Kochia (*Kochia scoparia* (L.) Schrad.) and Biennial Wormwood (*Artemisia biennis* Willd.) Interference with Sunflower (*Helianthus annuus* L.)

BY

DEREK WILLIAM LEWIS

A Thesis

Submitted to the Faculty of Graduate Studies

In Partial Fulfillment of the Requirements

for the Degree of

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FACULTY OF GRADUATE STUDIES

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Abstract

Lewis, Derek W. The University of Manitoba, February 2013. Kochia (*Kochia scoparia* (L.) Schrad.) and Biennial Wormwood (*Artemisia biennis* Willd.) Interference with Sunflower (*Helianthus annuus* L.)

Kochia and biennial wormwood are two weeds sometimes found growing in sunflower fields that may be difficult to control. Weed management in sunflowers is usually conducted using a combination of herbicides and mechanical weed control methods. Some farmers are growing sunflowers in reduced tillage systems, which may rely solely on herbicides to manage weeds; however, the spectrum of broadleaf weeds that can be controlled with herbicides is limited. Field experiments were conducted across southern Manitoba to determine the effect of kochia and biennial wormwood density and relative time of weed seedling recruitment on sunflower growth and development, yield and seed quality and to determine action thresholds for each weed. Early emerging kochia (plants that emerged at about the same time as the sunflowers) reduced sunflower yield by as much as 82%, which was greater than early emerging biennial wormwood plants, which reduced yield by as much as 27%. At low weed densities, each kochia plant reduced sunflower yield by 0.52% and each biennial wormwood plant reduced sunflower yield by 0.17%. As the density of early emerging kochia plants increased, sunflower height, stem diameter, leaf counts and head diameter were reduced in some of the experiments. Increasing densities of early emerging biennial wormwood plants had minimal effect on sunflower growth and development. Early emerging kochia and biennial wormwood plants both had the potential to reduce sunflower seed size and seed weight, while late emerging kochia and biennial wormwood (plants that emerged after the 4-leaf stage of the sunflowers) did not affect sunflower seed quality. The action threshold (5% sunflower yield loss) for early emerging kochia was 10 plants m^{-2} and the action threshold for early emerging biennial wormwood was 36 plants m^{-2} in the combined site-year analysis. Kochia or biennial wormwood plants that recruited after the 4-leaf stage of the sunflower crop did not affect sunflower yield, or seed quality.

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1.0 Introduction

In Manitoba, farmers grow a variety of broadleaf crops. In 2009, Manitoba farmers planted 1,295,000 ha of canola (*Brassica napus* L.), 167,900 ha of soybeans (*Glycine max* L. Merr.) and 64,700 ha of sunflowers (*Helianthus annuus* L.) (Anonymous 2009). About 85% of Canadian sunflower production occurs in Manitoba and about 80% of the sunflowers produced are confectionary varieties that are used in the snack food and baking industry (Anonymous 2006).

In central regions of Manitoba, nearly all of the sunflowers are planted in wide rows and weeds are controlled using inter-row cultivation and herbicides; however in the more arid, western portion of Manitoba, about half of the sunflowers are planted in narrow rows (Scott Day, Manitoba Agriculture Food and Rural Initiatives, personal communication, February 1, 2010). Farmers that plant sunflowers in narrow rows in western Manitoba typically use zero-tillage production systems and apply fertilizer in the same field operation as planting. Farmers that plant sunflowers with wide row spacing employ minimum tillage practices, using a tillage operation only to incorporate fertilizers, or soil-applied herbicides. Farmers in western Manitoba typically do not employ inter-row cultivation to control weeds, which leaves in-crop weed control solely dependent on herbicides.

Kochia (*Kochia scoparia* L. Schrad.) and biennial wormwood (*Artemisia biennis* Willd.) are difficult to manage weeds commonly found in sunflower fields (Anonymous 2012b). Kochia has increased in prevalence since the 1980s (Leeson et al. 2005) and infestations of biennial wormwood have also become increasingly common in recent years in agricultural fields (Kegode et al. 2007). There is limited information available about the ability of kochia and biennial wormwood to reduce sunflower yield, particularly in reduced tillage production systems.

The focus of the following research was to determine the potential for kochia and biennial wormwood to reduce sunflower yield and seed quality in reduced tillage systems.

The objectives of this research were to:

i) determine the effect of increasing densities of kochia and biennial wormwood on sunflower growth and development, yield and seed quality.

ii) determine action thresholds for kochia and biennial wormwood in sunflowers.

2.0 Literature Review

2.1 The History of Sunflowers

Originally, sunflowers were thought to have been domesticated in Peru, but current evidence suggests that sunflowers were domesticated in the United States by Native Americans (Heiser 1976). Sunflowers were introduced to Europe from North America, through Spain, and then spread to Russia, where concerted breeding efforts increased oil content from about 28% to 50%. These high-oil content sunflowers from Russia were re-introduced to North America in the 19th century. Continued breeding produced the larger, striped hull, confectionary type sunflowers.

Sunflower heads track the sun through the sky. The genus name *Helianthus* originates from the Greek words *helios,* meaning sun, and *anthus,* meaning flower (Heiser 1976). The French name for sunflowers is *tournesol*, which translated literally, means “turn with the sun.”

2.2 Sunflower Production Statistics

Globally, sunflower production was about 22,000,000 ha in 2009, which produced about 30,000,000 tonnes of seed (Anonymous 2011c). About 75% of global sunflower production occurs in Russia, Ukraine, Argentina and the European Union.

In Canada, approximately 85% of the sunflowers are grown in Manitoba, totalling about 98,000 tonnes of seed annually (Anonymous 2006). Confectionary sunflowers comprise about 80% of production in Manitoba and the remaining 20% of production are the smaller, black-hulled oilseed type. Sunflower production in Manitoba peaked in the

1980s, at about 121,400 ha and declined to about 25,500 ha in 1995. In 2007, sunflower production in Manitoba was 76,900 ha (Anonymous 2008a).

2.3 Uses of Sunflowers

2.3.1 Human Consumption

Confectionary sunflowers produced in Manitoba are usually sold after roasting and salting as a snack food, or are used in baking (Anonymous 2006). In the confectionary sunflower market, buyers desire large, high quality seeds that are free from insect and disease damage. Confectionary sunflowers that do not make the human consumption grade are often mixed into birdfeed. The smaller, black-hulled oilseed sunflowers are crushed for oil production. Sunflower oil is suitable for cooking, margarine and salad dressing.

2.3.2 Livestock Feed and Forage

Sunflower seeds can be used as an ingredient in animal rations. The remnant after oil extraction from sunflower seed is the meal. The protein content of sunflower meal is 28 to 42% and compared to soybean meal, which is commonly used as an animal feed source, sunflower meal is higher in fibre and methionine and lower in lysine than soybean meal (Putnam et al. 1990). Sunflower meal supplemented with the essential amino acid lysine can be used to replace soybean meal in broiler chicken rations (Mohme et al.1997) and can also be used as a protein source in swine feed (Rizzi et al. 2007).

Sunflowers may also be used as a forage crop. In one study, silage yield for sunflowers was about 6 t ha^{-1} compared to 8.5 t ha^{-1} for corn (*Zea mays* L.) (Murray et al. 1986). Crude protein content of sunflower silage was greater than corn and total digestible nutrients were similar between corn and sunflower.

2.4 Sunflower Morphology and Reproductive Biology

Sunflower morphology and biology are described in detail by Seiler (1997). Sunflower plants range from 50 to 500 cm tall with un-branched stems covered in dense hairs. The stems may be smooth, or ridged with a diameter between 25 and 60 mm. The first leaves of sunflower plants are opposite, but subsequent leaves can be alternate, or opposite depending on genotype. The leaves are large, petiolate and entire, or serrated. The inflorescence of a sunflower plant, referred to as the head, is variable in size and depends on genetic background and growing conditions. Heads are typically comprised of 300 to more than 1,000 disk flowers. On the outer perimeter of the head is a brightly coloured ring of ray flowers that range from bright yellow, to dark orange in colour. The face of the head can be concave, convex, or flat.

As sunflower heads develop, they face east in the morning, turn to the west as the day progresses and return to the east facing position during the night (Lang and Begg 1979). As anthesis progresses, the daily range of motion of the head decreases, and at the end of anthesis, the heads face east until physiological maturity. Presumably, the heads face east in the morning to dry the dew that tends to form overnight in order to reduce the incidence of head disease. At maturity, sunflower heads face the ground, which reduces the exposure of the seeds to rain and bird damage. The fruit of sunflower is an achene, which is a seed surrounded by a protective pericarp. The term achene and seed are often used interchangeably. Depending on the genotype, seed can be 7 to 25 mm long, 4 to 13 mm wide and may be round, oval, or linear in shape.

2.5 Sunflower Production Practices

In Manitoba, sunflowers are typically planted in May and ideally, seeding should be completed by early June to maximize yield potential (Anonymous 2006). Sunflowers reach maturity in about 120 days. To reduce the probability of frost damage in the fall, it is important to seed sunflowers early in the season, or if seeding is delayed until June, growers should plant an earlier maturing, oil-type variety, rather than a confectionary variety.

Sunflowers can be seeded in wide row spacing, to allow for inter-row cultivation to control weeds, or in narrow row spacing (Anonymous 2006). Sunflowers grow best in well drained soils. Seed must be placed into moist soil at planting, but no deeper than 7.6 cm. Sunflowers require an extended period of time in the fall to dry to adequate moisture content for storage; however, sunflowers can be harvested after a snowfall without loss in quality, which makes sunflowers a good crop for Manitoba conditions where snow is not uncommon before harvest. Sunflowers can be harvested when seed moisture is 20% or lower, but care must be taken when harvesting sunflowers if seeds are less than 10% moisture, to minimize damage to seeds.

2.5.1 Weed Management in Sunflowers

There are limited weed management options for sunflowers and several studies have documented that sunflowers do not compete well with weeds, especially at early developmental stages (e.g. Chubb and Friesen 1984, Durgan and Miller 1981, Durgan et al. 1990). Limited herbicidal weed control options, combined with the poor competitive ability of sunflowers early in the season, means that yield loss from weed interference can be significant.

2.5.1.1 Mechanical Weed Management

Mechanical weed management using inter-row cultivation and harrowing can be useful weed control methods for farmers growing sunflowers. In the past, inter-row cultivation was used in nearly all the sunflowers grown in North America (Blamey et al. 1997); however, some farmers in Manitoba are producing sunflowers using zero-till production systems (Barker 2007).

In conventional cropping systems, in-crop harrowing can be used to control small seeded weeds that emerge near the soil surface early in the season before the weeds develop extensive root systems (Blamey et al. 1997). In the absence of effective herbicides, in-crop harrowing is one of the main methods for controlling weeds that emerge within the sunflower row. Harrowing should be conducted in a diagonal direction across the sunflower rows before hypocotyl emergence, or when the sunflowers are at the four leaf stage using spring tooth harrows. To minimize crop damage, in-crop harrowing should be conducted in the morning, when sunflowers are at full turgor. After the window for in-crop harrowing has passed, inter-row cultivation is the only other means of mechanical weed control, but inter-row cultivation does not control weeds in the sunflower row.

2.5.1.2 Cultural Weed Management

Cultural weed management methods can be very effective tools to reduce weed interference in crops, especially when multiple tools are employed concurrently. Blackshaw et al. (2008) summarized the six cultural weed management practices that follow:

1) Zero tillage – although switching from conventional tillage to zero tillage may increase the densities of winter annual, biennial and perennial weeds, after five to ten years of zero tillage farming, many producers report overall decreased weed densities. Zero tillage production reduces weed densities because weed seeds on the soil surface are weathered and consumed by predators, weed seeds that fall on, or below the crop residue are inhibited from growing by either physical, or allelopathic means, and zero tillage farmers often use glyphosate, which is a highly efficacious herbicide.

2) Crop rotation – a diversified crop rotation can reduce weed populations in fields in several ways. Different crops are planted and harvested at different times of the season and require different herbicides. Crops sown early in the spring may establish quickly and out-compete late emerging weeds. Alternatively, crops that are planted late in the spring enable farmers to control early emerging weeds before seeding. Fall seeded crops, like winter wheat (*Triticum aestivum* L.), grow rapidly in the spring before weeds have an opportunity to establish.

3) Crop cultivar – canola was once considered a non-competitive crop, but with the introduction of hybrid varieties, it is now considered as competitive as wheat (Blackshaw et al. 2008). Hybrid canola establishes and grows more rapidly than open pollinated varieties early in the season (Koscielny 2011). Earlier canopy closure may shade weeds and reduce weed growth.

4) Crop seeding rate – increased seeding rates and reliable seeding equipment ensure farmers attain uniformly dense crop canopies that compete with weeds. Farmers may be reluctant to increase seeding rates because of increased seed cost and also for fear of running out of moisture during grain fill. According to Blackshaw et al. (2008), researchers have rarely been able to re-produce this moisture limitation effect in field experiments.

5) Fertilization – by placing fertilizer in sub-surface bands near the seed row, away from surface germinating weed seeds, a greater proportion of the fertilizer is utilized by the crop compared to surface broadcast fertilizer applications. Beres et al. (2010) showed that monocot weed biomass was reduced with fall banded applications of urea, compared to spring broadcast urea, but dicot biomass was unaffected by fertilizer application method.

6) Silage, green manure and cover crops – silage crops can be harvested before weeds reach maturity, which reduces the addition of weed seed to the soil seed bank. Cover crops are often used to add nitrogen to the soil (Thiessen-Martens et al. 2005) and they are also effective for reducing weed infestations (Nord et al. 2011).

2.5.1.3 Herbicidal Weed Management

A number of effective herbicides are available to control grassy weeds in sunflowers; however, the number of herbicides available to manage broadleaf weeds is limited (Anonymous 2011a). Some of the herbicides that control broadleaf weeds are pre-plant incorporated herbicides that only control a limited spectrum of weeds. Trifluralin must be applied to the soil in the fall, or early spring before sunflower planting and the soil must be cultivated to incorporate the herbicide. For farmers practicing zero tillage, or reduced tillage, pre-plant incorporated herbicides, like trifluralin, may not be a viable option for weed control.

In-crop, foliar applied herbicides available to control broadleaf weeds are limited in sunflowers. In Manitoba, there are only two broadleaf herbicides registered for application on non-herbicide tolerant sunflowers (Anonymous 2011a). Imazamethabenz provides good control of wild mustard (*Brassica kaber* L.) and stinkweed *(Thlaspi arvense* L.) and ethametasulfuron-methyl can be used to control flixweed (*Descurainia sophia* L.), hemp nettle (*Galeopsis tetrahit L.*), wild mustard, smartweed *(Polygonum sp.*) and stinkweed. There are certain problem weeds, such as kochia and biennial wormwood, for which there are no effective post-emergence herbicides registered. In the spring of 2011, sulfentrazone, a pre-plant, soil applied herbicide, was registered in Manitoba for sunflower production and provides in-crop control of kochia (Anonymous 2011a) and biennial wormwood (Kegode et al. 2007) through residual soil activity.

2.6 Crop Yield Loss Related to Weeds

The earlier that weeds emerge in the growing season, the more potential these weeds have to reduce crop yield when left uncontrolled (O'Donovan 1996). The time interval between weed and crop emergence can be quantified in growth stages (e.g. Knezevic et al. 1994), or in days (e.g. Blackshaw 1993). Researchers have also used relative emergence time, measured in thermal units, to determine the effect of the relative time of the emergence of weeds on crop yield (Willenborg et al. 2005). When wild oat (*Avena fatua* L.) plants emerged 92 growing degree days (GDD) before tame oat (*Avena sativa* L.), plants oat yield was reduced by up to 71% and when wild oats emerged 57 GDD after the oats, yield was reduced by up to 46%.

