SST 88 as ‘n hoogs kompeterende kultivar beskou weens sy medium groeikragtigheid en hoë

allelopatiese potensiaal terwyl PAN 3492 as ‘n gemiddelde kompeteerder en Tankwa as ‘n swak kompeteerder geklassifiseer is. Derhalwe is hierdie drie kultivars geselekteer om allelopatiese en kompetisiestudies mee uit te voer waar dit in teenwoordigheid van geselekteerde onkruidspesies gegroei word .

Die tweede eksperiment is uitgevoer om die allelopatiese invloed van drie geselekteerde lentekoring kultivars nl. PAN 3492, SST 88 en Tankwa op die ontkieming en vegetatiewe groei van geselekteerde onkruidspesies nl. *Lolium* spesies*, Raphanus raphanistrum, Oncosiphon suffruticosum, Stellaria media, Bromus diandrus* en *Avena fatua* uit te voer. Waterige aftreksels is berei van die drie lentekoring kultivars soos hierbo beskryf en dieselfde verdunnings as hierbo is berei. Dieselfde prosedure as hierbo rakende die invloed van die waterige aftreksels op die ontkieming en vegetatiewe groei van die onkruidspesies is gevolg. Die resultate wat verkry is het getoon dat waterige aftreksels van die koringkultivars ‘n beduidende inhiberende invloed op die ontkieming en groei van al die onkruidspesies behalwe *R. raphanistrum* gehad het. *Raphanus raphanistrum* ontkieming is gestimuleer by lae konsentrasies maar is geïnhibeer soos die konsentrasies gestyg het. Oor die algemeen het die allelopatiese potensiaal van die koringkultivars afgeneem in die volgorde van SST 88>PAN 3492>Tankwa.

Die derde eksperiment is uitgevoer om die allelopatiese potensiaal van verskillende onkruidspesies nl. *R. raphanistrum, O. suffruticosum, S. media, Lolium* spp*, A. fatua, B. diandrus, Phalaris minor* en *Cotula australis* op die ontkieming en vegetatiewe groei van drie geselekteerde koringkultivars nl. SST 88, PAN 3492 en Tankwa te bepaal. Die prosedures wat gevolg is om die waterige aftreksel te maak en die invloed daarvan op die ontkieming en groei van die koringkultivars te bepaal, was soortgelyk aan die prosedures wat in die eerste twee eksperimente gevolg is. Die resultate het aangedui dat onkruidspesies soos *Lolium* spp*., A. fatua, B. diandrus, O. suffruticosum* asook *P. minor* ‘n beduidende inhiberende invloed op die groei parameters van die lentekoring kultivars gehad het. Kultivar SST 88 was relatief meer bestand teen die negatiewe invloed van die waterige aftreksels van die onkruidspesies as PAN 3492 en Tankwa.

Die laaste eksperiment is uitgevoer om die kompeteringsvermoë van bogenoemde drie koringkultivars te ondersoek wanneer hulle moet kompeteer met drie belangrike grasonkruide

nl. *Lolium* spp., *B. diandrus* en *A. fatua.* Een plant van elke koringkultivar is saam met vier verskillende onkruiddigthede nl. 0 (kontrole = geen onkruid), 3, 6 en 9 onkruidplante gevestig in 8 cm X 8 cm potte in ‘n temperatuurbeheerde glashuis. Die resultate het getoon dat PAN 3492 meer kompeterend was as SST 88 en Tankwa. Onkruidspesies het die koringkultivars verskillend beïnvloed met *B. diandrus* meer kompeterend as *A. fatua* en *Lolium* spp. Toenames in onkruiddigtheid het die groei parameters van al die koringkultivars beduidend negatief beïnvloed.

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CHAPTER 1

Introduction

Wheat (*Triticum aestivum, L*) is the most important cereal crop produced, consumed and traded in the world today. It is the most important food crop and serves as a staple food for many countries (Delorit & Ahlgren, 1967). In South Africa it ranks number one among the cereal crops produced and plays an important role in the country's economy. A decrease in wheat production would severely affect the economy and negatively influence the well-being of the inhabitants of this country.

Weed infestation is one of the devastating factors which adversely influence crop yield. Weeds affect crop growth due to competition, allelopathy and providing habitat for other harmful organisms (allelomediations) (Khan *et al.,* 2002). Chemical weed control has been proven among others to be relatively efficient in controlling weeds in many crop production systems throughout the world. The effectiveness of herbicides allows farmers to grow a crop repeatedly on the same piece of land to optimize their income and meet the demand for the specific crop. The indiscriminate use of herbicides for weed control has resulted in serious ecological and environmental problems such as: increasing occurrence of herbicide resistance in weed species, negative effects of herbicides with long residual soil activities on subsequent susceptible crops, shifts to weed populations that are more closely related to the crops that they infest, minor weeds that become dominant, greater environmental pollution and health hazards and higher herbicide prices (Benbrook, 1996; Kohli *et al.,* 2006; Heap, 2008).

This has caused a growing awareness that the intensive use of herbicides does not fit well in sustainable agricultural systems. Herbicide resistance has been appearing in several weed species and to several herbicide classes especially where monoculture and minimum tillage are practiced. In the winter rainfall region in the Western Cape, resistance has been reported to the ACCase inhibitors, ALS inhibitors, Glycines and Bipyridiliums herbicide groups (A.L.P. Cairns, 2008, Department of Agronomy, University of Stellenbosch, pers. Comm.). *Raphanus raphanistrum, Oncosiphon suffruticosum, Stellaria media* and *Cotula spp.* are among the broadleaf weeds with *Lolium spp., Avena fatua, Bromus diandrus* and *Phararis minor* among the grass weeds that are very problematic in the winter wheat producing area of the country. Resistance to herbicide has been confirmed in all of the mentioned weed species (P.J. Pieterse, 2008, Department of Agronomy, University of Stellenbosch, pers. Comm.).

An increase in herbicide resistance, increases in the cost of production and interest in environmental protection have created a need to explore other non chemical methods of weed control that are equally or more effective and selective than the currently available synthetic herbicides. Cultural control methods may play an important role in reducing the over-reliance on herbicides. This includes crop rotation, use of cover, smother and green manure crops, crop residues, crop genotypes with better competitive and allellopathic ability, manipulation of sowing or planting date, crop density and crop pattern (Kohli *et al*., 2006). According to Jordan (1993), crop interference with weed growth is a fundamental method of non-chemical weed control in many cropping systems. Interference refers to the adverse effect that neighboring plants exert on each other's growth (Muller, 1969). The cause of interference mostly includes resource competition when plants utilize common resources that are in short supply and allelopathy when one species produces chemical compounds (allelopathic compounds) that negatively influence the other species (Muller, 1969). Example of herbicides developed from allelopathic compound includes glufosinate ammonium (Basta®) and Mesotrione (Callisto®).

A growing body of evidence indicates that wheat has the ability to interfere with weed growth through competition and allelopathy and can be used to control specific weed species and thus could potentially reduce the use of synthetic herbicides. Planting a more competitive wheat cultivar with allelopathic ability has proven to be an effective cultural practice that suppresses weed growth and seed production (Ogg & Seefeldt, 1999). The effectiveness of this method requires a sound knowledge of a cultivar's competitive characteristics and its effects on the germination and growth of weeds. Some of the competitive characteristics include morphological traits such as: leaf inclination, early vigour, plant height, tillering capacity, seed size, initial number of shoots, root growth and allelopathy (Christensen, 1995; Wu *et al*., 2000; Lemerle *et al*., 2001). The allelopathic cultivars can be used in crop rotations, as cover and smother crops and by retention of crop residues (Singh *et al.,* 2003). Many researchers around the world have identified differences in competitive ability of wheat cultivars with weeds (Lemerle *et al.,* 1996, 2001; Wu *et al*., 2000; Coleman *et al.,* 2001). Several studies showed that semi-dwarf wheat have low tolerance to weed competition and suffer greater yield loss from weeds than the older, lower yield potential standard types (Lemerle *et al.,* 1996; Vandeleur & Grill, 2004). Therefore, it is necessary to improve competitive ability of wheat cultivars, by simply choosing from available varieties or by breeding for competitiveness. It is also not known whether a reduction in wheat yield from weeds is due to competition or allelopathy.

Objectives

Keeping in mind the recognized importance of crop interference with weeds, the current study was conducted under glass house conditions with the following objectives:

a) To determine the interference potential of nine selected South African spring wheat cultivars in terms of competitiveness and allelopathy

b) To determine the interference potential of three selected South African spring wheat cultivars on selected broadleaf and grass weed species and *vice versa*

c) To determine the competitive ability of three selected South African spring wheat cultivars under varied densities of different weed species

Outlay of the thesis

This introductory chapter is followed by chapter 2, a literature review on competition and allelopathy as a factor influencing crop / weed interaction. Chapter 3 describes experiments conducted to determine the interference potential (competitiveness and allelopathy) of nine selected South African spring wheat cultivars, using *Lolium multiflorum* as a test species. In chapter 4, the allelochmical influence of three selected spring wheat cultivars on germination and growth of six selected weed species is investigated. Chapter 5 deals with the allelopathic effect of eight selected weed species on germination and growth of the three selected spring wheat cultivars. The competitive ability of three spring wheat cultivars is evaluated in chapter 6 by growing them in pots containing different densities of three grass weed species. General conclusions and recommendations are provided in chapter 7. Anova tables of all experiments carried out in this study are given in Appendixes. Due to the fact that each chapter is written as a scientific article, repetitions in some section of the chapters are inevitable.

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CHAPTER 2

Literature review

1.1 Effect of weeds on crops

According to Young & Evans (1976), weeds are opportunistic genotypes naturally selected in disturbed agricultural ecosystems. Others had defined weeds as plants growing where they are not wanted. Weed infestation has been reported as a major constraint to crop production all over the world (Tanner & Sahile, 1991). They compete for soil fertility, available moisture, nutrients, space and sunlight with crop plants, which result in yield reductions. Weeds hinder complete mechanized production of crop plants, deteriorate quality, yields, harvest efficiency and consequently reduce the market value of crops (Ashton & Crafts, 1973). Weeds harbour insects and plant pathogens and serve as hosts for parasitic weeds hence making it difficult to control crop pests (Qasem & Foy, 2001).

It is commonly assumed that reduction in crop yield due to weeds is the direct result of competition, allelopathy or of the two acting together (Rice, 1984). Weeds compete with crop plants for water, light, space and nutrients and to a lesser extent have a selective advantage because of allelopathic activities. Yield reductions are generally in proportion to the amount of light, water or nutrients weeds used at the expense of a crop. In a review of weed crop competition in soyabean by Burnside (1979), the key factors in crop yield reduction were identified which include: weed crop emergence, competition duration, weed lifecycle and growth habit, density of weeds and crop plants, crop species and cultivars, crop life cycle and growth habit, crop planting date, depth of planting, row spacing and climatic and biotic factors. In general, crop yield reduction occurs linearly with an increase in the number of weed plants occupying a given crop field, with greater yield reductions occurring as the weed density increases.

Duke (1985) stated that weeds are good competitors with crop plants because of their growth habits. Weeds grow quicker and taller than crop plants and produce a foliar canopy that shade crop plants. Weeds are reported to have greater root elongation and branching which result in a root system that absorbs more nutrients and water from the soil at the expense of the crop plant. Some weed species supplement competitiveness by production of phototoxic substances that adversely affect growth and development of crop plants. These chemicals are released into the soil as root exudates or as leachates of the living or dead plants.

Allelopathic effects have been reported in more than 240 weeds (Qasem & Foy, 2001) and these include some of the more difficult weeds to control. Weeds like chickweed (*Stellaria media*), common lambsquarters (*Chenopodium album* L), littleseed canary grass (*Phalaris minor*), velvetleaf *(Abutilon theophrasti*)), wild oat (*Avena fatua*), common ragweed (*Ambrosia artemisifolia L.*), redroot pigweed (*Amaranthus retroflexus* L), Kochia (*Kochia scoparia*), ryegrass (*Lolium multiflorum*) and *Parthenium hysterophorus* have been reported to reduce the germination and seedling growth of various crop plants under laboratory and field conditions (Tinnin & Muller, 1972; Wayne *et al*., 1977; Elmore, 1980; Cope, 1982; Rice, 1984; Einhellig, 1995a; Bansal & Singh, 1986; Kohli & Batish, 1994; Kohli *et al.,*1996; Inderjit & Dakshini, 1998).

Water extracts from 23 common weed species have been reported to inhibit germination and growth of wheat seedlings (Le Tourneau *et al*., 1956; Schumacher *et al.,* 1983; Qasem, 1995; Porwal & Gupta, 1996). Bhatia *et al.,* (1982) studied the allelopathic effects of some weeds on wheat and discovered that fresh plant material of *Phalaris minor* and *Melilotus indica* promoted wheat seedling growth while *Chenopodium album* and *Amaranthus viridis* inhibited the growth of wheat seedlings. Root exudates of wild oats (*Avena fatua*) were reported to reduce the above ground growth of wheat (Schumacher *et al.,* 1983). Kossanel *et al* (1977) found that root excudates of common lambsquarters (*Chenopodium album L*) in culture solutions retarded radicle growth and root growth in corn. This was supported by the work of Bhowmik & Doll (1979) on corn and soyabeans.

1.2 Weed control

Chemical, cultural, biological and mechanical weed control methods are used to control weeds in many cropping systems. Herbicides are the most important weed control tool used in modern agriculture and has been proven to be relatively efficient in controlling weeds. According to Lydon & Duke (1993) two third by volume of the pesticides used worldwide in agricultural production are herbicides. The over reliance on herbicide use exerted selection pressure on weeds which resulted in weeds developing resistance. Cultural control may be an important part of weed management focusing on reducing the over reliance on herbicides. This includes crop rotation, use of cover, smother and green manure crops, crop residues, crop genotypes with better competitive and allellopathic ability, manipulation of sowing or planting date, crop density and crop pattern (Kohli *et al*., 2006). Enhancing the competitive ability of crop species to compete with weeds is an attractive control option that can be integrated in weed management systems and it can be accomplished through improving crop

management practices (Kohli *et al*., 2006). Crop management practices include; narrow row spacing, increasing plant density, time of planting, use of certified and quality seed and fertilizer management.

1.3 Crop interference

Crop effects on weeds that reduce weed emergence, biomass and seed production is termed crop interference (Rice, 1974). According to Jordan (1993) crop interference with weed growth is a fundamental method of non chemical weed management in many cropping systems. Zimdahl (1999) has defined interference as the total adverse effect that plants exert on each other when growing in a common ecosystem. The main cause of interference is believed to include competition and allelopathy. Competition refers to the exclusion, depletion or removal of one or more of environmental resources such as nutrients, water or light. Conversely, allellopathy is the production and release of chemicals into the environment by living or decaying plant tissues which stimulate, inhibit or delay the growth of neighbouring plants (Rice, 1974).

Researchers have shown that considerable variability exists among crop cultivars with respect to interference with weeds. Plant variables examined by researches to determine crop interference in weeds among cultivars include growth attributes, light interception or seed production of crops and weeds (Rao, 2000). Selection for crop interference with weeds would help crops aggressively compete with weeds early in the growing season to minimize their water and nutrient consumption and to negatively impact on weed biomass and weed seed production. However, crop interference may not be obtained at the expense of other fitness factors like crop yield. Blackshaw (1994) has shown that crop cultivars selected for rapid establishment and high yield under weed free conditions should also be superior competitors against weeds because of their inherent aggressive growth regardless of which approach for increasing crop competitiveness is selected. Interference may act to reduce weed seed production. If competitive crop cultivars are reducing the amount of weed seeds being returned to the soil each year, the decrease of the weed seedbank would reduce weed density. Therefore, increased crop interference may be part of an integrated approach to weed management aimed at minimizing yield losses to crops by reducing the weed seedbank.

1.3.1 Competition

Competition occurs between two or more plants when the supply of one or more factors essential to growth and development falls below the combined demands (Donald, 1963).

Crop weed competition is complicated because various factors affect the extent to which it occurs. Crops and weeds compete for water, nutrients, space and light (Zimdahl, 2007). If any of these factors is limited the others cannot be used as effectively. The more competitive species usually dominate an intermixed community of weed and crop plants. This competitiveness is associated with differences between members of the plant community in growth habit and rate of root and shoot growth and development (Rao, 2000). Competitiveness is reported to be favored by greater root elongation and branching, resulting in a root system that absorbs water and nutrients from the soil at the expense of adjacent plants (Jordan, 1993). Competitiveness is also favoured by taller plant species that grow more quickly than adjacent plants or by plants that climb onto their neighbours such as vines, producing foliar canopies that shade slower growing or shorter plants in the community.

Determining when and how long weeds can compete with a crop is important particularly when developing a breeding programme for increasing crop competitiveness to weeds (Hall *et al*., 1992) and it would enable farmers to make the most efficient use of limited labour resources. It is also important to know how long weeds have to be controlled in a crop before the crop itself can effectively compete with late emerging weeds. Early weed removal has been shown to aid crop establishment, and there is an inverse relationship between crop stand and production of above ground weed biomass (Hall *et al*., 1992). Knowledge of critical periods of weed competition may help to determine the potential effectiveness of competitive cultivars and help producers to develop and implement appropriate weed control measures in order to minimize yield losses in crops (Zimdahl, 2007).

1.3.1.1 Competition for nutrients

Nitrogen, phosphorus and potassium are primary plant nutrients with nitrogen being the first nutrient to become limited in crop weed competition (Zimdahl, 2007). The nutrient depletion zone is the same as that for water provided that nutrients are utilized as it arrives at the root. Weeds require the same nutrients as crops and are believed to be more successful in obtaining them. The success in gaining nutrients may lead to more rapid growth and successful competition for water and light. It is reported that fertilization is used to improve crop growth, but may worsen the weed problem (Zimdahl, 2007). Applying fertilizer in a crop heavily infested with weeds to reduce competition for nutrients is reported to stimulate weed growth to the crop's detriment. With low fertility competition is primarily for nutrients and with high fertility competition is just as vigorous and primarily for light. Increasing fertilizer

application rate is not an economic and agronomic way of avoiding or reducing crop losses due to weed competition because in general weeds have a large nutrient requirement and absorb as much or more than the crop plants. According to Vingris *et al.* (1985), the rooting depth and root area of a plant determine it's ability to obtain resources and relative competitiveness for nutrients is largely determined by the soil volume occupied by roots of competing species and the differences among species is limited by the rate of utilization (Zimdahl, 2007).

1.3.1.2 Competition for water

Water is the primary environmental factor limiting crop production and it is the most critical of all plant growth requirements (King, 1966). Weeds compete with crops for water, reduce water availability and contribute to crop water stress (Rao, 2000). Weeds require just as much and often more water than crops and are often more successful in acquiring it (Rao, 2000). Roots grow more rapidly and earlier than shoots in a plant's life and competition for nutrients and water usually begin before competition for light (Patterson, 1985). Competition for water is determined by the relative root volume occupied by competing plants and may be greater when roots closely intermingle and crops and weeds try to obtain water from the same volume of soil (Zimdahl, 2007). Less competition occurs if roots of crops and weeds are concentrated in different soil areas. More competitive plants are reported to have fast-growing, large root systems so they are able to exploit a large volume of soil quickly (Rao, 2000). If plants have similar root lengths, those with more widely spreading and less branched root systems will have a comparative advantage in competition for water (Patterson, 1985).

1.3.1.3 Competition for light

Light regulates many aspects of plant growth and development and it is the most reliable of the several environmental resources for plant growth (Patterson, 1985). Photosynthesis processes in plants are driven by light which is transformed into chemical energy in the green leaf. Therefore, it is reported that it is the green leaf, not the plant as such, that is the site of potential competition for light (Rao, 2000). Neighbouring plants reduce light supply by direct interception (shading). Any time one leaf is shaded by another there is competition for light. In most cases light competition is more severe when there is high fertility and adequate moisture because plants grow vigorously and have large leaf areas (Rao, 2000). According to Holt (1995), plants with large leaf area indices have a competitive advantage and normally

out-compete plants with smaller leaf areas. Leaf area index, a measure of the photosynthetic surface over a given area (Zimdahl, 2007) is correlated with potential light interception.

Successful competitors for light do not necessarily have more foliage, but have foliage in the most advantageous position for light interception (Patterson, 1985). Thus a plant's ability to intercept light is influenced by its angle of leaf inclination and leaf arrangement (Zimdahl, 1999). It is also reported that plants with leaves disposed horizontal to the earth's surface are more competitive for light than those with upright leaves disposed more or less perpendicular to the earth's surface. Plants that are taller or erect have a more competitive advantage for light over short, prostrate plants. If a plant is heavily shaded it will suffer reduced photosynthesis which may lead to poor growth, a smaller root system and a reduced capacity for water or mineral uptake (Jordan, 1993). The effect of shading is independent of direct competition for water or nutrients and entirely under the influence of light (Holt, 1995). According to DiTomaso (1995) competition for a given factor is not independent of competition for other resources. The effect of limiting growing factors e.g. nutrients can alter the balance and the nature of competition for other resources e.g. light (Carlson & Hill, 1986; Liebman & Robicheaux, 1990). The greater the ability of one species to deplete nutrients from the soil relative to the other, the better it's chances to shade it's competitor. In addition, tall plants can capture sunlight more efficiently, leading to more vigorous growth and increased efficiency in exploiting soil nutrients.

1.3.2 Characteristics of a competitive crop.

A competitive crop is determined by its morphological, physiological and biochemical characteristics that enables it to capture resources from a weed, or utilize resources more efficiently than a poor competitive crop. This association is believed to be influenced by resource availability, the characteristics of the weed and other environmental conditions at the onset of competition (Zimdahl, 2007). According to Jordan (1993), crop competitiveness can be viewed in two different ways: the ability to tolerate competition (maintain yield in the presence of weeds) and the ability to suppress weeds. Lemerle *et al*., (1996) indicated that the competitive aspects of tolerance and suppression may be correlated. Characteristics reported to contribute to crop competitive ability with weeds includes: emergence rate, seedling growth rate, leaf area expansion rate, leaf area index, leaf angle, mineral nutrient uptake rate, tiller number, percentage light interception, plant height, aboveground biomass, indeterminate growth and canopy development rate (Challaiah *et al*., 1986; Wicks *et al*., 1986; Jordan, 1993; Lemerle *et al*., 1996; 2001). Some researchers have outlined crop

characteristics that influence shading ability or light interception. Characteristics that are correlated with shading ability includes flag leaf orientation, length of the first leaf and flag leaf (Lemerle *et al*., 1996), the overall leaf area, canopy structure (Seavers & Wright, 1999) and canopy diameter (Challaiah *et al*., 1986).

Bastiaans *et al.* (1997) has identified early crop vigour as one of the important traits for crop competitiveness. Vigorous growth characteristics enhance crop competitiveness by reducing the light quality and quantity beneath the crop canopy. This may impede weed seed germination and weed seedling growth. This has been demonstrated in wheat (*Triticum aestivum L*) and barley (*Hordeum vulgare L*) (Wicks *et al.,* 1986). Winter barley, because of it's long stalk, high soil coverage, high tillering capacity and a strong mass development suppress weed growth by reducing light penetration into the crop. Similarly, cultivars with big horizontal leaves allow less photosynthetic radiation to reach the soil and the weeds as compared to cultivars with narrow vertical leaves (Ashton & Monaco, 1991).

The presence of coleoptile tillers has been found to contribute significantly to the total plant leaf area and subsequently to early vigour with leaf expansion rate being 35% greater in plants with a coleoptile tiller (Lemerle *et al*., 1996). Vigorous growth attributes such as early emergence, high leaf area index (LAI), dense canopy and plant height were identified as superior weed competitive characteristics among several crops. In rice (*Orza sativa* L.) LAI and increased biomass at an early stage of growth were the characters most closely related to weed competitive ability (Garrity *et al*., 1992). In dry beans (*Phaseolus vulgaris L*) LAI and leaf size accounted for 73% of the total variation in weed biomass (Urwin *et al*., 1996), while Malik *et al.* (1993) found that high LAI enhanced by narrow spacing and increased crop density increased competitive ability of dry beans against weeds. Similar results were also reported for soybean where early emergence, leaf area expansion rate and rapid canopy closure were associated with reduced growth of several annual grass and broadleaf weed species (Bussan *et al.,* 1997).

In general, high competitive ability is associated with characteristics that allow crops to establish ground cover faster and intercept more light than weeds including plants that are tall, have higher leaf area index and faster leaf area growth rate. Several traits including maximum LAI, rate of canopy closure, height of LAI and leaf architecture has been reported to improve weed suppressive ability and crop tolerance to weed interference (Christensen, 1995; Forcella, 1997).

Research in rice, dry beans and soybeans by Urwin *et al.* (1996) has also identified profuse tillering, branching and growth habit as favorable competitive characteristics in these

crops. Many studies suggested that the importance of the parameters height or tillering to crop competitive ability may be linked to other factors such as early crop vigour, leaf characteristic or shading ability (Balyan *et al.*, 1991; Lemerle *et al*., 1996; Ogg &Seefeldt, 1999). According to Jordan (1993) the outcome of weed-crop competition for light is often influenced by the relative heights of competing species, leaf area index (LAI), vertical leaf area distribution and leaf angle. In case of wheat varieties a taller variety is said to be a better competitor against weeds than a shorter variety due to a greater shading ability. A study by Foster (1996), on winter wheat varieties found 14 – 30% higher yield reduction in semi-dwarf winter wheat varieties from downy brome (B*romus tectorum*) competition than did taller varieties. The same author found that winter wheat was more effective in suppressing quack grass than tall or semi-dwarf spring wheat. This was supported by the work of Lemerle *et al.,* (1996). Mahajan & Brar (2002) argued that height alone is not a consistent factor favoring crop competitiveness but that better canopy cover (leaf area) and a higher number of tillers have been positively correlated with crop shading or smoothing effects on grass weeds. Cultivars exhibiting early canopy cover and rapid growth can be more competitive than others.

Root size, distribution and uptake capacity per unit size were also reported to contribute to crop competitiveness (Bingham, 1995). Root distribution has a greater impact on species competitive ability than the size of the root system. A study by Bingham (1995) on *Avena ssp* and spring wheat plants found that the features of wheat that may contribute to its competitive ability include a greater number of seminal roots and a high specific root length (root length per unit weight). He also found that strong competitive species such as *Avena fatua* posses a root system with a large mass of fibre close to the soil surface, as well as main roots penetrating deeply into the soil. In contrast, a less competitive wheat variety had the major part of the root mass at a considerable distance from the soil surface, allowing weeds to become established, because of the scarcity of roots in the upper levels of the soil (Foster, 1996). This may indicate that the initial number of seminal axes can affect the rate of root growth and may therefore provide an early crop competitive ability, while the adventitious root system is also important for competitive ability especially during the later stages of crop development (Jordan, 1993).

1.3.3 Factors that maximize crop competitiveness

Enhancing the ability of the crop to compete with weeds can be accomplished by providing the best possible environment for crop growth combined with practices that reduce the

density and vigour of weeds (Zimdahl, 2007). Agronomic practices such as increased plant density, fertility management, narrow row spacing and appropriate time of planting are capable of shifting the competitive balance to favour crops over weeds (Malik *et al*., 1993; Teasdale, 1995).

1.3.3.1 Crop density and planting spacing

Population density of a given crop can dramatically improve its competitive ability with associated weed species (Inderjit *et al*., 2001). Decreasing row spacing and increasing crop plant density has been reported to increase competitiveness of many crops (Malik *et al*., 1993; Teasdale, 1995). In cereals, it was reported that increasing plant density through both increasing seeding rate and narrow spacing can be effective in suppressing weed growth (Moss, 1985; Froud-Williams, 1988). Sowing of cereals at narrow row spacing will also reduce weed development by increasing the rate of canopy closure and increased crop competition which may result in substantial reductions in the growth and development of many weed species (Malik *et al*., 1993). High seeding rates may be used to reduce weed competition in areas where sufficient moisture is available. Dense planting of barley seed has been reported to suppress quack grass (*Elytrigia repens*) infestations, gave the crop competitive advantages and resulted in higher yields than at lower seed rates (Moss, 1985). Froud-Williams (1988) found that increased seeding rates of winter wheat can reduce the number of flowering heads of black grass and the total biomass of sterile oat (*Avena sterilis*) and concluded that increased crop density and narrow row widths can be used to reduce competitive ability of wild oats. Also, increased seeding rates of wheat have been shown to suppress ryegrass (*Lolium rigidum*) and reduced total above ground dry weight of this weed (Gill & Holmes, 1997; Inderjit *et al.,* 2001). Lemerle *et al.* (2001) found that an increase in wheat density from 100 to 200 plants m^{-2} reduced the biomass of annual ryegrass from 100 to 50g m^{-2}. The same authors concluded that wheat plant density of 200 plants m^{-2} or more is required to suppress the growth of annual ryegrass. Teasdale (1985) found that growing corn in 108 cm wide rows with increased density compared to 76 cm rows improves weed control and reduced herbicide requirements. Younie & Taylor (1995) found that sowing the crop at a narrow spacing increased the rate of crop growth and ground cover and thereby reduced subsequent weed development.

1.3.3.2 Cultivar selection

Crop cultivars have different growth habits, rate of maturity and competitive ability and may be used to suppress weed populations and growth (Froud-Williams, 1988). Before planting a crop plant it is important to know what combinations of plant characteristics makes a cultivars more competitive. According to Christensen (1995) identifying and quantifying the characteristics linked to crop competitive ability against weeds is really difficult due to the fact that even though different cultivars have unique characteristics, many of these characteristics can change over development stage. The difference should be made between cultivars that tolerate weeds compared to those that actively suppress them - the latter being preferable. Several factors are commonly identified to increase crop's competitive ability to weeds. This includes rapid germination, early emergence, seedling vigour, early root development, extensive root systems, rapid leaf area and canopy establishment, large leaf area development and duration and greater plant height (Challaiah *et al.,* 1986; Wyse, 1994; Christensen, 1995). Crops that generally suppress weeds well are those exhibiting a rapid early development, those having a rather short vegetative period and those which form a dense canopy rather soon. Plant breeders are unlikely to select for certain traits such as taller cultivars because of problems associated with lodging. Conversely, many other varietal attributes including differential rooting patterns, early vigour, leaf size and allellopathy may influence the ability of a cultivar to suppress weeds and can be used for selection in breeding programmes (Lemerle *et al.,* 1996). A competitive cultivar should maintain its yield when competing with weeds and at the same time reduce the growth and seed production of weeds against which it is competing (Jordan, 1993). Correct choices of cultivars are not only essential in exploiting the crop's ability to compete with weed but also in maintaining crop quality.

1.3.3.3 Fertility management

Competition in the rhizosphere for nutrients and moisture is particularly important for crop vigour and for competitiveness with associated weed species. The fertility of the soil affects both the vigour of the crop plant and the vigour of the weeds. Many weeds are reported to utilize fertilizer better than crop plants (Zimdahl, 2007). The effect of weeds may be reduced by management strategies that maximize nutrient uptake by the crops and minimize nutrient availability to weeds (DiTomaso, 1995). If most of the weeds are suppressed or killed by tillage, then extra vigour is given to the crop by fertilizers and makes them good competitors. A study by Kirkland & Beckie (1998), found that weed density, biomass and nitrogen uptake

were 20% to 40% less and wheat yield was more where fertilizer was banded beside the crop row compared to a broadcasting application. Managing fertilizer application to benefit the crop may not only increase nutrient uptake by the crop, but will improve the competitiveness of the crop for other resources that might otherwise be available for weeds (Kirkland & Beckie, 1998). Sexsmith & Pittman (1992) found that broadcast and disked applications of nitrogen fertilizer increased the germination of wild oat seed present in the soil. Rao (2000) clearly stated that fertilizer treatment can be used to deplete seed reserves in fallow years by promoting weed seed germination from weed seedbanks and reduce the amount of seed returned to the soil in a crop year by combining fertilizer application with delayed crop seeding.