2.7 Weed Interference with Sunflowers

Several studies have examined the effect of weed interference on sunflower development and yield. Durgan et al. (1990) examined yield loss caused by kochia interference in sunflowers when kochia plants were left to grow only in the sunflower row (ie. a system that utilizes inter-row cultivation). Kochia was removed at 0, 2, 4, 6 and 8 weeks after sunflower emergence in addition to a treatment that was subjected to season long weed interference and a treatment that was kept weed-free for the entire season. Over the two years of the study, there was a difference in yield loss caused by kochia. In 1983, 6 kochia plants m^{-1} of sunflower row reduced sunflower yield by 20%, while in 1984, the same density of kochia reduced sunflower yield by 36%. The authors hypothesized that in 1983, there was more rainfall compared to the long-term average, which allowed the sunflowers to compete more effectively with the kochia. In 1984, rainfall was less than the long-term average and the kochia interfered more vigorously with the sunflowers in the dry conditions. Even though kochia interference reduced sunflower yield, kochia interference did not affect sunflower test weight, or oil content. Kochia interference with sunflowers began as early as 2 weeks after sunflower emergence.

Chubb (1975) conducted weed interference experiments with sunflowers at Morden, MB, Canada. With 75 wild oat, 40 green foxtail (*Setaria viridis* L.) and 20 broadleaf weeds m^{-2}, yield was reduced by 45%. By using inter-row cultivation to control weeds, the level of yield loss was reduced. Inter-row cultivation should be conducted during the critical period of weed control, which is 4-6 weeks after sunflower emergence.

In a study by Chubb and Friesen (1984), wild oats were planted at an average density of 69 plants m^{-2} into sunflowers. When wild oats were left in both the sunflower row and the inter-row space for the entire season, yield was reduced by 54% compared to the weed free control. When the wild oats were removed from the inter-row space and left in the sunflower row, yield was reduced by 38% compared to the weed free control and when wild oats were removed from the sunflower row and left in the inter-row space, yield was reduced by 39% compared to the weed free control. Weeds left in the sunflower row were just as detrimental to sunflower yield as weeds in the inter-row space.

In a study conducted in India, the effect of a mixture of three grass weed species, six broadleaf weed species and a sedge, with densities ranging from 0 to 178 weeds m^{-2} on sunflower yield was measured (Reddy et al. 2008). The authors determined that the critical period of weed competition in sunflowers was between 20 and 40 days after seeding. The lowest yields were in the weedy treatments. The highest sunflower yields were in the weed free control, and the treatments that were weed free for 50 to 60 days after planting. When sunflowers grew for 40 days without weed interference, any weeds that germinated after 40 days did not affect sunflower yield.

Lehoczky et al. (2006) studied a mixture of thirteen weed species with an average density of 152 plants m^{-2} in Baracska, Hungary. Weed interference lasting for the first five weeks after sunflower emergence caused a significant decrease in sunflower biomass when compared to the weed free control. Sunflowers treated with herbicides had 31% more biomass than weed infested plots that did not receive an herbicide application. Regression analysis determined that 1 kg of dry weed biomass resulted in a 370 g reduction in sunflower biomass.

Hemp sesbania (*Sesbania exaltata*) can be a very competitive weed in sunflower crops (Woon 1987). At the University of Arkansas, sunflower yield was reduced by 5% when hemp sesbania interfered until the 10 leaf stage of sunflower before it was removed. Sunflower yield was reduced by 25% when weed interference lasted until crop anthesis. When hemp sesbania interfered with the sunflowers for the entire growing season, yield was reduced by 35%. Reducing the sunflower row-spacing from 91 cm to 61 cm did not change the ability of sunflowers to compete with hemp sesbania.

2.8 Weed Interference Study Methods

2.8.1 Additive Design Experiments

Additive designs are commonly used to model weed interference in crops (e.g. Blackshaw 1993, Durgan et al. 1990, Knezevic et al. 1994). In additive design studies, the weed plant species is planted at increasing densities, while the density of the other species is kept constant (Radosevich et al. 2007). In additive design studies, increasing weed densities are expected to reduce crop yield. The arrangement of crop and weed are random in additive design experiments. Additive design experiments are applicable in agricultural systems where weeds are typically found in varying densities in fields and crops are planted at one density throughout the field.

2.8.2 The Rectangular Hyperbola Yield Loss Model

Numerous equations to describe crop yield loss in response to weed density have been proposed, but the rectangular hyperbola yield loss model has been shown to describe yield loss data better than many other models (Cousens 1985) leading to the rectangular hyperbola model being one of the most widely utilized yield loss models (e.g. Blackshaw 1993, Durgan et al. 1990, O'Donovan et al. 2008). A comparison of eighteen yield loss models, applied to twenty-two previously published data sets, found that the rectangular hyperbola model provided the best description of these data sets. The rectangular hyperbola model is only relevant in the analysis of additive design experiments. The relationship is described by the equation:

$$YL = Id/(1 + Id/A) \qquad \text{[eqn. 1]}$$

where YL, is the percent yield loss, I is the percent yield loss per weed as weed density approaches zero, d is weed density and A is the percent yield loss as weed density approaches infinity.

2.9 Kochia

2.9.1 Description of Kochia

Kochia is a bushy, tap-rooted, annual, herbaceous plant that is pyramidal in shape when not competing for space with other plants and grows 0.15 to 2.0 metres tall (Friesen et al. 2009). The erect stems break off at ground level late in the season, which allows kochia to tumble across open landscapes, spreading seed over long distances. The leaves are pale green, 1.5 to 6 cm long, fringed with short hairs and tapered to a point at the tip. Flowers are green, about 3 mm across and found either in leaf axils, or on dense spikes at the top of the plant. The brown seeds are oval and 1.5 to 2.0 mm long (Fig. 2.1). Kochia is a C_4 plant, which could give it an advantage over C_3 plants in certain environments (Friesen et al. 2009). C_4 plants have higher water use efficiency (WUE) than C_3 plants, providing a potential advantage over C_3 species in water limited, or high temperature environments (Collins and Jones 1986).

Unlike most weed species, kochia has potential economic value as a crop. Kochia extracts have been used to treat skin disease in Chinese medicine and as a remedy for diabetes mellitus and rheumatoid arthritis in Korea (Shin et al. 2004). Kochia seed, treated with hot water, or ethanol to remove the potentially toxic saponins, has been used as an alternative animal feed with 20% protein content (Coxworth et al. 1969). It was reported by Fuehring (1984), that a kochia population of 385,000 plants ha^{-1} produced 18,400 kg ha^{-1} of high quality hay. However, when horses, cattle and sheep grazed kochia high in saponins, toxic side effects including weight loss, photo-sensitization, depression, muscular weakness, excessive salivation and death have been observed (Thilsted et al. 1986 and Sprowls 1981).

2.9.2 Biology and Growth of Kochia

In Manitoba, kochia emerges early in the spring as early as 50 growing degree days (T_{base} 0c) have accumulated (Schwinghammer and Van Acker 2008). Kochia can emerge throughout the growing season if conditions are suitable, but the majority of seedlings emerge in the first spring flush. In annual cropping systems, most kochia seedlings emerge before the crop is planted, or before the first in-crop herbicide application. However, after the initial herbicide application, significant numbers of seeds may continue to recruit. Schwinghammer and Van Acker (2008) reported that an average of 68 kochia plants m^{-2} emerged after the in-crop herbicide application. Late emerging kochia escaped control and had the potential to produce viable seed.

Kochia has no innate seed dormancy, which means kochia has a transient seed bank that relies heavily on being replenished with a new cohort of seed each year (Schwinghammer and Van Acker 2008). Aside from the seed produced annually, there is very little seed carried over from year to year in the soil. By delaying seeding until late May, when most of the kochia plants have emerged, and controlling the emerged plants with tillage, or a non-selective herbicide application, farmers can reduce kochia infestations.

Kochia seedling recruitment is greatest from seeds near, or on the soil surface (Johnson et al. 1990). Recruitment of kochia seedlings on the soil surface was 80% and when kochia seed was buried 30 mm deep, seedling recruitment decreased to 65%. When kochia seed was buried 50 mm deep, seedling recruitment decreased to 15%, showing that kochia has limited ability to emerge from the soil when it is buried. Burial of kochia seed with tillage is a good method to reduce seedling recruitment.

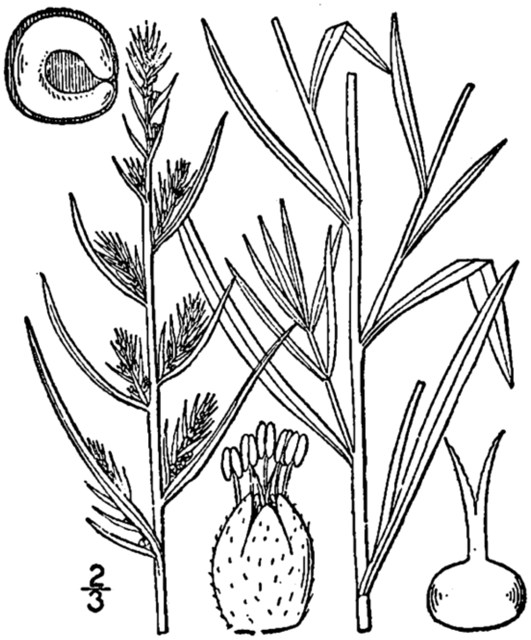

Figure 2.1. Depiction of kochia stems, florets and seeds (Britton and Brown 1913).

2.9.3 Geographic Distribution of Kochia

Kochia was introduced to North America as an ornamental plant from Asia and can be found in cultivated fields, gardens, ditches and waste areas (Friesen et al. 2009). Kochia is widely distributed throughout North America and in Canada, kochia is present in all provinces except Newfoundland and Labrador.

In the northwest United States, kochia spread faster than any other weed over ten decades (Forcella 1985). From 1881 to 1890, kochia was absent from all counties in the northwest USA, but by 1971 to 1980, kochia was found in 82 counties. One of reasons kochia may have spread so rapidly is the speed at which kochia seed germinates after entering the soil. Kochia seeds start to germinate two days after it enters soil and finishes germinating five days after it enters soil. A single kochia plant has the ability to spread seed long distances due to the tumbleweed nature that allows kochia plants to be blown across open fields spreading seeds (Friesen et al. 2009).

2.9.4 Herbicide Resistant Kochia

Acetolactate synthase (ALS) is an enzyme that is necessary for the synthesis of branch-chain amino acids, including valine, leucine and isoleucine (Whitcomb 1999). ALS-inhibitor herbicides inhibit the production of these amino acids, which are required for plant growth. In 1987, the first ALS-inhibitor herbicide resistant kochia population was discovered in a Kansas wheat field five years after ALS-inhibitor herbicides were introduced (Primiani et al. 1990). In Canada, the first reported cases of herbicide resistant kochia were in 1988 in Manitoba and Saskatchewan and then in Alberta in 1989

(Morrison and Devine 1994). About 90% of kochia populations collected from fields in southern Manitoba were cross-resistant to multiple ALS-inhibitor herbicides, which included the active ingredients thifensulfuron plus tribenuron mixture, flucarbazone, florasulam and imazemethapyr plus imazamox mixture (Friesen et al. 2009). ALS-inhibitor herbicide resistance in kochia is caused by a single point mutation in the ALS nuclear gene (Primiani et al. 1990).

Dyer et al. (1993) confirmed that ALS-inhibitor herbicide resistant kochia biotypes had a fitness advantage over susceptible accessions, especially under cold temperatures. Total germination of resistant and susceptible accessions tested was the same at all temperatures, but the susceptible accessions required more time to reach their maximum germination percentage compared to the resistant accessions. Even slight differences in the rate of germination may give ALS-inhibitor herbicide resistant plants a competitive advantage over herbicide susceptible plants, especially when moisture is a limiting factor, or when space is limiting.

2.9.5 Crop Yield Loss Caused by Kochia Interference

Kochia has the potential to be a particularly competitive weed compared to some other species. In sugar beets, to achieve the same level of yield loss as caused by kochia, green foxtail required five times the number of plants (Mesbah et al. 1994). Work near Fargo, ND, that investigated the effect of kochia interference on oat yield between 1991 and 1995, found that 30 kochia plants m^{-2} reduced oat yield by 12% to 31% in two years of the experiment (Manthey et al. 1996). The two years that kochia reduced oat yield were

1991 and 1994, which were years with average May and June temperatures that exceeded the 30 year average.

Replacement series experiments, where two plant species are grown both alone and together to determine the intensity of competition when the plants are grown together, have been used extensively in ecological studies (Rodriguez 1997). Fischer et al. (2000), conducted a controlled environment replacement series study with temperature and light regimes designed to replicate both warm and cool growing seasons. Under warm, dry growing conditions, wheat and barley CO_2 uptake was low and kochia CO_2 uptake was high, indicating kochia had greater photosynthetic rates than wheat, or barley growing in warm, dry conditions. When the experiment was repeated under cool growing conditions, the photosynthetic rates of the kochia plants decreased significantly, however, the photosynthetic rate of kochia did not drop below the photosynthetic rate of wheat and barley.

2.10 Biennial wormwood

2.10.1 Description of Biennial Wormwood

Biennial wormwood is a member of the Asteraceae family and the genus *Artemisia* (Kegode and Christoffers 2003). Biennial wormwood is a green, erect, hairless plant that can grow up to 2 m tall and may branch from the base if space permits. Leaves are lobed, often with toothed margins on the lower leaves (Fig. 2.2).

2.10.2 Biology and Growth of Biennial Wormwood

Biennial wormwood can behave as a biennial, as the name implies, but the biotypes found in agricultural fields are predominately annual biotypes (Kegode and Christoffers 2003). Biennial wormwood is very similar to annual wormwood (*Artemisia annua* L.) in appearance, but the panicle of annual wormwood is open and loose compared to the dense spike of biennial wormwood. Biennial wormwood begins to emerge in the spring and can continue to emerge until fall if conditions are favourable.

Seed bank persistence of biennial wormwood depends on soil moisture content. In an experiment investigating the potential for biennial wormwood seeds to persist in the soil, seeds were buried and recovered 23 months later (Kegode et al. 2009). In dry soil conditions, biennial wormwood had the potential to form persistent soil seed banks, but in wet soil conditions, biennial wormwood seed was subject to rapid decay.

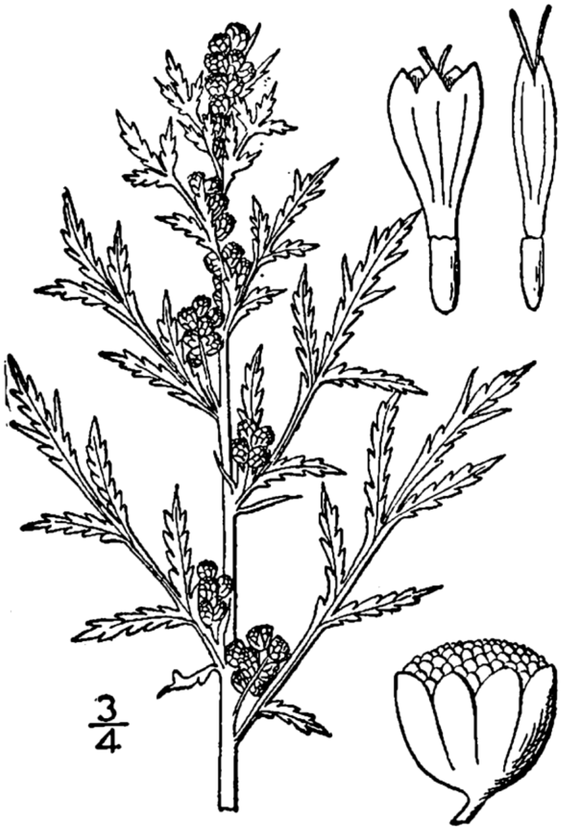

Figure 2.2. Depiction of biennial wormwood stem, florets and seed heads (Britton and Brown 1913).