1.3.3.4 Seed quality and size

Seed cleanliness, vigor and percent germination are characteristics that can influence the competitive ability of the crop seedlings (Zimdahl, 2007). High seed quality may ensure uniform, vigorous, rapid emergence of crop seedlings and early good stand establishment (Naylor & Drummond, 2002). Early vigour is the expression of high relative growth rates, rate of emergence or larger initial size often correlated with seed size (Zimdahl, 2007). A crop species with a rapid rate of early growth is believed to have a competitive advantage over its weed neighbours (Lemerle *et al.,* 1996). Plants that emerge first in the field are reported to have a competitive advantage, may improve herbicide selectivity and may increase the flexibility in optimum timing of weed removal (Rasmussen & Rasmussen, 2000). Several researchers have indicated that larger initial crop seed size can significantly improve early crop establishment and hence increase the competitive ability of crops. Seed size was also reported to increase the competitiveness of cereal grain crops, particularly during the early stages. More rapid emergence and vigorous early plant development have been reported with large seeds relative to small seeds (Zimdahl, 2007).

2 Allellopathy

Rice, (1984) defined allelopathy as any direct or indirect detrimental or beneficial effect by one plant on another through the production of chemical compounds exerted into the environment. The term covers biochemical interactions, both beneficial and harmful between plant species including fungi and bacteria. Allelopathy has been reported as far back as 300 B. C. by Theophrastus (Rice, 1984). Negative allelopathic effects are due to inhibitory substances that are actively released from living plants into the environment by means of four

ecological processes: root exudation, volatilization, leaching and decomposition of plant residues (Rice 1984; Barnes & Putnam, 1986; Wu *et al.,* 2001a). These phytotoxic substances are termed allelochemicals (Whittaker & Feeny, 1971). Allellochemicals are synthesized within the plants as secondary plant metabolites that serve as a defensive adaptation in plants, but play no role in primary metabolic processes essential for plant survival (Siegler, 1996).

Allelochemicals are able to affect both germination and growth of plants by influencing the metabolic processes (Einhellig, 1995b). Plant processes that have been found to be influenced by allellochemicals include: cell division and elongation (Rice, 1984; Ortega *et al*., 1988; Einhellig, 1995b), respiration (Muller, 1969; Ortega *et al*., 1988), photosynthesis (Patterson, 1981; Einhelling *et al*., 1993), mineral uptake (Al-Saadawi *et al*., 1986; Brooker, *et al*., 2001), hormonal imbalances (Retig *et al.,* 1972; Ray *et al*., 1980; Einhellig, 1995b; Saxena *et al*., 1996), protein synthesis (Schuab *et al*., 2001), action of certain enzymes (Einhellig, 1995b) and membrane permeability (Reting *et al.*,1972; Rice, 1974). There is however no proven record on specific mode of action of the allelochemicals (Einhellig, 1995b).

When plants are exposed to allelochemicals, their growth and development will be affected. Inhibition or retarded germination rate; reduced root or radicle and increased number of seminal roots, swelling or necrosis of root tips, curling of the root axis, lack of root hairs, seeds darkened and swollen, shoot coleoptile extension, discolouration, reduced dry weight accumulation and lowered reproductive capacity are some of the reported symptoms of allelopathic effects (Rice, 1974; An *et al*., 1998). According to Rice (1974) these morphological effects may be secondary manifestations of primary events, caused by a variety of more specific effects acting at the cellular or molecular level in the receiver plants. The biological activities of allellochemicals depend upon concentration at a given time, cultivar, age and metabolic stage of the donor plant, their contact with other plants and environmental conditions (Einhellig, 1995a). Lovett & Ryuntyu (1992) reported that the responses to allelochemicals are characteristically stimulatory or attraction at low concentrations changing to inhibition or repellence as the concentration increases.

2.1 Production of allellochemicals

Plants are believed to produce numerous chemicals during their growth and development. Allelochemicals are produced by any plant organ such as: stems, pollen, rhizomes, flowers roots, seeds and leaves and their concentration are believed to be different from one part to another (Rice, 1984; Qasem & Foy, 2001). Allellochemicals enter the environment through

volatilization, foliage leaching or root exudation and also result from decomposition of plant residues (Rice, 1984). The production of allellochemicals is influenced by genetic as well as environmental factors and thus includes intensity, quality and duration of light with a greater quantity produced under ultraviolet (UV) light and long days (Aldrich, 1984).

In a crop/weed situation, the canopy of a crop plant is expected to overshadow weeds and to filter the ultraviolet light resulting in production of lower quantities of allellochemicals by weeds. It is also known that different plant species and different crop cultivars are widely different regarding production of various allelochemicals and in their ability to produce certain toxins in different parts (Qasem & Foy, 2001). It is reported that greater quantities of allellochemicals are produced under conditions of mineral deficiency, drought stress and cool temperatures than at more optimal growing conditions (Zimdahl, 2007). According to Rice (1984) stress conditions accentuate the involvement of allellopathy in crop/weed interference and that the competition for limited resources may increase the allellopathic potential or sensitivity of the weeds, crops or both.

2.2 Allellopathy in weed management

There is proven evidence that suggests that allellopathy can be utilized in weed management strategies. Allelopathy can be used in weed management in the form of allelopathic cover or smother crops, allelopathic rotational or companion crops, toxic extracts from allelopathic plants, mulch or incorporation of crop residues, natural herbicides and breeding of allelopathic crop cultivars with weed suppressing potential (Barnes & Putnamn, 1986; Putnam, 1988; Duke & Abbas, 1995; Wu *et al*., 1998, 1999; Batish *et al*., 2001; Duke *et al*., 2002; Singh *et al*., 2003). Assumptions have been made that many plants have allellochemical effects when they are presented in the right amount, form and concentration and at the appropriate time (Zimdahl, 2007).

Numerous crops have been investigated thoroughly for allelopathic activity towards weeds. A suppressive effect on weeds, possibly mediated by the release of allelochemicals has been reported for a wide range of crops such as: *Secale cereale* (rye), *Triticum aestivum* (wheat), *Sorghum bicolor* (sorghum), *Oryza sativa* (rice), *Medicago sativa* (alfalfa), *Hordeum vulgare* (barley), *Avena sativa* (oats), *Ipomoea batatas* (sweet potato) and *Helianthus annuus* (sunflower) (Guenzi & McCalla, 1966; Fay & Duke, 1977; Leather, 1993; Barnes & Putnam, 1986; Dilday *et al*., 1994 Einhellig, 1995 a; b; Weston, 1996; Wu *et al.,* 2000; Belz & Hurle, 2004; Duke *et al*., 2007). Reduced weed problems within such crops may indicate that the seed germination or development of weedy species is inhibited by the release of

allelochemicals from the crop. It is possible that these crop cultivars can be planted to take advantage of their allellopathetic potential and minimize the use of synthetic herbicides. Putnam (1988) has listed six classes of allelochemicals derived from over thirty families of aquatic plants and terrestrial plants and it includes benzoxazinones, alkaloids, ethylene, cinnamic acid derivatives, flavonoids, cyanogenic compounds and other seed germination stimulants. All these chemicals posses potential phytotoxicity. Studies by Guenzi & McCalla (1966) on sorghum proposed that the reduced weed seed germination was due to phenolic acids and cyanogenic glucosides secreted by sorghum. The same study also found allellopathic phenolic acids in wheat, corn and oat residues.

2.3 Wheat allelopathy

Wheat (*Triticum aestivum* L.) has been found to possess allelopathic potential and has shown its potential for biological weed control (Steinsiek *et al*., 1982; Lodhi *et al.,* 1987; An *et al*., 1998; Lemerle *et al*., 1996; 2001; Wu *et al*., 1999a; 2000; 2001a). The allelopathic effect of wheat has been demonstrated in fields in relation to its use as green manure or straw where residues are mulched on the soil surface. Wheat straw mulch significantly inhibited emergence, seedling growth and dry matter accumulation of various weed species (Steinsiek *et al*., 1982; Liebl & Worsham, 1983; Lemerle *et al.,* 2001). Wheat residues suppress weeds due to the physical effect and to the production of allelochemicals. The phytotoxicity of water extracts from wheat residues was observed in the 1960`s (Kimber, 1967) and allelochemicals have been identified and isolated from different parts of the wheat plant. Phenolic acids, hydroxamic acids and short chain fatty acids (aliphatic acids) are the main phytotoxic substances identified in wheat plants and are suspected of causing allelopathic effects (Lodhi *et al.,* 1987; Niemeyer, 1988; Blum *et al*., 1991; Wu *et al.,* 1998; 2001; Ma, 2005). *p*-Hydroxybenzoic, vanillic, *p*-coumaric, syringic and ferulic acids have been regarded as some of the major phenolic acids predominantly identified in wheat stubbles and in the soil (Guenzi & McCalla, 1967; Lodhi *et al*., 1987; Blum *et al*., 1991; 1992; Wu *et al*., 1998). In addition to the phenolic acids, one of the hydroxamic acids, 2, 4-dihydroxy-7-methoxy-1, 4-benzoxazin-3-one (DIMBOA), has also been reported as an active allelochemical in wheat (Niemeyer, 1988; Blum *et al*., 1992; Copaja *et al*., 1999; Wu *et al*., 2001a). The phytotoxicity of these compounds has been clearly demonstrated in the laboratory and in field conditions (Liebl & Worsham, 1983; Lodhi *et al*., 1987; Niemeyer, 1988; Blum *et al*., 1991; Shilling *et al*., 1995; Wu *et al*., 1999). It was also reported that the allelopathic ability of wheat aqueous extracts differ significantly between wheat cultivars (Guenzi & McCalla, 1966*,* Wu *et al*., 1998).

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CHAPTER 3

Determining the interference potential of nine selected South African spring wheat cultivars on *Lolium multiflorum*

INTRODUCTION

Weed control is a basic requirement and major component of crop management in any production system (Young *et al.,* 1996). In the winter rainfall region of South Africa, weed infestations pose serious problems. Herbicides are used extensively by farmers as an effective method to control weeds. The over-reliance on herbicide use exerted selection pressure on weeds which resulted in weeds developing resistance to herbicides. In order to sustain spring wheat production in the winter rainfall region of South Africa, alternative weed control tools to manage weeds are needed. This is necessary to reduce the over-reliance of farmers on herbicides as well as reducing selection pressure towards further resistance development. Planting more competitive crop cultivars has been suggested as a cultural practice to suppress weed growth. According to Jordan (1993) yield losses from weed competition can be reduced if crop competitiveness is improved by methods such as fertilizer placement, a diverse crop rotation and by using varieties with strong competitiveness and allelopathy (Rice, 1995). Thus, identification of those characteristics which enhance crop competitive ability against weeds is important for the successful management of weeds in crops (Lemerle *et al*. 2001b). A competitive crop is believed to suppress weed growth and seed production, and can therefore assist in longer-term weed population management.

Selection of more competitive cultivars can be conducted either by direct screening whereby crop cultivars are evaluated under weedy conditions or by indirect selection whereby crop cultivars are evaluated under weed-free conditions in which selection is based on attributes associated with competitive ability (Lemerle *et al.,* 1996). The competitive ability of a crop is believed to occur in two forms: exploitation competition and interference competition (Aarssen, 1983). Exploitation competition is attributed mainly to morphological characteristics of a crop while interference competition is attributed to allelopathy and other factors that are limiting access to resources (Aarssen, 1983).

Variation among crop cultivars in their ability to compete with weeds has been well documented for many crops including wheat (Reeves & Brooke, 1977; Balyan *et al*., 1991;

Lemerle *et al.,* 1996; 2001a; Cousens & Mokhtari, 1998; Ogg & Seefeldt, 1999). According to Lemerle *et al.* (2001b) morphological, physiological and biochemical traits are thought to control plant competitiveness. Characteristics commonly identified as associated with the competitive ability of wheat includes: rapid germination and rapid root development (Blackshaw, 1994; Lemerle *et al*., 1996; Coleman *et al*., 2001), greater plant height (Verschwele & Niemann, 1993; Blackshaw, 1994; Huel & Hucl, 1996; Lemerle *et al.*, 1996; Champion *et al*., 1998), higher number of tillers (Challaiah *et al.,* 1986; Lemerle *et al*., 1996; Mahajan & Brar, 2002), early vigour (Lemerle *et al.*, 1996; Coleman *et al*., 2001), greater leaf area index (Christensen, 1995; Forcella, 1997) and allelopathy (Steinsiek *et al*., 1980; Shilling *et al*., 1985; Wu *et al.,* 1998; 1999; 2000). The morphological and physiological characteristics of a competitive cultivar will enable it to capture resources from a weed or utilize resources more efficiently than poor competitive cultivars (Lemerle *et al*., 2001b). Similarly, a competitive cultivar is believed to justify a reduced herbicide rate compared to a poor competitive cultivar (Christensen, 1995; Lemerle *et al*., 1996; Gibson *et al*., 2001).

Up to about 1998, chemical weed control in the winter rainfall region of South Africa was highly successful and there was little need to investigate alternative weed management programs, such as utilizing competitive cultivars to suppress weed populations (P.J. Pieterse, Department of Agronomy, Stellenbosch University, pers. com). Because of poor understanding of competitive ability, its importance, mechanisms and components to date little has been done to determine the competitiveness of South African spring wheat. A better understanding of the characteristics that makes a crop cultivar competitive against weeds is required in order to assist South African plant breeders in developing competitive cultivars more quickly and effectively, and also to justify the use of plant breeding to increase crop competitive ability. If more competitive South African spring wheat cultivars can be bred, farmers will be provided with information on competitive ability as part of the cultivar characteristics so that they can choose strongly competitive cultivars to be sown in weedy fields in order to manage herbicide resistance. Therefore, the objective of this study was to determine the competitiveness and identify the competitive traits among nine selected South African spring wheat cultivars using *Lolium multiflorum* as a test species.

MATERIALS AND METHODS

Wheat vigour

The experiment was conducted during the winter season (June – August) in a temperature controlled glasshouse (15/20 ºC night/day temperature) at Welgevallen experimental farm of

Stellenbosch University. Nine spring wheat cultivars that were grown in the National Cultivar Testing trials in the Western Cape in 2007 were used in this experiment. Spring wheat cultivars selected were Baviaans, Kariega, PAN 3408, PAN 3492, SST 015, SST 027, SST 57, SST 88 and Tankwa. Eighteen three liter plastic pots for each cultivar (18 X 9 = 162 pots in total) were filled with pure river sand and five seeds were planted at an equal depth of 1 cm and equal spacing of about 3 cm apart using a grid. Germination was recorded on a daily basis for two weeks. Germination rate was calculated using the following expression (Heydecker, 1973).

$$\sum_{i=1}^{K} \frac{n_i}{D_i.n_i}.100$$

where n = the number of seeds germinated on Day i and D = Day i. Plants were watered regularly with a standard Steiner feeding solution (Steiner, 1984). Two weeks after emergence seedlings were thinned to one seedling per pot. Four weeks after thinning, three pots of each cultivar were harvested to determine the following growth parameters: plant height, number of leaves; number of tillers, leaf area index (LAI), shoot dry mass, root dry mass and total plant dry mass. Plant height (height of plant from soil surface to the leaf tip of the tallest leaf) was measured using a ruler, while the leaf area index was measured using a leaf area index meter. The total dry mass of the plant was determined by washing the sand out of the roots as best as possible and by drying the whole plant in an oven at 45 °C for 72 hours before it was weighed. Every second week (14 days) thereafter, three sets of pots for each cultivar were harvested and the same parameters were measured. Three pots of each cultivar were left to grow to maturity. Plant height, total plant dry mass and numbers of ears per plant were determined during the final harvest. The experiment was factorially arranged in a randomized block design with factors Time and Cultivar.

Wheat aqueous extraction

Aqueous extracts were prepared from the wheat material based on the method described by An *et al*. (1997) and Wu *et al.* (2000) with slight modifications. Plant material of the abovementioned nine spring wheat cultivars was collected and oven dried at 45 ˚C for 72 hours. The material was grounded in a mill to pass through a 0.1 mm sieve screen. From each wheat cultivar 200 g of the milled material were diluted in 2000 ml of distilled water in a 4 L plastic container and placed in a growth chamber for 5 days in the dark at 20˚ C. The pulpy mixture was filtered by squeezing it through four layers of cheese cloth. The resulting filtrate was then filtrated through a funnel with Whatman No. 1 filter paper. The solution was

sterilized by passing it through a 0.2 μm pore size Whatman Puradisc polyethersulfone membrane millipore filter. The sterilized filtrate was designated as the full strength (100%) solution. The full strength solution was then diluted with distilled water to different concentrations i.e. 0 % (pure distilled water), 25%, 50%, 75% and 100% (full strength). In order to take into account that results obtained from different spring wheat aqueous solutions were possibly not purely due to allelopathic effects of the solution but to osmotic effects of the solution, the osmolalities of the solutions were measured using a Roebling digital micro-osmometer. The reading from the Roebling osmometer is given in mOsm kg^{-1}.

Germination inhibition

Seeds of a commercial *Lolium multiflorum* (ryegrass) cultivar (cv Midmar) were used as a test species because it exhibits reliable and quick germination and is closely related to the weedy *Lolium* spp. occurring in wheat fields. Twenty ryegrass seeds were placed in plastic petri dishes lined with two layers of Whatman No. 1 filter papers. In each petri dish, 5 ml of the different aqueous extract concentrations from the different wheat cultivars was administered. The distilled water (0% concentration) was used as a control treatment. The petri dishes were sealed within a plastic bag to prevent evaporation. All petri dishes were placed in a growth chamber at a constant temperature of 20 ˚C in the light and were arranged in a randomized complete block design with four replicates. Germination counts were made daily. Seeds were considered germinated when the radicles were 1 mm long. The experiment was ended after about 12 days of incubation when no further seed germination was observed for three successive days. Because of the visible effect of the various aqueous solutions on the root length of ryegrass, root length was measured on the last day of monitoring. The germination percentage was calculated as follows: Final germination percentage = number of germinated seeds / total number of seeds planted X 100. The germination rate was calculated using the following equation (Heydecker, 1973).

$$\sum_{i=1}^{K} \frac{n_i}{D_i . n_i} .100,$$

where n = the number of seeds germinated on Day i and D = Day i.

The experiment was arranged in a completely randomized factorial design replicated four times with factors Cultivar and Concentration

Growth inhibition

In this experiment, the phytotoxic effect of wheat aqueous solutions on the growth of the ryegrass cultivar described above was evaluated in a temperature controlled glasshouse (15/20 ºC night/day temperature). Ryegrass seeds were sown in pure river sand in 8 cm X 8 cm square plastic pots and thinned to one plant per pot after emergence. Plants were watered with a standard Steiner feeding solution (Steiner, 1984). The solution was administered to plastic trays in which the pots were placed so that it could take up nutrients from the bottom. Two weeks after the seedlings were well established, 10 ml of different concentrations of aqueous solution (0% (pure distilled water); 25%; 50%; 75%; 100% (full strength) from nine different spring wheat cultivars described above was added to water the seedlings. The seedlings were watered with this solution every second day for two weeks. During this period, the same feeding solution described above was administered twice to prevent nutrient deficiencies developing. After two weeks the whole plant was harvested. The roots were washed to remove sand before it was separated from the shoot. Both shoots and roots were oven dried at 45 ºC for 72 hours. Plant height, number of leaves, leaf colour, root dry weight and shoot dry weight were determined. Leaf colour was determined by ranking the leaf colour on a scale from 0 (Normal green colour – no effect) to 5 (Dark purple, no chlorophyll). The experiment was arranged in a completely randomized factorial design replicated four times with factors Cultivar and Concentration.

Statistical analysis

Statistical analyses of the data were conducted using the Statistica package (Software, version 8.02). Analysis of variance (ANOVA) was conducted to determine the interaction of factors. Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P \leq 0.05$) differences among the treatments. When referring to significant or non-significant differences and/or interactions "significant" means $P < 0.05$ and "non-significant" means $P > 0.05$.

RESULTS

Wheat vigour

Statistical analyses of the germination data showed that the rate of germination differed significant between the spring wheat cultivars. A higher rate of germination was observed in cultivars such as PAN 3408, PAN 3492 and SST 027 while cultivars such as Baviaans and Tankwa showed a slower rate of germination (Figure 3.1). Wheat cultivars with a rapid rate

of emergence are believed to have a competitive advantage over its weed neighbours (Lemerle *et al.,* 1996; Seavers & Wright, 1999). In this experiment cultivars such as PAN 3408, PAN 3492 and SST 027 showed a statistically significant higher germination rate than cultivars Baviaans, Kariege, SST 027, SST 015 and Tankwa. Cultivar Baviaans and Tankwa emerged very slowly and this may enable weeds to establish first and have a competitive advantage over the crop. No difference was observed among cultivars regarding germination percentage, results are therefore not discussed.

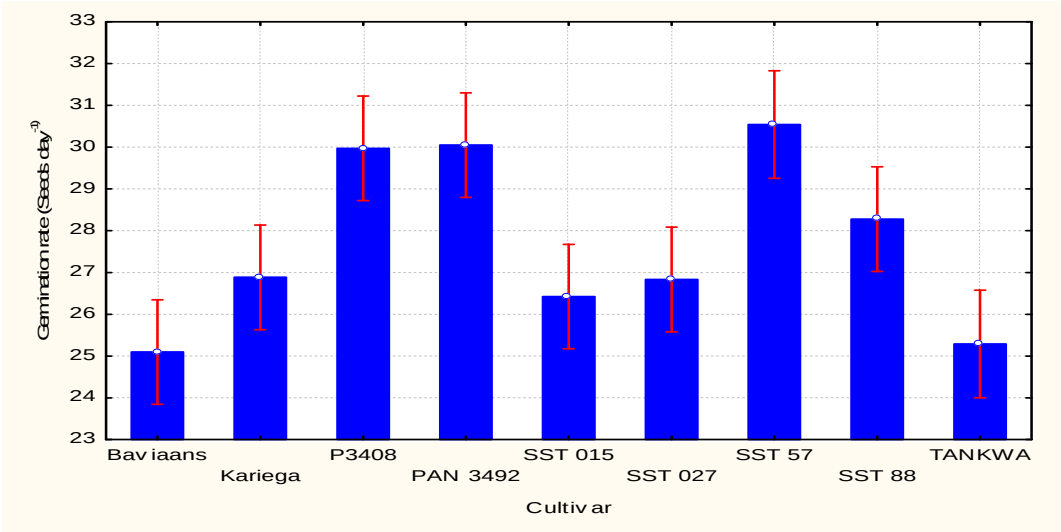


Figure 3.1 The germination rate of nine spring wheat cultivars grown in pots in a glasshouse (The whiskers represent standard error of means).

The statistical analysis of the vegetative growth data showed a significant interaction between Cultivar and Time regarding plant height (Appendix A: Table 1 A). There was no significant difference observed between cultivars in terms of plant height at week four (first harvest) (Figure 3.2). Kariege attained a significantly taller height than SST 015 and Tankwa at week six (second harvest). At week eight (third harvest) PAN 3492 was significantly higher than Baviaans, Kariege and Tankwa but did not differ significantly from the rest of the cultivars. A comparison of plant height at the first and second harvests showed that SST 015, SST 027, SST 88 and Tankwa did not significantly increase in terms of plant height whilst Baviaans, Kariege, PAN 3408, PAN 3492 and SST 57 did. All cultivars except Baviaans and Kariege showed a significant increase in their height from the second harvest to the third harvest. This indicates that these two cultivars exhibited more vigorous growth than the other cultivars during the first six weeks after establishment. However, cultivars such as SST 015, SST 27, SST 88 and Tankwa which did not significantly increase in height between the first

and second harvests, did show a significant height increase from the second to the third harvests. This shows that these cultivars initially grew slowly but had an accelerated growth rate during later stages. All cultivars showed a reduced height increase from the third to the fourth harvests (week ten).

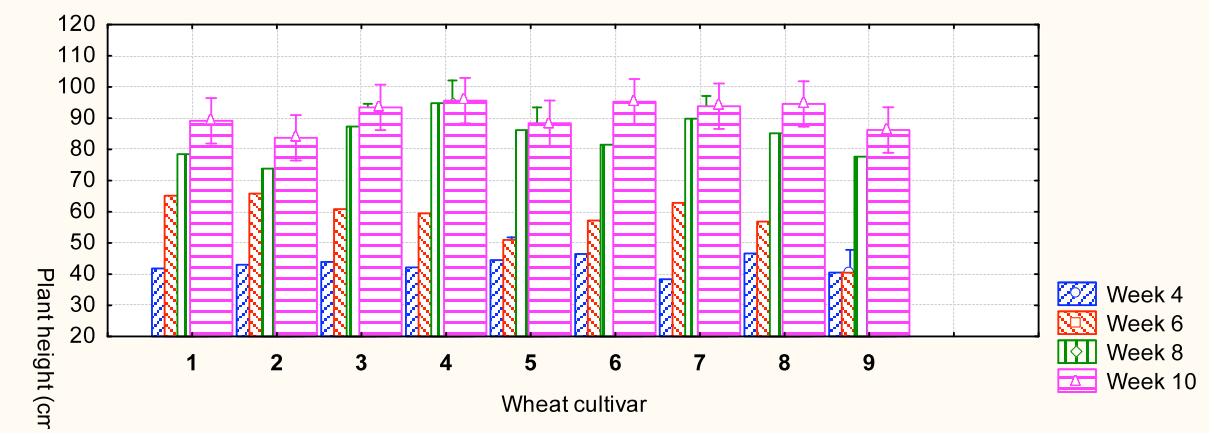
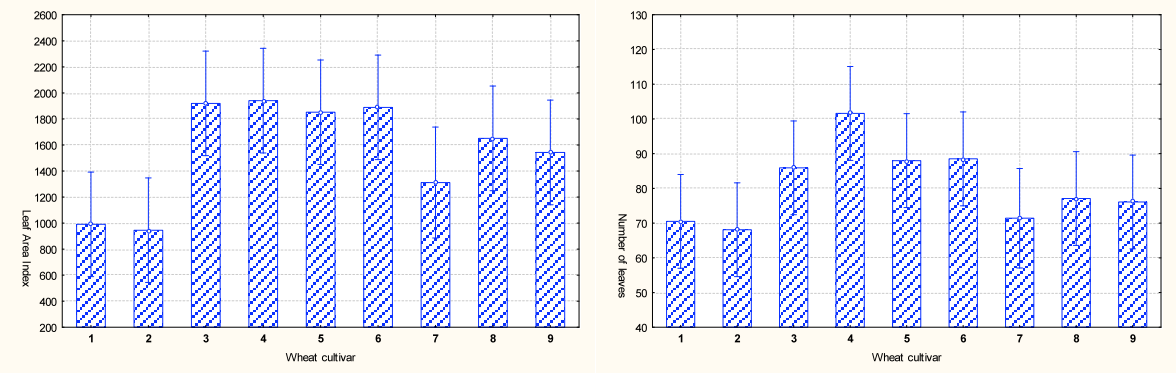


Figure 3.2 Plant heights of nine spring wheat cultivars grown in pots in a glasshouse at different harvest times (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

Statistical analysis of the data showed no interaction between Cultivar and Time regarding number of tillers, number of leaves and LAI but a significant difference was revealed between cultivars regarding number of leaves and LAI (Appendix A: Tables 2, 3 and 4). Although the ANOVA analysis showed no significant difference ($p = 0.07$) between cultivars in terms of number of tillers, the Bonferroni post-hoc test ($p = 0.029$) showed that PAN 3492 differed from Kariege, SST 57, SST 88 and Tankwa (results not shown). A significant difference was observed between cultivars in terms of LAI. Baviaans and Kariega had significantly lower LAI compared to other cultivars but not significantly different from cultivar SST 57, SST 88 and Tankwa (Figure 3.3a). A significant difference was observed between cultivars in terms of leave numbers (Figure 3.3b). PAN 3492 produced significantly more leaves than Baviaans, Kariege and SST 57.



a) b)

Figure 3.3 a) LAI and b) number of leaves of nine spring wheat cultivars grown in pots in a glasshouse (data from different harvest times combined) (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

The total dry mass of all growth parameters (leaves, tiller and root) indicated differences in growth among the spring wheat cultivars. The different parameters showed the same trends and therefore only the total dry mass results are presented here (Figure 3.4). No interaction was observed between Cultivar and Time regarding total dry mass of the plants (Appendix A: Table 5), but there were significant differences between cultivars. PAN 3408 and PAN 3492 produced the highest total dry mass over all the harvests, but only Kariega produced significantly less total dry mass than PAN 3408 and PAN 3492 (Figure 3.4).

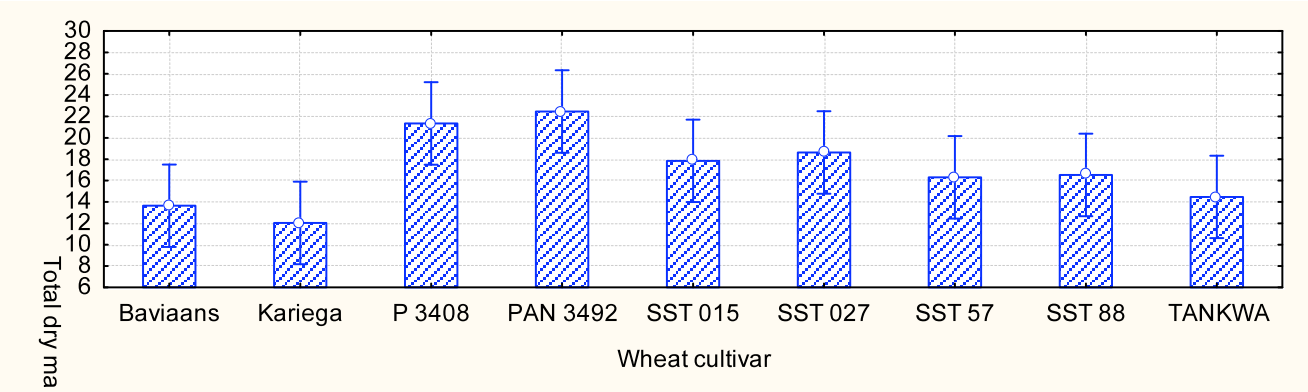
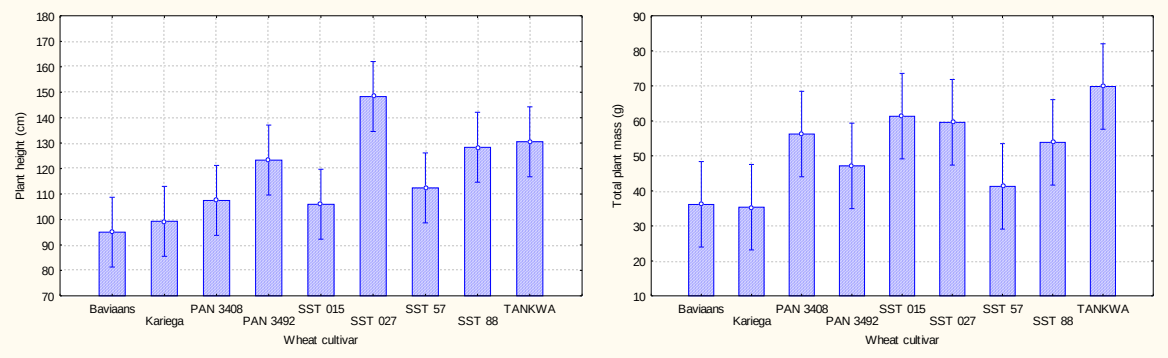
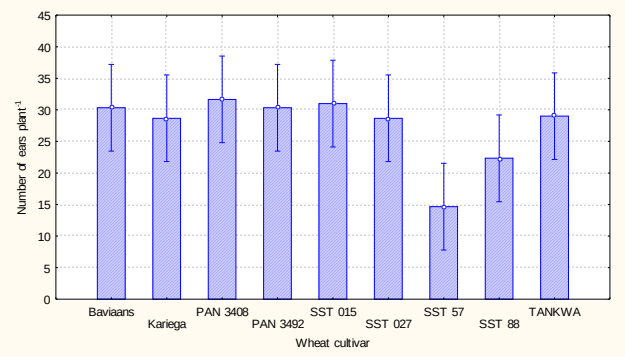


Figure 3.4 Total dry mass of nine spring wheat cultivars grown in pots in a glasshouse (data from different harvest times combined) (The whiskers represent standard error of means).

At maturity, only plant height, total plant dry mass and number of ears per plant was determined due to problems with the threshing machine that resulted in inaccurate yield data. Statistical analyses of the data revealed a significant difference between cultivars regarding the three parameters investigated (Appendix A: Tables 6, 7 and 8). SST 027 was found to be the tallest among all cultivars but did not differ significantly from cultivars PAN 3492, SST88 and Tankwa (Figure 3.5a). Baviaans was the shortest but did not differ significantly from cultivars Kariega, PAN 3408, SST 015 and SST 57. Regarding total dry mass of the plant, Tankwa had the highest dry mass but did not differ significantly from cultivars SST 88, SST 027, SST 57, PAN 3492 and PAN 3408 (Figure 3.5b). Although a significant difference was observed among cultivars regarding number of ears, the difference was due to SST 57 which produced significantly less ears than all the other cultivars except for SST 88 (Figure 3.5c). These two cultivars had the lowest number of ears per plant compared to other cultivars.



a) b)



c)

Figure 3.5 a) Plant height, b) total dry mass and c) number of ears at maturity of nine spring wheat cultivars grown in pots in a glasshouse (The whiskers represent standard error of means).

Wheat allelopathy

According to the work of Wanjura & Buxton (1972) and Smith (1989), an osmotic potential of 100 mOsm kg^{-1} is the threshold value believed not to affect seed germination and seedling growth of many weed species including ryegrass. Any osmotic potential above the threshold value is believed to affect germination and seedling growth. The osmotic pressure of the aqueous solutions from all nine spring wheat cultivars used in this experiment was found to fall below 100 mOsm kg^{-1} in concentration solutions of 25% and 50%, while the 75% and 100% concentration solution exceeded the threshold value of 100 mOsm kg^{-1}. This data are presented in Table 3.1. Therefore, the effects of the 75% and 100% concentration solutions on germination and growth of ryegrass are not exclusively due to allelopathic substances present in the aqueous solutions, but also due to osmotic potential of the solutions. Although the data were not statistically compared, there are no apparent differences in osmolality of all cultivar at 75% except for cultivars PAN 3408 and SST 027 which showed the lowest osmolalities. At the 100% concentration solutions, the differences between cultivars were also not that large. Therefore, differences between cultivars with regard to their effect on germination and seedling growth are most probably due to differences in the allelopathic potential of the different cultivars.

Table 3.1 The osmotic potential of aqueous solutions of nine different spring wheat cultivars (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa).

Cultivars	Concentration 25%	Concentration 50%	Concentration 75%	Concentration 100%
1	40 mOsm kg^{-1}	45 mOsm kg^{-1}	101 mOsm kg^{-1}	113 mOsm kg^{-1}
2	45 mOsm kg^{-1}	49 mOsm kg^{-1}	103 mOsm kg^{-1}	124 mOsm kg^{-1}
3	37 mOsm kg^{-1}	41 mOsm kg^{-1}	84 mOsm kg^{-1}	108 mOsm kg^{-1}
4	43 mOsm kg^{-1}	53 mOsm kg^{-1}	101 mOsm kg^{-1}	110 mOsm kg^{-1}
5	45 mOsm kg^{-1}	58 mOsm kg^{-1}	107 mOsm kg^{-1}	121 mOsm kg^{-1}
6	43 mOsm kg^{-1}	49 mOsm kg^{-1}	82 mOsm kg^{-1}	110 mOsm kg^{-1}
7	44 mOsm kg^{-1}	49 mOsm kg^{-1}	105 mOsm kg^{-1}	120 mOsm kg^{-1}
8	35 mOsm kg^{-1}	44 mOsm kg^{-1}	101 mOsm kg^{-1}	119 mOsm kg^{-1}
9	42 mOsm kg^{-1}	52 mOsm kg^{-1}	103 mOsm kg^{-1}	110 mOsm kg^{-1}

Germination inhibition of ryegrass seeds

Extract solutions from all spring wheat cultivars inhibited ryegrass germination at all concentrations compared to the control treatment (0% concentration = distilled water) (Figure 3.6). Statistical analysis of the data showed a significant interaction between Cultivar and

Concentration in terms of germination rate and germination percentage of ryegrass (Appendix A: Tables 10 and 11). The results showed that the phytotoxicity of different wheat cultivar extract solutions in inhibiting the germination of ryegrass varied significantly. No significant differences were observed between cultivars at 25% concentration, but significant differences were observed between cultivars at other concentrations. Differences between PAN 3408, PAN 3492, SST 015, SST 57 and Tankwa were insignificant at 25% and 50% concentration. Ryegrass germination was inhibited more than 50% at concentration solutions of 75% in all cultivars except for Baviaans and SST 57. Germination percentages ranged from about 19% for SST 88 to about 43% for Tankwa at the 100% concentration solution (Figure 3.6). No difference was observed between Kariega and SST 88 at any concentration, both appearing to inhibit germination of ryegrass seeds quite dramatically, particularly at the 50% concentration. The degree of inhibition increases in all cultivars with increases in extract concentrations from 25% to 100% (Figure 3.6). Germination rate results followed the same pattern and are therefore not shown.

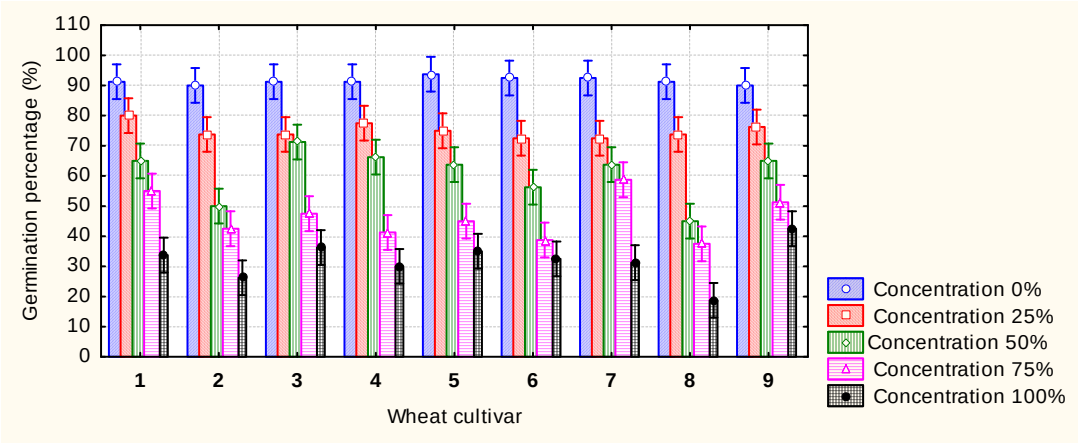


Figure 3.6 The effect of different extract solution concentrations from nine spring wheat cultivars on total percentage germination of ryegrass seed (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

Root growth inhibition of ryegrass

A significant interaction was observed between Cultivar and Concentration regarding root length of ryegrass. The root length of ryegrass in petri dishes was reduced by different wheat extracts, the extent of which was dependent on the solution concentrations and cultivars (Figure 3.7). SST 88 severely affected the root length of ryegrass from concentrations as low

as 25%. In contrast, no significant differences were observed in Tankwa between the control, 25% and 50% concentration treatments. Aqueous solutions from Tankwa and Kariega appeared to have the smallest effect on root growth. Generally, increased solution concentrations resulted in reduced root lengths. This cannot be attributed to allelopathic effects alone but to a combination of allelopathic and osmotic effects, particularly in the case of the 100% solution concentrations with osmolalities higher than 100 mOsm kg^{-1}. The roots of ryegrass appeared stunted, if visible at all, with different solution concentrations when compared to the control treatments.

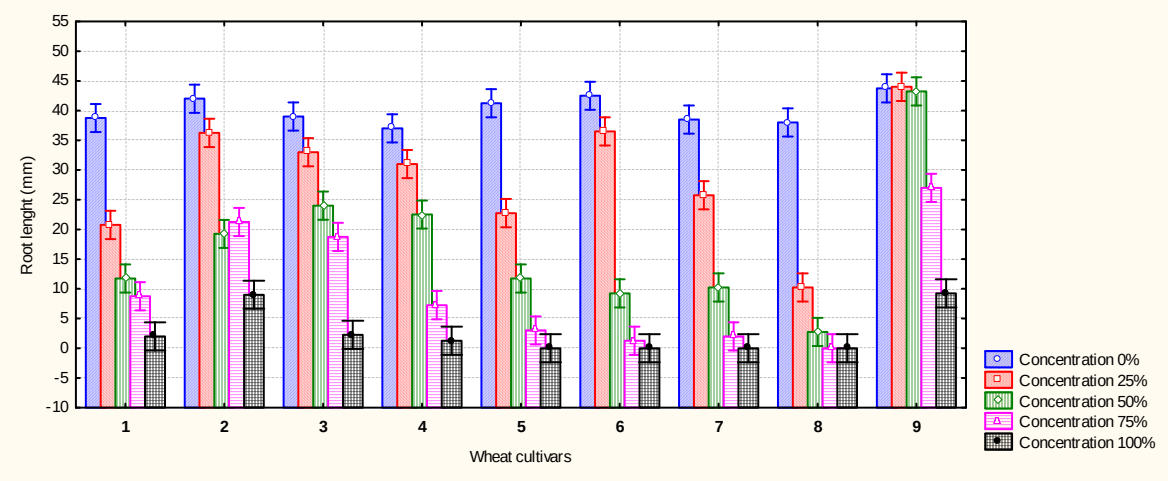


Figure 3.7 The effect of different extract solution concentrations from nine spring wheat cultivars on the root length of ryegrass germinated in petri dishes (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

Vegetative growth of ryegrass

A significant interaction was observed between Cultivar and Concentration in terms of plant height, root dry mass and leaf colour of ryegrass (Appendix A: Tables 12, 13 and 14) but there was no significant interactions in terms of leave number, number of tillers, shoot dry mass and total dry mass of ryegrass (Appendix A: Table 15 and 16). The plant height of ryegrass was reduced by different wheat extracts, the extent of which was dependent on the solution concentrations and cultivars (Figure 3.8). Baviaans, Kariege and SST 027 severely reduced the plant height of ryegrass from concentrations as low as 25%. In contrast, no significant differences were observed in PAN 3408, PAN 3492, SST 57 and Tankwa between the control, 25% and 50% concentration treatments. Aqueous solutions from these cultivars appeared to have the smallest effect on plant height.

Although no significant interactions were observed for number of leaves, a significant difference was observed between cultivars. SST 88 significantly differed from SST 015 and Tankwa but did not differ from the rest of the cultivars (Figure 3.9). This clearly shows that a cultivar such as SST 015 and Tankwa had little effect on number of leaves of ryegrass. Number of tillers showed the same pattern as number of leaves, therefore results are not shown.

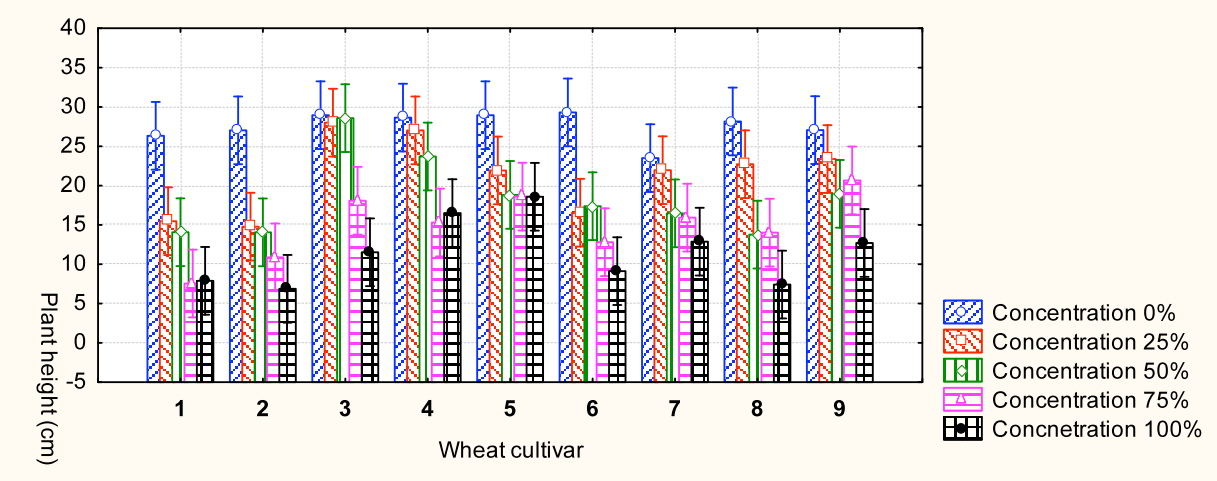


Figure 3.8 The effect of different extract solution concentrations from nine spring wheat cultivars on plant height of ryegrass (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

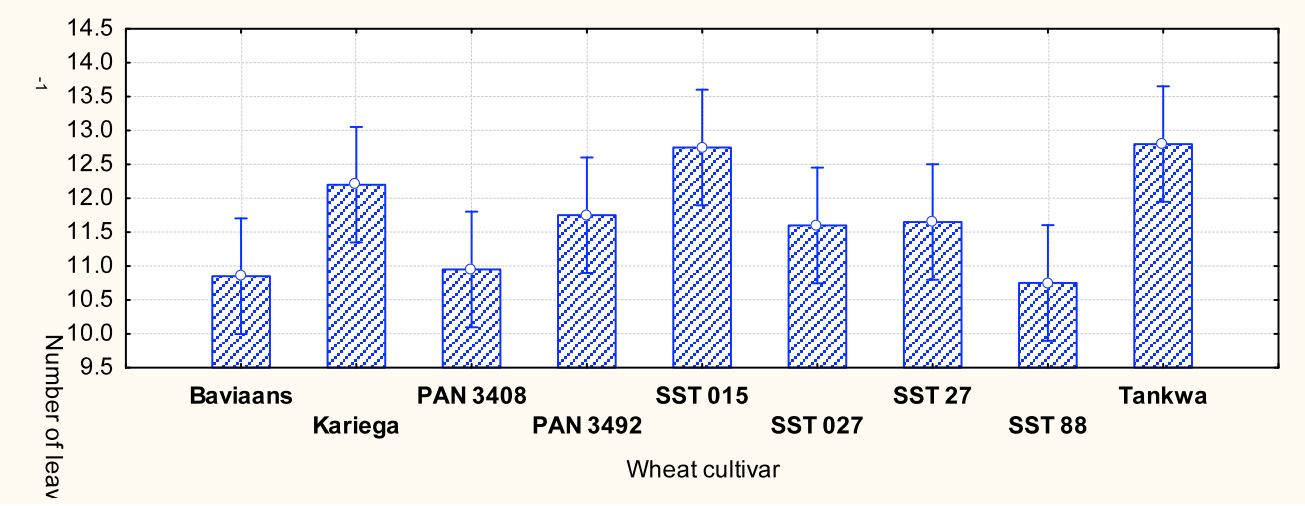


Figure 3.9 The effect of extract solutions from nine spring wheat cultivars on number of leaves of ryegrass (The whiskers represent standard error of means).

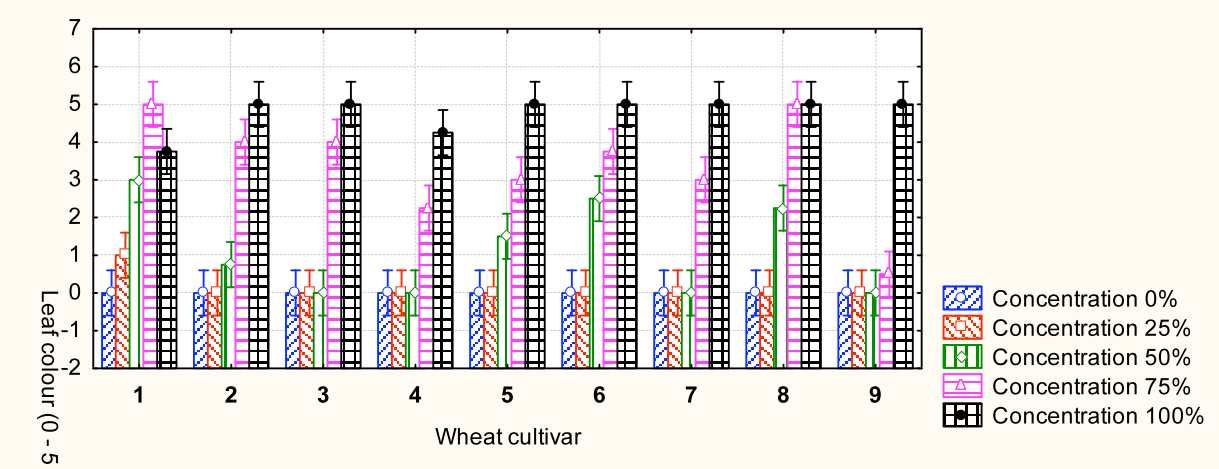


Figure 3.10 The effect of different extract solution concentrations from nine spring wheat cultivars on leaf colour of ryegrass (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

The effects of spring wheat cultivar extract solution concentrations also showed significant differences in leaf colour of ryegrass (Figure 3.10). The leave appearance of ryegrass changed from green (ranked 0) to a brown or purple discoloration (ranked 5) at concentration solutions as low as 25% in a more allelopathic cultivar such as Baviaans. No changes in leaf colour were observed in Tankwa at all concentration solutions except for the 100% concentration solution. Kariega, PAN 3408, PAN 3492, SST 57 and Tankwa did not significantly differ from each other in all concentration solutions except for the 75% and 100% concentration solutions. These cultivars showed less effect on ryegrass leaves colour than the rest of the cultivars. The effects were also found to be concentration dependent.

Ryegrass roots were found to be exceptionally sensitive to spring wheat extract solutions. The root dry mass of ryegrass was severely affected by concentrations as low as 25% in more allelopathic cultivars such as Kariega, SST 027, SST 57 and SST 88 (Figure 3.11). Again the allelopathic effect increased with an increase in extract concentration in all cultivars and was found to be greatest in SST 027 and least in PAN 3408. For shoot dry mass no significant interactions were revealed in any of the factors results are therefore not showed.

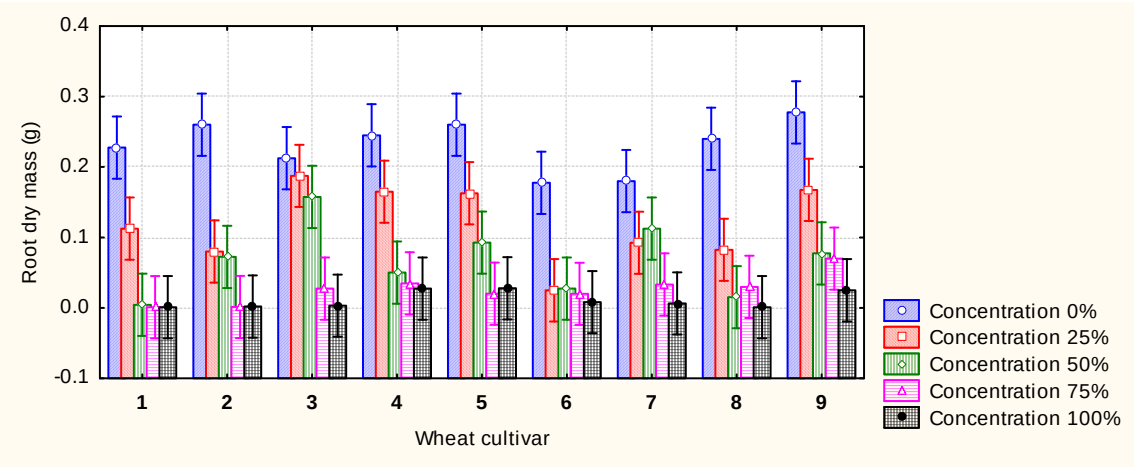


Figure 3.11 The effect of different extract solution concentrations from nine spring wheat cultivars on root dry mass of ryegrass (1 = Baviaans, 2 = Kariega, 3 = PAN 3408, 4 = PAN 3492, 5 = SST 015, 6 = SST 027, 7 = SST 57, 8 = SST 88, 9 = Tankwa) (The whiskers represent standard error of means).

For total dry mass Tankwa differed significantly from SST 88 and Baviaans but did not differ with the rest of the spring wheat cultivars (Figure 3.12). This implies that Tankwa have little effect on total dry mass whilst SST 88 and Baviaans had a significantly more severe effect on ryegrass total dry mass production.

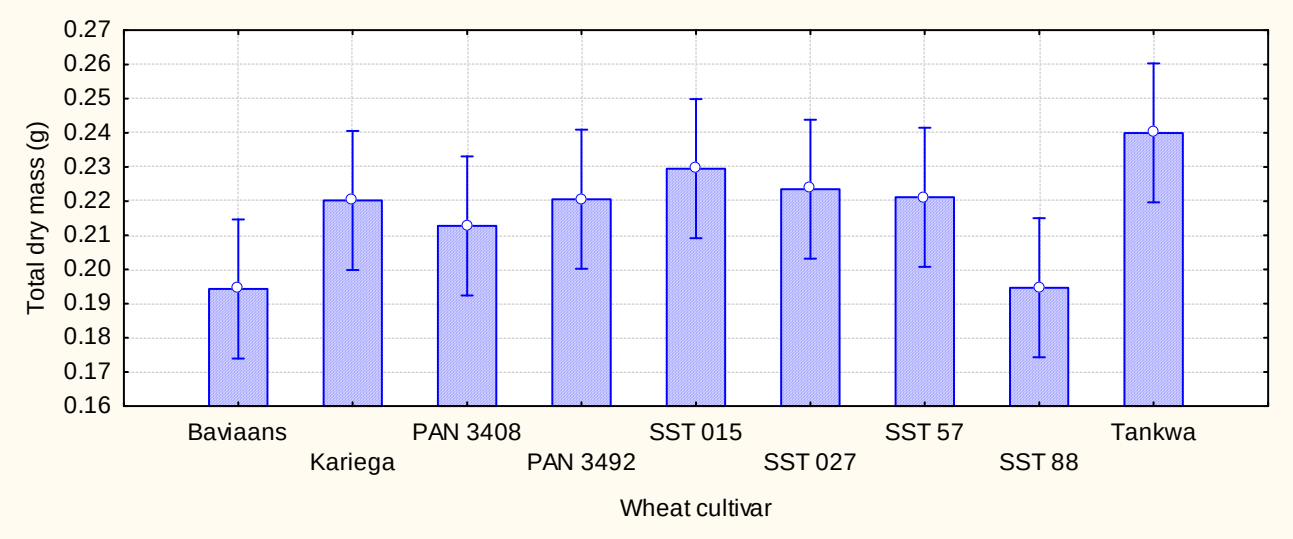


Figure 3.12 The effect of extract solutions from nine spring wheat cultivars on total dry mass production of ryegrass (The whiskers represent standard error of means).

DISCUSSION AND CONCLUSION

From the results of this experiment, it can be concluded that the different spring wheat cultivars differ in terms of growth pattern. According to the literature, highly competitive cultivars are generally tall, emerge rapidly, show high tillering potential with strong early vigour and have a prostrate habit with long, broad leaves (Grundy *et al*., 1993; Blackshaw, 1994; Lemerle *et al.,* 1996; Pester *et al.,* 1999; Lemerle *et al.,* 2001a; b). In this study, not all the components of competitiveness as described above was found to be present in the same cultivars hence making it difficult to select and identify the most competitive cultivars. The ranking of some of the characteristics such as plant height and leaf morphology have changed over the different development stages making it indeed complicated to identify the best cultivar and characteristics that are associated with competitive ability against weeds. Except for cultivars such as PAN 3408 and PAN 3492 which exhibited nearly all of these characteristics none of the cultivars exhibited all of these characteristics.

Plant height is one of the characteristics associated with wheat competitiveness (Lemerle *et al.,* 2001a; b). According to Lanning *et al*. (1997) shorter stature cultivars are less competitive than taller cultivars. Greater plant height increases the crop's resource capture, especially light and that happens at the expense of the weeds. In this experiment due to greater plant height observed in cultivars such as PAN 3408, PAN 3492, SST 57 and SST 88, these cultivars are regarded as competitive while cultivars such as Baviaans, Kariega and SST 015 are regarded as less competitive with cultivars SST 027 and Tankwa as intermediate competitive in terms of plant height. This implies that these (taller) cultivars are able to compete better with weeds. On the contrary, because of slow growth rates cultivars such as SST 015, SST 027 and Tankwa will not be regarded as competitive to weeds. Overall, a rapid seedling growth and a greater plant height were observed in cultivars PAN 3408, PAN 3492 and SST 57 at different harvest times.

Leaves are the site of light competition in plant. It is reported that plants with larger leaf area indices have competitive advantages over plants with smaller leaf areas (Zimdahl, 2007). From the findings of this experiment cultivars such as PAN 3408, PAN 3492, SST 015, SST 027 and Tankwa had more potential for leaf production compared to cultivar such as Baviaans, Kariega and SST 57 and can be regarded as more competitive in terms of leaf area indices. In fact, because of greater leaf area indices in these cultivars, they may be able to increase their resource capture during competition at the expense of weeds, in particular by reducing light quantity beneath the crop canopy and thereby reducing weed growth (Blackshaw, 1994). A higher dry mass production observed in PAN 3408 and PAN 3492 may have resulted from the cultivar's greater number of leaves that may capture more light and

produce more assimilates leading to a vigorous growth. To conclude, it is clear that PAN 3492 performed exceptionally well compared to the other cultivars but did not differ significantly from cultivars PAN 3408 and SST 88 in terms of rapid emergence, greater plant height, greater leaf area indices and higher number of ears per plant and therefore these three cultivars are regarded as the most competitive cultivars.

All nine spring wheat cultivars studied inhibited the germination, root elongation and vegetative growth of ryegrass. This is in agreement with many well documented reports that identify wheat as an allelopathic crop. Overall, cultivars SST 015, SST 88 and Kariega had the greatest allelopathic potential at all concentrations and Tankwa and Baviaans had the lowest. These results are in accordance with other studies which reported that allelopathic effects may vary among crop cultivars (Challaiah *et al.,* 1986; Lemerle *et al*., 1996; 2001a, b; Wu *et al*., 1998; 2000; 2001). The present study also found that wheat competitive parameters such as plant height, LAI and early vigour in spring wheat cultivars showed little or no correlation to wheat allelopathy. The results has showed that wheat cultivars with vigorous growth such as cultivar PAN 3492 did not show strong allelopathic effects and *vice versa* those that showed strong allelopathic effects did not show vigorous growth. This finding is supported by the work of Lockerman & Putnam (1981) who found that the allelopathic activity of cucumbers did not correlate to relative growth rate and the net assimilation rate in cucumber seedlings. Similarly, it was found that allelopathic potential in rice did not correlate to plant height and to the root biomass of rice plants (Olofsdotter & Navarez, 1996; Bach Jensen *et al.,* 1999).

The inhibitory effect of the spring wheat cultivar extract solutions was found to be more severe on root elongation than on germination and seedling growth. This result is in agreement with the findings of others (Olofsdotter & Navarez 1996; Wu *et al*., 2000). The roots of ryegrass appeared stunted, if visible at all with different extract concentrations when compared to the control treatment. This might be due to the rapid inhibiting effect on respiration of root tips which ultimately reduce cell division and elongation, as reported by Qasem (1993). The change in leave pigments could be due to phenolic compounds present in wheat extracts and it is believed to affect photosynthesis (Heijl *et al*., 1993).

This experiment showed clearly that some spring wheat cultivars possess stronger allelopathic effects than others. It is suggested that the difference in allelopathic effects of spring wheat cultivars may be attributed to the genetic differences among the cultivars, since the extract solutions were the same concentration and osmotic pressure was in the same range. Results of this study are similar to those obtained by others (Dilday *et al*., 1994;

Olofsdotter *et al*., 1995; An *et al.,* 1997; Chung *et al*., 1997; Wu *et al*., 2000; 2003), who also concluded that genetic variation in allelopathic activity existed among crop cultivars. This may propose that allelopathy is an inherited trait. The difference in allelopathic potential of the nine spring wheat cultivars tested may offer some genetic collection to plant breeders to select and transfer the allelopathic genes into other spring wheat cultivars for weed suppression. A further screening is needed to confirm the finding of this work before any initiation of breeding programs to develop spring wheat cultivars with highly allelopathic potential or before any recommendation to farmers is done. These results also imply that inhibitory substances present in spring wheat cultivars should be tested as possible natural herbicide sources. It is also suggested that cultivars with good early seedling vigour might eventually result in less herbicide required to control weeds in the field and may thus reduce production costs.

From this experiment it can be concluded that PAN 3492 is regarded as the best competitor in terms of vigorous growth and SST 88 is regarded as the best allelopathic spring wheat cultivar. Tankwa which was least in terms of vigorous growth and allelopathy is regarded as the least competitive among the nine selected spring wheat cultivars. Overall SST 88 is regarded as the most competitive cultivar because of its moderate growth habit and high allelopathic potential. These three cultivars (PAN 3492, SST 88 and Tankwa) will be compared in terms of their interference effects on different weed species in subsequent experiments.

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CHAPTER 4

Allelopathic potential of three South African spring wheat cultivars on germination and growth of selected weed species

INTRODUCTION

Weeds are one of the major problems in most crop production systems. In the winter wheat producing region of South Africa, weed species which infest wheat fields are numerous. *Raphanus raphanistrum, Oncosiphon suffruticosum, Stellaria media, Lolium* spp*., Bromus diandrus* and *Avena fatua* are some of the problematic weeds of wheat fields in the winter rainfall wheat producing region of the country. Herbicides are the principal tools used to manage weeds within wheat cropping systems. The continuing success of herbicides is threatened by development of resistant weed biotypes and disappearance of susceptible weeds as a result of the extensive and repetitive use of particular herbicides (Heap, 2008). In addition, herbicides cause environmental pollution, unsafe agricultural products and human health concerns (Khanh *et al.,* 2005). There is a proven record that most of these weeds found in this region has developed resistance to the major herbicides currently used (Cairns & Eksteen, 2001; Heap, 2008). It is also reported that in many cases when a particular weed species develops resistance to one herbicide class, it may develop cross resistance and multiple resistance to other herbicide classes (Heap, 1997; Cairns & Eksteen, 2001). Consequently, alternation of different herbicide groups on its own will not be effective in preventing herbicide resistance. Therefore, a non herbicidal innovation to manage these weeds is increasingly needed.

The potential for using allelopathy in weed management has been well documented (Rice, 1995; An *et al*., 1998). Allelopathy refers to a chemical process that a plant uses to keep other plants out of its place. Rice (1984) defines allelopathy as the direct or indirect harmful or beneficial effects of one plant on another through the production of chemical compounds that escape in the environment. The chemical compounds are termed allelochemicals, which are water soluble substances released into the surroundings through volatilization, leaching and decomposition of plant residues and root exudation (Rice, 1984). This phenomenon is regarded as a natural and environmentally friendly technique which may prove to be a unique tool for weed control, increase crop yields, decrease the reliance on synthetic herbicides and improve the ecological environment (Putnam & Tang, 1986; Duke *et al*., 2000; Khanh *et al.,* 2005). Many crop cultivars are reported to have strong allelopathetic effects against the growth of many weed species (Wu *et al*., 1999). Allelopathic crop cultivars can be used in weed control in crops by many ways such as: use of the phytotoxic

crop residues as cover crops and mulches, allelopathic plants in crop rotations, crop mixtures and intercropping, germplasm selection and allelopathic crop water extracts (Putnam, 1988; Blum *et al*., 1992; Wu *et al*., 2000; Duke *et al*., 2001).