2.10.3 Geographic Distribution of Biennial Wormwood

The *Asteraceae* genus originated in central Asia, but biennial wormwood is native to the lower 48 United States and was introduced into Canada and Alaska (Kegode and Christoffers 2003). In Manitoba, biennial wormwood was found in 1.1% of 631 fields surveyed in 2002, which ranked it as the forty-third most prevalent weed in Manitoba (Leeson et al. 2002). In the same survey, there were areas of Manitoba where biennial wormwood was found in greater frequencies. For example, around Killarney, MB, biennial wormwood was found in 13.6% of fields, making biennial wormwood the fifteenth most prevalent weed in that area. In the Pilot Mound, MB region, biennial wormwood was found in 11.1% of the fields, ranking it the twelfth most prevalent weed in that area.

The following four scenarios may have led to the increase in biennial wormwood abundance:

1) There has been an increase in zero till production in both Canada and the United States. Initially, biennial wormwood was reported as a weed commonly found in zero till fields. Biennial wormwood can emerge throughout the growing season, often after pre-seed glyphosate applications, which allows biennial wormwood to escape control and proliferate (Kegode and Christoffers 2003).

2) There has been a dramatic increase in soybean acreage. In Manitoba, soybean production increased from about 325 ha in 1996 (Froese et al. 2006) to about 344,000 ha in 2012 (Anonymous 2012c). Many of the herbicides commonly used on non-herbicide tolerant soybeans are ineffective for controlling biennial wormwood (Kegode and Christoffers 2003). There has also been widespread adoption of glyphosate-resistant

(GR) soybeans (Fronning and Kegode 2004). In 1996, GR soybeans were introduced in North America, and since then, GR soybeans have been widely adopted by farmers, with approximately 92% of the soybeans planted in the United States in 2008 being tolerant to this herbicide (Anonymous 2008b). The season–long emergence of biennial wormwood, combined with the fact that glyphosate has no residual soil activity, allows some biennial wormwood to escape control.

3) The leaf shape of biennial wormwood resembles common ragweed (*Ambrosia artemisiifolia* L.). Many of the herbicides that control common ragweed do not control biennial wormwood, so there may have been mis-directed herbicide applications that did not control biennial wormwood (Kegode and Christoffers 2003).

4) There may have been large amounts of seed produced by biennial wormwood in the 1990s leading to its rapid spread across the northern great plains. Biennial wormwood thrives in moist soil conditions and precipitation during the 1990s was greater than average (Kegode and Christoffers 2003).

2.10.4 Biennial Wormwood Management

Tillage is one of the most effective management methods for biennial wormwood, but there are also several herbicides available to control biennial wormwood (Kegode et al. 2007). When applying non-residual herbicides, the emergence patterns of weeds are critical factors that determine the effectiveness of the treatment (Hilgenfeld et al. 2004). To control species that have the potential to emerge later in the growing season, it is important to either delay herbicide applications, or use multiple applications. Even if the time of herbicide application is altered to control a weed, other weeds may increase in prevalence, which results in a shift in species composition. There is limited research examining yield loss caused by biennial wormwood interference in crops, but yield loss in soybeans resulting from biennial wormwood interference can be as great as 44% at densities of 10 biennial wormwood plants m^{-2} (Nelson and Kegode 2005).

2.11 Experiment Objectives

This research addressed two separate objectives. These were:

(i) To determine the effect of increasing densities of kochia and biennial wormwood on sunflower growth and development, yield and seed quality

(ii) To determine action thresholds for kochia and biennial wormwood in sunflowers.

3.0 Effect of Kochia (*Kochia scoparia* L. Schrad.) Interference on Sunflower (*Helianthus annuus* L.) Yield

Abstract. Kochia is a common weed found in some agricultural fields across the Northern Great Plains. However there is no information about the competitive ability of kochia plants in reduced tillage sunflower production fields that only use herbicides to manage weeds. Field experiments were conducted from 2009 to 2011 to determine the effect of kochia density and relative time of kochia seedling recruitment on sunflower growth and development, yield and seed quality. Kochia seed was broadcast on the soil surface into sunflowers planted in 75 cm rows at rates of about 0, 25, 125, 250, 500, or 1000 viable kochia seeds m^{-2}, either at the same time as the sunflower crop was planted (early weed seedling recruitment), or when the sunflowers were at about the 4-leaf stage (late weed seedling recruitment). When kochia plants emerged at about the same time as the sunflowers, yield was reduced by up to 91.4% and sunflower head diameter, stem diameter, height and the number of leaves per sunflower plant were reduced in some experiments. Additionally, early recruiting kochia seedlings reduced sunflower seed size and weight, in some experiments. Kochia plants that emerged after the 4-leaf stage of the sunflower crop did not affect sunflower yield, or seed quality.

3.1 Introduction

Wide inter-row spacing, low plant density and delayed canopy closure make sunflowers susceptible to yield loss from weed interference early in the growing season (Chubb 1975, Chubb and Friesen 1984, Durgan et al. 1990, Grenze et al. 2008, Lehoczky et al. 2006, Reddy et al. 2008). Farmers in Manitoba, where the majority of Canadian sunflowers are produced, are planting sunflowers in reduced tillage systems that depend on herbicides to control weeds and in conventional tillage systems that use a combination of herbicides and tillage to control weeds (Anonymous 2006). There are several in-crop herbicides registered to control grassy weed species in sunflowers, but the selection of herbicides for in-crop broadleaf weed control in sunflowers is limited (Anonymous 2011a).

Kochia is an annual, bushy weed that is 0.15 to 2 m tall and is a serious concern across the Great Plains of North America (Friesen et al. 2009). Kochia has been increasing in prevalence in recent weed surveys, moving up in rank from 24th in relative abundance in the 1980s, to 10th in the 2000s (Leeson et al. 2005). In Manitoba, the majority of kochia seeds will germinate in the spring, after as few as 50 growing degree days (T_{base} 0 C) have accumulated and subsequent smaller flushes of seedlings may continue to recruit into the summer providing conditions are favourable (Schwinghammer and Van Acker 2008). The rapid, early season seedling recruitment of kochia may provide a competitive advantage over other plant species that emerge later in the spring when soil moisture may be limiting (Dyer et al. 1993).

Previous studies have documented the competitive ability of kochia. In sugar beets, 0.2 kochia plants m^{-1} of row reduced yield by up to 18% (Mesbah et al. 1994) and kochia reduced oat yield by 12 to 31% at a density of 30 plants m^{-2} (Manthey et al. 1996). Kochia reduced wheat yield by 40 to 60% at densities of 240 to 520 plants m^{-2} respectively, in a field study carried out in Manitoba (Friesen et al. 1991). Kochia growing only in the crop row reduced sunflower yield by 27% at a density of 6 plants m^{-1}

of row (Durgan et al. 1990). The effect of kochia growing in both the inter-row space and in the crop row, as is the case in a reduced tillage system, has not been examined.

In Canada, most farmers apply herbicides as a prophylactic measure to prevent yield loss from weed interference regardless of the economic gains, or losses likely to be realized (O'Donovan 1996). The unnecessary use of herbicides may lower profit margins, contribute to environmental damage, such as ground water contamination and increase selection pressure for herbicide resistant weeds. By using action thresholds, farmers may be able to determine when it is necessary to initiate weed control measures and avoid unnecessary herbicide applications (Knezevic et al. 1994). An action threshold is a level of yield loss at which weed control is initiated and is determined by economic, risk aversion, sociological, or aesthetic factors (Coble 1992).

Experiments with locations throughout southern Manitoba were initiated to determine the effect of kochia density and relative time of kochia seedling recruitment on sunflower growth and development, yield and seed quality. The data were used to determine the action threshold (5% yield loss) for kochia in sunflowers.

3.2 Materials and Methods

3.2.1 Experimental Locations

Field experiments were conducted from 2009 to 2011 at the Ian N. Morrison Research Farm at Carman, MB, (49^{o} 30' 5.80" N, 98^{o} 01' 39.75" W), at Winnipeg, MB (49° 48' 14.94" N, 97^{o} 09' 14.47" W) and near the town of Melita, MB (49° 16' 7.71" N, 100^{o} 59' 41.94" W). Soil texture, pH and soil organic matter are summarized in Table 3.1. At

Carman, the soil was a Rignold, Gleyed Black, fine sandy loam soil (Mills and Halaschuck 1993). At Winnipeg, the soil was a Riverdale silty clay (Wiens et al. 2006). At Melita, in 2009 the soil was a fine sandy loam, Gleyed Black Chernozem member of the Cameron Association and in 2010, the soil was a sandy loam Gleyed Black Chernozem member of the Waskada Association (Anonymous 2012a). All the experiments were planted on cereal stubble, with the exception of the Winnipeg experiments which were planted on oat green manure in 2009 and fallow in 2011. In 2010, a second experiment was established at Carman (designated Carman2), 27 days after the first experiment was planted at Carman (Table 3.2).

Soil nutrient status (N, P, K and S) was analyzed prior to seeding each year and nitrogen and phosphorus fertilizers were applied to ensure adequate soil fertility (Table 3.3). At Carman and Winnipeg, granular fertilizer was broadcast and incorporated prior to planting and at Melita, liquid fertilizer was applied at the time of planting. Daily temperature and precipitation data and long-term temperature and precipitation averages (1971-2000) were obtained from the closest weather stations (Table 3.4).

Table 3.1. Soil texture, pH and organic matter content at the experiment locations investigating the effect of kochia interference on sunflower growth and development, yield and seed quality.

Experiment	Soil texture	pH	OM (%)
Melita 2009	fine sandy loam	7.1	^
Winnipeg 2009	silty clay	8.0	5.2
Carman 2010	fine sandy loam	6.1	3.6
Carman2 2010	fine sandy loam	5.9	4.2
Melita 2010	sandy loam	7.4	3.7
Carman 2011	fine sandy loam	5.8	5.5
Winnipeg 2011	silty clay	8.1	5.1

^ - not available

Table 3.2. Summary of the planting dates of sunflowers and kochia for each of the experiments.

Experiment	Sunflower	Early kochia recruitment	Late kochia recruitment
	----------------------	planting date	-------------------
Melita 2009	May 29	May 28	June 25
Winnipeg 2009	June 3	June 3	June 26
Carman 2010	May 18	May 19	June 23
Carman2 2010	June 14	June 14	July 8
Melita 2010	June 2	June 9	June 28
Carman 2011	May 19	May 19	June 17
Winnipeg 2011	May 20	May 20	June 20

Table 3.3. Summary of the nutrient status at each of the experiment locations prior to seeding each year and the fertilizer that was added to each of the experiments.

Experiment	N*	P**	K	S***	N	P
	-----------pre-seed soil analysis------------				---fertilizer applied---	
	kg ha^{-1}	---ppm---		kg ha^{-1}	----actual kg ha^{-1}----	
Melita 2009	30	20	268	537	90	34
Winnipeg 2009	153	20	556	515	0	0
Carman 2010	25	10	137	40	70	20
Carman2 2010	33	17	231	65	70	20
Melita 2010	49	5	260	339	90	34
Carman 2011	39	22	456	56	70	20
Winnipeg 2011	19	22	502	212	100	0

* nitrate (0-60 cm), ** Olsen, *** sulfate (0-60 cm)

Table 3.4. Mean monthly temperature and precipitation during the growing season (May to September) and long-term (1971-2000) averages at the experimental locations.

Location	Year	May	June	July	August	September	Growing season
Air temperature (^oC)							Average
Carman[1]	2010	11.6	16.4	19.6	18.7	11.8	15.6
	2011	10.4	16.7	20.3	19.3	14.0	16.1
Long term average[3]		12.4	17.2	19.7	18.1	12.2	15.9
Melita[1]	2009	9.9	15.0	16.9	17.1	17.4	15.3
	2010	11.0	16.7	19.2	18.5	11.7	15.4
Long term average[3]		12.6	17.1	19.5	18.5	12.2	16.0
Winnipeg[2]	2009	11.0	16.0	17.6	17.7	18.6	16.2
	2011	11.3	17.6	21.9	21.0	14.7	17.3
Long term average[3]		12.0	17.0	19.5	18.5	12.3	15.9
Precipitation (mm)							Total
Carman[1]	2010	159.2	73.2	48.0	138.4	106.5	525.3
	2011	72.0	59.2	37.6	12.2	64.5	245.5
Long term average[3]		59.8	75.5	73.5	66.8	59.5	335.1
Melita[1]	2009	14.8	49.0	65.4	44.0	53.9	227.1
	2010	97.7	109.4	67.6	89.6	35.0	399.3
Long term average[3]		47.8	85.3	67.4	58.5	50.7	309.7
Winnipeg[2]	2009	64.0	88.1	110.8	92.2	44.5	399.6
	2011	52.0	47.2	14.1	22.0	61.8	197.1
Long term average[3]		58.0	89.5	70.6	75.1	51.9	345.1

[1] Manitoba Agriculture Food and Rural Initiatives Weather Program

[2] University of Manitoba, Department of Plant Science Weather Station

[3] Environment Canada 30 year averages

3.2.2 Experimental Design and Plot Establishment

The experiment was a two-way factorial design laid out as a split-block, randomized complete block design, with four replicates. The main block was the time of kochia seedling recruitment relative to the crop, targeting recruitment at either the same time as the sunflowers (designated early seedling recruitment), or after the 4-leaf stage of the sunflowers (designated late seedling recruitment). The six sub-plots in the experiment were kochia plant density, arranged using an additive design. To achieve a range of kochia densities, kochia seed was hand broadcast evenly over the entire plot area at rates of about 0, 25, 125, 250, 500 and 1000 viable kochia seeds m^{-2}. In 2011, the kochia seeding rates were doubled to increase kochia densities.

Each 3 m wide, by 4 m long sub-plot consisted of four rows of sunflowers planted 75 cm apart. Prior to planting each year, a weed-free seed bed was prepared by controlling weeds with cultivation at Winnipeg and Carman and a pre-seed glyphosate application at a rate of 1334 g acid equivalent (a.e.) ha^{-1} at Melita. Sunflower cultivar 6946 (Seeds 2000, Breckenridge, MN) was planted about 2.5 cm deep using a small plot seeder at a rate of 54,340 seeds ha^{-1}, when field conditions were favourable in the spring (Table 3.2). After the sunflower plants emerged, sethoxydim (500 g a.i. ha^{-1}) plus Merge (0.5% v/v), a non-ionic surfactant, was applied as recommended using an ATV mounted sprayer to control grassy weed species as required. All other weeds except kochia were hand pulled, or hoed during the growing season to eliminate interference from non-target weed species.

3.2.3 Data Collection

Data were collected over the course of the growing season to measure the effect of kochia interference on sunflower growth and development. Sunflower plant population in each plot was determined by counting all the sunflower plants in the centre two rows of each plot (8 m of row) at about the eight leaf stage. With the exception of sunflower populations, all other measurements were conducted excluding the first and last metre of the plot, and 75 cm on each side of the plot. Kochia density was determined at the same time as the sunflower populations, using two 0.25 m^2 quadrats randomly placed in the sampling area of each plot. Sunflower plant heights were determined by measuring the average height of five randomly selected plants per sub-plot in late August. Sunflower plant stem diameter was determined on ten plants, 30 cm from the soil surface using digital calipers in late August. The number of leaves per sunflower plant was counted on five plants per sub-plot once the crop had headed. The proportion of anthesis completed was determined when the sunflowers were at the R5 stage (Schneiter and Miller 1981). Five plants from each plot were selected at random and the portion of the head that had completed anthesis was rated on a scale of 1-10 (Fig. 3.1). Head diameter was determined at harvest by measuring the diameter of ten heads per plot.