Wheat (*Triticum aestivum)* is an example of an allelopathic crop (Putnam *et al*., 1983; Wu *et al*., 1998; 1999; 2000; 2001). Allelopathy in wheat refers to the fact that wheat can chemically affect the growth of other plants including weeds by exuding secondary metabolites such as phenolics, hydroxamic acids and 2,4-dihydroxy-7-methoxy-1,4-benzoxazine-3-one (DIMBOA) into the surrounding environment during active growth and subsequent decomposition of the straw (Wu *et al*, 1999). It has been found that the water extracts of wheat residues are allelopathic to many weed species and have consistently reduced weed germination and seedling growth under laboratory conditions (Steinsiek *et al*., 1982; Liebl & Worsham, 1983; Wu *et al*., 2000). The natural allelopathic effect of wheat residues has been confirmed in field conditions whereby residues are mulched on the soil surface and it was found to significantly inhibit emergence, seedling growth and dry matter accumulation of many weed species (Steinsiek *et al*., 1982; Shilling *et al*., 1985; Wu *et al.,* 1999). The phytotoxins from wheat straw are believed to be water soluble and can be leached into the soil to affect the germination and growth of weeds in the vicinity (Shilling *et al*., 1985). Rizvi (2004) demonstrated allelopathy of 200 wheat cultivars and discovered that some cultivars inhibited weed growth up to 75%, similar to hand weeding. This may imply that wheat allelopathy can be exploited to minimise weed populations below the threshold in order to reduce the application of synthetic herbicides. It is also reported that wheat cultivars differ in their effects on specific weed species and weed species respond differently to wheat extracts (Steinsiek *et al*., 1980; 1982; Wu *et al.,* 1998; 1999). This may suggest that allelochemicals in wheat may selectively influence the growth of certain weeds.

Therefore, the present study was undertaken to determine the allelopathic potential of extract solutions of three different spring wheat cultivars on the germination and growth of some major weed species found in the winter rainfall wheat producing area of the Western Cape, South Africa.

MATERIALS AND METHODS

Preparation of wheat extracts

The experiment was conducted in a temperature controlled glasshouse at the Department of Agronomy of Stellenbosch University. Three spring wheat cultivars that were selected from a previous experiment (See Chapter 3) were used for this experiment. These cultivars were:

PAN 3492; SST 88 and Tankwa. Similar procedures were followed as in Chapter 3 whereby plant material of the three spring wheat cultivars was collected and oven dried at 45 ˚C for 72 hours. The dried material was ground in a mill to pass through a 1 mm sieve screen. Of the milled material, 200 g of material powder from each wheat cultivar were diluted in 2000 ml of distilled water in a plastic bottle container and placed in a growth chamber for 5 days at a constant temperature of 20˚C in the dark. The pulpy mixture was filtered by squeezing it through four layers of cheese cloth. The resulting filtrate was then filtrated through a funnel with Whatman No. 1 filter paper. The solution was sterilized by passing it through 0.2μm pore size Whatman Puradisc polyethersulfone membrane millipore filters. The sterilized filtrate was designated as full strength (100%) solution and different concentration dilutions were developed from this solution, i.e. 0 % (distilled water), 25%, 50%, 75% and 100% (full strength). The osmolality of the three different spring wheat cultivars extract solutions was measured using a Roebling digital micro-osmometer.

Germination inhibition

Seeds of the six selected weed species i.e. *Lolium* spp. (ryegrass), *Raphanus raphanistrum* (wild radish), *Oncosiphon suffruticosum* (calomba daisy), *Stellaria media* (chickweed), *Bromus diandrus* (ripgut brome) and *Avena fatua* (wild oats) were used in this experiment. Twenty seeds of each weed species were placed in petri dishes lined with two layers of Whatman No. 1 filter paper. Five ml of different concentrations of aqueous extract from three different spring wheat cultivars was administered into the petri dishes. The distilled water was used as a control treatment. The Petri dishes were sealed in a plastic bag to prevent evaporation. Because of different germination requirements of weed species, petri dishes with *B. diandrus* seeds were placed in a growth chamber at a 10/15 °C (night/day) temperature in the dark after a cold treatment (5 ºC) for 14 days. For the other weed species *viz*. *Lolium spp.* (ryegrass), *R. raphanistrum* (wild radish), *O. suffruticosum* (calomba daisy) and *S. media* (chickweed), petri dishes were placed in a growth chamber at a constant temperature of 20˚C in the light. Petri dishes were arranged in a randomized complete block design and each treatment was replicated three times. Germination counts were made daily after germination was observed from the control treatment. Seeds were considered germinated when the radicle was about 1 mm long. The experiment was ended after about 16 days of incubation when no further seed germination was observed for three successive days. Because of the visible effect of cultivar aqueous solutions on the root length of weed species, three seedlings of each weed species from each treatment were picked randomly and root

length was measured on the last day of monitoring. The germination percentage was calculated as follows: Final germination percentage = number of germinated seeds / total number of seeds planted X 100. The germination rate was calculated using the following expression (Heydecker, 1973).

$$\sum_{i=1}^{K} \frac{n_i}{D_i.n_i}.100,$$

where n = the number of seeds germinated on Day i and D = Day i.

Vegetative growth inhibition

The phytotoxic effects of the aqueous solution concentrations of the three spring wheat cultivars on the growth of different weed species was evaluated in a temperature controlled glasshouse at 18/22°C night/ day temperatures. Because of difficulties experienced in establishing seedlings of *Oncosiphon suffruticosum* (calomba daisy) and *Stellaria media* (chickweed), these two weed species were excluded from the experiment. Only four weed species were used i.e. *Lolium* spp. (ryegrass), *R. raphanistrum* (wild radish), *B. diandrus* (ripgut brome), and *A. fatua* (wild oats). Because of difficulties experienced to establish seedlings of *R. raphanistrum* (wild radish) and *B. diandrus* (ripgut brome) directly in 8 cm X 8 cm square plastic pots, seeds of these weed species were germinated in a growth cabinet and then transplanted into the pots. Seeds of ryegrass and wild oats were sown directly in 8 cm X 8 cm square plastic pots and thinned to one plant per pot after emergence. During the establishment phase, the pots were watered from the bottom with a balanced feeding mixture as described by Steiner (1984). Two weeks after the seedlings were well established, 10 ml of different concentrations of aqueous solution (0% (pure water), 25%, 50%, 75% and 100% (full strength) from three different spring wheat cultivars described above was added from the top to water the seedlings every second day for two weeks. The whole plant was harvested after two weeks of watering with the aqueous solutions. The roots were washed to remove sand before it was separated from the shoot. Both shoots and roots were oven dried at 45 ºC for 72 hours. Plant height, number of leaves, number of tillers, root dry mass, shoot dry mass and total dry mass were determined. Due to the morphological structure of *R. raphanistrum*, no measurement was taken on its height as well as number of tillers. Leave area index was not measured, since some of the leaves in weed species such as *A. fatua* and *Lolium spp.* have lost chlorophyll pigments due to the treatments and it was therefore difficult to classify the leaves as alive or dead. The experiment was a factorial design with three factors and

replicated three times. The factors were: Wheat cultivar, extract solution Concentration and Weed species.

Statistical analysis

Statistical analysis of the data was performed using the Statistica package (Software, version 8.02). Analysis of variance (ANOVA) was conducted to determine the interaction of factors. Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P< 0.05$) differences among the treatments. When referring to significant or non-significant differences and/or interactions "significant" means $P < 0.05$ and "non-significant" means $P> 0.05$.

RESULTS

The osmotic potential of extract solutions of spring wheat cultivars

Osmotic potentials above 100 mOsm kg^{-1} are believed to affect germination and seedling growth of many weed species (Wanjura & Buxton, 1972; Smith, 1989). Others have reported osmotic potentials of 150 mOsm kg^{-1} to be inhibitory to seed germination (Leather & Einhellig, 1986), while Buchanan *et al.,* (1978) found osmotic potentials of 148 mOsm kg^{-1} to have no influence on germination of terrestrial grasses and cereals. Bell, (1974) found an osmotic potential of greater than 75 mOsm kg^{-1} to be inhibitory. There is no precise information on the effects of osmotic potential on germination and seedling growth of the weed species used in this study. It is difficult to compare data from this study with data from other studies since the test crop and experimental conditions differ. In spite of this, it will be considered that the effects of extract solutions on germination and seedling growth are not exclusively due to allelopathic substances present in the extract solutions, but also due to osmotic potential of the solution. The data on osmotic potential of extract solutions of spring wheat cultivars are presented in Table 4.1. There are no apparent differences in osmolality of the three spring wheat cultivars. Therefore, the differences between cultivars regarding their effect on germination and seedling growth are most likely due to the differences in the allelopathic potential of the three cultivars.

Table 4.1 Osmotic potential of the aqueous extract solutions of three spring wheat cultivars

Cultivar	Concentration 25%	Concentration 50%	Concentration 75%	Concentration 100%
PAN 3492	45 mOsm kg^{-1}	58 mOsm kg^{-1}	107 mOsm kg^{-1}	124 mOsm kg^{-1}
SST 88	42 mOsm kg^{-1}	62 mOsm kg^{-1}	105 mOsm kg^{-1}	126 mOsm kg^{-1}
Tankwa	40 mOsm kg^{-1}	55 mOsm kg^{-1}	110 mOsm kg^{-1}	129 mOsm kg^{-1}

Germination and germination rate

Extract solutions from three different spring wheat cultivars inhibited the germination percentage of all weed species at all concentrations compared to the control treatment except that of *R. raphanistrum* (Figure 4.1). Statistical analysis of the data revealed significant third order interactions between Cultivar, Weed species and Concentration in terms of germination percentage and germination rate of weed species (Appendix B: Tables 1 and 2). Germination percentage of *Lolium* ssp*, B. diandrus*, *S. media, O. suffruticosum* and *A. fatua* was significantly decreased by extract solutions of different spring wheat cultivars at different concentration levels (Figure 4.1). Weed species interactions were due to *R. raphanistrum* which showed an increase in germination percentage at 25% and 50% concentrations compared to the control and a reduction in germination percentage at 75% and 100% concentrations. The rest of the weed species showed reduced germination percentages at increased extract concentrations of the spring wheat cultivars. In addition, Cultivar interactions were due to SST 88 which differed from PAN 3492 and Tankwa. The Bonferroni post-hoc comparisons showed that aqueous extracts from SST 88 differred significantly with extracts from PAN 3492 and Tankwa by severely reducing the germination percentage of *Lolium spp* at the 25% concentration. Similarly, germination of weed species such as *O. suffruticosum, S. media* and *B. diandrus* were affected by extract solutions of 50% to 100% concentration, but no significant differences were observed between the effects of the different spring wheat cultivars. The degree of inhibition increased with increases in extract concentrations from 25% to 100% in all weed species except in *R. raphanistrum*. In general, SST 88 had the most severe effect on the germination percentage of the weed species, in particular *Lolium spp*. and *A. fatua*. The low germination percentage and no differences between species at the 100% concentration may be due to osmolality effects.

Regarding germination rate, a significant difference was revealed between cultivars at 75% and 100% concentrations. Germination rate of *B. diandrus* and *O. suffruticosum* was significantly prolonged by extract concentration of 75% from SST 88 compared to extracts from PAN 34922 and Tankwa (Figure 4.2). Germination rate of all weed species was

inhibited by 100% concentration extracts from SST 88 whilst extracts from PAN 3492 and Tankwa only inhibited germination rate of *B. diandrus, S. media* and *O. suffruticosum*. No significant difference was revealed between cultivars at 25% and 50% concentration regarding germination rate.

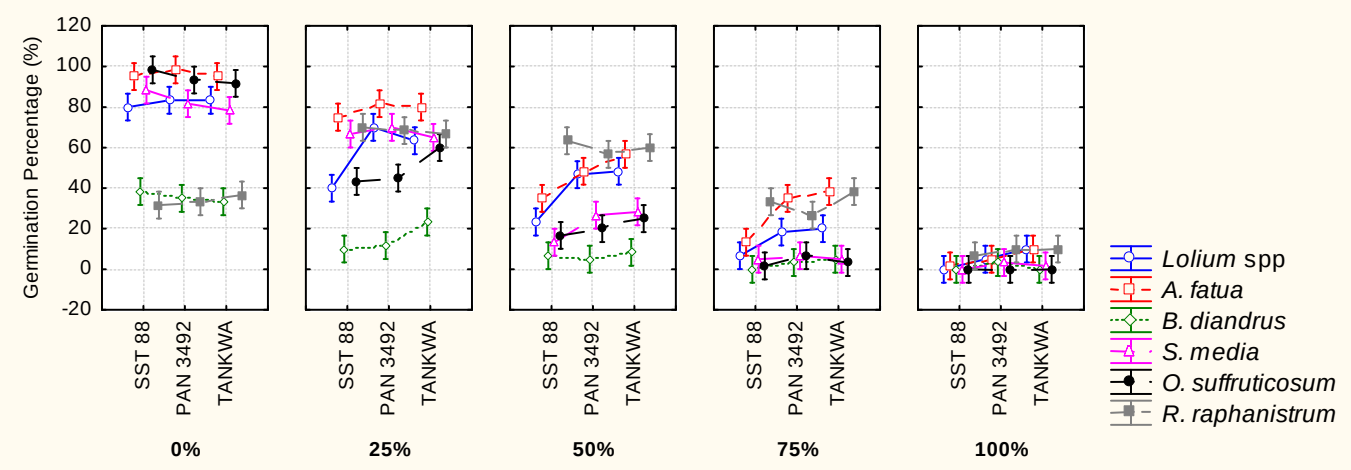


Figure 4.1 Effects different extract solution concentrations from different spring wheat cultivars on germination percentage of different weed species *(Lolium* spp. *= Lolium species, A. fatua = Avena fatua, B. diandrus = Bromus diandrus, O suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media* and *R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

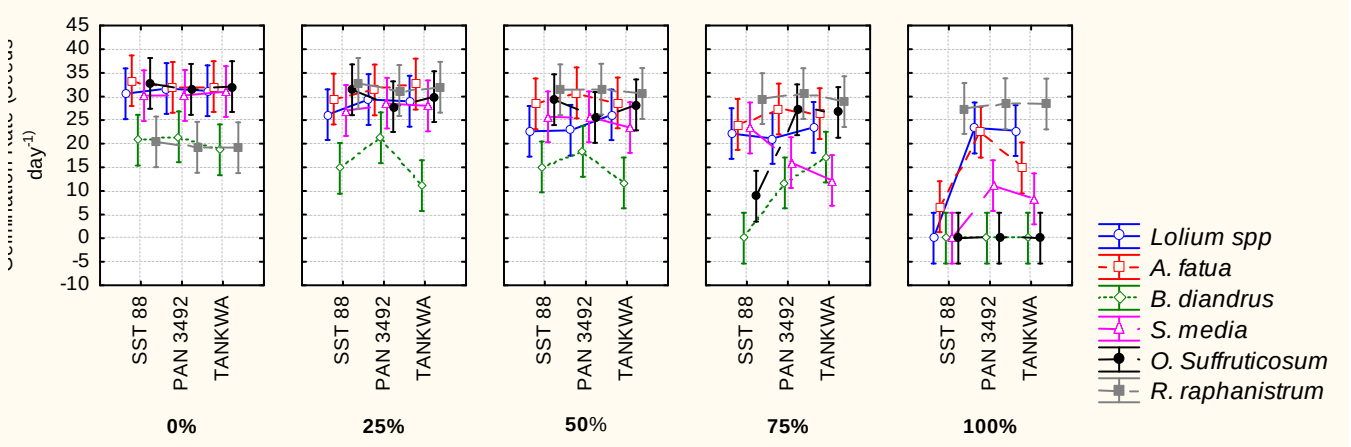


Figure 4.2 The effect of different extract solution concentrations from different spring wheat cultivars on germination rate of different weed species *(Lolium spp. = Lolium species, A. fatua = Avena fatua, B. diandrus = Bromus diandrus, O. suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media and R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

The root length of all weed species in petri dishes treated with extract solutions from different spring wheat cultivars was significantly reduced compared to the control. Statistical analysis of the data revealed no significant interactions between Cultivar, Concentration and Weed species, Weed species and Cultivar as well as between Cultivar and Concentration (Appendix B: Table 3). Root length was affected by a significant interaction between Weed species and Concentration. Post–hoc analysis (Bonferroni) of the Weed species and Concentration interaction showed that all weed species did not differ significantly from each other at any concentration except for *Lolium* spp. and *A. fatua* which differed from *O. suffruticosum* and *R. raphanistrum* at 25% concentration. The root length of all weed species was significantly reduced by extract solutions of concentrations as low as 25% (Figure 4.3). The roots of all weed species appeared stunted, if visible at all particularly at 75% to 100% extract solution concentrations. An example of reduced root length is showed in Plate 1.

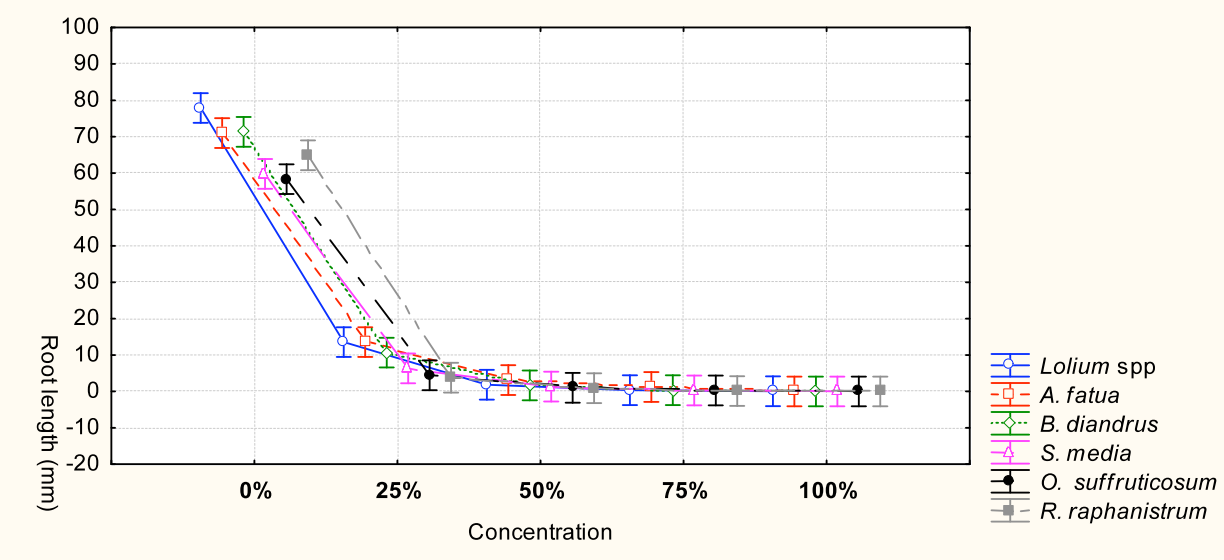
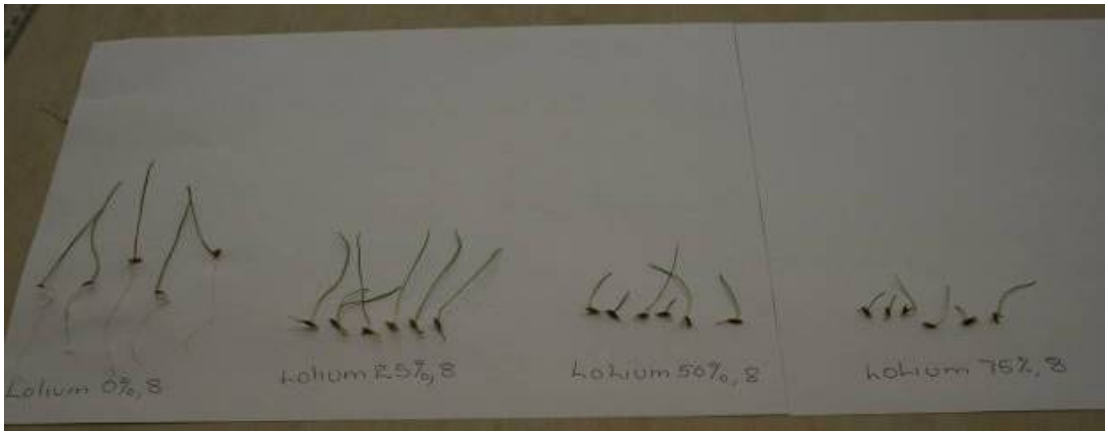


Figure 4.3 Effects of different extract solutions from spring wheat cultivars on root length of weed species *(Lolium* spp. = *Lolium species, A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, O. suffruticosum* = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

a)



b)

c)

Plate 4.1 Illustration of effects of different extract solution concentrations of different spring wheat cultivars on root length of *Lolium spp* and *A. fatua* seedlings (a- Tankwa on *Lolium* spp; b- SST 88 on *Lolium* spp; c- PAN 3492 on *A. fatua*).

Vegetative growth of weed species

Statistical analysis of the data of the effects of extract solutions of three spring wheat cultivars on plant height of the weed species revealed no significant interactions between

Cultivar, Weed species and Concentration. A significant interaction was however revealed between Weed species and Concentration as well as between Cultivar and Concentration (Appendix B: Table 4; Figure 4.4 and 4.5). Post-hoc comparisons (Bonferroni) of the Weed species and Concentration interaction showed significant differences between *Lolium* spp and the other two species at 50% to 100% concentration but no significant differences were observed between *A. fatua* and *B. diandrus* at any concentration (Figure 4.4). This implies that *Lolium* ssp was more sensitive to cultivar extract solutions than *B. diandrus* and *A. fatua*. *Bromus diandrus* and *A. fatua* were less affected by extract solutions. Post-hoc comparisons of the Cultivar and Concentration interaction revealed that the interaction was due to SST 88 which significantly differed from PAN 3492 and Tankwa at 75% and 100% concentration, but PAN 3492 did not differ significantly from Tankwa at any concentration (Figure 4.5). This may indicate that extract solutions from SST 88 have the greatest effects on plant height of the weed species.

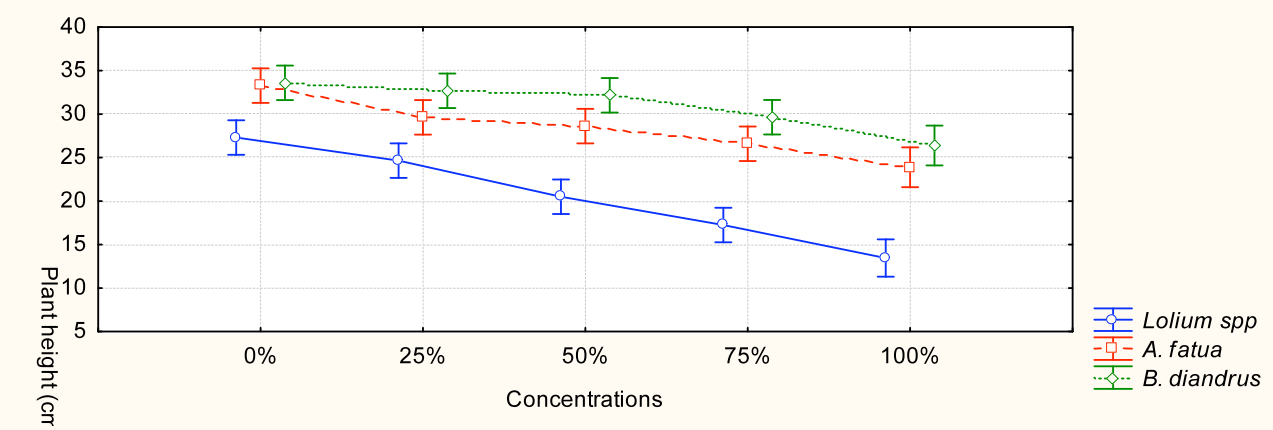


Figure 4.4 Plant heights of weed species as affected by spring wheat cultivars extract solution concentrations (*Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus*) (The whiskers represent standard error of means).

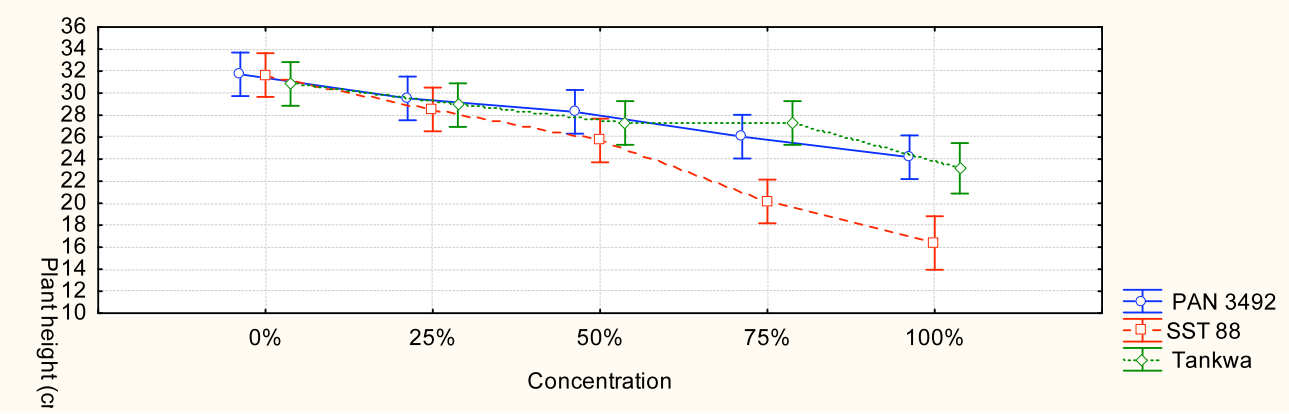


Figure 4.5 Effect of different extract solution concentrations of spring wheat cultivars on plant height of weed species (The whiskers represent standard error of means).

Regarding the number of leaves of weed species, statistical analyses of the data showed no significant interactions between Cultivar, Concentration and Weed species, but significant interactions were observed between Weed species and Concentration, Weed species and Cultivar as well as between Cultivar and Concentration (Appendix B: Table 5). Post-hoc analysis (Bonferroni) of the Cultivar and Concentration interaction showed that the difference were significant for SST 88 which differed from PAN 3492 and Tankwa at 75% concentration only (Figure 4.6). PAN 3492 and Tankwa did not differ at any concentration. This may imply that these cultivars had similar effects on number of leaves of weed species. For the Weed species and Concentration interaction the differences were due to *Lolium* specie and *R. raphanistrum* being more severely affected at 75% and 100% concentrations (Figure 4.7). In terms of the Weed species and Cultivar interaction, the most probable reason for the significant interaction is the large effect that SST 88 had on the number of leaves of *A. fatua* and the small effects that Tankwa had on *Lolium* spp (Figure 4.8). No significant difference was observed between cultivars in *B. diandrus* and *R. raphanistrum*. This may imply that the wheat cultivars have similar effects on these weed species.

Leaves of weed species such as *Lolium* and *A. fatua* were visibly seen to lose chlorophyll pigment in pots treated with extract solution concentrations of above 50% from all cultivars. Effects from SST 88 were visibly seen in pots treated with extract solution of 25% for *Lolium* spp and 50% for *A. fatua*. Plate 4.2 shows how leaves change colour with increases in cultivar extract concentrations. It was also found that cultivars differed in their effect on leaf colour as SST 88 shows greater effect on ryegrass leaves than PAN 3492 at the same concentration (Plate 2c). For *R. raphanistrum* leaves from pots treated with extract solutions of 75% to 100% concentration from all spring wheat cultivars died. Only *B. diandrus* leaf colour were found not to be affected by cultivar extract solutions. Number of tillers of *Lolium* species, *A. fatua* as well as *B. diandrus* also followed the same pattern as number of leaves and results are therefore not shown.

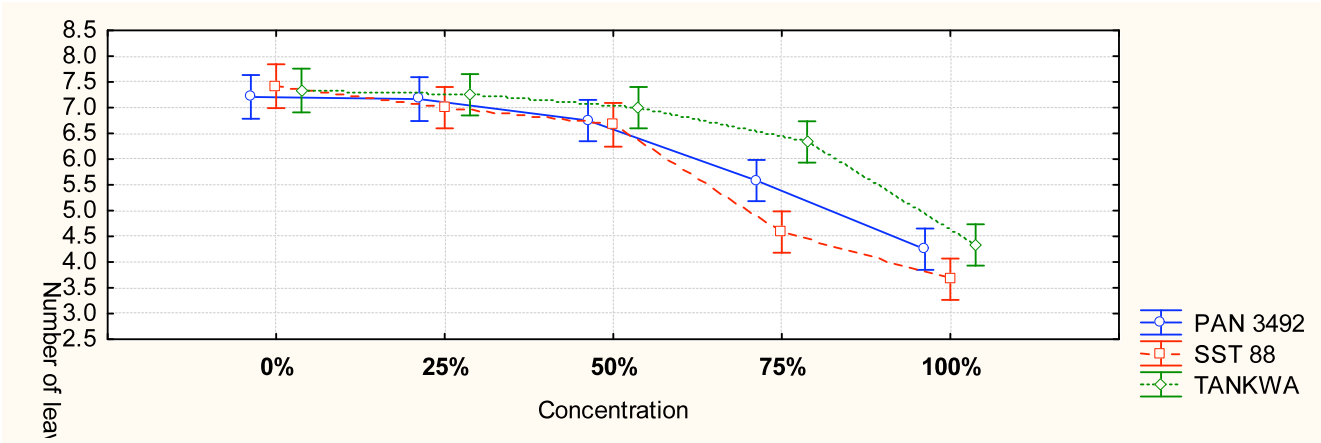


Figure 4.6 Effect of different extract solution concentrations of spring wheat cultivars on number of leaves of weed species (The whiskers represent standard error of means).