To determine yield, heads were hand harvested at physiological maturity, when the bracts on the back of the head were brown. In each plot, the heads from 2 m from each of the middle two rows of the plot were collected. The heads were bagged, air dried, and threshed with a stationary small plot combine (Wintersteiger Nursery Master Classic, Salt Lake City, UT, USA) at Winnipeg. After threshing, samples were cleaned using a seed cleaner (Clipper M2BC, Blount/Ferrell-Ross, Bluffton, IN, USA) fit with a #26 round sieve on the top and #10 round sieve on the bottom and then weighed to determine yield. Sunflower seed size and thousand kernel weight (TKW) from each plot were determined by generating a digital image of about 150 sunflower seeds on a flat-bed computer scanner and then using Assess 2.0 Image Analysis Software (The American Phytopathological Society 2008) to measure seed size and count the seeds. The same sample was then weighed in order to determine TKW. The seed was dried to equilibrium for 72 hours at 65 C, gravimetric moisture content of the seed was determined (eqn. 2) and the yield and TKW were adjusted to 10% moisture content.

$$\text{\% seed moisture content} = \frac{(\text{wet seed weight (g)} - \text{dry seed weight (g)})}{\text{wet seed weight (g)}} \times 100 \qquad \text{[eqn.2]}$$

Figure 3.1. Proportion of anthesis completed was rated according to the percent of the head that had completed anthesis on the rating date. In the pictures above, the head on the left was rated as 50% completed anthesis (rated 5.0) and the head on the right was rated as 80% completed anthesis (rated 8.0).

3.2.4 Statistical Analysis

Statistical analysis was conducted using SAS 9.2 software (SAS Institute, Carey, NC, USA). Prior to analysis, outliers were removed based on studentized residuals (Lund 1975). Initially, experiments were analyzed individually because of the variability in kochia density among years and differences in environmental conditions among the site-years. Subsequently, a combined analysis, including all site years, was performed to calculate model parameters that could be used to estimate yield loss due to kochia interference for multiple environments and years. The most appropriate method to analyze the relationship between yield loss and weed density in additive experimental designs is to use regression analysis (Cousens 1988). The relationship between yield loss and kochia density was determined using a non-linear, rectangular hyperbola regression model (Cousens 1985) that is commonly used in weed interference studies (e.g. Blackshaw 1993, Knezevic et al. 1994, Swinton et al. 1994). The relationship is described by the equation:

$$YL = Id/(1 + Id/A) \qquad \text{[eqn. 3]}$$

where YL, is the percent yield loss, I is the percent yield loss per weed as weed density approaches zero, d is weed density and A is the percent yield loss as weed density approaches infinity. The percent yield loss (YL) for each treatment was determined on treatment averages (eqn. 4). The NLIN procedure produced parameter estimates for I and A that were used to generate yield loss curves. These model parameters were then used to calculate action thresholds to determine the kochia density that resulted in 5% yield loss in sunflowers.

$$\%\ YL = 100 – ((\text{average treatment yield}/\text{average weed free treatment yield}) \times 100) \qquad \text{[eqn. 4]}$$

The relationships between sunflower growth and development, seed quality parameters, and increasing kochia densities were determined using PROC GLM to test for significance of linear and quadratic components.

3.3 Results and Discussion

3.3.1 Kochia Seedling Recruitment

The level of kochia seedling recruitment varied among years and locations (Table 3.5). The maximum kochia plant density achieved for the early seeded treatments at each site ranged from a low of 28 kochia plants m^{-2} (2.8% seedling recruitment) at Melita 2010, to 905 kochia plants m^{-2} (45.3% seedling recruitment) at Winnipeg 2011. The late recruiting kochia plant densities in 2009 and 2011 were comparable to the early recruiting kochia plant densities in those years. In 2010, precipitation was greater than the long-term average (LTA) at both Carman (157% of LTA) and Melita (129% of LTA) from May to September. The greater than average growing season precipitation may have reduced kochia plant recruitment because kochia plants thrive under warm, dry conditions (Friesen et al. 2009).

3.3.2 Sunflower Yield and Yield Loss

Sunflower yield in the weed-free treatments ranged from 2355 to 3360 kg ha^{-1} (Table 3.6). The experiments planted in May tended to yield greater than the experiments planted in June. Previous research reported greater yields for early seeded wheat (Blackshaw et al. 2005), canola (Smith et al. 2006), oats (May et al. 2009), peas, lentils and chickpeas (Miller et al. 2006). Excess moisture led to the termination of the Winnipeg 2010 and Melita 2011 experiments.

When kochia plants emerged at about the same time as the sunflowers, the rectangular hyperbola model adequately described the observed yield loss at four of the seven site-years (Table 3.6). At these four site-years, the model parameter *A* (maximum yield loss) ranged from 31.0 to 91.4 % and was greatest at the Winnipeg 2011 location. The high level of yield loss at Winnipeg 2011 was probably due to the relative time of kochia seedling recruitment and the environmental conditions during the growing season that year. At Winnipeg 2011, kochia plants emerged about eight days before the sunflowers (Table 3.6) and previous research clearly demonstrated that the time of weed seedling recruitment relative to the crop affects the level of yield loss resulting from weed interference in sunflowers (Chubb 1975, Chubb and Friesen 1985, Durgan and Miller 1981 and Durgan et al. 1990). Over the course of the growing season, precipitation was

Table 3.5. The actual levels of kochia seedling recruitment (SEM) measured for early and late recruiting kochia plants at each of the experiments.

Experiment	Emergence time	Kochia density treatment											
		1		2		3		4		5		6	
		# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM
Melita 2009	Early	0	(0) c	7	(4) bc	10	(3) bc	13	(1) bc	27	(6) ab	44	(11) a
Winnipeg 2009		0	(0) c	7	(1) c	14	(2) bc	21	(7) bc	55	(12) b	120	(20) a
Carman 2010		0	(0) c	2	(1) bc	8	(2) abc	14	(4) abc	30	(13) ab	33	(13) a
Carman (2) 2010		0	(0) b	7	(4) b	10	(3) b	22	(9) b	37	(11) ab	66	(15) b
Melita 2010		0	(0) c	2	(1) c	7	(2) bc	9	(2) bc	19	(3) ab	28	(7) a
Carman 2011		0	(0) d	41	(7) cd	141	(18) cd	261	(65) bc	485	(62) b	829	(75) a
Winnipeg 2011		0	(0) d	34	(3) d	201	(34) cd	340	(64) c	563	(28) b	905	(78) a
Melita 2009	Late	0	(0) b	3	(3) b	5	(4) b	10	(4) b	27	(12) b	59	(8) a
Winnipeg 2009		0	(0) c	5	(2) c	10	(3) bc	21	(3) bc	43	(5) b	107	(17) a
Carman 2010		0	(0) b	2	(2) b	2	(2) b	9	(4) ab	15	(5) a	21	(7) a
Carman (2) 2010		0	(0) a	1	(0) a	1	(1) a	1	(1) a	2	(1) a	0	(0) a
Melita 2010		0	(0) a	1	(0) a	0	(0) a	0	(0) a	1	(1) a	3	(2) a
Carman 2011		0	(0) d	63	(11) d	276	(30) cd	480	(49) bc	682	(29) b	1189	(175) a
Winnipeg 2011		0	(0) c	37	(14) c	144	(15) c	493	(115) b	732	(64) b	1302	(92) a

m^{-2} is the actual density of kochia plants that recruited m^{-2}.

Means across rows followed by the same letter are not significantly different according to Tukey-Kramer LSD at the 0.05 level of significance.

57% of the long-term average and daily temperatures were above average. The warm, dry conditions combined with excellent kochia seedling recruitment, likely increased the ability of kochia to reduce sunflower yield. In oats, kochia reduced yield more in dry years than wet years (Manthey at al. 1996).

The values for model parameter *I* (percent yield loss per weed as weed densities approach zero) ranged from 0.8 to 5.2% (table 3.6) indicating that the competitive ability of kochia at low densities was variable among site-years. The model parameter *I* was greatest at Winnipeg 2011, likely due to the same reasons that the *A* value was greatest at Winnipeg 2011. At Winnipeg 2011, the number of sunflower heads harvested decreased as the density of early recruiting kochia plants increased (Fig. 3.2). When sunflower plant population was determined at about the 8 leaf stage, increasing kochia densities did not affect sunflower plant densities in any of the site-years. The reduction in the number of sunflower heads harvested appeared to be determined after the 8-leaf stage.

The only site-year where yield loss data conformed to a linear model was at Carman 2011 (Fig. 3.3). It should be noted the mean yield reduction at the third density of kochia was not considered an outlier (based on studentized residuals) and as a result was included in the analysis. Visually, this mean does not appear to conform to the rectangular hyperbola model. When this mean is excluded, these data conform to the rectangular hyperbola model with *I* and *A* values of 0.11% and 75.7% respectively (appendix Fig. 7.3).

Although the rectangular hyperbola model is widely cited and noted for being biologically realistic, results of the present study show that it may not apply to all situations. Numerous regression equations that model yield loss resulting from weed interference have been evaluated (eg. Cousens 1985, O'Donovan et al. 2005). Cousens

(1985) evaluated several previously published yield loss models and found other models such as those proposed by Watkinson (1981) and Hakassson (1983) to be nearly equivalent to the rectangular hyperbola in predictive ability.

Table 3.6. Relative time of seedling recruitment between kochia and the sunflower crop, weed-free yields determined in the experiments (SEM) and parameter estimates (+/- SE) for the rectangular hyperbola model for early recruiting kochia plants.

Experiment	Interval between weed and sunflower emergence[a]	Observed weed free yield	Model parameter[b]	
			I	*A*
	days	--kg ha^{-1}--	------------%------------	
Melita 2009	-1	3126 (150)	1.1 (0.6)	44.9 (31.9)
Winnipeg 2009	-2	2355 (277)	0.8 (0.7)	39.9 (31.7)
Carman 2010	0	3217 (252)	ns[c]	ns
Carman2 2010	-2	2409 (284)	3.6 (4.1)	31.0 (13.1)
Melita 2010	0	2536 (215)	ns	ns
Carman 2011	2	3360 (231)	ns	ns
Winnipeg 2011	-8	3166 (488)	5.2 (1.1)	91.4 (2.6)

[a] a negative interval indicates that the kochia plants emerged before the sunflower crop.

[b] *I* is the percent yield loss per weed as weed density approaches zero, and *A* represents the asymptote, which is the percent yield loss as weed density approaches infinity.

[c] ns indicates that the data did not conform to the rectangular hyperbola yield loss model

When kochia plants emerged at the same time as the crop at Carman and Melita 2010, the yield loss data could not be described adequately using the rectangular hyperbola, linear, or quadratic models (see appendix). This may have been due to the low level of kochia seedling recruitment observed at these locations (maximum seedling recruitment was 33 kochia plants m^{-2} at Carman 2010 and 28 kochia plants m^{-2} at Melita 2010), or the greater than average precipitation and less than average temperatures during the 2010 growing season. The environmental conditions may have reduced the competitive ability of kochia. At Carman in 2010, kochia seedling recruitment in the later seeded, Carman2 2010, (June 14 planting date) experiment was greater than the earlier seeded Carman 2010 (May 19 planting date) experiment. The precipitation in June 2010 at Carman, when the second experiment was planted, was roughly equal to the LTA. This is in contrast to the first experiment planted at Carman in May, when precipitation was 266% of the LTA in May.

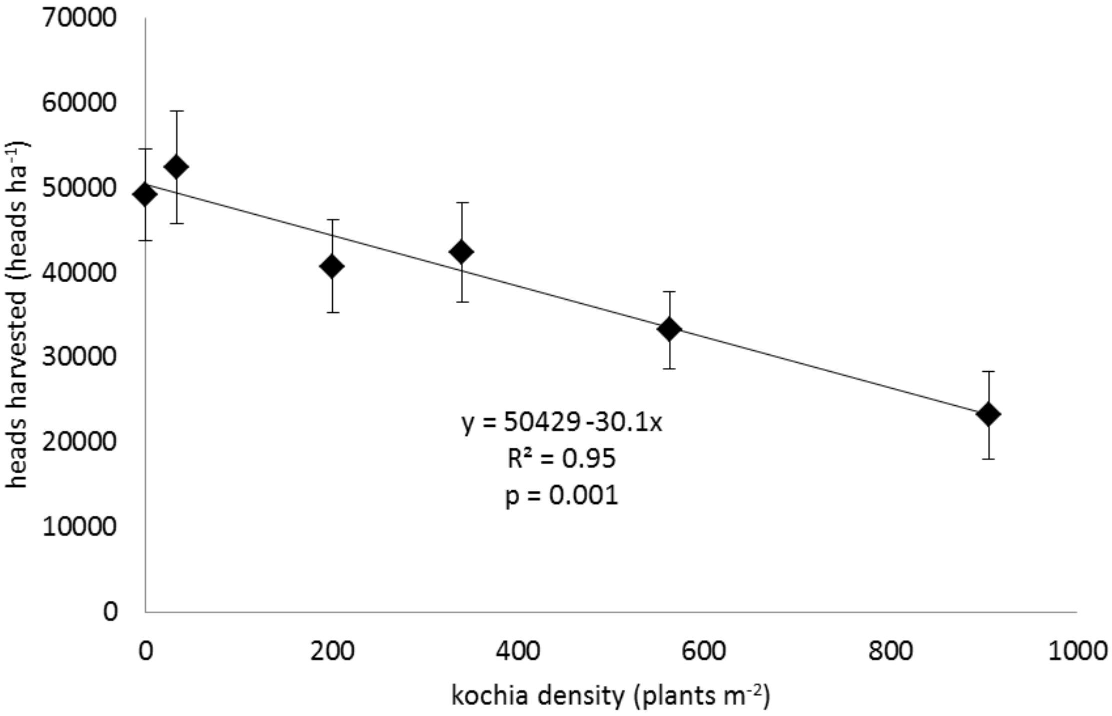

Figure 3.2. The effect of density of early recruiting kochia seedlings on the number of sunflower heads harvested at Winnipeg 2011. The regression equation and coefficient of regression are indicated. Bars indicate plus/minus one standard error of the mean.

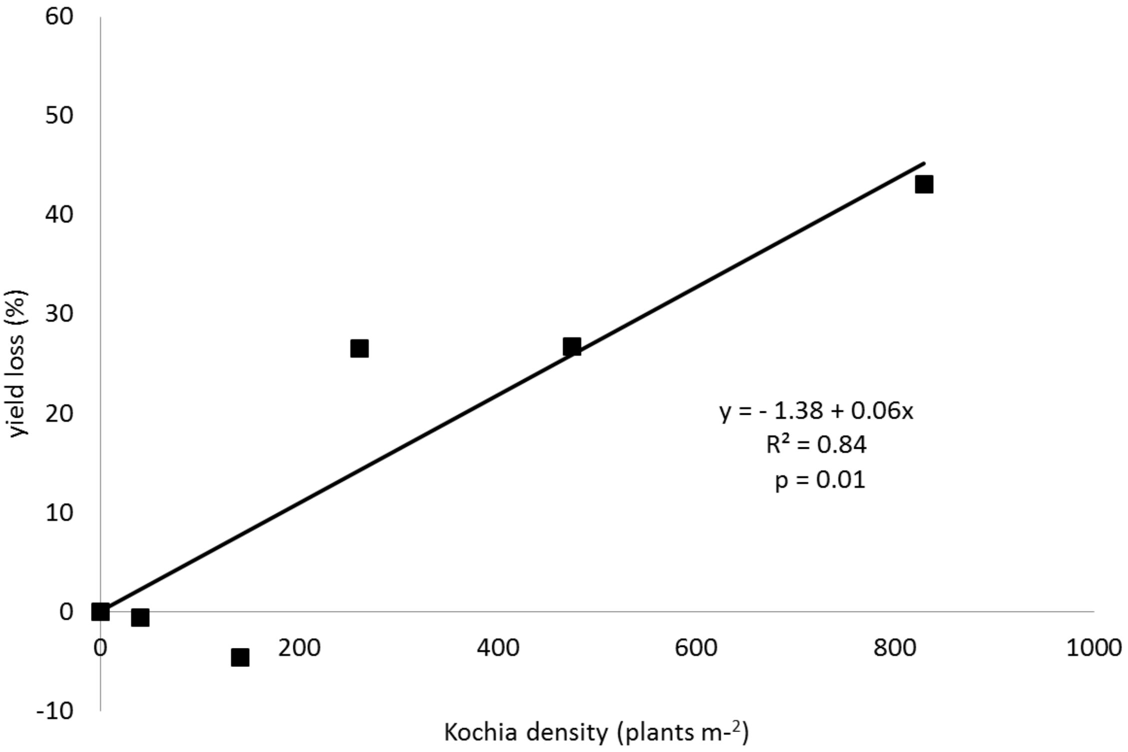

Figure 3.3. Yield loss resulting from increasing densities of early recruiting kochia seedlings at Carman 2011. The regression equation and coefficient of regression are indicated. Standard errors of the mean are not indicated because the yield loss is calculated as a percent of the weed-free treatment using treatment averages.

Yield loss resulting from increasing kochia plant densities that emerged after the 4-leaf stage of the sunflowers could not be described adequately using the rectangular hyperbola, linear, or quadratic models even when the kochia seedling recruitment was excellent (appendix Fig. 7.1). The sunflower canopy closed about 7 weeks after planting (based on visual observations) and the late recruiting kochia seedlings were still relatively small at this time and were never able to interfere effectively with the sunflowers. The inability of late recruiting weeds to reduce sunflower yield has been documented in previous research (Chubb 1975, Chubb and Friesen 1984 and Durgan et al. 1990).

There are several factors that determine the ability of a weed to reduce crop yield. Potential yield loss resulting from weed interference depends on the weed species, plant density, and the time of weed seedling recruitment relative to the crop (Kropff 1988). Weeds that emerge early in the season are more competitive than weeds that emerge later in the season (e.g. Willenborg et al. 2005, Hock et al. 2006). In corn, time of seedling recruitment of redroot pigweed (*Amaranthus retroflexus* L.) was a more important factor in determining yield loss in corn than redroot pigweed density (Knezevic et al. 1994) and the same has been reported for downy bromegrass (*Bromus tectorum* L.) in wheat (Blackshaw 1993). Based on the results of this research, time of weed emergence also was an important factor that determined the ability of kochia to reduce sunflower yield.

3.3.3 Effect of Kochia Interference on Sunflower Growth and Development

In order to elucidate additional information about sunflower yield loss due to kochia interference, sunflower growth and development parameters were measured during the growing season. When early recruiting kochia plants reduced sunflower yield, concomitant reductions in sunflower stem diameter, sunflower height, sunflower head diameter and the number of leaves on each sunflower plant were observed in one or more of the experiments (Table 3.7). Head diameter was the most frequently affected parameter. This might be expected, as head diameter is expected to be closely related to yield. At Winnipeg 2011, sunflower leaf number, stem diameter, height and head diameter all decreased as kochia densities increased (Table 3.7). At Melita 2009, increasing densities of early recruiting kochia plants only reduced head diameter, while stem diameter, leaf number and sunflower height remained unaffected. At Winnipeg 2009, sunflower leaf number and height were reduced, but head diameter was unaffected by increasing densities of early recruiting kochia plants.

Changes in the growth and development of sunflower plants due to weed interference may be a cause for concern for several reasons. Sunflower plants with small diameter stems may be more susceptible to lodging in high winds, which would increase yield loss, or create problems during harvest. In previous research, sunflower plants with more live leaf tissue during grain filling yielded greater than plants with less live leaf tissue (Rawson and Turner 1983). The small plot size required in these experiments, due to the need for hand weeding to control unwanted weeds, meant that destructive measurements, such as leaf area could not be conducted.

At Winnipeg 2011, the sunflowers were noticeably chlorotic in the early recruiting kochia treatments, but not in the late recruiting kochia treatments, which may indicate low levels of available nitrogen in the early recruiting kochia treatments. This is of concern for farmers because nitrogen deficiency during early vegetative developmental stages of sunflower can decrease the number of leaves, reduce leaf expansion, and ultimately reduce the speed of sunflower growth (Connor and Sadras 1992).

Increasing densities of early recruiting kochia plants delayed sunflower anthesis in some experiments. Sunflower anthesis was delayed at Winnipeg 2009 ($y = 3.6 - 0.015x$, $R^2 = 0.95$, $p = 0.01$) and Carman 2011 ($y = 7.4 - 0.002x$, $R^2 = 0.90$, $p = 0.003$) as early recruiting kochia plant densities increased. Sunflowers take about 120 days to reach maturity (Anonymous 2006). There are on average about 130 frost free growing days in south central Manitoba (Anonymous 2001). Delays in sunflower development may be a serious concern for farmers because sunflowers, a crop that is typically harvested late in Manitoba, may be more susceptible to frost damage when an early fall frost event occurs.

Late emerging kochia had minimal effect on sunflower growth and development. Late recruiting kochia plants did not affect sunflower yield, thus it is not surprising that head diameter, leaf count, stem diameter and height were also unaffected by increasing densities of late recruiting kochia plants (see appendix). At Winnipeg 2009, the proportion of anthesis completed on the rating date increased linearly as late recruiting kochia plant densities increased (Fig. 3.4). There are no obvious reasons for this finding, but there are many different types of interactions among plants in addition to direct competition (Radosevich et al. 2007).

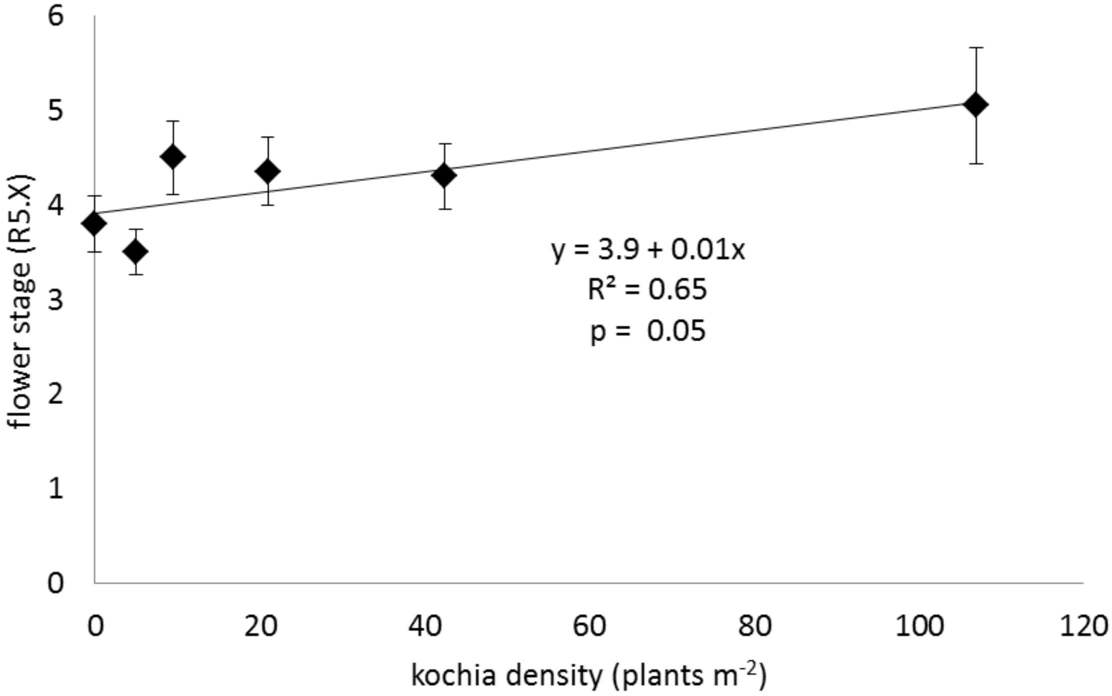

Figure 3.4. Relationship between late recruiting kochia plant densities and proportion of anthesis completed at Winnipeg 2009. The regression equation and coefficient of regression are indicated. Bars indicate plus/minus one standard error of the mean.

3.3.4 Effect of Kochia Interference on Sunflower Seed Quality

Test weight, seed size, heated seed and insect damage are key considerations in sunflower seed grading (Anonymous 2011b). In order to be considered No. 1 Canada, the grain has to be uniformly large with low levels of damaged, diseased and immature seed and also have low levels of foreign material. At both Winnipeg 2009 and Melita 2009, seed size decreased as the density of early recruiting kochia plants increased (Table 3.8). When kochia plants emerged at the same time as the sunflowers, increasing kochia densities reduced TKW at Melita 2009 and Carman 2011 by 0.391 and 0.019 g 1000 seeds^{-1}, respectively, for each kochia plant (Table 3.8). Increasing densities of late recruiting kochia plants did not affect sunflower seed size, or seed weight.

Sunflower head diameter appeared to be more sensitive to kochia interference than individual seed size. When kochia interference caused a significant reduction in head diameter, the size of the sunflower heads was reduced by an average of 24%, while seed size was reduced by only 7%.

The number of sunflower seeds per unit area is determined by the number of plants per unit area, the diameter of the heads and the size of the individual seeds. At Carman 2011 when kochia plants emerged at the same time as the sunflowers, the number of sunflower seeds produced per unit area decreased (Fig. 3.5) with a concomitant increase in yield loss (Fig 3.3) in response to increasing kochia density. When yield was reduced, and the number of seeds m^{-2} was stable, the decrease in yield may have been the result of smaller sunflower seeds, or a lower mass per sunflower seed. Increasing densities of early emerging kochia plants did not affect the number of sunflower seeds produced per unit area at any other site-year even when there was a significant yield reduction.

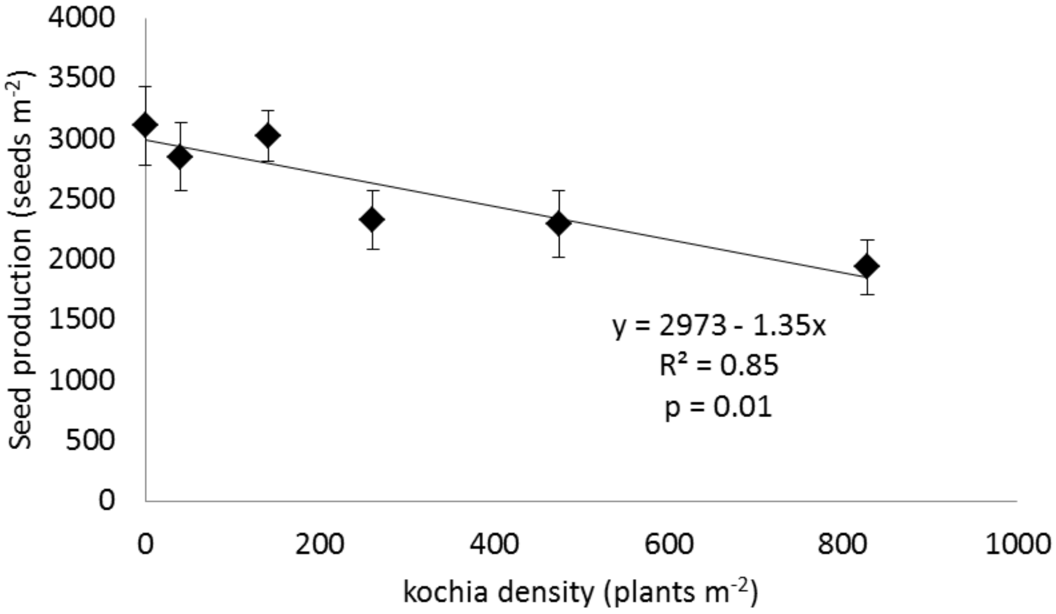

Figure 3.5. Relationship between early recruiting kochia seedlings and the number of sunflower seeds produced per square meter at Carman 2011. The regression equation and coefficient of regression are indicated. Bars indicate plus/minus one standard error of the mean.

Table 3.7. Summary of regression equations describing the effect of early recruiting kochia plants on sunflower leaf count, stem diameter, height and head diameter for the experiments that conformed to either the rectangular hyperbola, or linear model. Coefficients of regression and p values are indicated.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Head diameter (cm)		
Site-year	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	ns[a]	-	-	ns	-	-	ns	$y = 16.9 - 0.036x$	0.65	0.05
Winnipeg 2009	$y = 22.1 - 0.101x$ $+ 0.0006x^2$	0.95	0.03	-	-	ns	$y = 145.4 - 0.708x$ $+ 0.00385x^2$	0.95	0.04	-	-	ns
Carman2 2010	-	-	ns	$y = 30.3 - 0.072x$	0.73	0.03	-	-	ns	$y = 18.6 - 0.034x$	0.7	0.04
Carman 2011	-	-	ns	$y = 28.9 - 0.007x$	0.77	0.02	-	-	ns	$y = 18.4 - 0.003x$	0.88	0.01
Winnipeg 2011	$y = 23.0 - 0.024x$ $+ 0.00002x^2$	0.99	0.01	$y = 17.5 - 0.011x$	0.64	0.05	$y = 146.5 - 0.052x$	0.74	0.03	$y = 13.0 - 0.009x$	0.72	0.03

[a] ns indicates that there was no linear, or quadratic relationship between the parameter and kochia density

Table 3.8. Summary of regression equations describing the effect of early recruiting kochia plants on sunflower seed size and thousand kernel weight (TKW) for the experiments that conformed to either the rectangular hyperbola, or linear model. Coefficients of regression and p values are indicated.

	seed size (cm^2 $seed^{-1}$)			TKW (g 1000 $seeds^{-1}$)		
Site-year	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	$y = 0.7036 – 0.0014x$	0.87	0.01	$y = 111.3 – 0.391x$	0.86	0.01
Winnipeg 2009	$y = 0.7091 – 0.0003x$	0.7	0.04	-	-	ns
Carman2 2010	-	-	ns[a]	$y = 104.9 - 0.24x + 0.003x^2$	0.85	0.03
Carman 2011	-	-	ns	$y = 115.0 – 0.019$	0.65	0.05
Winnipeg 2011	-	-	ns	-	-	ns

[a] ns indicates that there was no linear, or quadratic relationship between the parameter and kochia density

Previous research that showed a reduction in sunflower yield in response to weed interference linked the yield loss to reduced seed numbers and lower TKW, and determined that head biomass was highly sensitive to weed interference (Grenz et al. 2008). The results of this study support these previous findings. Although head biomass was not measured directly in this research, head diameter (which would be expected to be correlated with head biomass) was reduced as a result of kochia interference.

3.3.5 Action Thresholds for Kochia Control in Sunflowers

Knezevic et al. (1994) used 5% yield loss as the action threshold at which a farmer should implement weed management practices for redroot pigweed in corn. In the present study, when kochia plants emerged at the same time as the sunflowers, the kochia density required to reduce sunflower yield by 5% varied from 1.0 (Winnipeg 2011) to 7.2 plants m^{-2} (Winnipeg 2009) for the experiments in which the data conformed to the rectangular hyperbola model (Table 3.9). At Carman 2011, the data fit a linear model and 106.2 kochia plants m^{-2} were required to reduce yield by 5%. This is a considerably greater density than the predictions for the locations that conformed to the rectangular hyperbola model.