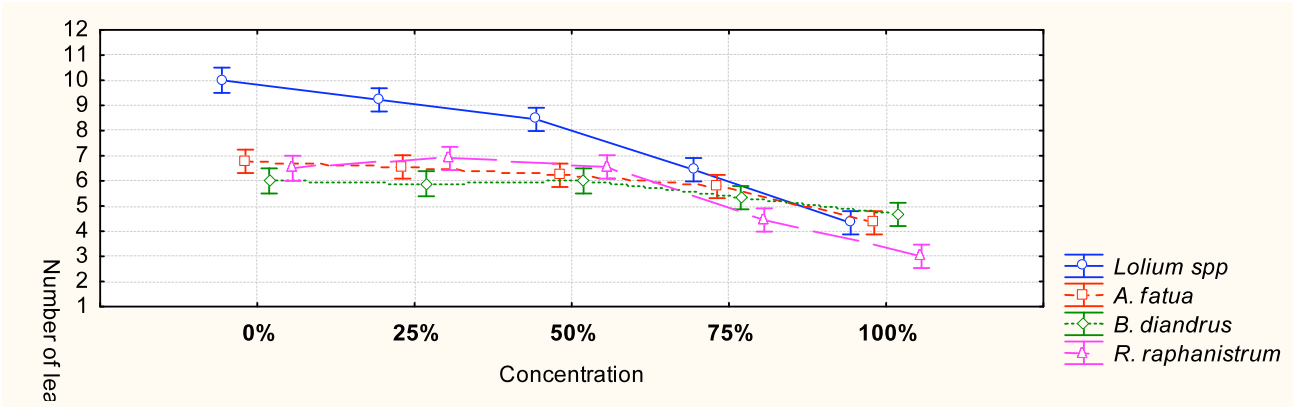


Figure 4.7 Number of leaves of weed species as affected by spring wheat cultivars extract solution concentrations (*Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

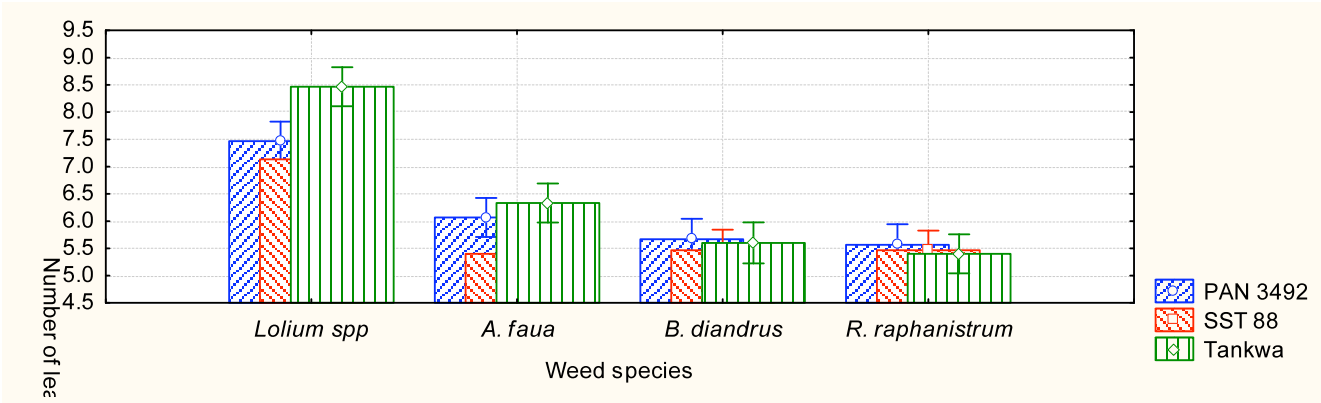
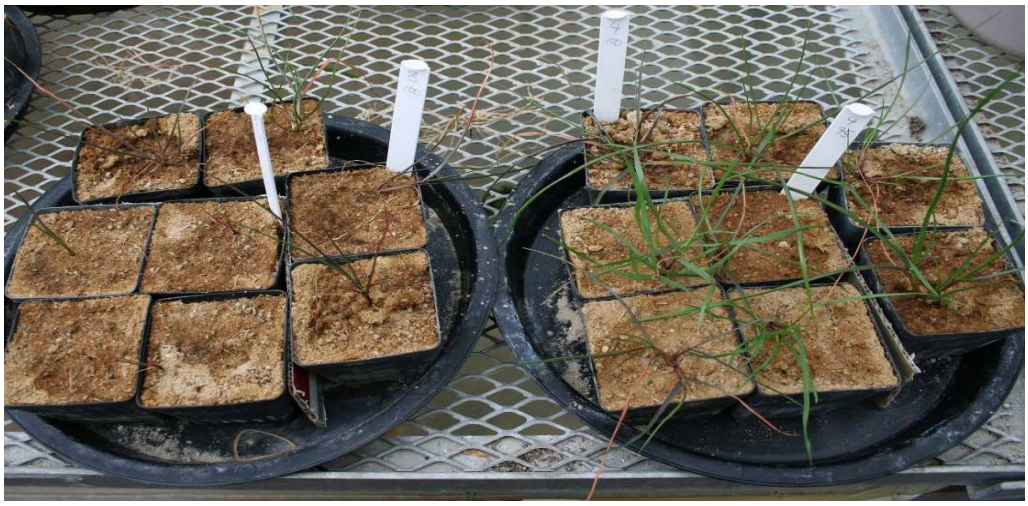


Figure 4.8 Effects of aqueous extract solutions spring wheat cultivars on number of leaves of weed species (*Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus*

diandrus and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

a)

b)



c)

Plate 4.2 Illustration of changes in leaf colour of weed species treated with aqueous extract solutions of spring wheat cultivars (a, = *A. fatua* treated with extract from Tankwa, b, = *A. fatua* treated with extract from SST 88, c (left), = *Lolium* ssp under 75% and 100% concentration solution from SST 88, c (right), = *Lolium* spp under 75% and 100% concentration solution from PAN 3492).

A significant interaction between Cultivar, Concentration and Weed species regarding shoot dry mass of weed species was observed (Appendix B: Table 6). Figure 4.9 shows that the SST 88 extract solution reduced shoot dry mass of particularly *Lolium spp.* significantly more than Tankwa from concentrations as low as 50%. Tankwa and PAN 3492 showed smaller effects on *B. diandrus* shoot dry mass. Effects on *R. raphanistrum* were only observed at concentrations of 75% and 100% in all cultivars.

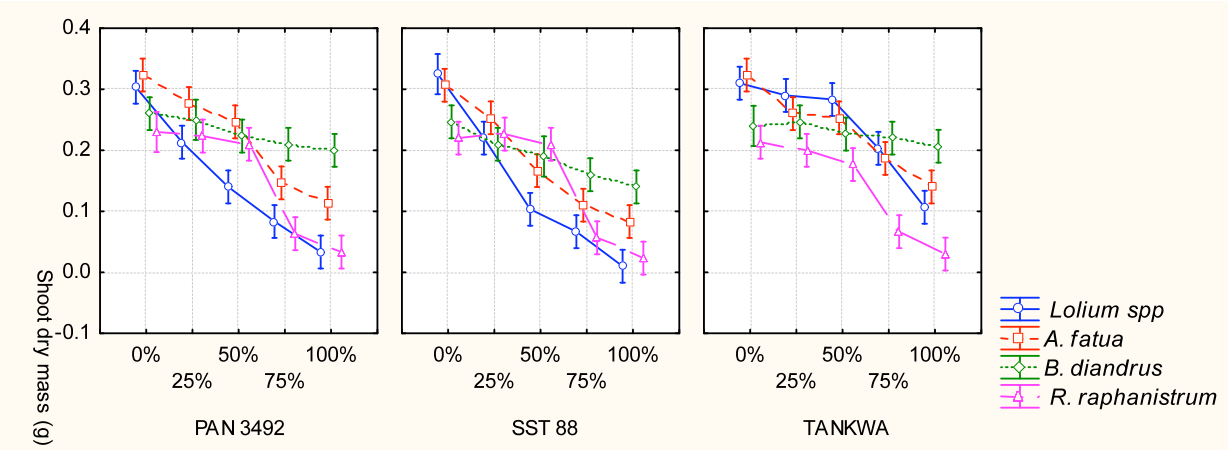


Figure 4.9 Effects of extract solution concentrations of spring wheat cultivars on shoot dry mass of weed species (*Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

The effect of increasing extract solution concentrations of different spring wheat cultivars on root dry mass production of weed species is shown in Figure 4.10. Statistical analysis of the data showed significant interactions between Cultivar, Concentration and Weed species (Appendix B: Table 7). Post-hoc analysis (Bonferroni) showed that the interaction was due to SST 88 which significantly differed from PAN 3492 and Tankwa at the 50% concentration regarding the effect on root dry mass of *Lolium* spp. It is clearly shown in Figure 4.10 that extracts from SST 88 inhibited the root dry mass of all weed species significantly more at low concentrations compared to PAN 3492 and Tankwa. *Lolium*

spp. was significantly affected by extract solutions, particularly that of SST 88 at concentrations as low as 50%. *Bromus diandrus* was less affected by extract solutions from Tankwa and PAN 3492 with no significant differences observed between concentrations. No significant difference was observed between the effects of different cultivars on *R. raphanistrum.* Generally Tankwa did not show much effect on root dry mass production of weed species except for *Lolium* spp. The root dry mass production of *A. fatua* was least affected by Tankwa.

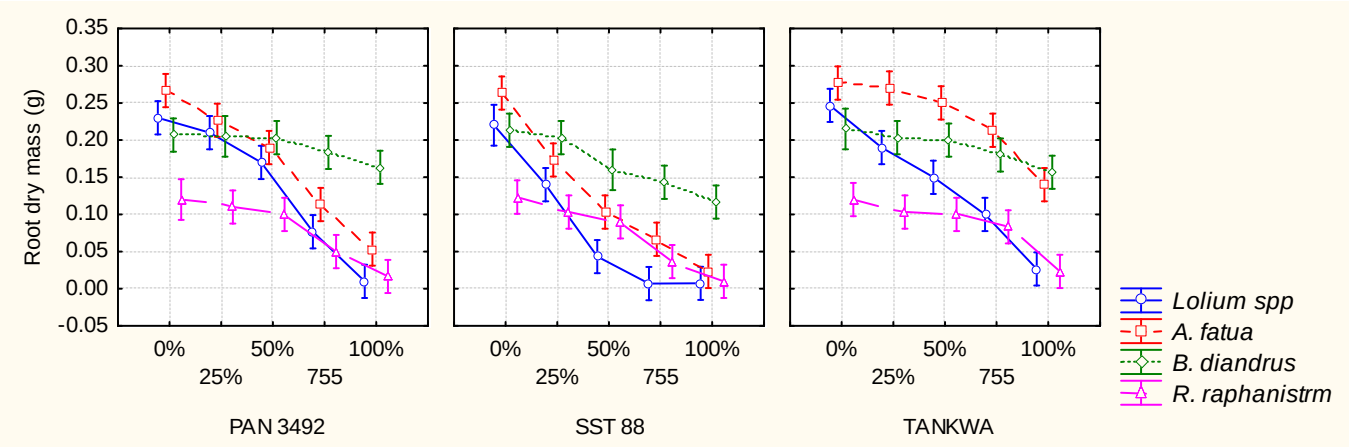


Figure 4.10 Effects of extract solution concentrations of three spring wheat cultivars on root dry mass of different weed species (*Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

Because of unreliable results obtained from other growth parameter measurements, total dry mass production has been reported to be a better indicator of injury caused by extract solutions (Leather & Einhellig, 1986). Total dry mass production of weed species under increasing concentration solutions from different spring wheat cultivars is shown in Figure 4.11. Statistical analysis of the data showed that the third order interaction of Cultivar, Concentration and Weed species was significant (Appendix B: Table 8). It is clearly shown in Figure 4.11 that extracts from SST 88 were more inhibitory to dry matter production of weed species such as *B. diandrus, A. fatua* and *Lolium* ssp than extracts from PAN 3492 and Tankwa at 50% and 75% concentrations. *Lolium* spp. was found to be more severely affected by cultivar extracts than any of the other weed species. The response of *B. diandrus* to extract from PAN 3492 and Tankwa was similar with no significant differences observed between concentrations. This implies that *B. diandrus* was least effected by extracts from PAN 3492

and Tankwa. *Raphanus raphanistrum* was not significantly affected by concentrations of 25% and 50% of any of the spring wheat cultivars (no difference between control and that of 25% and 50% concentration from all cultivars), but total dry mass production was significantly reduced by 75% and 100% concentration solutions from all cultivars. It was visually observed that whole plants of *R. raphanistrum* died when treated with 75% and 100% concentration solutions. This may have indicated that 75% and 100% concentration solutions of all cultivars were too toxic for *R. raphanistrum* seedlings to survive.

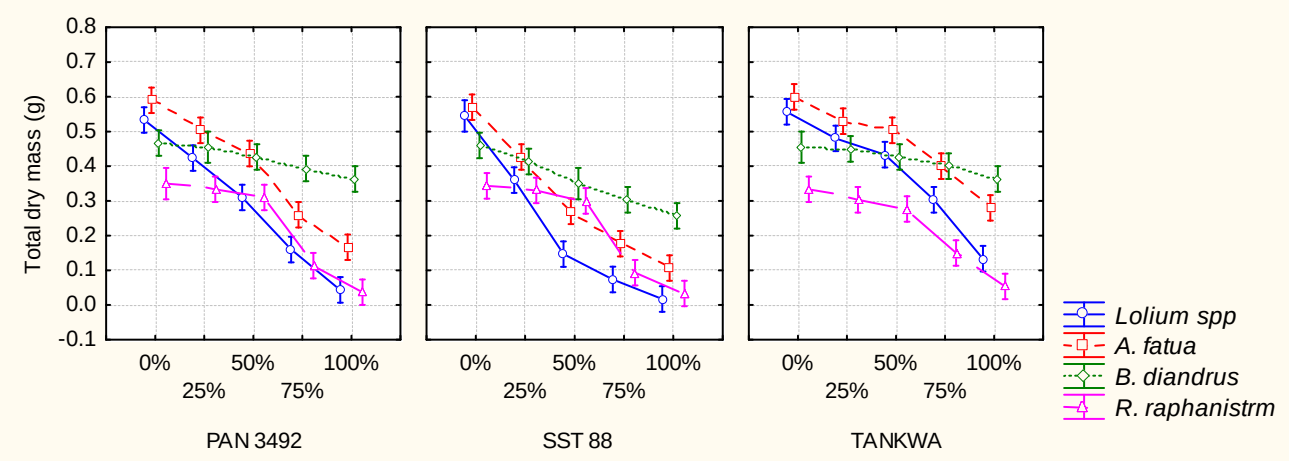


Figure 4.11 Effects of extract solution concentrations of spring wheat cultivars on total dry mass of different weed species (*Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

DISCUSSION AND CONCLUSION

Results of this study showed that the interaction of Cultivar, Concentration and Weed species as the main factors has significant effects on weed species growth parameters measured except for root length, plant height as well as number of leaves. A significant interaction was shown between weed species and concentration in all growth parameters measured.

Germination and germination rate

The study demonstrated that aqueous extracts of spring wheat cultivars exhibited significant inhibition effects on seed germination and germination rate of all weed species tested except that of *R. raphanistrum*. This may indicate the susceptibility of weed species such as *Lolium* spp, *A. fatua, B. diandrus, O. suffruticosum* as well as *S. media* to inhibitory substances from spring wheat cultivars. Germination of *Lolium* spp was most inhibited by extract solutions from SST 88 in comparison with extracts from other spring wheat cultivars. The degree of

toxicity of the extracts was found to depend on cultivars, weed species and concentration. The tendency was increased inhibition as the solution increased. Greater inhibition occurred at 75% and 100% extract concentration of all cultivars. The reduction in germination percentages of weed species at 75% and 100% is probably not exclusively due to allelopathic effects of the solution, but to a combination of osmolality and allelopathic effects of the extract solutions.

According to Lovett (1989) biological activities of receiver plants to allelochemicals are concentration dependent with response thresholds which are characteristically, stimulation at low concentration of allelochemicals and inhibitory as the concentration increases. The present study found *R. raphanistrum* seed germination to significantly increase at spring wheat extract solutions of 25% and 50% concentrations compared to the control. This could be due to the presence of certain chemicals that act as *R. raphanistrum* seed germination stimulants at low concentrations and seed germination inhibitors at higher concentrations. It is interesting to note that seed germination of some weed species were inhibited while others were stimulated by the same extract solution concentrations. Therefore the same extract may act differently on two different weed species because of the physiological and biological processes involved in such cases.

The root length of all weed species was reduced by extract solutions from all spring wheat cultivars. It appears that root growth is more sensitive to cultivar extracts than germination and germination rate. This could be due to the fact that allelochemicals are usually taken up by a plant through its roots and it is likely that inhibitory effects on other parts are delayed till advanced stages of development. Qasem (1993) reported that a reduction in root length was due to reduced cell division and elongation caused by a rapid inhibitory effect on respiration of root tips.

Growth

The growth parameters of all weed species measured were all significantly reduced compared to the control with increasing extract concentrations of all spring wheat cultivars. The degree of inhibition was found to be dependent on Cultivar, Concentration and Weed species. From the results of this study it appears that extracts of SST 88 are more inhibiting on weed growth than extracts from Tankwa and PAN 3492. The results are in agreement with others who stated that wheat cultivars differed in their allelopathic effects against germination and growth of weed species (Wu *et al.,* 1998). Phenolic acids, hydroxamic acids and short chain fatty acids are phytotoxic substances reported to cause allelopathic effects in wheat (Wu *et*

al., 2001). The same authors (2001) found that the production of allelopathic compounds, particularly phenolic acids differs among cultivars, with strong allelopathic cultivars producing higher amounts of allelochemicals compared to weakly allelopathic cultivars. It could be the case with the finding of the present study that cultivars such as SST 88 which showed significant effects on germination and growth of weed species have more allelopathic effects than cultivars such as Tankwa.

The results also demonstrated that weed species differed significantly in their growth response to cultivar extracts with *Lolium* spp. being affected the most followed by *A. fatua* and *R. raphanistrum* with *B. diandrus* being least affected. This may imply that allelochemicals are selective in influencing the growth of certain weeds. This is supported by the work of Steinsiek e*t al.* (1982) who reported that weed species differed in their response to wheat extracts. The present study found that the growth of *R. raphanistrum* was not affected by extract solutions of 25% and 50% concentrations, but 75% and 100% concentrations were toxic resulting in the demise of the seedlings. According to Narwal (1994) allelochemicals which inhibited the growth of some species at certain concentrations may stimulate the growth of the same or different species at lower concentrations. Rice (1984) stated that allelopathic compounds that were inhibitory at some concentrations were stimulatory to the same processes in very small concentrations. This was the case in this study with germination of *R. raphanistrum*.

Allelopathic effects are generally expressed largely during germination and establishment of crop plants when competition with weeds is most severe. It is suggested from this study that aqueous extracts of spring wheat cultivars such as SST 88 as well as PAN 3492 can be used to inhibit seed germination and seedling growth of weed species such as *Lolium ssp, A. fatua* and *B. diandrus* in order to reduce the reliance on pre-emegence herbicides. This can be achieved by leaving substantial residues and stubbles of these spring wheat cultivars on the soil surface under no - till or minimum tillage systems to decompose and leach into the soil to affect the germination and growth of weeds. Wu *et al,* (2003) found that aqueous extracts of wheat residues significantly inhibited germination and root growth of a herbicide resistant biotype of annual ryegrass more than the susceptible biotype. If spring wheat cultivars, particularly SST 88 and PAN 3492 are more allelopathic to herbicide resistant ryegrass biotypes than to herbicide susceptible biotype then it is suggested that wheat growers can make use of such cultivars in controlling the resistant biotypes while the susceptible biotypes can be controlled by use of herbicides.

There is also a possibility of utilizing spring wheat cultivar residues to induce the germination of weed species such as *R. raphanistrum* that can then be controlled with herbicides before planting the crop. More work, however is required to screen the efficacy of these spring wheat cultivars in field situations since these results were obtained in controlled conditions. These may or may not present allelopathic potential under field conditions, where environmental factors (temperature, fainfall and soil type) may greatly influence the allelopathic interactions and microoganisms that may reduce or eliminate the impact of allelopathic effects.

In conclusion, the present study demonstrated that spring wheat cultivars exhibit allelopathic effects on germination and seedling growth of all weed species tested. Overall, the allelopathic potential of spring wheat cultivars on germination and seedling growth increased with increased concentration and varied among cultivars ranking from the most to the least allelopathic in the following order: SST 88, PAN 3492 and Tankwa, although this order varied slightly depending on the weed species under consideration and parameters measured. Seed germination and seedling growth of *Lolium* spp. were more sensitive to cultivar extract solutions than *A. fatua* and *B. diandrus*. *Bromus diandrus* was comparatively more tolerant among the weed species to aqueous extracts from all cultivars. Germination of *R. raphanistrum* was stimulated by lower extract concentrations and inhibited at higher concentrations while the growth was not stimulated at lower concentrations. The suppression of seed germination and seedling growth by cultivar extract solutions may be attributed to the presence of allelopathic substances. It is concluded that all spring wheat cultivars extracts used in this study exhibited the potential as natural herbicides and hence show promise to be used in an integrated weed control system.

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CHAPTER 5

Determining the allelopathic effect of eight weed species on germination and seedling growth of three South African spring wheat cultivars

INTRODUCTION

Weed infestation is one of the major causes of yield reduction in crop plants. It is commonly assumed that reduction in crop yield due to weed infestation is the direct result of competition, allelopathy or of the interaction of the two factors. Weeds compete with crops for available space and other conditions necessary for growth. Weeds are believed to be more competitive than crop plants, due to their ability to grow rapidly and because they can tolerate environmental stress (Weston & Duke, 2003). In addition, weeds supplement their competitiveness by producing large quantities of allelochemicals that act as plant growth inhibitors and help them to establish weedy monocultures. The allelochemicals are believed to adversely affect growth and development of crop plants thus resulting in low yields (Qasem & Foy, 2001; Bhowmik & Inderjit, 2003). The allelochemicals are released into the soil as root exudates or as leachates of the living or dead plants. According to Einhellig (1986) the allelochemicals includes simple phenols, phenolic acid derived from benzoic and cinnamic acids, coumarins, flavonoids, isoflavonoids, tannins and a variety of phenolic conjugates. Their presence and accumulation in the soil is believed to reach the threshold concentrations for inhibition of pre-emergence seed germination or post germination growth and other plant functions (Einhellig, 1986; Patterson, 1986).

A large number of weed species are reported to possess allelopathic properties which have growth inhibitory effects on crops (Singh *et al*., 1998; Qasem & Foy, 2001). Qasem & Foy (2001) had reported allelopathic effects in more than 240 weed species and these include some weeds that are difficult to control. Weed species such as Italian ryegrass (*Lolium multiflorum*) (Smith & Martin, 1994), common lambsquarters (*Chenopodium album* L.) (Bhatia *et al.,* 1982; Mallik *et al*., 1994), redroot pigweed (*Amaranthus retroflexus* L) (Qasem, 1995), littleseed canary grass (*Phalaris minor*) (Tinnin & Muller, 1971; Bhatia *et al*., 1982), velvetleaf *(Abutilon theophrasti*) (Colton & Einhellig, 1980; Bhowmik & Doll, 1984), wild oat (*Avena fatua*) (Schumacher *et al.,* 1983; Perez & Ormeno-Nunez, 1991), common ragweed (*Ambrosia artemisifolia L*.) (Rice, 1984), Kochia (*Kochia scoparia*) (Batish *et al*., 2001), chickweed (*Stellaria media*) (Inderjit & Dakshini, 1998), *Parthenium hysterophorus (*Bhowmil & Doll, 1983; Kohli *et al.,* 1996), wild radish (*Raphanus*

raphanistrum) (Norsworthy, 2003) and *Bromus tectorum* (Rice, 1984) have been reported to reduce the germination and seedling growth of various crop plants under laboratory and field conditions.

Kossanel *et al.* (1977) found that root exudates of common lambsquarters (*Chenopodium album L*) in culture solutions retarded radicle and root growth in corn. This was supported by the work of Bhowmik & Doll (1979) on corn and soyabeans. Several *Asteraceae* species have been reported as having allelopathic effects on plant species, particularly when grown in rotation they reduce seed germination and emergence of succeeding small grain crops (Muehlchen *et al.,* 1990). Water extract from 23 common weed species have been reported to inhibit germination and the growth of wheat seedlings (Le Tourneau *et al*., 1956; Schumacher *et al*., 1983; Porwal & Gupta, 1996; Qasem, 1995). Bhatia *et al.* (1982) studied the allelopathic effects of some weeds on wheat and discovered that fresh plant material of *Phalaris minor* and *Melilotus indica* promoted wheat seedling growth while *Chenopodium album* and *Amaranthus viridis* inhibited the growth of wheat seedlings. Root exudates of wild oats (*Avena fatua*) were reported to reduce the growth of wheat tillers (Schumacher *et al*., 1983).

In the winter rainfall wheat producing region of South Africa, *Raphanus raphanistrum, Oncosiphon suffruticosum, Stellaria media, Lolium* spp*., Avena fatua, Bromus diandrus, Phalaris minor* and *Cotula australis* are some of the weed species found to infest winter wheat fields of the region and their infestation may severely reduce yields of the crop (P.J. Pieterse, 2008, Department of Agronomy, University of Stellenbosch, pers. comm.). Information about the allelopathic potential of these weed species on local spring wheat cultivars remains scarce. If these weed species are found to have allelopathic effects on spring wheat crop, then a greater emphasis will be placed on prevention of weed establishment and seed production. Therefore, this study was conducted with the aim of determining the allelopathic effects of this problematic weed species on germination and seedling growth of three selected South African spring wheat cultivars namely: PAN 3492, SST 88 and Tankwa.

MATERIALS AND METHODS

Extract preparation

Experiments were conducted at Welgevallen, the experimental farm of the University of Stellenbosch, in the Western Cape Province of South Africa. Weed species that were used in

this study were *R. raphanistrum, O. sufruticosa, S. media, Lolium* spp*, A. fatua, B. diandrus, P. minor* and *C. australis*. Whole plants were collected from wheat fields of the Western Cape during their vegetative stages. After collection, the plant material was oven dried at 45 ^{0}C for 72 hours. The dried material was then ground in a mill to pass through a 1 mm sieve. An aqueous extract was obtained from each weed species by mixing 200 g of the milled materials with 2000 ml of distilled water in a polyethylene bottle container and left for five days in a growth chamber at a constant temperature of 20 ^{0}C in the dark. The pulpy mixture was then filtered using four layers of cheese cloth. The resulting filtrate was then filtered through a funnel with Whatman No. 1 filter paper and sterilized by passing it through 0.2μm pore size Whatman Puradisc polyethersulfone membrane millipore filters. The sterilized filtrates were designated as full strength (100%) solution. Distilled water was used to establish varying concentration solutions i.e. 0 % (pure distilled water), 25% (75% distilled water), 50% (50% distilled water), 75% (25% distilled water) and 100% (full strength = no distilled water added) from the original full strength filtrates. A Roebling digital micro-osmometer was used to determine the osmotic potential of the extract solutions of the weed species.

Effect on germination

Seeds of three spring wheat cultivars, namely SST 88, PAN 3492 and Tankwa were used in this experiment. These are the cultivars that were selected from the first experiment (Chapter 3) because they were regarded as highly, intermediately and poorly competitive spring wheat cultivars respectively. Twenty seeds of each cultivar were placed in petri dishes lined with two layers of Whatman No. 1 filter paper. Petri dishes were each treated with 5 ml of different concentrations of aqueous extracts from the different weed species, while the control was treated with 5 ml of distilled water. Each treatment was replicated three times and placed in a growth chamber at a constant temperature of 20 ˚C in the light in a completely randomized factorial experimental design with factors: Weed species, Cultivar and Concentration. The petri dishes were sealed in a plastic bag to prevent evaporation. Germination counts were made daily. Seeds were considered germinated when the radicle was about 1 mm long. The experiment was stopped after about 12 days of incubation when no further seed germination was observed for three successive days. The germination percentage was calculated as follows: Final germination percentage = (number of germinated seeds / total number of seeds incubated) X 100. The germination rate was calculated using the following equation (Heydecker, 1973):

$\sum_{i=1}^{K} \frac{n_i}{D_i.n_i}.100,$

where n = the number of seeds germinated on Day i and D = Day i.

Effect on vegetative growth

The phytotoxic effects of extract solutions of different weed species on the growth of three spring wheat cultivars were evaluated in a fully temperature controlled glasshouse at 18/22 °C night/day temperatures. Seedlings of spring wheat cultivars SST 88, PAN 3492 and Tankwa were established in pure river sand in 8 cm x 8 cm square plastic pots. The sand was moistened by allowing capillary uptake of a balanced feeding solution as described by Steiner (1984). Two weeks after the seedlings were well established, 10 ml of different concentrations of aqueous solution (0% (pure water); 25%; 50%; 75%; 100% (full strength) from the different weed species described above was used to water the seedlings every second day for two weeks. The experiment was arranged in a completely randomized factorial design replicated three times with factors: Weed species, Cultivar and Concentration. The whole plant was harvested two weeks after commencement of the watering with the aqueous solutions. The roots were washed to remove sand before it was separated from the shoots. Both shoots and roots were oven dried at 45 ºC for 72 hours. Growth parameters measured were plant height, number of tillers, number of leaves, leaf area index (LAI), root dry mass, shoot dry mass and total dry mass of the whole plant. Total dry mass was calculated as the sum of root dry mass and shoot dry mass.

Statistical analyses

Statistical analyses of the data were performed using the Statistica package (Software, version 8.02). Analysis of variance (ANOVA) was conducted to determine the interaction of factors. Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P< 0.05$) differences among the treatments. When referring to significant or non-significant differences and/or interactions "significant" means $P < 0.05$ and "non-significant" means $P> 0.05$.

RESULTS

The osmotic potential of weed species extracts

Based on the data from different published reports many factors are believed to modify the results of allelopathic effects on seed germination as well as seedling growth and osmotic

potential is one of those factors. According to the work of Leather & Einhellig (1986), extracts of 4 g of dried sunflowers tissues in 100 ml of water was found to have an osmotic potential of 150 milliosmoles, and 150 mOsm is believed to be inhibitory to seed germination. Buchanan *et al.* (1978) however found that osmotic potentials of 148 milliosmoles had no influence on germination of the terrestrial grasses and three cereals they examined. On the other hand, Bell (1974) found an osmotic potential of greater than 75 milliosmoles to be inhibitory. The literature cited above do not give exact information about the osmotic potential of extracts and the effect it may have had on seed germination. Most of the weed species included in the present study have been studied by others. As the test crop and the experimental conditions differ it would be difficult to make a meaningful comparison. However, by keeping in mind the osmotic potential of the different aqueous solution extract concentrations, it will hopefully be possible to ascribe differences in the effects of the different solutions on wheat germination and growth to allelopathic effects. The osmotic potentials of the solution extracts from the different weed species are presented in Table 1.

Table 1 The osmotic potential of aqueous solutions of eight different weed species

Weed species	Concentration 25%	Concentration 50%	Concentration 75%	Concentration 100%
*P. minor**	43 mOsm kg^{-1}	107 mOsm kg^{-1}	173 mOsm kg^{-1}	243 mOsm kg^{-1}
Lolium spp	53 mOsm kg^{-1}	110 mOsm kg^{-1}	167 mOsm kg^{-1}	222 mOsm kg^{-1}
A. fatua	49 mOsm kg^{-1}	105 mOsm kg^{-1}	171 mOsm kg^{-1}	235 mOsm kg^{-1}
B. diandrus	43 mOsm kg^{-1}	111 mOsm kg^{-1}	168 mOsm kg^{-1}	239 mOsm kg^{-1}
C. australis	46 mOsm kg^{-1}	108 mOsm kg^{-1}	179 mOsm kg^{-1}	221 mOsm kg^{-1}
O. suffruticosum	49 mOsm kg^{-1}	110mOsm kg^{-1}	174 mOsm kg^{-1}	233 mOsm kg^{-1}
S. media	44 mOsm kg^{-1}	103 mOsm kg^{-1}	166 mOsm kg^{-1}	217 mOsm kg^{-1}
R. raphanistrum	41 mOsm kg^{-1}	110mOsm kg^{-1}	175 mOsm kg^{-1}	234 mOsm kg^{-1}

* *P. minor = Phalaris minor, Lolium* spp. *= Lolium* species*, A. fatua = Avena fatua, B. diandrus = Bromus diandrus, C. australis = Cotula australis, O suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media* and *R. raphanistrum = Raphanus raphanistrum.*

Germination and germination rate

The effects of different extract solutions from different weed species on germination percentage of three spring wheat cultivars are presented in Figures 5.1 and 5.2. Statistical analysis of the data showed that the third order interaction (Cultivar, Weed species and Concentration) was not significant (Appendix C: Table.1). A significant interaction was however revealed between Weed species and Concentration whilst significant differences between cultivars were observed within the Cultivar factor (Appendix C Table 2; Figures 5.1 and 5.2). Post–hoc analysis (Bonferroni) of the Weed species and Concentration interaction

showed that *O. suffruticosum, B. diandrus, A. fatua* and *Lolium* ssp did not differ significantly from each other at any concentration except for *A. fatua* which differed from these species at 25% concentration (Figure 5.1). Extracts from these four weed species significantly inhibited seed germination of spring wheat cultivars at concentrations as low as 25%. Moreover, these four weed species had a significantly more severe inhibitory effect (lower germination percentage) on spring wheat cultivars than *S. media, R. raphanistrum, C. australis* and *P. minor*. Similarly, these four species did not differ from each other and showed a less pronounced effect on germination percentage of the three spring wheat cultivars at most concentrations except at 100% concentration. Post-hoc analysis (Bonferroni) showed that the significant difference within the cultivar factor was due to Tankwa which differed significantly from SST 88 and PAN 3492 (Figure 5.2). This indicates that Tankwa was more affected than SST 88 and PAN 3492. However, the effect could also be due to lower viability and vigour of Tankwa seeds since in the control treatment germination percentages of this particular cultivar were also low.