The rectangular hyperbola and linear regression models utilized in the analysis of these data have important differences. The rectangular hyperbola model intersects the origin; therefore, when there are no weeds, there is no yield loss. At low weed densities, the rectangular hyperbola model is linear and each additional weed reduces yield by an equal amount due to primarily interspecific interference. As weed density increases, the effect of each additional weed decreases until each additional weed has no additional effect on yield due to both interspecific and intraspecific interference. Maximum yield loss for the rectangular hyperbola model is constrained and cannot exceed 100%. In a linear model, each weed reduces yield by an equivalent amount regardless of weed density, ignoring the effect of intraspecific weed competition. Linear models normally only intersect the origin when forced through this point. Additionally, linear models are not constrained to a maximum yield loss value, so predicted yield loss may exceed 100%. The rectangular hyperbola model is biologically realistic, which makes it a superior starting point for the analysis of yield loss data compared to linear regression.

When all seven experiments were analyzed together, the parameters for the rectangular hyperbola model were 0.52% and 81.8% for *I* and *A*, respectively (Fig. 3.6). The kochia density at which 5% yield loss occurred was 10.1 kochia plants m^{-2}. It follows that combining the site-years together into one model may provide the most robust prediction of yield loss in sunflowers because it includes data collected over multiple growing seasons and locations. The yield loss predictions from a combined site-year analysis do not take into account the environmental variability among site-years, which may lead to poor predictive ability in certain extreme years. In cool, wet years, such as 2010, data from 2010 may be more accurate than the combined site-year analysis for predicting yield loss due to kochia interference. In hot, dry years, such as 2011, on the other hand, data from that year alone may provide better predictive ability than the combined site-year analysis for predicting yield loss due to kochia interference.

Table 3.9. Kochia densities that resulted in 5% yield loss when the kochia seedlings recruited at the same time as the sunflower crop.

Experiment	Model choice	Kochia density (plants m^{-2})
Melita 2009	Rectangular hyperbola	5.2
Winnipeg 2009	Rectangular hyperbola	7.2
Carman 2010	ns[a]	-
Carman2 2010	Rectangular hyperbola	1.7
Melita 2010	ns	-
Carman 2011	Linear regression	106.2
Winnipeg 2011	Rectangular hyperbola	1.0

[a] ns indicates that the data did not conform to any of the models tested.

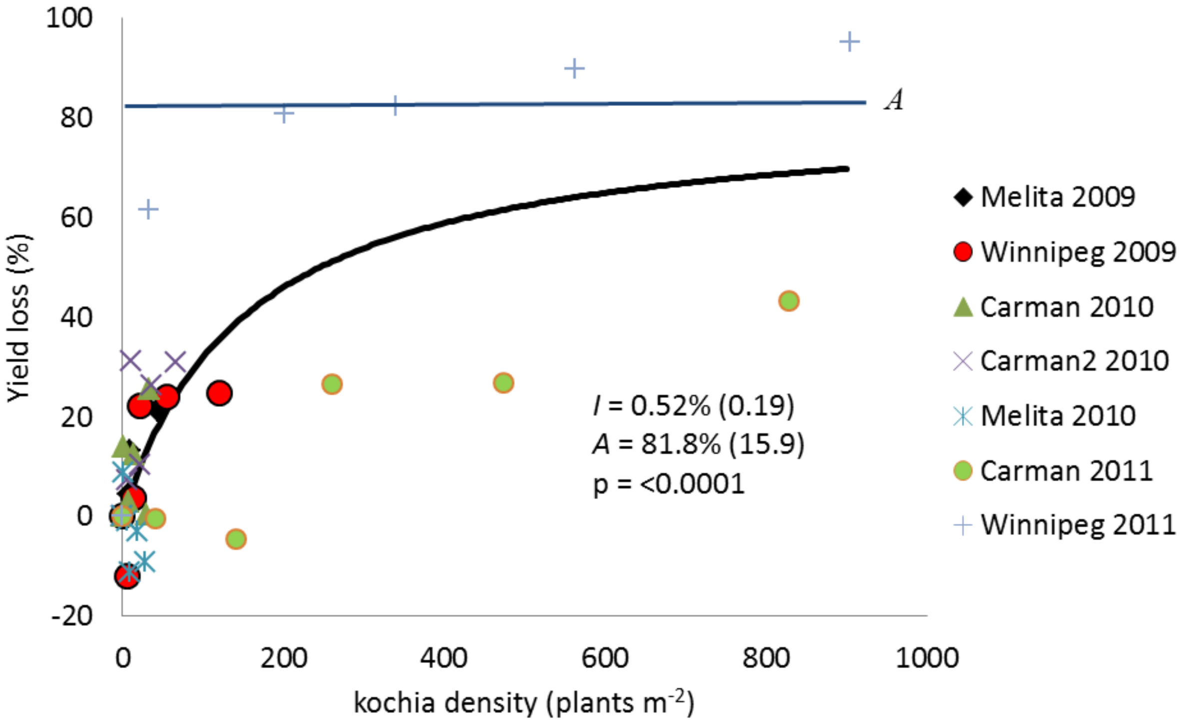

Figure 3.6. Sunflower yield loss as a function of kochia density when the kochia plants emerged at about the same time as the sunflowers (all experiments combined). *I* is the percent yield loss per weed at low weed densities and *A* is the maximum yield loss at high weed densities. The percent yield loss per weed at low weed densities (*I*) and the maximum yield loss at high weed densities (*A*) are indicated. Approximate standard error of the model parameters are indicated in parentheses.

3.4 Conclusion

Time of kochia seedling recruitment was an important factor that determined the competitive ability of kochia in these experiments. Kochia plants that emerged at about the same time as the sunflower crop significantly reduced sunflower yield, particularly when kochia seedling recruitment was excellent. When kochia emerged at the same time as sunflowers, the 5% yield loss action threshold was 10.1 kochia plants m^{-2}. This early emerging kochia also reduced sunflower head diameter, stem diameter, number of leaves per sunflower plant and height in some experiments. Sunflower seed size and seed weight were reduced in some experiments as a result of early season kochia interference. To maximize sunflower yield and ensure sunflowers meet the quality requirements to be sold into human consumption markets, sunflower growers should control kochia when this weed recruits before the 4-leaf stage of the crop, particularly in warm, dry years when kochia thrives.

4.0 Effect of Biennial Wormwood (*Artemisia biennis* Willd.) Interference on Sunflower (*Helianthus annuus* L.) Yield

Abstract. Biennial wormwood is a relatively uncommon weed that has been increasing in prevalence in Manitoba, but there is limited information available on the potential of biennial wormwood to reduce crop yields. Field experiments were conducted throughout southern Manitoba in 2010 and 2011 to determine the effect of increasing biennial wormwood densities and relative time of seedling recruitment on sunflower growth and development, yield and seed quality. Biennial wormwood was broadcast over sunflowers planted in 75 cm rows at six densities, either at the same time as the sunflower crop was planted (early weed seedling recruitment), or when the sunflowers were at about the 4-leaf stage (late weed seedling recruitment). When biennial wormwood seedlings recruited at about the same time as the sunflowers, yield was reduced by up to 46%. Early recruiting biennial wormwood seedlings had minimal effect on sunflower growth, but did reduce sunflower seed size and individual seed weight in some experiments. Biennial wormwood plants that recruited after the 4-leaf stage of the sunflower crop did not affect sunflower yield, or seed quality.

4.1 Introduction

The prevalence of biennial wormwood has been increasing in certain areas of the Northern Great Plains in recent years (Fronning and Kegode 2004). The ability of biennial wormwood to adapt to both conventional and reduced tillage systems, mis-identification of biennial wormwood as common ragweed (*Ambrosia artemisiifolia* L.), the use of ineffective herbicides, an extended seedling recruitment period and preference for moist soil conditions have been identified as potential reasons for the increase in biennial wormwood infestations (Kegode et al. 2007).

Biennial wormwood plants are typically 1 to 2 metres tall, with smooth, red tinged stems and hairless, toothed leaves (Kegode and Christoffers 2003). As the name implies, biennial wormwood may assume a biennial lifecycle, however the biennial wormwood plants infesting agricultural fields are primarily annual biotypes (Kegode et al. 2007). Annual plants that emerge early in the spring can produce about 435,000 seeds plant^{-1}, while plants that emerge later in the summer produce 500 to 3,000 seeds plant^{-1} (Mahoney and Kegode 2004). Biennial wormwood forms a slow growing rosette after seedling emergence, then bolts as day length declines in late July.

In Manitoba, biennial wormwood was found in 1.1% of 631 fields surveyed in 2002 and was ranked the forty-third most prevalent weed in Manitoba (Leeson et al. 2002); however, there are areas of Manitoba where biennial wormwood was found in greater frequencies. Around Killarney, MB, biennial wormwood was found in 13.6% of fields surveyed, ranking biennial wormwood the fifteenth most prevalent weed in that area and around Pilot Mound, biennial wormwood was found in 11.1% of the fields surveyed, ranking biennial wormwood the twelfth most prevalent weed. In a survey of South Dakota soybean fields, biennial wormwood was found in 92% of the fields surveyed (Snyder 1997). Biennial wormwood has been identified as one of the ten most problematic weeds in sunflower fields in a survey conducted in Canada and the USA (Anonymous 2012b).

A search of the literature reveals that little is known about the competitive ability of biennial wormwood in field crops. Biennial wormwood densities as low as 10 plants m^{-2}

reduced soybean yield by 44% in a North Dakota study (Nelson and Kegode 2005). That yield loss resulted directly from biennial wormwood interference with soybeans and also indirectly from harvesting inefficiencies. Biennial wormwood matures late in the growing season, so farmers may completely avoid harvest of densely infested areas. In a replacement series greenhouse study, when soybean and biennial wormwood were grown together, soybean height decreased due to interference, while biennial wormwood height increased in response to interference (Nelson and Kegode 2005). In the same study, the competitive ability of biennial wormwood increased with increasing nitrogen fertility and soil moisture.

The objective of this experiment was to determine the effect of increasing biennial wormwood densities and the relative time of biennial wormwood seedling recruitment on sunflower growth and development, yield and seed quality. The data were used to determine the action threshold (5% yield loss) for biennial wormwood control in sunflowers.

4.2 Materials and Methods

4.2.1 Experimental Locations

Field experiments were conducted in 2010 and 2011 at the same locations identified in chapter 3. Soil texture, pH and organic matter (Table 3.1), planting dates (Table 3.2), nutrient status and fertilizer amendments (Table 3.3) were summarized in chapter 3. In 2010, a second experiment was established at Carman (designated Carman2), 27 days after the first experiment was planted at Carman (Table 3.2). Daily temperature and precipitation data and long-term temperature and precipitation averages (LTA) were obtained from the closest weather stations (Table 3.4).

4.2.2 Biennial Wormwood Seed Source

The initial sample of biennial wormwood seed was obtained for this research by collecting mature plants from field margins and ditches in southern Manitoba in the fall of 2009. The plants were hand threshed and the material was passed through a 3/64 round hand sieve to obtain the seed sample. Biennial wormwood seeds are extremely small, at about 13,000 seeds g^{-1} (Mahoney and Kegode 2004), therefore it was not possible to sieve the threshed plant material effectively to obtain a pure seed sample without losing a large amount of seed. The seed material spread over the plots was a combination of seed and other plant residue. A 1.0 g sample of the seed material planted in the greenhouse resulted in 605 seedlings.

4.2.3 Experimental Design and Plot Establishment

The experiment was a two-way factorial design, laid out as a split-block, randomized complete block with four replicates. The main block was the time of seedling recruitment of biennial wormwood relative to the crop. Biennial wormwood seedling recruitment was targeted for the same time as the sunflowers (designated early recruitment), or after the 4-leaf stage of the sunflowers (designated late recruitment) and the six sub-plots in the experiment were biennial wormwood plant density. The biennial wormwood seeding rates were 1x, 5x, 10x, 20x, 40x and a control treatment that was maintained weed free for the entire growing season. In 2010, the 1x seeding rate of biennial wormwood was 0.2 g seed material m^{-2} and in 2011 the 1x seeding rate was increased to 0.3 g seed material m^{-2} to achieve greater biennial wormwood seedling densities.

Each 3 m wide by 4 m long sub-plot consisted of four rows of sunflowers planted 75 cm apart. Sunflower cultivar 6946 (Seeds 2000, Breckenridge, MN) was planted with a small plot seeder at a rate of 54,340 seeds ha^{-1}, when field conditions were favourable in the spring (Table 3.2). All weeds except biennial wormwood were controlled with herbicides, hand pulled, or hand-hoed during the growing season to eliminate interference from non-target weeds as described in chapter 3.

4.2.4 Data Collection

Data were collected to measure the effect of biennial wormwood interference on sunflower growth and development, yield and seed quality. Data collection procedures were outlined in chapter 3. In brief, sunflower plant population was determined by counting all the sunflower plants in the centre two rows of each plot and biennial wormwood density was counted in two randomly placed 0.25 m^2 quadrats at the 8-leaf sunflower stage. Sunflower plant height, stem diameter and the number of leaves per sunflower plant were determined in late August each year. Progression of anthesis was determined by visual ratings when the sunflowers were in the R5 stage (Fig. 3.1) (Schneiter and Miller 1981).

To determine head diameter and yield, heads were hand harvested at physiological maturity, when the bracts on the back of the head were brown. After the head diameter was measured, the heads were bagged, air dried, and threshed with a stationary small plot combine. Samples were cleaned and weighed to determine seed yield. Sunflower seed size and thousand kernel weight (TKW) from each plot were determined by generating a digital image of about 150 sunflower seeds on a flat-bed computer scanner and then using Assess 2.0 Image Analysis Software (The American Phytopathological Society 2008) to measure seed size and count the seeds. Seed yield and TKW values were adjusted to 10% moisture content.

4.2.5 Statistical Analysis

Statistical analysis was conducted as described in chapter 3. Briefly, the relationship between sunflower yield loss and biennial wormwood density was fitted to a non-linear, rectangular hyperbola regression model (Cousens 1985). The model is described by the equation:

$$YL = Id/(1 + Id/A) \qquad \text{[eqn. 3]}$$

where YL, is the percent yield loss, I is the percent yield loss per weed as weed density approaches zero, d is weed density and A is the percent yield loss as weed density approaches infinity. The percent yield loss for each treatment was determined using treatment averages (eqn. 5). The NLIN procedure produced parameter estimates for I and A that were used to generate yield loss curves. The model parameters were then used to calculate action thresholds to determine the biennial wormwood density that resulted in 5% yield loss in sunflowers.

$$\%YL = 100-((\text{average treatment yield} / \text{average weed free treatment yield}) \times 100) \quad \text{[eqn. 4]}$$

The effect of increasing biennial wormwood densities on sunflower growth and development and seed quality was analyzed using PROC GLM to test for the significance of linear and quadratic components of the relationship between weed density and the response variable.

4.3 Results and Discussion

4.3.1 Biennial Wormwood Seedling Recruitment

Biennial wormwood seedling recruitment varied among site-years (Table 4.1). For the early emerging weed treatments, the biennial wormwood seedlings recruited at about the same time as the crop (1 to 2 days before, or after the crop). The maximum recruitment of biennial wormwood seedlings for the early seeded treatments ranged from a low of 213 plants m^{-2} (Winnipeg 2011) to 1732 plants m^{-2} (Carman 2011).