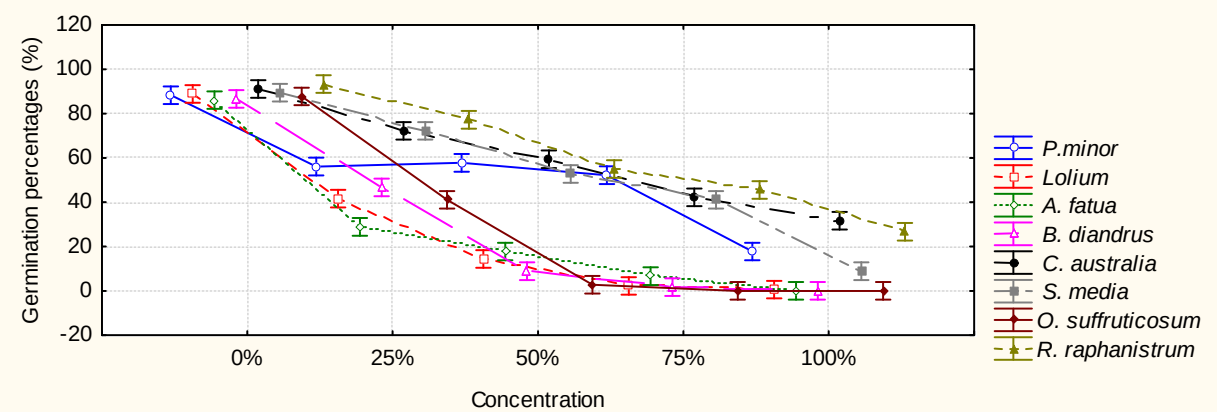

Figure 5.1 Effects of weed species and extract solution concentration on germination percentage of spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula australis, O. suffruticosum* = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

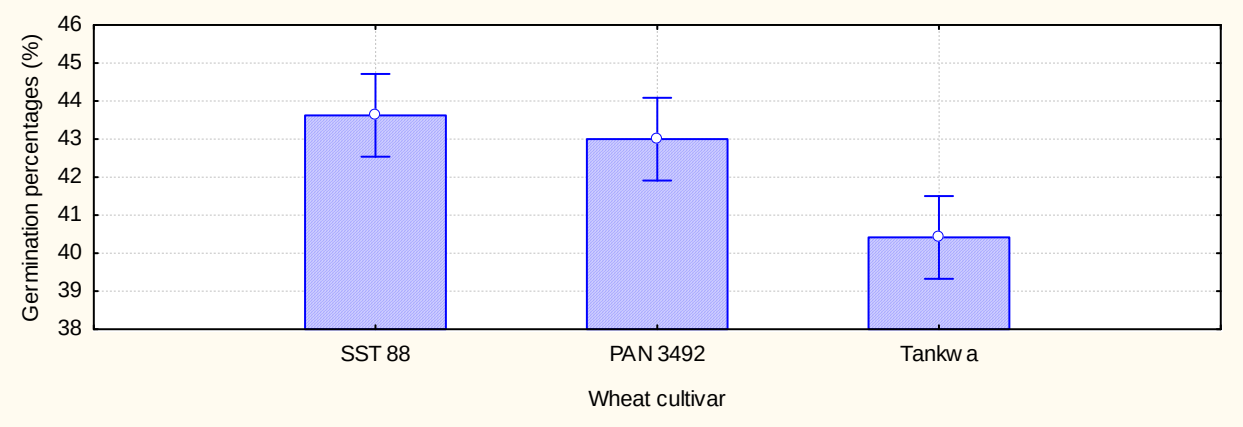

Figure 5.2 The mean germination percentage of three spring wheat cultivars over all weed species and extract solution concentration treatment combinations (The whiskers represent standard error of means).

Statistical analysis of the results reveals no significant interaction between Weed species, Concentration and Cultivar (Appendix C: Table 2) regarding the germination rate of spring wheat cultivars. Germination rate was affected by a significant interaction between Weed species and Concentration (Figure 5.3). Figure 5.3 shows that germination rate was severely affected by *O. suffruticosum, Lolium* spp., *A. fatua* and *B. diandrus* at concentrations as low as 50% compared to a much less severe effect by the rest of the weed species. This implies that these four weed species prolonged or inhibited the germination process. The level of the influence of these weed species increased with increases in extract concentration. *Phalaris minor, C. australis, R. raphanistrum and S. media* had little effect on germination rate and the slight difference from the control treatment could have resulted from the effects of the osmolalities of the solutions.

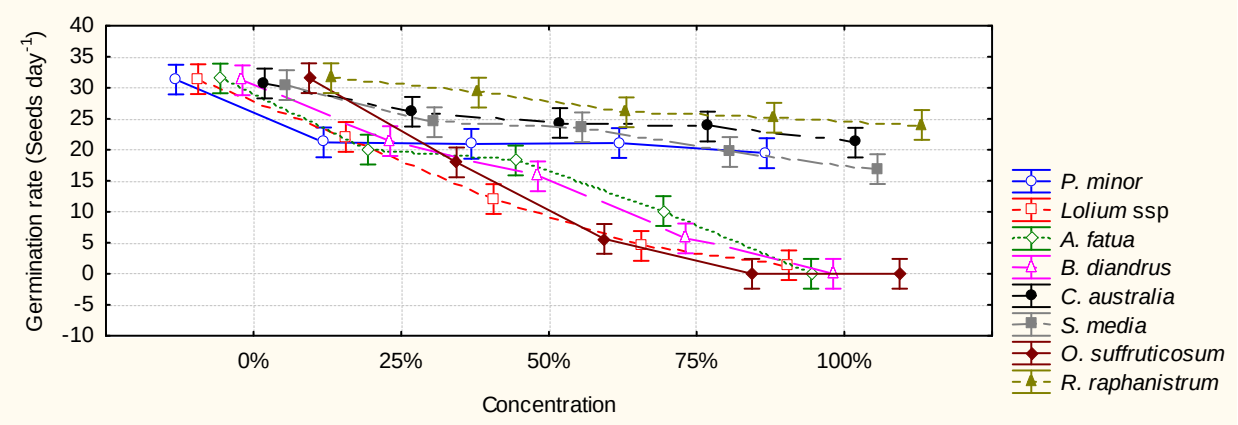

Figure 5.3 Effects of different extract solution concentration from different weed species on germination rate of spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula*

australis, O. suffruticosum = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

Vegetative growth

Statistical analysis showed that the third order interaction of Cultivar, Weed species and Concentration in terms of plant height of spring wheat cultivars was not significant (Appendix C: Table 3). However, second order interactions between Weed species and Concentration as well as between Weed species and Cultivar were significant (Appendix C: Table 3; Figures 5.4 and 5.5). Post-hoc analysis (Bonferroni) of the Weed species and Concentration interaction showed that *B. diandrus, A. fatua, Lolium* spp. and *O. suffruticosum* at concentrations of 50%, 75% and 100% had a significant inhibitory effect on height growth of spring wheat (Figure 5.4). Extracts from *C. australis, S. media, P. minor* and *R. raphanistrum* caused no significant reductions in plant height. This indicates that these weed species have little or no effect on plant height of the wheat cultivars.

Post-hoc analysis (Bonferroni) of the Weed species and Cultivar interaction showed that *O. suffruticosum, Lolium* spp., *A. fatua* and B. *diandrus* inhibited growth in all spring wheat cultivars significantly more than the other four weed species (Figure 5.5). All weed species except for *P. minor* had the least effect on cultivar SST 88, indicating the specific cultivar's resistance to negative effects from the extract solutions. The parameter number of leaves showed the same trend as plant height and therefore the results will not be discussed.

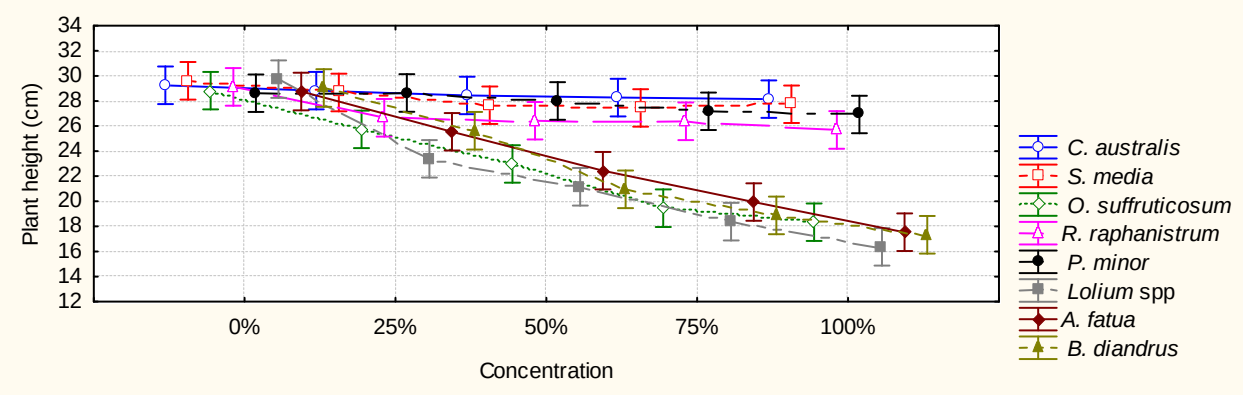

Figure 5.4 Effects of different extract solution concentrations from different weed species on plant height of spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula australis, O suffruticosum* = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

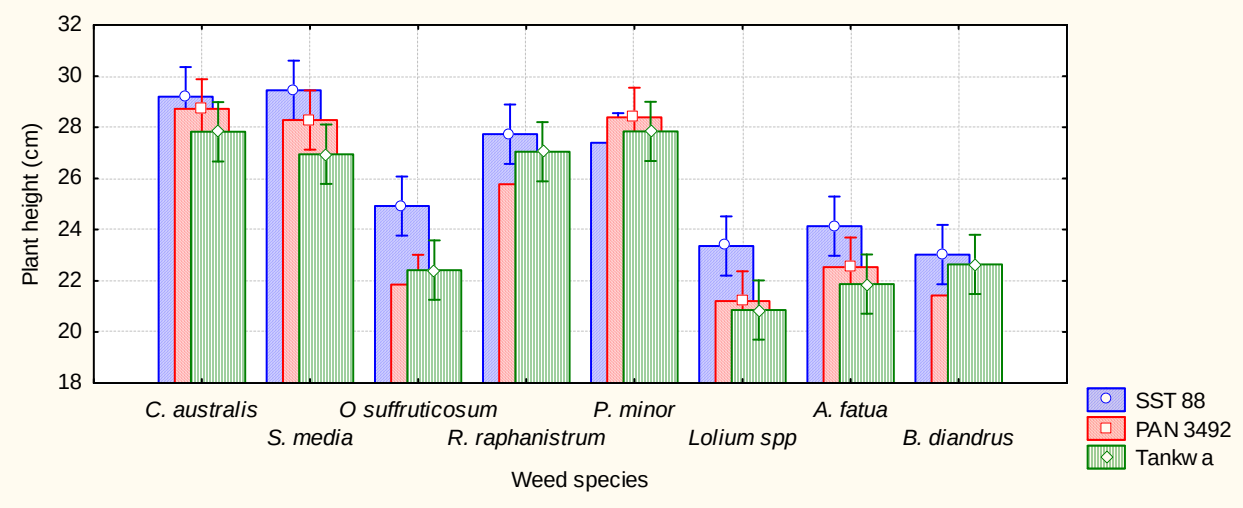

Figure 5 Effect of extract solutions from different weed species on plant height of three spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula australis, O suffruticosum* = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

In terms of number of tillers no significant third order interactions were observed between the main factors (Weed species, Concentration and Cultivar) but a significant interaction occured between Weed species and Concentration (Appendix C: Table 4). There were also no significant differences within the Cultivar factor. Figure 5.6 shows that *O. suffruticosum, Lolium* spp., *A. fatua* and *B. diandrus* severely affected the tillering capacity of spring wheat cultivars from concentrations as low as 50%. Similarly, *C. australis, S. media, R. raphanistrum* and *P. minor* did not differ from one another at any of the concentrations but differed significantly from the other four species at concentrations of 50% and higher.

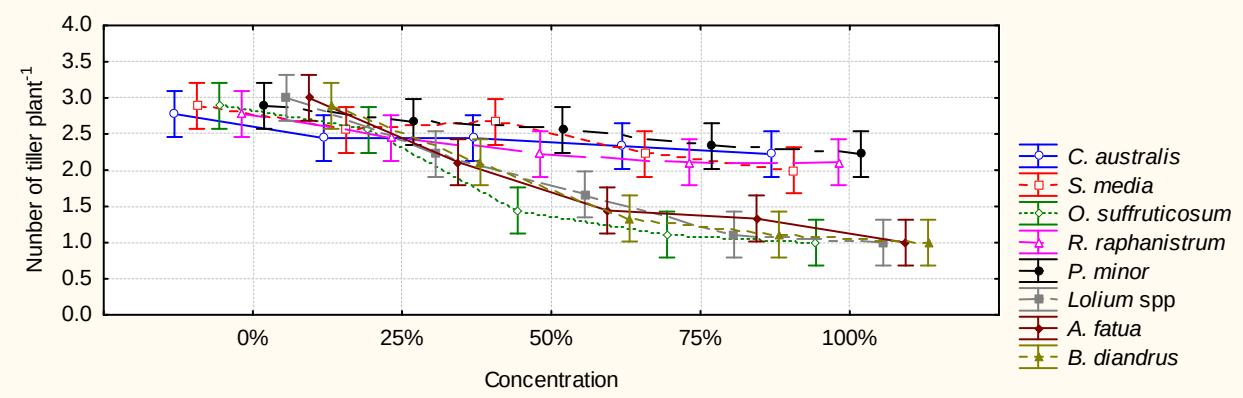

Figure 5.6 Effects of different extract solution concentrations from different weed species on number of tillers of spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula*

australis, O suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media and *R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

Significant interactions were observed between Weed species and Concentration but no significant interactions were observed between the main factors (Weed species, Concentration and Cultivar) regarding LAI of the spring wheat cultivars (Appendix C: Table 5). There were however, significant differences between spring wheat cultivars within the Cultivar factor. The interaction between Weed species and Concentration was due to *Lolium* spp., *A. fatua, B. diandrus* as well as *O. suffruticosum* which differed from the other four weed species from concentrations above 25% (Figure 5.7). These weed species severely reduced the LAI of the spring wheat cultivars at concentrations as low as 50% (Figure 5.7). *Cotula australis, S. media, R. raphanistrum* and *P. minor* showed little effect on LAI of the spring wheat cultivars. SST 88 showed a significantly higher LAI than PAN 3492 and Tankwa (Figure 5.8). This implies that SST 88 was not influenced more by the extracts from the weed species than the other two cultivars since there is no difference between control and treatments.

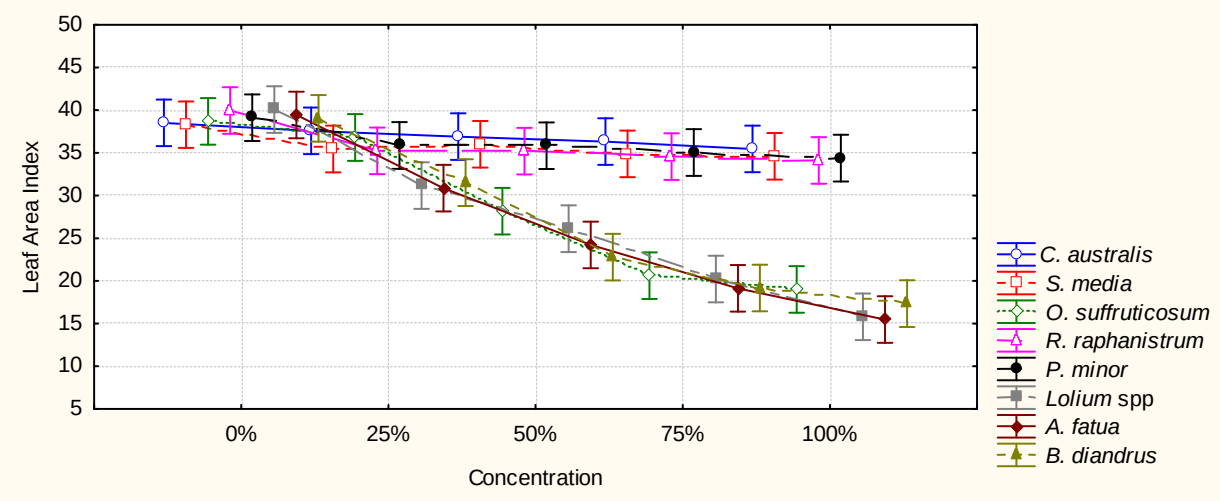

Figure 5.7 Effects of different extract solution concentrations from different weed species on Leaf Area Index of spring wheat cultivars (*P. minor = Phalaris minor, Lolium* spp. *= Lolium* species, *A. fatua = Avena fatua, B. diandrus = Bromus diandrus, C. australis = Cotula australis, O suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media* and *R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

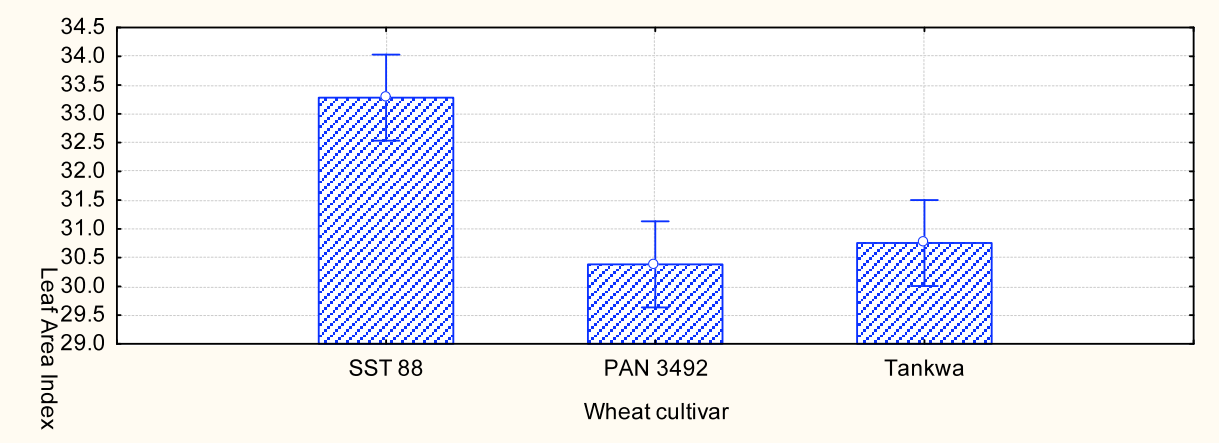

Figure 5.8 Mean Leaf Area Index of three spring wheat cultivars over all Weed species and Concentration treatment combinations (The whiskers represent standard error of means).

Although no significant third order interaction was observed between the main factors (Weed species, Concentration and Cultivar) regarding shoot dry mass of spring wheat cultivars, three significant second order interactions occurred between Weed species and Concentration, Weed species and Cultivar as well as Cultivar and Concentration (Appendix C: Table 6; Figures 5.9 and 5.10). For the Weed species and Concentration interaction, post-hoc (Bonferroni) comparisons showed significant differences between the group of *Lolium* spp*., A. fatua, O. suffruticosum* and *B. diandrus* and the other four weed species at concentrations of 50%, 75% and 100% (Figure 5.9). In terms of the Weed species and Cultivar interaction, the most probable reason for the significant interaction is the large effect that *B. diandrus* had on the shoot dry mass of PAN 3492 compared to SST 88 and Tankwa (Figure 5.10). Similarly, Tankwa was more severely affected by *Lolium* spp than PAN 3492 and SST 88. SST 88 was generally least affected by the weed species. For the Cultivar and Concentration interaction, post-hoc (Bonferroni) comparisons showed that the differences were due to SST 88 which differed significantly from Tankwa at concentration 75% and 100% but did not differ from PAN 3492 at any concentration. Similarly, Tankwa did not differ from PAN 3492 at any concentration. This may have given an indication that SST88 was tolerant to the effects from the weed species, with Tankwa being more affected although it did not signicantly differed from PAN 3492.

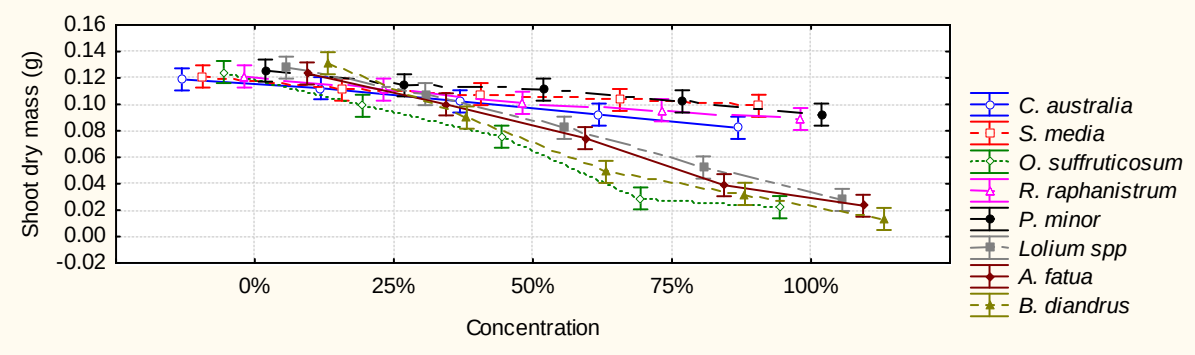

Figure 5.9 Effects of different extract solution concentrations from different weed species on shoot dry mass of spring wheat cultivars (*P. minor = Phalaris minor, Lolium spp. = Lolium* species*, A. fatua = Avena fatua, B. diandrus = Bromus diandrus, C. australis = Cotula australis, O suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media* and *R. raphanistrum = Raphanus raphanistrum*).

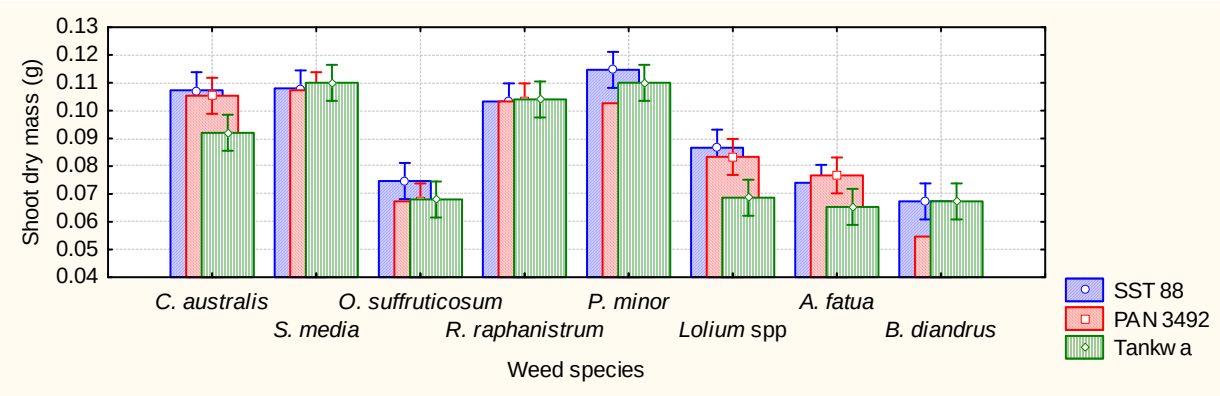

Figure 10 Effect of extract solutions from different weed species on shoot dry mass of three spring wheat cultivars (*P. minor = Phalaris minor, Lolium* spp. *= Lolium* species*, A. fatua = Avena fatua, B. diandrus = Bromus diandrus, C. australis = Cotula australis, O. suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media* and *R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

Cultivar, Weed species and Concentration as the main factors did not show any significant interactions in terms of root dry mass but two second order interactions between Weed species and Concentration as well as Weed species and Cultivar were statistically significant at the 5% level (Appendix C: Table 7). It is clearly showen in Figure 5.11 that weed species differed in their effects on root dry mass production of spring wheat cultivars. The difference was due to *Lolium* spp.*, A. fatua, B. diandrus, O. suffruticosum* and *P. minor* (the last mentioned species only at the higher concentrations of 75% and 100%) that had a significantly larger inhibitory effect on root dry mass production of the wheat cultivars than

the rest of the weed species. Similarly, *C. astralis, S. media* and *R. raphanistrum* did not differ from each other in terms of effects on root dry mass production at any concentration.

In terms of the Weed species and Cultivar interaction, the most probable reason for the significant interaction is the large effect that *P. minor* had on the root growth of PAN 3492 compared to SST 88 and Tankwa (Figure 5.13). Tankwa was more severely affected by *A. fatua* and *Lolium* spp. than PAN 3492 and SST 88.

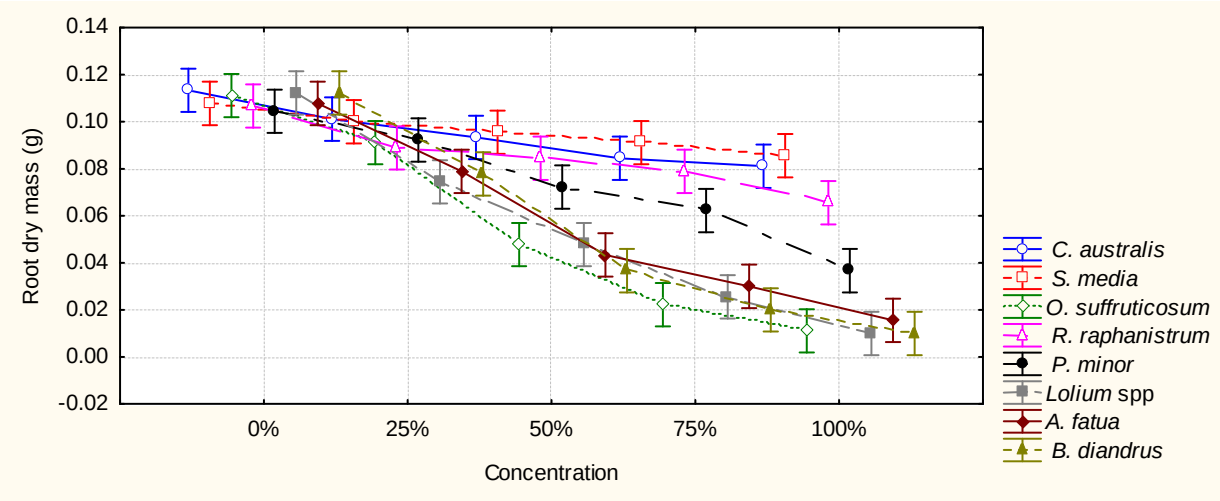

Figure 5.12 Effects of different extract solution concentrations from different weed species on root dry mass of spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula australis, O. suffruticosum* = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

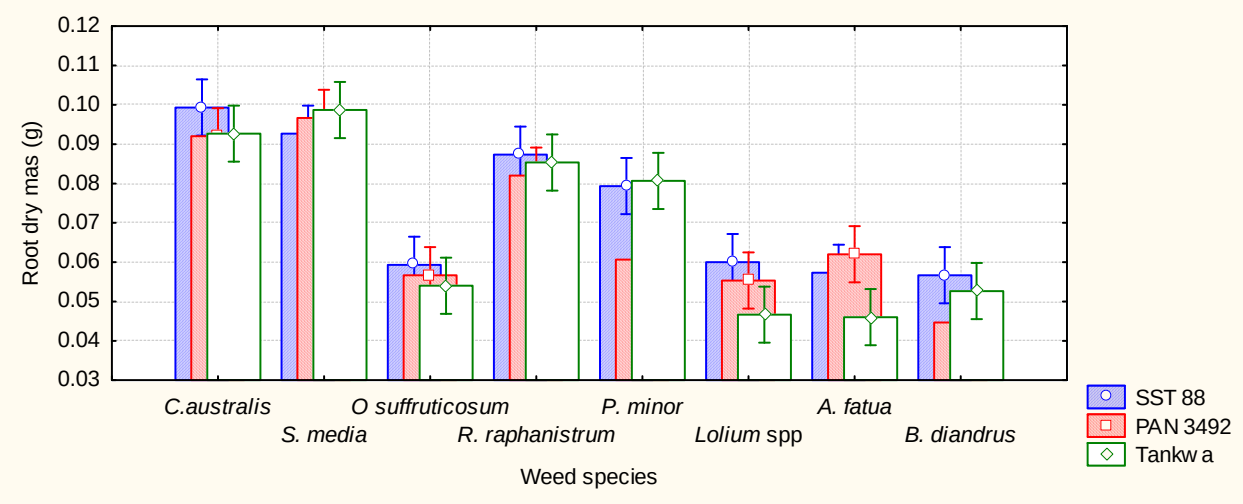

Figure 13 Effect of extract solutions from different weed species on root dry mass of three spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula australis, O.*

suffruticosum = *Oncosiphon suffruticosum, S. media* = *Stellaria media* and *R. raphanistrum* = *Raphanus raphanistrum*) (The whiskers represent standard error of means).

Leather & Einhellig (1986) had considered total dry weight to be a better indicator of injury caused by extract solutions because of unreliable results obtained from other growth parameter measurements. Statistical analysis of the data shows that the third order interaction of Cultivar, Weed species and Concentration was not significant in terms of total dry mass production (Appendix C: Table 8). However the second order interactions between Weed species and Concentration as well as between Weed species and Cultivar were significant (Appendix C: Table 8; Figures 5.14 and 5.15). In terms of the Weed species and Concentration interaction post-hoc comparisons (Bonferroni) showed that *Lolium* spp., *A. fatua, O. suffruticosum,* and *B. diandrus* at all concentrations above 0% had a significantly larger effect on total dry mass production than the other four weed species (Figure 5.14). This implies that *Lolium* spp., *A. fatua, O. suffruticosum,* and *B. diandrus* had significantly retarded the growth of spring wheat cultivars.

Figure 5.15 shows the same trend *viz.* that *Lolium* spp., *A. fatua, O. suffruticosum* and *B. diandrus* had a significantly larger negative effect on the growth of the wheat cultivars than the other four weed species. The significant interaction was due to the varying effects of the different weed species on the total dry matter production of the three wheat cultivars e.g. *B. diandrus* extracts had a significantly larger negative effect on cultivars PAN 3492 and Tankwa than on SST 88, whereas in the case of *O. suffruticosum* there was no significant difference between the effects on the different cultivars.

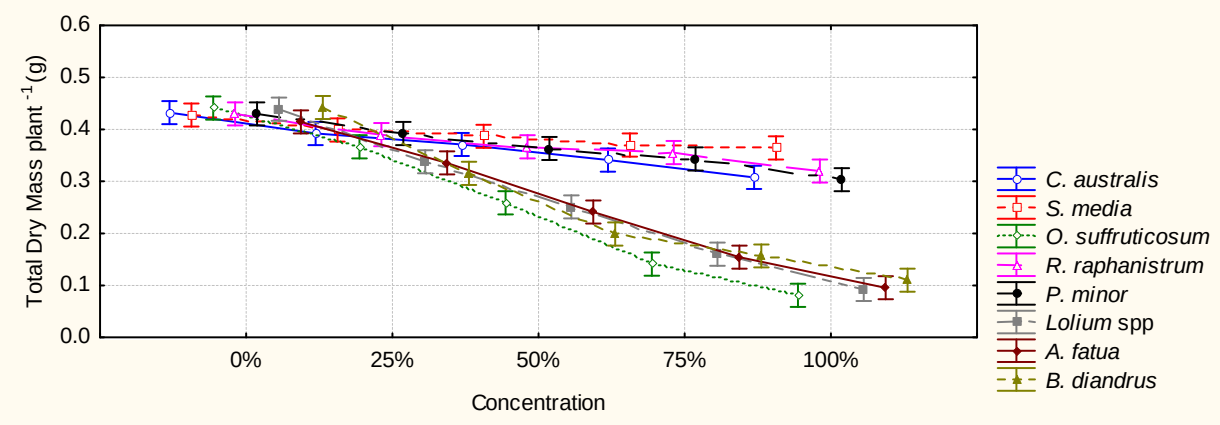

Figure 5.14 Effects of different extract solution concentrations from different weed species on total dry mass of spring wheat cultivars (*P. minor* = *Phalaris minor, Lolium* spp. = *Lolium* species, *A. fatua* = *Avena fatua, B. diandrus* = *Bromus diandrus, C. australis* = *Cotula*

australis, O suffruticosa = Oncosiphon suffruticosum, S. media = Stellaria media and *R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

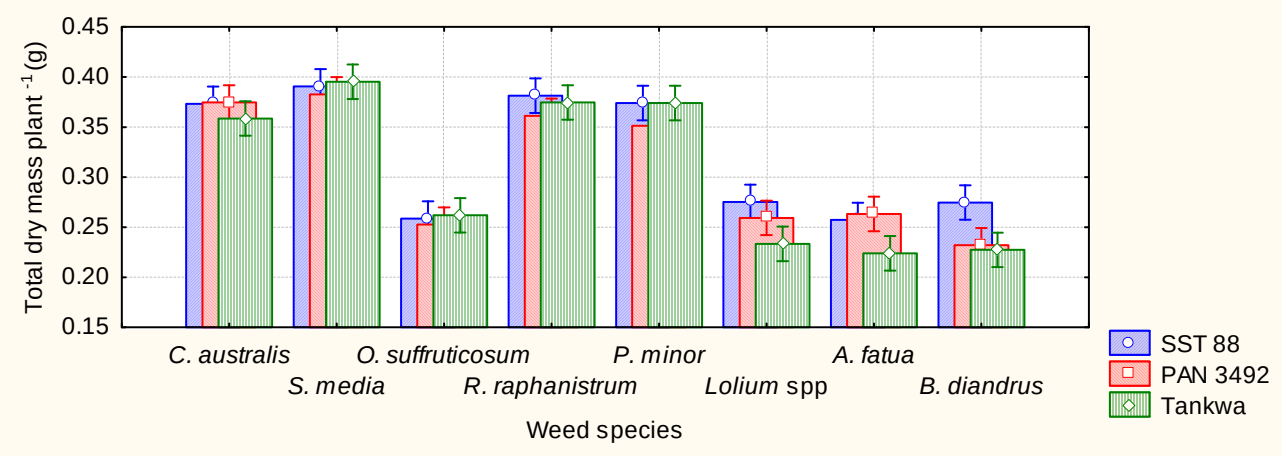

Figure 5.15 Effect of extract solutions from different weed species on root dry mass of three spring wheat cultivars (*P. minor = Phalaris minor, Lolium* spp. *= Lolium* species*, A. fatua = Avena fatua, B. diandrus = Bromus diandrus, C. australis = Cotula australis, O suffruticosum = Oncosiphon suffruticosum, S. media = Stellaria media* and *R. raphanistrum = Raphanus raphanistrum*) (The whiskers represent standard error of means).

DISCUSSION

Results obtained in this study showed that the interaction of Weed species, Cultivars and Concentration had no significant effects on spring wheat cultivar parameters measured. A significant effect was shown due to Weed species and Concentration interaction in all cultivar parameters measured and Weed species and Cultivar interaction in some of the parameters investigated.

The study demonstrated that aqueous extracts of weed species such as *Lolium* spp, *A. fatua, B. diandrus, O. suffruticosum* as well as *P. minor* exhibited significant inhibitory effects on seed germination and germination rate of three spring wheat cultivars (Figures 5.1 and 5.3). The degree of inhibition increases with increase in extract concentration (Figure 5.1). In weed species such as *Lolium* spp*., A. fatua, B. diandrus* and *O. suffruticosum* extract solutions above 50% resulted in complete inhibition of seed germination. Although the other weed species reduced germination percentage of the cultivars compared to the control treatment, the degree of inhibition was not as severe as that of the above mentioned weed species. The total reduction in germination percentage could be a result of the combined effects of allelopathic substances and osmolality of the solution.

The present study found weed species such as *Lolium* spp*., A. fatua, B. diandrus* and *O. suffruticosum* to significantly reduce growth parameters of spring wheat cultivars with increasing extract concentrations. This may propose the presence of secondary metabolites with allelopathic potential which may play a role in retarding wheat growth. It is widely accepted that production of secondary metabolites, particularly phenolic compounds, can play a direct role in self defense and plant protection to cope with the stress created by external conditions in particular during competition for space and growth factors (Bhowmik & Doll, 1984).

Phenolic acids have been shown to be toxic to germination and plant growth processes (Einhellig, 1995). According to Inderjit (1996) allelopathic activity in field situations is thought to be often due to joint action of mixtures of allelochemicals that has synergetic inhibitory effects depending on their concentration rather than to one allelochemical. This study indicated that all extracts above 50% concentration in more allelopathic weed species can effectively affect the germination and growth of wheat cultivars whereas extracts below 50% concentration had little or no effect. This response may be attributed to the amount of allelopathic substances present in the solution. Thus, in the present study, the decreased growth parameters of spring wheat cultivars from extract solutions from weed species such as *Lolium* ssp*., A. fatua, B. diandrus, O. suffruticosum* and *P. minor* compared to extract solutions of weed species such as *C. australis, S. media* and *R. raphanistrum* as well as the control may be due to the inhibitory effect of the extracts on physiological processes (e.g. reduced dry matter accumulation and amylase activity in seedlings) that translates to growth (Rivzi & Rivzi, 1992; An *et al.,* 1997).

The extract solutions from *O. suffruticosum* appear to have more inhibitory effects indicating that this weed species contains more allelopathic substances than the other broad leaf weed species investigated. Grass weed species such as *A. fatua, B. diandrus* and *Lolium* species also showed greater allelopathic effects in this study. This is in agreement with many well documented reports. Nielsen *et al.,* (1960) reported *in vitro* toxicity of water extracts of dry straw of *A. sativa*, a species closely related to *A. fatua*. This was also supported by the work of Guenzi & McCalla (1962) who reported inhibition of wheat growth from *A. sativa* water extracts. The same authors (1966) demonstrated the presence of five phenolic acids in the straw of *A. sativa* such as ferulic, p-coumaric, p-hydroxybenzoic, syringic and vanillic acids. These compounds were found to significantly inhibit the growth of wheat seedlings. Similarly, Schumacher *et al.,* (1983), reported the presence of coumaric and vinillic acid in

root exudates of wild oats (*Avena fatua*) which were reported to reduce the growth of wheat shoots.

Inderjit & Dakshini (1998) reported the allelopathic effects of chickweed on wheat. They found that soil amended with chickweed had a high phenolic content and had significant effects on wheat seedling growth. The present study could not establish any inhibitory effect of *S. media* on all growth parameters measured except for germination percentages. *Phalaris minor* showed little or no effects on the growth parameters of the three spring wheat cultivars. Bhatia *et al.* (1982) reported that *P. minor* promotes the growth and yield of wheat. Bhatia *et al.* (1984) reported the stimulatory effects by fresh plant mass of *P. minor* but dry mass had inhibitory effects on wheat. Gutam & Singh (1984) reported a reduction in wheat yield due to the presence of *P. minor*. In this study the only significant inhibitory effect of *P. minor* was on root dry mass production of PAN 3492 but no stimulatory effects of *P. minor* extracts could be observed.

In summary, *A. fatua, B. diandrus, Lolium* spp. and *O. suffruticosum* have shown allelopathic potential to inhibit germination and growth of spring wheat cultivars. Although weed species such as *R. raphanistrum* and *P. minor* were also found to posses inhibitory effects, their effects were not as severe as those of the mentioned weed species. The inhibitory effect increased with increased extract concentrations in all weed species. This suggests higher concentrations of allelochemicals at higher than at lower extract concentrations. The negative effects of higher concentrations of allelochemicals from weed species is probably not entirely due to allelopathy but the extracts may also have exerted negative osmotic effects on germination and growth of the wheat cultivars.

Cotula australis and *S. media* had little or no allelopathic effects on any of the three spring wheat cultivars. The spring wheat cultivars varied in their response to the allelochemicals from weed species. Although little significant difference was observed among spring wheat cultivars, SST 88 was comparatively more tolerant to the extract solutions of the weed species that exhibited more inhibitory effects. Tankwa was severely affected by extract solutions of allelopathic weed species, but did not differ significantly from PAN 3492. The greater tolerance to allelopathic effects observed in SST 88 compared to PAN 3492 and Tankwa may confirm the findings in the spring wheat interference experiment (Chapter 3) where it was regarded as a more competitive spring wheat cultivar.

CONCLUSION

The study has emphasized that weed species such as *A. fatua, B. diandrus, Lolium* spp. and *O. suffruticosum* as well as (to a lesser extent) *R. raphanistrum* and *P. minor* have allelopathic effects on germination and growth of wheat. The reduction in crop yields in fields infested by these weed species might be due to allelopathic interference as one of the factors. For weed species such as *C. australis* and *S. media* yield losses might have resulted from competitive ability of weeds for growth factors at the expense of the crop. The information obtained in this study is important for farmers, since the knowledge of allelopathic potential of weed species would benefit practices aimed at avoiding or limiting weed interference with crops. Also, a further screening of allelopathic weed species is required in order to verify the finding of this experiment under natural conditions as well as to determine the allelopathic potential of these weed species on the germination and growth of other weed species in order to utilize them in controlling other weeds. It is also advisable for farmers to grow wheat cultivars such as SST 88 which can withstand the allelopathic pressure from weeds.

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CHAPTER 6

Determining the competitive ability of three spring wheat cultivars against selected weed species

INTRODUCTION

Weeds are important obstacles to crop production over the world. Weeds compete with crop plant for light, moisture, nutrients and space causing great losses in yields (Anderson, 1983). Weeds are controlled by means of cultural and chemical control methods. Removal of grass weeds by hand weeding in a broadcasted wheat crop is practically impossible during the early growth stage due to the similar morphology of grass weeds and wheat. Thus, farmers tend to delay hand weeding until weeds are visually distinct from the crop plant, exposing the crop to weed competition for an extended period. Chemical weed control on the other hand necessitated the use of relatively expensive selective herbicides which farmers may not be able to afford, and alternatively, could lead to the development of herbicide resistance in weeds.

According to Jordan (1993), one of the control options is to grow competitive crop cultivars to reduce weed growth and seed production, while maintaining grain yield in the presence of weeds. The competitive ability of crop cultivars is defined by two components: weed suppression ability and weed tolerance. Weed suppression ability of a crop refers to the ability of a crop to reduce weed growth through competition while weed tolerance refers to the ability of cultivars to achieve high yield despite weed competition. Weed suppression ability and weed tolerance are characteristics that differ genetically and agronomically in crop cultivars (Lemerle *et al.,* 2001). Weed tolerance is measured by yield in competitive conditions, but cultivars with high weed tolerance do not necessarily reduce weed germination and seed set while weed suppression ability is often associated with traits such as allelopathic potential, early vigorous growth, resistance to loss of tillers under competitive pressure, greater height, overall leaf area and canopy structure (Wicks *et al.,* 1986, Seavers & Wright, 1999; Wu *et al.,* 1999). Weed suppressive cultivars have the potential to reduce within season weed pressure, thereby limiting yield losses, lowering weed seed production and recruitment into the soil seed bank and thus the potential to reduce weed control costs and yield losses in subsequent years (Jordan, 1993).

According to Wicks *et al.* (2004) wheat cultivars are genetically and agronomically different in their ability to compete with weeds and reduction in wheat grain yield depend on the cultivars ability to compete with weeds. Huel and Huel (1996) found that higher yielding

spring wheat cultivars under weed free conditions were not always highest yielding under weedy condition. Many researchers has reported dissimilar yield reductions in wheat cultivars because of differences in competitive ability against *Avena ludoviciana* (wild oat) (Balyan *et al.,* 1991), *Lolium rigidum* (Lemerle *et al.* 2001) and *Bromus tecrorum L.* (Blackshaw, 1994). According to Cousens (1985) and Wilson *et al.* (1995), crop yield reductions are dependent on both crop competitiveness and weed density. Generally, higher weed densities lead to greater yield losses. In chapter 3, it is shown that some spring wheat cultivars are more competitive in terms of vigorous growth and allelopathy than others.

The objective of this work was to determine the competitiveness of three spring wheat cultivars that was selected from the first experiment (Chapter 3) under weed competition conditions. The cultivars that were selected as exhibiting weed suppression ability characteristics were investigated to determine if they will be able to withstand weed pressure.

MATERIALS AND METHODS

The experiment was conducted in a temperature controlled glass house (15 / 20 ºC night/day temperature) at the Agronomy department of Stellenbosch University. In this experiment, three spring wheat cultivars i.e. SST 88, PAN 3492 and Tankwa that were selected from the first experiment (Chapter 3) because they were regarded as highly, intermediately and poorly competitive spring wheat cultivars respectively, were grown in competition with *Lolium species* (ryegrass), *Avena fatua* (wild oats) and *Bromus diandrus* (ripgut brome). The other weed species used in earlier experiments (Chapters 4 and 5) were not considered due to problems with establishing plants from seed within the acceptable time span required for competition studies.

Each spring wheat cultivar were established together with four varying densities (0 (control= no weed), 3, 6 and 9 plants) of weed species in 8 cm X 8 cm pots. To ensure that all weed species were at the same growth stage with the crop, seeds of ryegrass and wild oats were sown directly in the pots together with seeds of the three spring wheat cultivars while for ripgut brome seeds were first germinated in a growth chamber at 10/15 °C (night/day) temperature in the dark and then transplanted a day after the crop has germinated. Plants were irrigated regularly with a balanced feeding solution as described by Steiner (1984). After four weeks, plants were harvested and plant height, number of tillers, number of leaves, leave area index as well as total dry mass was determined.

Statistical analyses

The experiment was a factorial design replicated three times with factors: wheat Cultivars, weed Species and weed Density. Analysis of variance (ANOVA) was conducted to determine the interaction of factors using Statistica package (Software version 8.02). Means were separated using Bonferroni studentised range for testing least significant differences at the 5% level when ANOVA revealed significant ($P < 0.05$) differences among the treatments. When referring to significant or non-significant differences and/or interactions "significant" means $P < 0.05$ and "non-significant" means $P > 0.05$.

RESULTS

Statistical analyses of the data showed that wheat Cultivar, weed Species and weed Density as the main factors did not show any significant third order interactions in terms of plant height and no significant second order interactions either. Significant differences were however found within the weed Density factor as well as within the wheat Cultivar factor (Appendix D: Table 1). For the weed Density factor, post-hoc analysis showed that there was no significant difference between the effctes of 0 and 3 as well as 6 weed densities but the 3 weed density significantly differed from 6 and 9 weed densities (Figure 6.1). Therefore, after an initial (non-significant) increase in plant height at low weed densities the higher weed densities caused significant plant height decreases in the wheat plants. Post-hoc analysis showed that the significant difference within the wheat Cultivar factor was due to PAN 3492 which differed significantly from Tankwa (Figure 6.2). This indicates that PAN 3492 was more tolerant to weed competition than Tankwa, although it did not differ significantly from SST 88. However, the difference could also be due to the vigorous growth of these two cultivars as it was shown in Chapter 3.

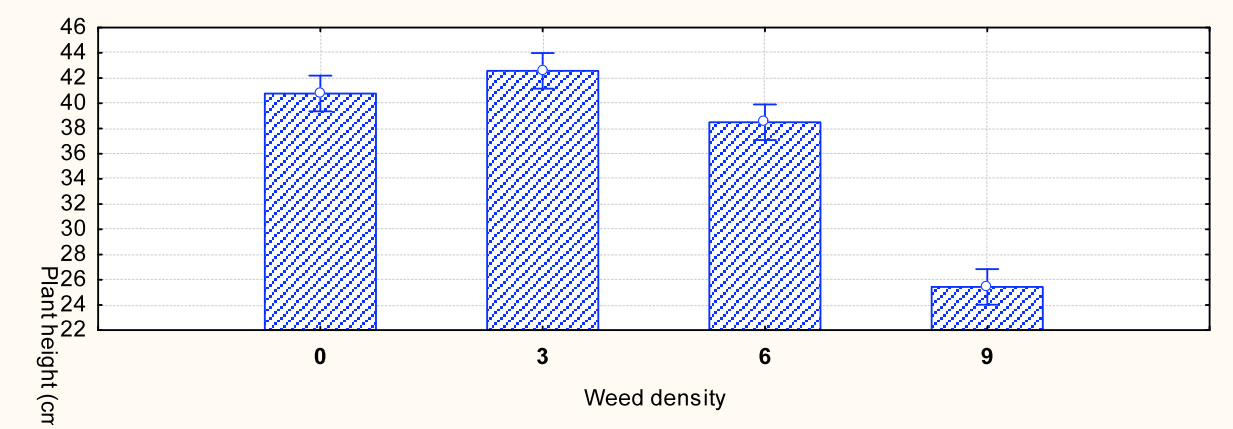

Figure 6.1 Effects of weed density of different weed species on plant height of three spring wheat cultivars (The whiskers represent standard error of means).

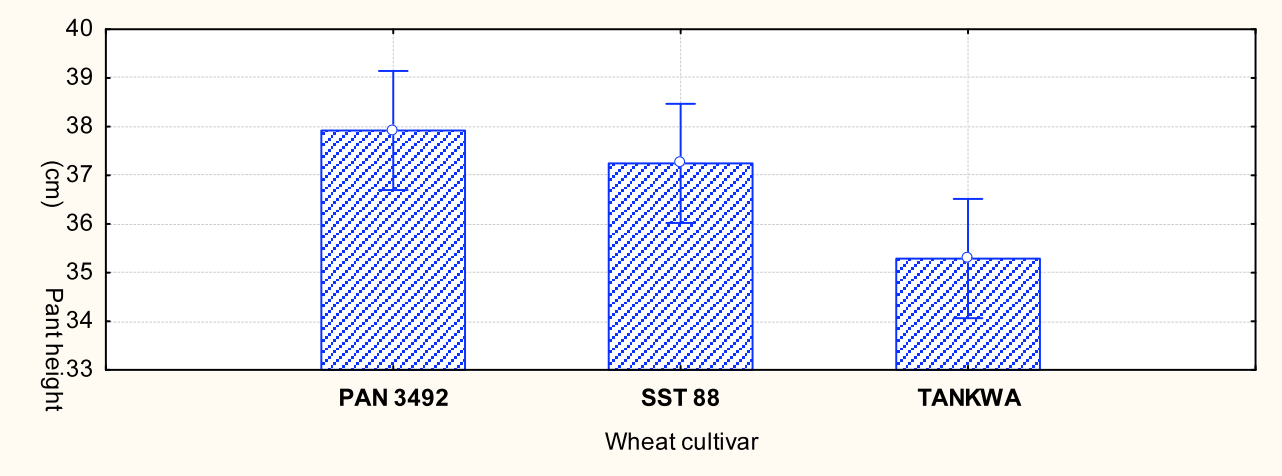

Figure 6.2 The mean plant height of three spring wheat cultivars over all Weed species and Density treatment combinations (The whiskers represent standard error of means).

Significant second order interactions were observed between wheat Cultivar and weed Species but no significant other second order and third order interactions were observed between the main factors (wheat Cultivar, weed Species and weed Density) regarding number of leaves as well as LAI (leaf area index) of the spring wheat cultivars (Appendix D: Table 2 and Table 3). The number of leaves parameter showed the same trends as LAI and therefore only the LAI results are showed. There were however, significant differences within the weed Density factor. The LAI of cultivars were reduced with an increased weed density from 3 to 9. The interaction between wheat Cultivar and Weed species was due to SST 88 which was significantly affected by *B. diandrus* compared to the other two cultivars (Figure 6.3). The figure shows that PAN 3492 had higher LAI compared to SST 88 and Tankwa. This implies that PAN 3492 withstands the competition from weed species better than other cultivars, but this could also result from its vigorous growth (Chapter 3).

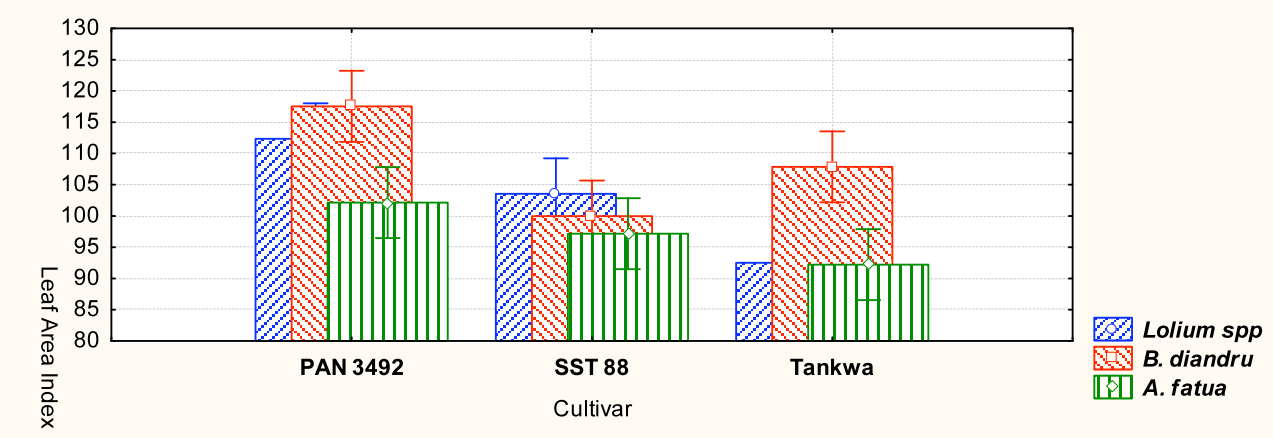

Figure 6.3 Effects of weed density of different Weed species on LAI of three spring wheat

cultivars (*B. diandrus* = *Bromus diandrus, Lolium* spp. = *Lolium* species and *A. fatua* = *Avena fatua)* (The whiskers represent standard error of means).

In terms of number of tillers no significant second- or third order interactions were observed between the main factors (wheat Cultivar, weed Species and weed Density) (Appendix D: Table 4). Significant differences were revealed within the weed Density factor as well as the wheat Cultivar factor. Post-hoc analysis (Bonferroni) showed that the significant difference within the wheat Cultivar factor was due to Tankwa which produced significantly less tillers than SST 88 and PAN 3492 (Figure 6.4). Weed Density was found to be statistically different within the factor and the differences was due to 6 and 9 weed density which severely affected the tillering capacity of the cultivars compared to 0 and 3 weed density (Figure 6.5).

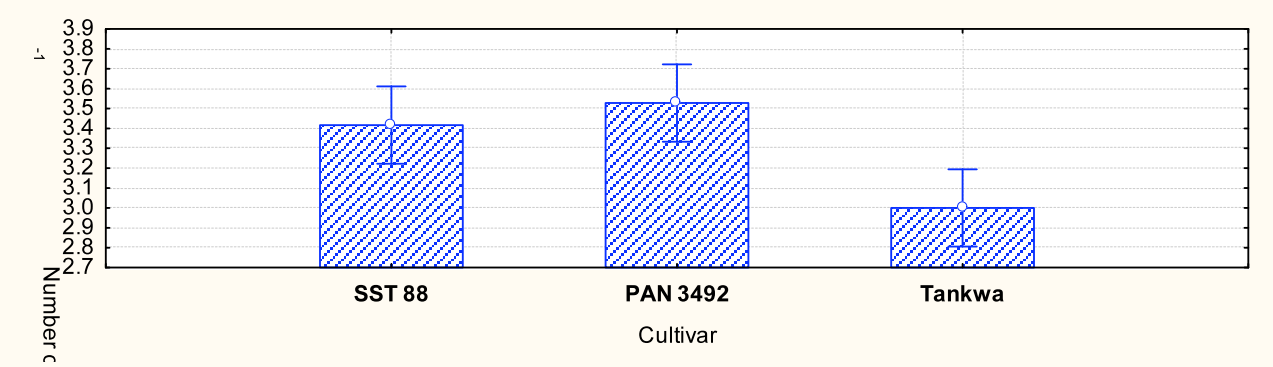

Figure 6.4 Mean tillers produced by three spring wheat cultivars over all weed Species and weed Density treatment combinations (The whiskers represent standard error of means).

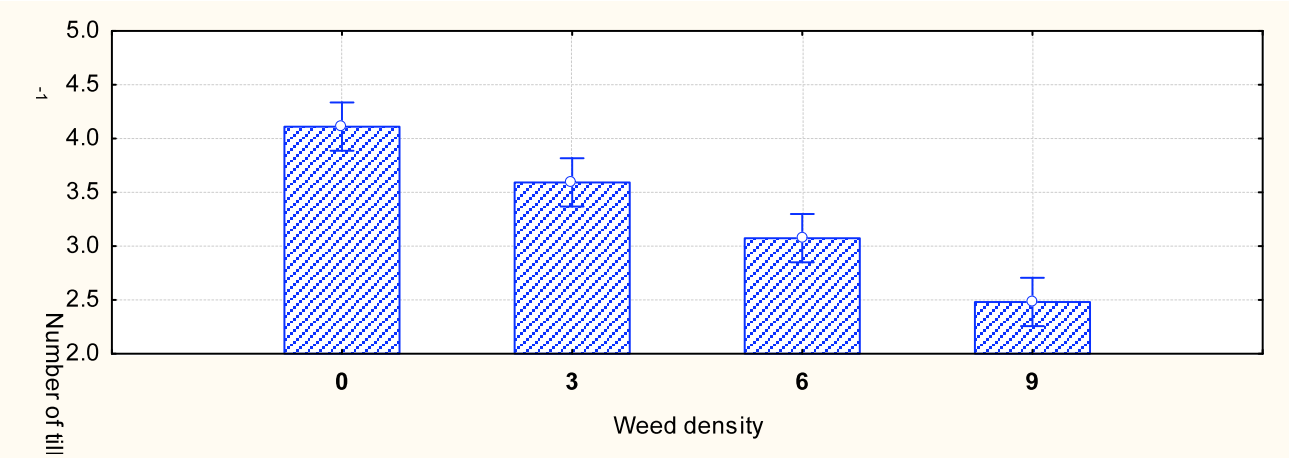

Figure 6.5 Effects of weed density on number of tillers of spring wheat cultivars (The whiskers represent standard error of means).

In terms of total dry mass of spring wheat cultivars no significant third order interactions were observed but weed Species and weed Density as well as wheat Cultivar and weed Species showed statistically significant interactions (Appendix D: Table 5). Figure 6.6 clearly

shows that weed Species differed in their effect on total dry mass of spring wheat Cultivars at different weed Specie densities. The interaction was due to *B. diandrus* which had significant larger effects on total dry mass of all cultivars in comparison with *Lolium* spp and *A. fatua* at 3, 6 and 9 weed densities. Similarly, *Lolium* spp. and *A. fatua* did not differ from each other in terms of effects on total dry mass production at any density (Figure 6.6). The wheat Cultivar and weed Species interaction was due to SST 88 which was significantly more severely affected by *B. diandrus* than PAN 3492 but not significantly more than Tankwa. Similarly, Tankwa was more severely affected by *A. fatua* than PAN 3492 and SST 88. *Lolium* spp showed little differences in its effects on total dry mass production of all cultivars (Figure 6.7).

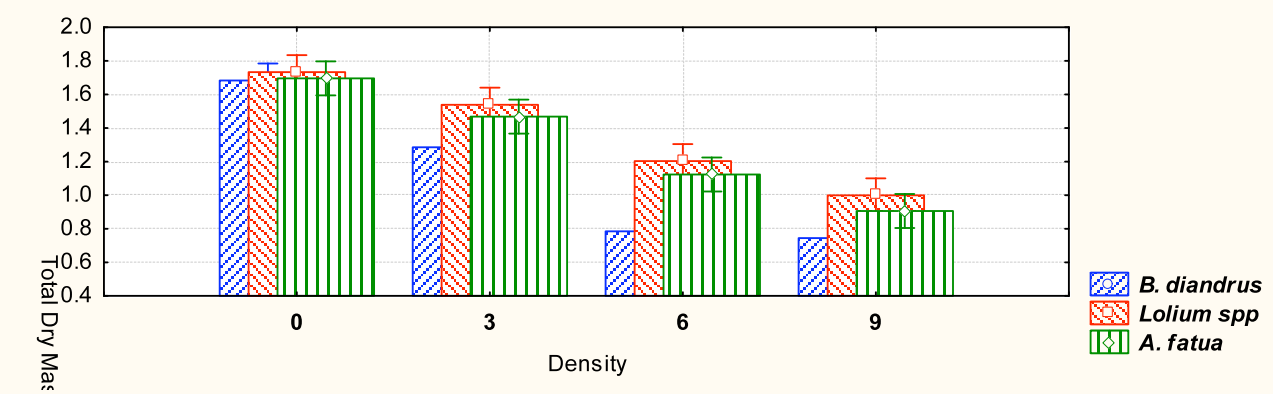

Figure 6.6 Effect of different weed densities of different weed species on total dry mass of spring wheat cultivars (*B. diandrus* = *Bromus diandrus, Lolium* spp. = *Lolium* species and *A. fatua* = *Avena fatua* (The whiskers represent standard error of means).

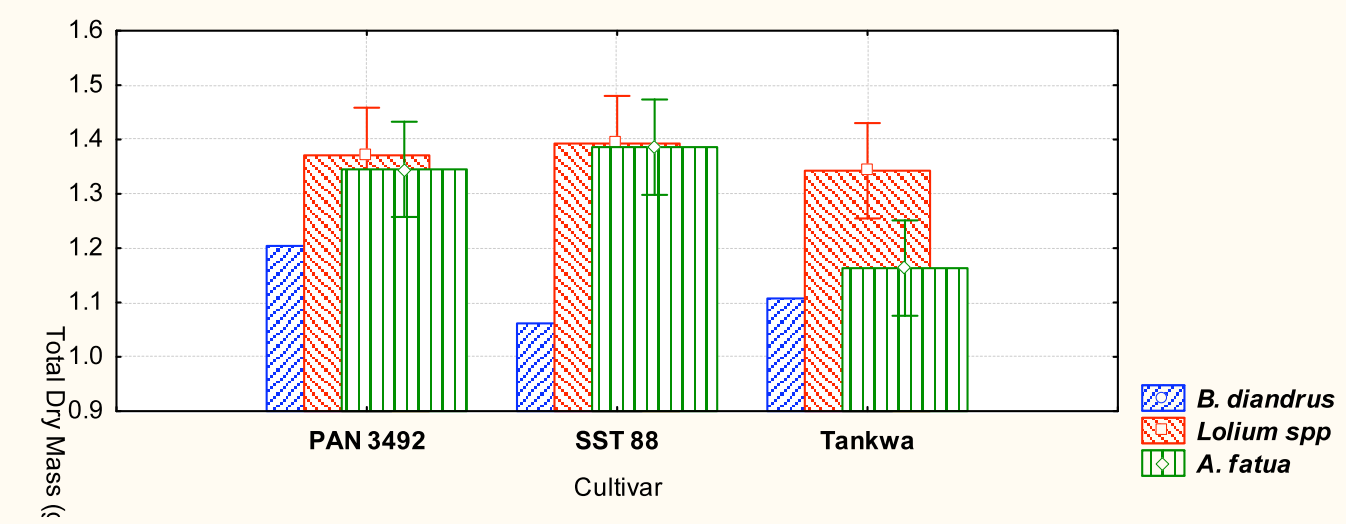

Figure 6.7 Effect of different weed species on total dry mass of spring wheat cultivars (*B. diandrus* = *Bromus diandrus, Lolium* spp. = *Lolium* species and *A. fatua* = *Avena fatua)* (The whiskers represent standard error of means).