The densities of late recruiting biennial wormwood plants varied among experiments (Table 4.1). At Winnipeg 2011, there was no late seedling recruitment of biennial wormwood, likely due to dry soil conditions in July and August. At Carman 2011, the density of late recruiting biennial wormwood seedlings was greater than the density of early recruiting biennial wormwood seedlings.

4.3.2 Sunflower Yield and Yield Loss

Sunflower yield in the weed free treatments ranged from 1639 kg ha^{-1} (Carman2 2010) to 4415 kg ha^{-1} (Winnipeg 2011) (Table 4.2). The lowest yielding experiment, Carman2

2010, was seeded late, on June 14, which may have contributed to the low yield. Growing season precipitation was 67% of the LTA at Winnipeg in 2011 (Table 3.4). The roots of sunflower plants grow deeper than many other crops, allowing sunflowers to extract water from deep in the soil profile (Angadi and Entz 2002a). This deep rooting trait may provide sunflowers with a competitive advantage over shallow rooted plants in years when soil moisture near the top of the profile is limited.

When biennial wormwood plants emerged at about the same time as the sunflowers, the rectangular hyperbola model adequately described sunflower yield loss in three of the five experiments (Table 4.2). The data from Carman 2011 conformed to the rectangular hyperbola yield loss model, but only at a density of 817 plants m^{-2} (Fig. 4.1). Interestingly, at the two highest weed densities (1362 and 1732 plants m^{-2}), the percent yield loss was less than at a density of 817 biennial wormwood plants m^{-2}. This may be due to the fact that it was a drier than average growing season. Four weeks after planting, sunflowers have a deeper root system than biennial wormwood (Fig 4.2). Soil moisture in the upper soil profile may have been limiting at Carman 2011 and the sunflowers may have had the ability to extract the required water from deeper in the soil profile. Based on visual observation, the early emerging biennial wormwood plants appeared flaccid about 8 weeks after seedling recruitment (indicative of moisture stress), while the sunflowers showed no visually obvious symptoms of moisture stress.

The rectangular hyperbola model parameter *A*, ranged from about 34% (Carman 2011 and Winnipeg 2011) to 46% (Melita 2010) (Table 4.2). In 2010, biennial wormwood seedling recruitment was about three times greater at Melita than the two experiments at Carman

(Table 4.1), which likely contributed to Melita 2010 generating the only yield loss data that could be adequately described by the rectangular hyperbola model in 2010.

The values for model parameter *I* ranged from 0.13 to 2.41% among the site-years indicating that the competitive ability of biennial wormwood varied greatly among site-years (Table 4.2). Unexpectedly, the model parameter *I* was greatest at Winnipeg 2011 even though it was a relatively dry growing season (Table 3.4). Parameter *I* was 0.12 and 0.15 for Melita 2010 and Carman 2011, respectively. Model parameter *A* was similar between Winnipeg 2011 and Carman 2011.

When biennial wormwood seedlings recruited after the 4-leaf stage of the sunflowers, yield loss in sunflower could not be adequately described using the rectangular hyperbola yield loss model, or linear regression even at biennial wormwood densities as high as 3358 plants m^{-2} at Carman 2011(appendix Fig. 7.2). When the biennial wormwood seedlings that were planted at the 4-leaf sunflower stage recruited, the sunflowers were already well established. When the crop canopy closed, about seven weeks after sunflower planting (based on visual observations), the biennial wormwood was still too small to interfere effectively with the sunflowers.

Table 4.1. Biennial wormwood seedling recruitment (SEM) for early and late emergence for each of the experiments

Experiment	Emergence time	Biennial wormwood density treatment											
		1		2		3		4		5		6	
		# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM	# m^{-2}	SEM
Carman 2010	Early	0	(0) c	15	(5) c	38	(13) c	70	(20) bc	174	(27) ab	258	(65) a
Carman (2) 2010		0	(0) c	7	(3) c	38	(7) bc	62	(16) bc	106	(3) b	219	(40) a
Melita 2010		0	(0) b	21	(6) b	106	(16) b	230	(46) b	652	(182) a	723	(132) a
Carman 2011		0	(0) c	126	(49) c	401	(81) bc	817	(74) b	1362	(157) a	1732	(153) a
Winnipeg 2011		0	(0) d	14	(8) cd	31	(15) bcd	76	(27) b	81	(28) bc	213	(28) a
Carman 2010	Late	0	(0) b	2	(1) b	3	(1) b	16	(6) b	105	(41) ab	205	(60) a
Carman (2) 2010		0	(0) b	2	(1) b	4	(2) ab	10	(6) ab	31	(29) ab	102	(51) a
Melita 2010		0	(0) a	1	(1) a	11	(9) a	15	(14) a	64	(59) a	201	(113) a
Carman 2011		0	(0) b	528	(105) b	2688	(432) a	2955	(319) a	3232	(362) a	3358	(143) a
Winnipeg 2011		0	(0) a	0	(0) a	0	(0) a	0	(0) a	0	(0) a	0	(0) a

m^{-2} is the actual density of biennial wormwood plants that recruited.

Means across rows followed by the same letter are not significantly different according to Tukey-Kramer LSD at the 0.05 level of significance.

Table 4.2. Weed free yields measured in each experiment (SEM) and parameter estimates (+/- SE) for the rectangular hyperbola model for the biennial wormwood plants that recruited at the same time as the sunflower crop.

Experiment	Observed weed free yield	Model parameter[a]	
		I	*A*
	---(kg ha^{-1})---	-----%-----	
Carman 2010	2393 (426)	ns[b]	ns
Carman2 2010	1639 (97)	ns	ns
Melita 2010	2266 (210)	0.13 (0.08)	46.4 (22.1)
Carman 2011	2716 (173)	0.15 (0.03)	34.3 (3.8)
Winnipeg 2011	4415 (179)	2.41 (1.09)	34.6 (4.2)

[a] *I* is the percent yield loss per weed as weed density approaches zero, and *A* represents the asymptote, which is the percent yield loss as weed density approaches infinity.

[b] ns indicates that the data did not conform to the rectangular hyperbola yield loss model

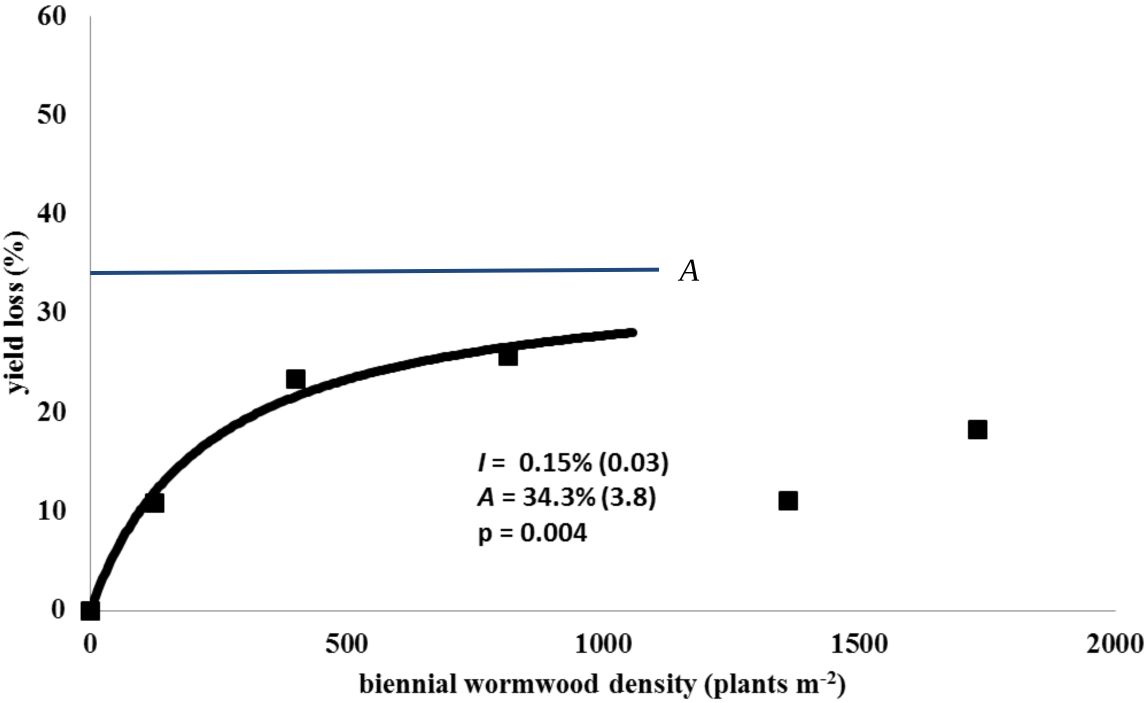

Figure 4.1. The effect of increasing densities of early recruiting biennial wormwood plants on sunflower yield at Carman 2011. Approximate standard error of the model parameters are indicated in parentheses.

4.3.3 Effect of Biennial Wormwood Interference on Sunflower Growth and Development

Early recruiting biennial wormwood plants had minimal effect on sunflower growth and development. The number of leaves per sunflower plant, height, stem diameter and time of flowering of the sunflower plants were unaffected by increasing densities of early recruiting biennial wormwood plants. Increasing densities of early recruiting biennial wormwood plants resulted in a decrease in sunflower head diameter at Carman 2010 (Fig. 4.3). The reduction of head diameter was statistically significant, but it may be of limited practical importance as sunflower yield was unaffected by increasing densities of early emerging biennial wormwood at Carman 2010. The reduction in head diameter is equivalent to a 0.04% reduction in head size per kochia plant.

Increasing densities of late recruiting biennial wormwood plants did not reduce sunflower yield, but there were some effects on sunflower growth and development. At Melita 2010, there was a quadratic response of the number of leaves per sunflower plant with increasing biennial wormwood densities ($y = 24.04 + 0.07x - 0.0003x^2$, $R^2 = 0.94$) where at low biennial wormwood densities, leaf numbers increased slightly and then decreased at greater densities of biennial wormwood (data not shown). At Carman2 2010 there was a quadratic response of stem diameter to increasing biennial wormwood densities ($y = 27.79 + 0.1159x - 0.0012x^2$, $R^2 = 0.99$) where at low biennial wormwood densities, stem diameter increased slightly, then decreased at greater biennial wormwood densities (data not shown). These effects are likely of little practical significance since yield was unaffected.

Figure 4.2. Relative size of sunflowers (on the left) and biennial wormwood about four weeks after emergence of the sunflower and biennial wormwood plants.

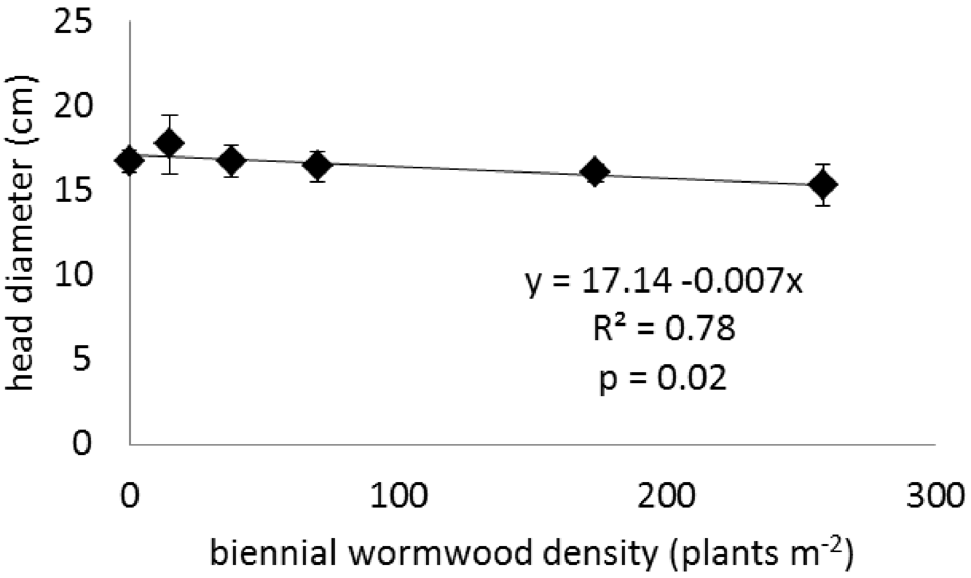

Figure 4.3. The effect of increasing densities of early recruiting biennial wormwood seedlings on sunflower head diameter at Carman 2010. The regression equation and coefficient of regression are indicated. Bars indicate plus/minus one standard error of the mean.

4.3.4 Effect of Biennial Wormwood Interference on Sunflower Seed Quality

Although early recruiting biennial wormwood plants had little effect on sunflower growth and development, early recruiting biennial wormwood seedlings did affect seed quality in sunflowers in some experiments. The effect of increasing densities of early recruiting biennial wormwood seedlings on TKW was described using a linear relationship at Carman 2010 and a quadratic relationship at Carman2 2010 (Fig 4.4). At Carman 2010, as the density of early recruiting biennial wormwood plants increased, sunflower seed size decreased (Fig 4.5). Test weight and seed size are just two of the factors considered when sunflower seed is graded. Sunflower seed must also have low levels of foreign material, damage, disease and immature seed to be graded No. 1 Canada (Anonymous 2011b). For farmers producing confectionary sunflower seed, early recruiting biennial wormwood plants may be a concern because of the possibility of decreased seed quality, even when yield is unaffected. The number of sunflower seeds produced m^{-2} decreased with increasing densities of early recruiting biennial wormwood plants at Melita 2010 (Fig. 4.6).

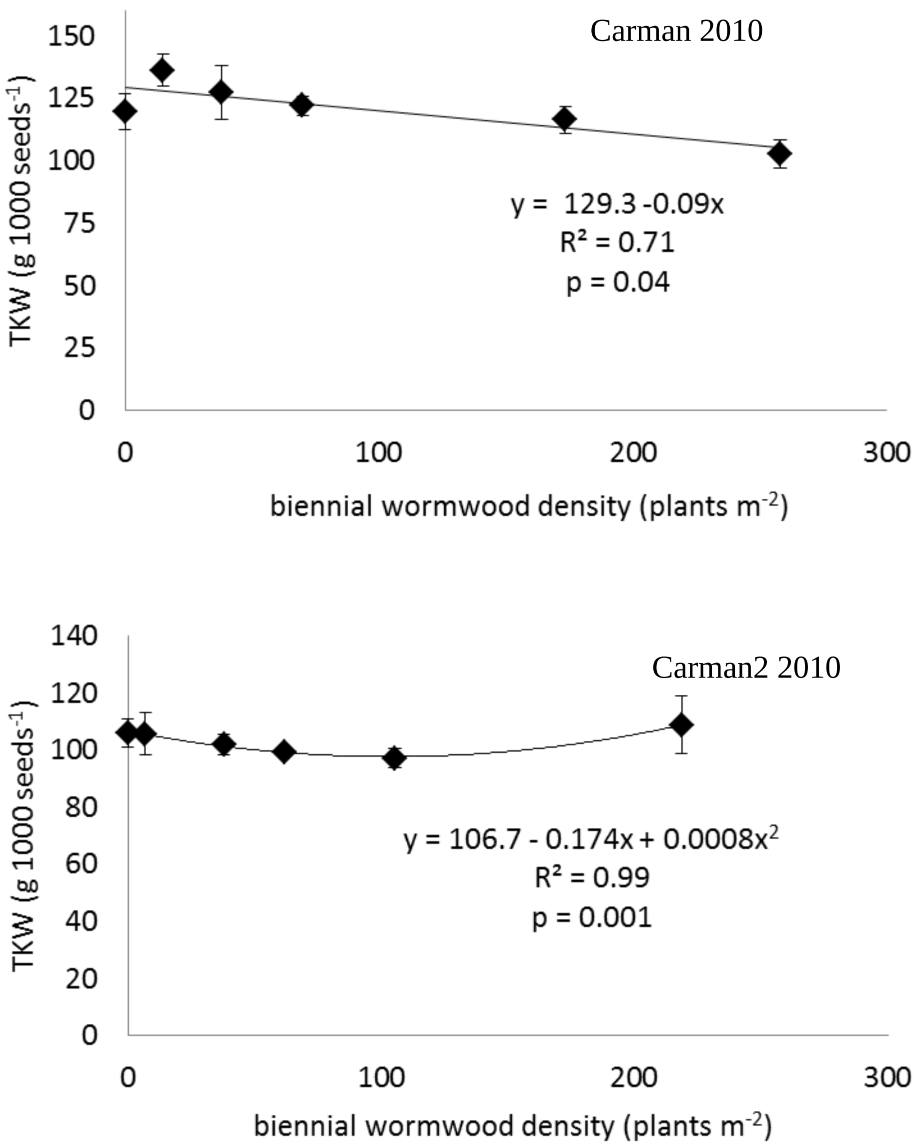

Figure 4.4. The effect of increasing densities of early recruiting biennial wormwood seedlings on thousand kernel weight (TKW) of sunflower seed at Carman 2010 (top) and Carman2 2010 (bottom). Regression equations and coefficients of regression are indicated. Bars are plus/minus one standard error of the mean.