DISCUSSION AND CONCLUSION

Crop competitiveness is expressed as the ability of a crop to maintain its yield when grown in the presence of weeds and its ability to suppress weed growth. The results obtained in this study showed that spring wheat cultivars differed in their competitive ability with weed species. Generally, PAN 3492 was found to be a more competitive cultivar than SST 88 and Tankwa in terms of vigorous growth under weed free conditions (Chapter 3). The result of this work shows that PAN 3492 maintained its competitive status under weedy conditions. No significant difference was observed between PAN 3492 and SST 88 with *Lolium spp* and *A. fatua* competition but a significant difference was observed between the two cultivars with *B. diandrus* competition.

Similarly, SST 88 was more competitive than Tankwa under weed free conditions. However, these results showed that SST 88 can be less competitive than Tankwa under weedy conditions depending on weed species (Figure 6.3 and 6.6). Overall, Tankwa was the least competitive cultivar in weed free conditions and showed a weak performance in weedy conditions signifying its poor competitive ability.

Increasing weed density of the three weed species tested significantly reduced crop growth parameters measured regardless of cultivar type. *Bromus diandrus* was found to have greater effects on spring wheat cultivars followed by *A. fatua* and *Lolium ssp*. Further studies are however required to verify the finding of this study under field conditions.

To conclude, it can be said that this study showed that different spring wheat cultivars do differ with regards to their competitiveness with different weed species and cultivars such as PAN 3492 and SST 88 have better interference potential. Better intereference potential of such cultivars can be exploited to enhance the effect of weed suppression. Similarly, a reduction in crop growth from increased weed density could be due to allelopathic effects from weed species. It's therefore argued that farmers try to prevent or limit such weed species to interfer with crops. Crop competition, may or may not provide sufficient weed management alone. However, by combining increased crop competitiveness with herbicides targeted at specific weed problems producers will improve weed control in the current year and weed problems may be diminished over the long-term.

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CHAPTER 7

General conclusions

The development of herbicide resistance in weeds is one of the major factors hampering profitable crop production worldwide and the winter rainfall region of South Africa is not an exception. Lack of sufficient different mode of action herbicide groups that can be rotated in this condition necessitate the need to investigate other weed control strategies that will not involve herbicide usage. One of the alternative weed control strategies is to maximize crop competition to the weed population. This can be achieved by planting crop cultivars that have greater interference potential than others. Planting more competitive cultivars with allelopathic potential has been suggested as a cultural practice to suppress weed growth. Because of poor understanding of competitive ability, its importance, mechanisms and components to date little has been done to determine the competitiveness of South African spring wheat cultivars. Therefore, the primary aims of this study were to a) determine the interference potential of nine selected South African spring wheat cultivars in terms competitiveness and allelopathy, b) determine the allelopathic potential of selected broadleaf and grass weed species on three selected spring wheat cultivars and *vice versa,* c) determine the competitive ability of three selected South African spring wheat cultivars under varying densities of weed species.

The study has showed that different spring wheat cultivars differ in terms of growth pattern. Not all the components of wheat competitiveness as described in the literature was found to be present in the same cultivars hence making it indeed difficult to select and identify the most competitive cultivars. Some of the characteristics that are associated with competitiveness were found to change over developmental stage except for cultivars such as PAN 3408 and PAN 3492 which exhibited nearly all the characteristics. It was found that PAN 3492 performed exceptionally good compared to the other cultivars but did not differ significantly from cultivars PAN 3408 and SST 88 in terms of rapid emergence, greater plant height, greater leaf area indices and higher number of ears per plant and therefore these three cultivars are regarded as the most competitive cultivars in terms of vegetative growth. In conclusion, cultivars such as PAN 3492, PAN 3408 as well as SST 88 can be introduced as the most competitive cultivars in terms of vigorous growth in this study. In contrast, competitive ability of Tankwa compared to other cultivars was the least. Although Tankwa was found to exhibit the lowest growth vigour in this study, results obtained from National Cultivar Testing trials showed that Tankwa performed better in terms of yields. Thus it can be argued that although Tankwa did perform better in those trials in terms of yield, it can not

be regarded as competitive since the trials were conducted under relatively weed free conditions and its vegetative growth was not compared with other cultivars. It is noteworthy to mention that differences in wheat competitive ability existed in the present study, but ranking for competitive ability is often confounded with morphological characters changing over developmental stages, making recommendations for farmers unreliable. Seeds used in this experiment was obtained from different sites and treated with different seed dressings and this has a huge impacts on germinability of seeds. Therefore, it is recommended from this study that further research on these cultivars be done by obtaining seeds from the same site that are not subjected to any seed dressing treatment in order to obtain reliable results. Similarly, it's recommended that research be done under natural weedy condition before any recommendation or initiation of breeding programmes for competitive cultivars can be carried out.

All nine spring wheat cultivars studied inhibited the germination, root elongation and vegetative growth of ryegrass and it was found clearly that some spring wheat cultivars possess stronger allelopathic effects than others. SST 015, SST 88 and Kariega had the greatest allelopathic potential at all concentrations and Tankwa and Baviaans had the lowest. The present study found that spring wheat cultivars with vigorous growth such as PAN 3492 did not show strong allelopathic effects and *vice versa* those that showed strong allelopathic effect did not show vigorous growth. From this experiment it can be concluded that PAN 3492 is regarded as the best competitor in terms of vigorous growth and SST 88 is regarded as the best allelopathic spring wheat cultivar. Tankwa which was least in terms of vigorous growth and allelopathy is regarded as the least competitive among the nine selected spring wheat cultivars. Overall, SST 88 is regarded as the most competitive spring wheat cultivar because of its moderate growth habit and high allelopathic potential in this study.

The study on allelopathic potential of three spring wheat cultivars indicated that aqueous extracts of spring wheat cultivars exhibited significant inhibitoty effects on seed germination and germination rate of all weed species tested except that of *R. raphanistrum*. This indicate that weed species such as *Lolium* spp, *A. fatua, B. diandrus, O. suffruticosum* as well as *S. media* are susceptible to inhibitory substances from spring wheat cultivars. Germination of *Lolium* spp was most inhibited by extract solutions from SST 88 in comparison with extracts from other spring wheat cultivars. The degree of toxicity of the extracts was found to depend on cultivars, weed species and concentration. The tendency was increased inhibition as the extract concentration increased. Greater inhibition occurred at 75% and 100% extract concentration of all cultivars and this is probably not exclusively due to

allelopathic effects of the solution, but to a combination of osmotic and allelopathic effects of the extract solutions. The present study found *R. raphanistrum* seed germination to significantly increase at spring wheat extract solutions of 25% and 50% concentration compared to the control. This could be due to the presence of certain chemicals that act as *R. raphanistrum* seed germination stimulants at low concentrations and seed germination inhibitors at higher concentrations. It was also found that root growth is more sensitive to cultivar extracts than germination and germination rate.

The growth parameters of all weed species measured were all significantly reduced compared to the control with increasing extract concentrations of all spring wheat cultivars. From the results of this study it was found that extracts of SST 88 are more inhibiting on weed germination and seedling growth than extracts from Tankwa and PAN 3492. The results also demonstrated that weed species differed significantly in their growth response to cultivar extracts with *Lolium* spp. being affected the most followed by *A. fatua* and *R. raphanistrum* with *B. diandrus* being least affected. This may imply that wheat allelochemicals are selective in influencing the growth of certain weeds. It is therefore suggested from this study that substantial residues and stubbles of spring wheat cultivars such as SST 88 as well as PAN 3492 can be used under no-till or minimum tillage systems to decompose and leach into the soil to inhibit seed germination and seedling growth of weed species such as *Lolium* ssp*, A. fatua* and *B. diandrus* in order to reduce the weed density. It is also suggested that there is a possibility of utilizing spring wheat cultivar residues to induce the germination of weed species such as *R. raphanistrum* that can then be controlled with herbicides before planting the crop. More work, however is required to screen the efficacy of these spring wheat cultivars in field situations since these results were obtained in controlled conditions. These spring wheat cultivars may or may not present allelopathic potential under field conditions, where environmental factors (temperature, fainfall and soil type) may greatly influence the allelopathic interactions and microoganisms that may reduce or eliminate the impact of allelopathic effects. It`s also possible to determine the allelochemicals involved before any possibility of utilising wheat allelopathy in weed control can be realised.

The study on weed allelopathy demonstrated that aqueous extracts of weed species such as *Lolium* spp*, A. fatua, B. diandrus, O. suffruticosum* as well as *P. minor* exhibited significant inhibitory effects on seed germination and germination rate of three spring wheat cultivars. The degree of inhibition increases with increases in extract concentration. In weed species such as *Lolium* spp*., A. fatua, B. diandrus* and *O. suffruticosum* extract solutions above 50% resulted in complete inhibition of seed germination. The extract solutions from *O.*

suffruticosum appear to have more inhibitory effects indicating that this weed species contains more allelopathic substances than other weed species investigated but did not differ significantly from weed species such as *A. fatua, B. diandrus* and *Lolium* spp. The present study could not establish any inhibitory effect of *S. media* to all cultivar growth parameters measured except for germination percentages. *Phalaris minor, C. australis* and *S. media* showed little or no effects on the growth parameters of the three spring wheat cultivars. It was established that spring wheat cultivars varied in their response to the allelochemicals from weed species. Although no significant difference was observed among spring wheat cultivars, SST 88 was comparatively more tolerant to the extract solutions of the weed species that exhibited more inhibitory effects. Tankwa was severely affected by extract solutions of allelopathic weed species, but did not differ significantly from PAN 3492. The study has established that weed species such as *A. fatua, B. diandrus, Lolium* spp. and *O. suffruticosum* as well as (to a lesser extent) *R. raphanistrum* and *P. minor* have allelopathic effects on germination and growth of wheat. It can be concluded from the results of this study that reduction in crop yields in fields infested by these weed species might be due to allelopathic interference as one of the factors. For weed species such as *C. australis* and *S. media* yield losses might have resulted from competitive ability of weeds for growth factors at the expense of the crop. The information obtained in this study is important for farmers, since the knowledge of allelopathic potential of weed species would benefit practices aimed at avoiding or limiting weed interference with crops. It is also advisable for farmers to grow wheat cultivars such as SST 88 which can withstand the allelopathic pressure from weeds.

Crop competition, may or may not provide sufficient weed management alone. However, by combining increased crop competitiveness with herbicides targeted at specific weed problems farmers may improve weed control in the current year and weed problems may be diminished over the long-term. It is suggested that information from this study might result in many differences regarding the competitive ability of South African spring wheat cultivars. Since the experiment was conducted in a temperature controlled environment, more studies are needed under natural weedy conditions.

APPENDICES

APPENDIX A

Analysis of variance (ANOVA) tables for chapter 3

Table 1 Analysis of variance of plant height of different spring wheat cultivars at different harvest times.

	SS	DF	MS	F	P- value
Intercept	506334.8		506334.8	12653.60	0.000000
Time	39861.2	3	13287.1	332.05	0.000000
Cult	1194.7	8	149.3	3.73	0.001079
Time*Cultivar	1937.9	24	80.7	2.02	0.012115
Error	2841.1	71	40.0		

Table 2 Analysis of variance of number of tillers of different spring wheat cultivars at different harvest times.

	SS	DF	MS	F	P - value
Intercept	29968.33	1	29968.33	1286.039	0.000000
Time	3929.13	3	1309.71	56.204	0.000000
Cult	350.52	8	43.81	1.880	0.076611
Time*Cultivar	709.88	24	29.58	1.269	0.218084
Error	1654.50	71	23.30		

Table 3 Analysis of variance of leave area index of different spring wheat cultivars at different harvest times.

	SS	DF	MS	F	P - value
Intercept	259298310	1	259298310	532.7195	0.000000
Time	110169121	3	36723040	75.4462	0.000000
Cult	14788800	8	1848600	3.7979	0.000927
Time*Cultivar	14339015	24	597459	1.2275	0.249715
Error	34558865	71	486745		

Table 4 Analysis of variance of leave dry mass of different spring wheat cultivars at different harvest times

	SS	DF	MS	F	P – value
Intercept	5394.660	1	5394.660	554.7533	0.000000
Time	2389.106	3	796.369	81.8936	0.000000
Cult	264.086	8	33.011	3.3946	0.002354
Time*Cultivar	252.697	24	10.529	1.0827	0.384592

Error	690.434	71	9.724		

Table 5 Analysis of variance of total dry mass of different spring wheat cultivars at different harvest times.

	SS	**DF**	**MS**	**F**	**P - value**
Interception	31326.00	1	31326.00	696.7649	0.000000
Time	20641.00	3	6880.33	153.0350	0.000000
Cult	1142.22	8	142.78	3.1757	0.003868
Time*Cultivar	1440.88	24	60.04	1.3354	0.174066
Error	3237.06	72	44.96		

Table 6 Analysis of variance of plant height of different spring wheat cultivars at maturity

	SS	**DF**	**MS**	**F**	**P - value**
Intercept	368013.5	1	368013.5	2872.604	0.000000
Cultivar	7090.1	8	886.3	6.918	0.000337
Error	2306.0	18	128.1		

Table 7 Analysis of variance of plant dry mass of different spring wheat cultivars at maturity

	SS	**DF**	**MS**	**F**	**P – value**
Intercept	70757.38	1	70757.38	697.1652	0.000000
Cultivar	3435.32	8	429.42	4.2310	0.005272
Error	1826.87	18	101.49		

Table 8 Analysis of variance of number of head per cultivar of different spring wheat cultivars at maturity (Figure 5 c)

	SS	**DF**	**MS**	**F**	**P - value**
Intercept	20281.48	1	20281.48	633.0636	0.000000
Cultivar	725.85	8	90.73	2.8321	0.031726
Error	576.67	18	32.04		

Table 9 Analysis of variance of germination rate of *Lolium multiflorum* exposed to different concentration solution of different spring wheat cultivars.

Source	**SS**	**DF**	**MS**	**F**	**P -value**
Intercept	106252.9	1	106252.9	41352.33	0.000000
Cultivar	216.8	8	27.1	10.55	0.000000
Treatment	2102.8	4	525.7	204.59	0.000000
Cult*Trt	266.6	32	8.3	3.24	0.000001
Error	346.9	135	2.6		

Table 10 Analysis of variance of germination percentage of *Lolium multiflorum* exposed to different concentration solution of different spring wheat cultivars (Figure 5)

Source	SS	DF	MS	F	P- value
Intercept	671611.3	1	671611.3	19791.00	0.000000
Cult	2747.5	8	343.4	10.12	0.000000
Trt	78976.9	4	19744.2	581.82	0.000000
Cult*Trt	2958.1	32	92.4	2.72	0.000033
Error	4581.3	135	33.9		

Table 11 Analysis of variance of plant height of *Lolium multiflorum* exposed to different concentration solution of different spring wheat cultivars

	SS	DF	MS	F	P – value
Intercept	63138.83	1	63138.83	3330.510	0.000000
Cultivar	1651.02	8	206.38	10.886	0.000000
Concentration	5459.38	4	1364.85	71.994	0.000000
Cultivar*Concentration	1049.60	32	32.80	1.730	0.016620
Error	2559.29	135	18.96		

Table 12 Analysis of variance of number of leaves of *Lolium multiflorum* exposed to different concentration solution of different spring wheat cultivars

	SS	DF	MS	F	P - value
Intercept	30031.25	1	30031.25	2027.363	0.000000
Cultivar	327.30	8	40.91	2.762	0.007392
Concentration	3427.00	4	856.75	57.838	0.000000
Cultivar*Concentration	709.70	32	22.18	1.497	0.059112
Error	1999.75	135	14.81		

Table 13 Analysis of variance of root dry mass of *Lolium multiflorum* exposed to different concentration solution of different spring wheat cultivars (Figure 8)

	SS	DF	MS	F	P - value
Intercept	1.498964	1	1.498964	751.9689	0.000000
Cultivar	0.096737	8	0.012092	6.0661	0.000001
Concentration	1.133195	4	0.283299	142.1194	0.000000
Cultivar*Concentration	0.132995	32	0.004156	2.0849	0.001987
Error	0.269107	135	0.001993		

Table 14 Analysis of variance of leaves coluor of *Lolium multiflorum* exposed to different concentration solution of different spring wheat cultivars (Figure)

	SS	DF	MS	F	P - value
Intercept	634.6889	1	634.6889	1730.970	0.000000
Cultivar	38.9111	8	4.8639	13.265	0.000000
Concentration	645.4222	4	161.3556	440.061	0.000000
Cultivar*Concentration	83.4778	32	2.6087	7.115	0.000000
Error	49.5000	135	0.3667		

APPENDIX B

Analysis of variance (ANOVA) tables for chapter 4

Table 1 Analysis of variance of germination percentage of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	342757.0	1	342757.0	10169.71	0.000000
Cultivar	1780.2	2	890.1	26.41	0.000000
Weed spp	37785.2	5	7557.0	224.22	0.000000
Concentration	168479.1	4	42119.8	1249.71	0.000000
Cultivar*Weed spp	1994.3	10	199.4	5.92	0.000000
Cultivar*Concentration	1078.1	8	134.8	4.00	0.000218
Weed spp*Concentration	47212.0	20	2360.6	70.04	0.000000
Cultivar*Weed spp*Concentration	2447.4	40	61.2	1.82	0.004576
Error	6066.7	180	33.7		

Table 2 Analysis of variance of germination rate of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	118232.8	1	118232.8	6938.765	0.000000
Cultivar	179.9	2	89.9	5.278	0.005924
Weed spp	8663.7	5	1732.7	101.689	0.000000
Concentration	8917.9	4	2229.5	130.842	0.000000
Cultivar*Weed spp	695.8	10	69.6	4.084	0.000044
Cultivar*Concentration	1004.4	8	125.5	7.368	0.000000
Weed spp*Concentration	5302.1	20	265.1	15.558	0.000000

Cultivar*Weed spp*Concentration	2315.4	40	57.9	3.397	0.000000
Error	3067.1	180	17.0		

Table 3 Analysis of variance of root length of weed species in petri dishes as exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	54718.6	1	54718.63	991.9844	0.000000
Cultivar	42.3	2	21.16	0.3836	0.681961
Weed spp	808.2	5	161.63	2.9302	0.014380
Concentration	181552.5	4	45388.13	822.8335	0.000000
Cultivar*Weed spp	39.3	10	3.93	0.0713	0.999961
Cultivar*Concentration	202.9	8	25.36	0.4598	0.882983
Weed spp*Concentration	1851.0	20	92.55	1.6778	0.040490
Cultivar*Weed spp*Concentration	1345.5	40	33.64	0.6098	0.966987
Error	9928.9	180	55.16		

Table 4 Analysis of variance of plant height of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	90790.80	1	90790.80	10136.32	0.000000
Cultivar	298.77	2	149.39	16.68	0.000001
Weed spp	2464.29	2	1232.14	137.56	0.000000
Concentration	1496.14	4	374.03	41.76	0.000000
Cultivar*Weed spp	59.73	4	14.93	1.67	0.165144
Cultivar*Concentration	276.94	8	34.62	3.86	0.000635
Weed spp*Concentration	176.90	8	22.11	2.47	0.018630
Cultivar*Weed spp*Concentration	66.86	16	4.18	0.47	0.956500
Error	761.34	85	8.96		

Table 5 Analysis of variance of number of leaves of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	6577.121	1	6577.121	13387.06	0.000000
Cultivar	9.873	2	4.937	10.05	0.000095
Weed spp	138.195	3	46.065	93.76	0.000000
Concentration	261.309	4	65.327	132.97	0.000000

Cultivar*Weed spp	11.401	6	1.900	3.87	0.001492
Cultivar*Concentration	12.407	8	1.551	3.16	0.002874
Weed spp*Concentration	66.245	12	5.520	11.24	0.000000
Cultivar*Weed spp*Concentration	13.814	24	0.576	1.17	0.282835
Error	56.500	115	0.491		

Table 6 Analysis of variance of shoot dry mass of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	6.123697	1	6.123697	11040.90	0.000000
Cultivar	0.052893	2	0.026446	47.68	0.000000
Weed spp	0.139585	3	0.046528	83.89	0.000000
Concentration	0.778944	4	0.194736	351.10	0.000000
Cultivar*Weed spp	0.060448	6	0.010075	18.16	0.000000
Cultivar*Concentration	0.024010	8	0.003001	5.41	0.000009
Weed spp*Concentration	0.142818	12	0.011902	21.46	0.000000
Cultivar*Weed spp*Concentration	0.025293	24	0.001054	1.90	0.013176
Error	0.063783	115	0.000555		

Table 7 Analysis of variance of root dry mass of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	3.387686	1	3.387686	8868.693	0.000000
Cultivar	0.074565	2	0.037283	97.603	0.000000
Weed spp	0.308399	3	0.102800	269.121	0.000000
Concentration	0.464240	4	0.116060	303.836	0.000000
Cultivar*Weed spp	0.043867	6	0.007311	19.140	0.000000
Cultivar*Concentration	0.024838	8	0.003105	8.128	0.000000
Weed spp*Concentration	0.088381	12	0.007365	19.281	0.000000
Cultivar*Weed spp*Concentration	0.019249	24	0.000802	2.100	0.004947
Error	0.043928	115	0.000382		

Table 8 Analysis of variance of total dry mass of weed species exposed to different extract concentrations of different spring wheat cultivars.

Source	SS	DF	MS	F-value	p
Intercept	18.59555	1	18.59555	17964.76	0.000000
Cultivar	0.25138	2	0.12569	121.42	0.000000

Weed spp	0.86962	3	0.28987	280.04	0.000000
Concentration	2.45403	4	0.61351	592.70	0.000000
Cultivar*Weed spp	0.12889	6	0.02148	20.75	0.000000
Cultivar*Concentration	0.09008	8	0.01126	10.88	0.000000
Weed spp*Concentration	0.39659	12	0.03305	31.93	0.000000
Cultivar*Weed spp*Concentration	0.05155	24	0.00215	2.08	0.005592
Error	0.11904	115	0.00104		

APPENDIX C7

Analysis of variance (ANOVA) tables for chapter 5

Table 1 Analysis of variance of germination percentage of spring wheat cultivars as exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F-value	p
Intercept	645583.4	1	645583.4	17606.82	0.000000
Weed sp	74491.6	7	10641.7	290.23	0.000000
Cultivar	694.3	2	347.2	9.47	0.000110
Concentration	269063.5	4	67265.9	1834.52	0.000000
Weed sp*Cultivar	239.0	14	17.1	0.47	0.949314
Weed sp*Concentration	28408.7	28	1014.6	27.67	0.000000
Cultivar*Concentration	182.8	8	22.8	0.62	0.758095
Weed sp*Cultivar*Concentration	1511.7	56	27.0	0.74	0.914068
Error	8800.0	240	36.7		

Table 2 Analysis of variance of germination rate of spring wheat cultivars exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F-value	p
Intercept	133922.4	1	133922.4	10038.16	0.000000
Weed sp	11158.7	7	1594.1	119.49	0.000000
Cultivar	24.7	2	12.4	0.93	0.396932
Concentration	19132.3	4	4783.1	358.52	0.000000

Weed sp*Cultivar	216.6	14	15.5	1.16	0.307318
Weed sp*Concentration	6227.7	28	222.4	16.67	0.000000
Cultivar*Concentration	111.1	8	13.9	1.04	0.406054
Weed sp*Cultivar*Concentration	594.0	56	10.6	0.80	0.846401
Error	3201.9	240	13.3		

Table 3 Analysis of variance of plant height of spring wheat cultivars as exposed to different extract concentrations of different weed species.

Source	SS	DF	MS	F-value	P
Intercept	228657.2	1	228657.2	44053.21	0.000000
Cultivar	162.9	2	81.5	15.69	0.000000
Weed spp	2706.0	7	386.6	74.48	0.000000
Concentration	2168.1	4	542.0	104.43	0.000000
Cultivar*Weed spp	132.2	14	9.4	1.82	0.036558
Cultivar*Concentration	25.6	8	3.2	0.62	0.763489
Weed spp*Concentration	1162.2	28	41.5	8.00	0.000000
Cultivar*Weed spp*Concentration	146.1	56	2.6	0.50	0.998624
Error	1245.7	240	5.2		

Table 4 Analysis of variance of number of tillers of spring wheat cultivars as exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F-value	P
Intercept	1596.011	1	1596.011	6840.048	0.000000
Cultivar	0.272	2	0.136	0.583	0.558824
Weed spp	42.656	7	6.094	26.116	0.000000
Concentration	83.294	4	20.824	89.244	0.000000
Cultivar*Weed spp	4.928	14	0.352	1.509	0.108464
Cultivar*Concentration	1.756	8	0.219	0.940	0.483733
Weed spp*Concentration	25.594	28	0.914	3.918	0.000000
Cultivar*Weed spp*Concentration	7.489	56	0.134	0.573	0.992868
Error	56.000	240	0.233		

Table 5 Analysis of variance of Leaf Area Index of spring wheat cultivars as exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F	P
Intercept	356584.7	1	356584.7	20620.44	0.000000
Cultivar	597.3	2	298.7	17.27	0.000000
Weed spp	8197.4	7	1171.1	67.72	0.000000
Concentration	8346.1	4	2086.5	120.66	0.000000
Cultivar*Weed spp	269.7	14	19.3	1.11	0.345857
Cultivar*Concentration	80.2	8	10.0	0.58	0.794066
Weed spp*Concentration	4553.5	28	162.6	9.40	0.000000
Cultivar*Weed spp*Concentration	320.1	56	5.7	0.33	0.999998
Error	4150.3	240	17.3		

Table 6 Analysis of variance of shoot dry mass of spring wheat cultivars as exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F	P
Intercept	2.814302	1	2.814302	17348.44	0.000000
Cultivar	0.002532	2	0.001266	7.80	0.000521
Weed spp	0.115144	7	0.016449	101.40	0.000000
Concentration	0.218118	4	0.054530	336.14	0.000000
Cultivar*Weed spp	0.006615	14	0.000472	2.91	0.000423
Cultivar*Concentration	0.003035	8	0.000379	2.34	0.019508
Weed spp*Concentration	0.075979	28	0.002714	16.73	0.000000
Cultivar*Weed spp*Concentration	0.008041	56	0.000144	0.89	0.701756
Error	0.038933	240	0.000162		

Table 7 Analysis of variance of root dry mass of spring wheat cultivars as exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F	P
Intercept	1.803418	1	1.803418	9156.987	0.000000
Cultivar	0.001911	2	0.000955	4.850	0.008608
Weed spp	0.113302	7	0.016186	82.186	0.000000
Concentration	0.228035	4	0.057009	289.466	0.000000
Cultivar*Weed spp	0.007569	14	0.000541	2.745	0.000870
Cultivar*Concentration	0.002962	8	0.000370	1.880	0.063847
Weed spp*Concentration	0.057534	28	0.002055	10.433	0.000000
Cultivar*Weed spp*Concentration	0.009203	56	0.000164	0.834	0.788407
Error	0.047267	240	0.000197		

Table 8 Analysis of variance of total dry mass of spring wheat cultivars exposed to different extract concentrations of different weed species

Source	SS	DF	MS	F-value	P
Intercept	35.26884	1	35.26884	30787.54	0.000000
Cultivar	0.01934	2	0.00967	8.44	0.000287
Weed spp	1.37423	7	0.19632	171.37	0.000000
Concentration	2.26436	4	0.56609	494.16	0.000000
Cultivar*Weed spp	0.04054	14	0.00290	2.53	0.002189
Cultivar*Concentration	0.00638	8	0.00080	0.70	0.694863
Weed spp*Concentration	0.73700	28	0.02632	22.98	0.000000
Cultivar*Weed spp*Concentration	0.04819	56	0.00086	0.75	0.899152
Error	0.27493	240	0.00115		

APPENDIX D

Analysis of variance (ANOVA) tables for chapter 6

Table 1 Analysis of varience of plant height of spring wheat cultivars under different density of different weed species

Source	SS	DF	MS	F-value	p
Intercept	146397.8	1	146397.8	10784.29	0.000000
Cultivar	134.4	2	67.2	4.95	0.009676
Weed spp	13.4	2	6.7	0.49	0.613528
Density	4893.8	3	1631.3	120.17	0.000000
Cultivar*Weed spp	8.8	4	2.2	0.16	0.956580
Cultivar*Density	28.6	6	4.8	0.35	0.907199
Weed spp*Density	178.6	6	29.8	2.19	0.053351
Cultivar*Weed spp*Density	74.7	12	6.2	0.46	0.932061
Error	977.4	72	13.6		

Table 2 Analysis of varience of number of leaves of spring wheat cultivars under different density of different weed species.

Source	SS	DF	MS	F-value	p
Intercept	16975.15	1	16975.15	10241.99	0.000000
Cultivar	30.57	2	15.29	9.22	0.000272
Weed spp	23.35	2	11.68	7.04	0.001606
Density	914.41	3	304.80	183.90	0.000000
Cultivar*Weed spp	18.09	4	4.52	2.73	0.035631
Cultivar*Density	14.76	6	2.46	1.48	0.195807
Weed spp*Density	20.20	6	3.37	2.03	0.072345
Cultivar*Weed spp*Density	36.13	12	3.01	1.82	0.061334
Error	119.33	72	1.66		

Table 3 Analysis of varience of LAI of spring wheat cultivars under different density of different weed species.

Source	SS	DF	MS	F-value	p
Intercept	1141615	1	1141615	11728.73	0.000000
Cultivar	3467	2	1733	17.81	0.000001
Weed spp	2293	2	1147	11.78	0.000038
Density	47350	3	15783	162.16	0.000000
Cultivar*Weed spp	1346	4	337	3.46	0.012182
Cultivar*Density	533	6	89	0.91	0.490483
Weed spp*Density	615	6	102	1.05	0.399099
Cultivar*Weed spp*Density	2025	12	169	1.73	0.077130
Error	7008	72	97		

Table 4 Analysis of varience of number of tillers of spring wheat cultivars under different density of different weed species.

Source	SS	DF	MS	F-value	p
Intercept	1186.704	1	1186.704	3463.892	0.000000
Cultivar	5.574	2	2.787	8.135	0.000653
Weed spp	0.907	2	0.454	1.324	0.272383
Density	39.519	3	13.173	38.450	0.000000
Cultivar*Weed spp	2.315	4	0.579	1.689	0.161874
Cultivar*Density	2.204	6	0.367	1.072	0.387307
Weed spp*Density	1.093	6	0.182	0.532	0.782562
Cultivar*Weed spp*Density	1.019	12	0.085	0.248	0.994702
Error	24.667	72	0.343		

Table 5 Analysis of varience of total dry mass of spring wheat cultivars under different density of different weed species.

Source	SS	DF	MS	F-value	p
Intercept	172.4703	1	172.4703	7423.398	0.000000
Cultivar	0.2024	2	0.1012	4.356	0.016369
Weed spp	1.1368	2	0.5684	24.466	0.000000
Density	11.2906	3	3.7635	161.988	0.000000
Cultivar*Weed spp	0.2764	4	0.0691	2.974	0.024833
Cultivar*Density	0.2304	6	0.0384	1.652	0.145313

Weed spp*Density	0.3711	6	0.0618	2.662	0.021739
Cultivar*Weed spp*Density	0.2177	12	0.0181	0.781	0.668056
Error	1.6728	72	0.0232		