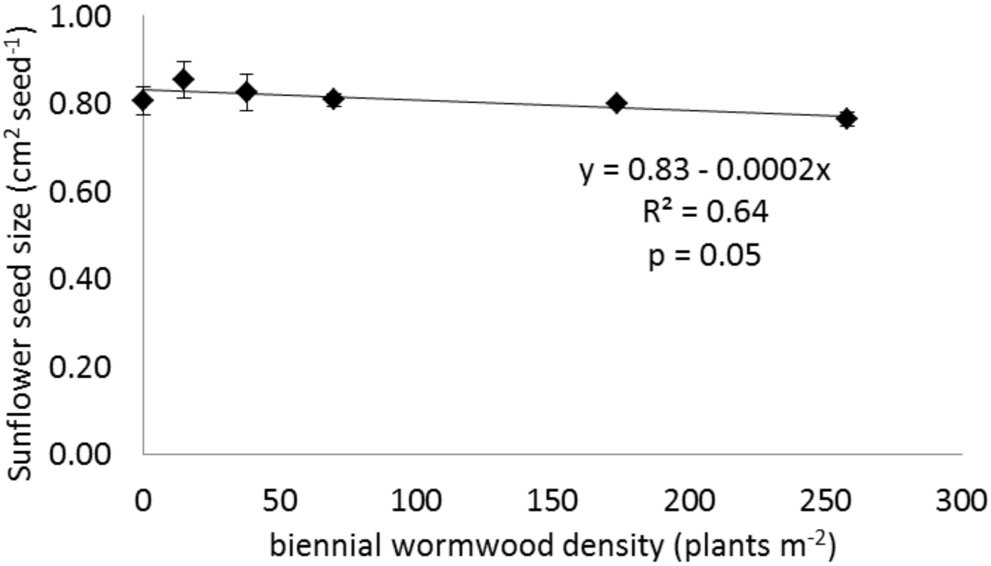

Figure 4.5. The effect of increasing densities of early recruiting biennial wormwood seedlings on sunflower seed size at Carman 2010. The regression equation and coefficient of regression are indicated. Bars indicate plus/minus one standard error of the mean.

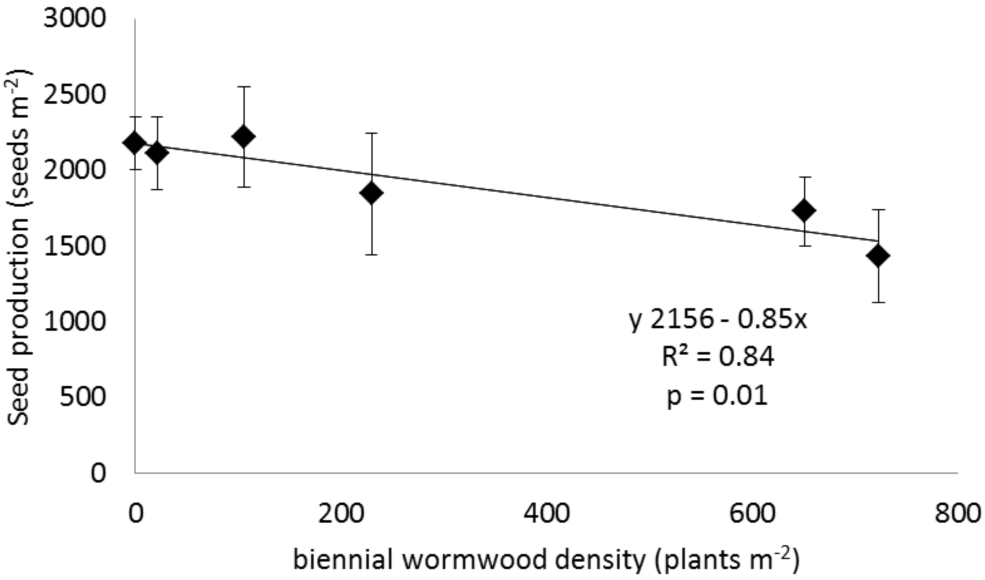

Figure 4.6. The relationship between increasing densities of early recruiting biennial wormwood seedlings and the number of sunflower seeds produced per square meter of land at Melita 2010. The regression equation and coefficient of regression are indicated. Bars indicate plus/minus one standard error of the mean.

4.3.5 Action Thresholds for Biennial Wormwood Control in Sunflowers

In these experiments, the action threshold (5% yield loss) for biennial wormwood seedlings that recruited at the same time as the sunflowers varied from 3 (Winnipeg 2011) to 45 plants m^{-2} (Melita 2010) for the experiments that were adequately described using the rectangular hyperbola model (Table 4.3). When all the experiments, including those that did not conform to the rectangular hyperbola yield loss model, were analyzed together, the model parameters *I* and *A* were 0.17 and 27.2 %, respectively (Fig. 4.7). All the experiments were included in the combined site-year analysis because even though an individual site-year may not have fit the model on its own, the data can still contribute to the overall model for multiple site-years. A combined analysis provides yield loss predictions based on multiple site-years, but the predictions may not be applicable to all environmental conditions, especially in years with extreme conditions.

For the combined site-year analysis, the biennial wormwood density at which 5% yield loss occurred was 36 plants m^{-2}. Combining the data into one model should produce the most robust yield loss model that could be applied to multiple years and locations. In cool, wet years, such as 2010, however, the data from 2010 may be more accurate than the combined site-year analysis for predicting yield loss due to biennial wormwood interference. In hot, dry years, such as 2011, that data may provide better predictive ability than the combined site-year analysis for predicting yield loss due to biennial wormwood interference.

Table 4.3. Biennial wormwood plant densities that resulted in 5% yield loss when the biennial wormwood plants recruited at the same time as the sunflower crop.

Experiment	biennial wormwood density (plants m^{-2})
Carman 2010	ns[a]
Carman2 2010	ns
Melita 2010	45
Carman 2011	41
Winnipeg 2011	3

[a] ns indicates that the yield loss data did not conform to the models tested.

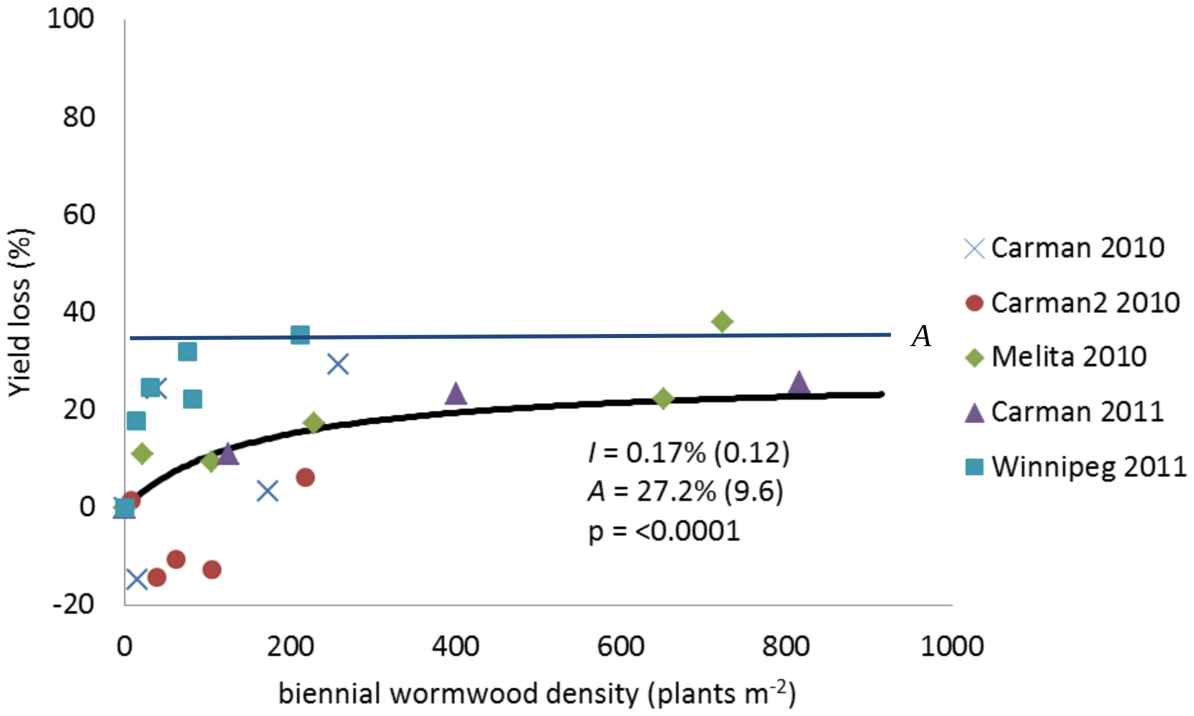

Figure 4.7. Sunflower yield loss as a function of biennial wormwood density when the biennial wormwood seedlings recruited at about the same time as the sunflowers (all experiments combined). The percent yield loss per weed at low weed densities (*I*) and the maximum yield loss at high weed densities (*A*) are indicated. Approximate standard error of the model parameters are indicated in parentheses.

4.4 Conclusion

Biennial wormwood reduced sunflower yield by up to 27% in the combined analysis and up to 46% at Melita 2010 in the individual analysis. The results of the present study indicate that the competitive ability of biennial wormwood can be variable among locations and environments. On average, over five site years, the action threshold for early emerging biennial wormwood (5% sunflower yield loss) was 36 biennial wormwood plants m^{-2}, but varied from 3 to 45 plants m^{-2}. For these action thresholds to be adopted by farmers, more experiments may be required to predict yield loss more accurately. In wet years such as 2010, the maximum potential yield loss resulting from biennial wormwood may be greater than in dry years, but the results from Winnipeg 2011 indicate that even in dry years, biennial wormwood may reduce sunflower yield.

5.0 General Discussion

5.1 Kochia and Biennial Wormwood Interference in Sunflowers

The level of yield loss observed in crops is determined by the weed species, time of weed seedling recruitment relative to the crop, weed density and environmental conditions (Blackshaw 1993). The preceding experiments were designed to investigate the effect of kochia and biennial wormwood density and relative time of kochia and biennial wormwood seedling recruitment on sunflower yield and seed quality with the goal of determining action thresholds for each weed.

Time of weed seedling recruitment relative to the sunflower crop was the most important factor that determined the competitive ability of kochia and biennial wormwood. In many cases, kochia and biennial wormwood seedlings that recruited at about the same time as the sunflower crop reduced sunflower yield; however, when kochia and biennial wormwood seedlings recruited after the 4-leaf stage of the sunflower crop, sunflower yield was not affected. In the combined site-year analysis, kochia reduced sunflower yield by as much as 82%, which was about 3-times greater than biennial wormwood, which was 27%. At low levels of weed infestation, each kochia plant m^{-2} reduced sunflower yield by 0.52% and each biennial wormwood plant m^{-2} reduced sunflower yield by 0.17% indicating that kochia plants were about 3-times more competitive with sunflowers than biennial wormwood.

The action thresholds for kochia and biennial wormwood varied among years. For kochia over seven site-years, the action threshold for early emerging kochia (5% sunflower yield loss) was 10 kochia plants m^{-2} on average, but varied from 1 to 106 plants m^{-2}. For biennial wormwood over five site-years, the action threshold for early emerging biennial wormwood (5% sunflower yield loss) was 36 plants m^{-2} on average, but varied from 3 to 45 plants m^{-2}.

5.2 The Effect of Environmental Conditions on Kochia and Biennial Wormwood Interference

Environmental conditions during the growing season may have affected the ability of kochia and biennial wormwood to reduce sunflower yield. Before making weed control decisions, farmers should consider the environmental conditions. Kochia reduced sunflower yield more at site-years where precipitation was less than the LTA and temperatures were greater than the LTA and less at site-years where precipitation was greater than the LTA and temperatures were less than the LTA. This result supports the findings of other researchers that found kochia to be more competitive in dry years than wet years (Durgan et al. 1994, Fisher et al. 2000 and Manthey et al. 1996). Biennial wormwood reduced sunflower yield in both wet and dry years, but the greatest yield loss was observed in 2010, which was a wet year. This supports previous research that showed that as soil moisture increased, the competitive ability of biennial wormwood increased (Nelson and Kegode 2005).

5.3 Integrated Weed Management in Sunflowers

Previous research demonstrated the susceptibility of sunflowers to yield loss due to weed interference (eg. Chubb 1975, Chubb and Friesen 1984, Durgan et al. 1990, Grenze et al. 2008, Lehoczky et al. 2006, Reddy et al. 2008). Integrated weed management tools may increase the competitive ability of the sunflower crop. Herbicides should only be considered part of a weed management program. Planting into a weed free seed bed, using high quality seed with excellent germination and vigour, side-banding fertilizer with the seed, choosing seeding rates to achieve the optimal plant stand and planning rotations that include a variety of crops are all practices that have been shown to be effective for managing weeds, especially when multiple practices are utilized at the same time (O'Donovan 1996).

The pre-emergent, soil applied herbicide sulfentrazone, which was registered for use in sunflowers in Manitoba in 2011, controls kochia resistant to ALS-inhibiting herbicides (Anonymous 2011a) and provides greater than 80% control of biennial wormwood under normal conditions (Kegode et al. 2007). Farmers might apply sulfentrazone on sunflower fields as a preventative measure to control weeds that would be expected to emerge during the season. There are no in-crop herbicides available to effectively manage kochia and biennial wormwood in sunflowers. Although this research showed that season-long kochia and biennial wormwood control is unnecessary, sulfentrazone applications may be the only option for farmers who need to manage these weeds in-crop, especially in systems that do not use inter-row cultivation. Knowledge of field history, that includes weed species and weed density in previous years, combined with the yield loss equations generated by this research, will help farmers decide whether it may be beneficial to apply sulfentrazone, other herbicides, or other weed management techniques. Using the combined site-year analysis and weed free yields averaged across all site-years, the economic threshold for kochia plants was 5.5 plants m^{-2} and the economic threshold for biennial wormwood plants was 19.6 plants m^{-2} assuming a crop price of \$0.55 kg^{-1} and control cost of \$44 ha^{-1} if a farmer uses sulfentrazone to control these weeds.

The economic threshold weed densities are less than the action threshold weed densities discussed previously in this thesis. From the perspective of a farmer, an economic threshold may be a more valuable piece of information than an action threshold because the economic threshold will help a farmer determine if it is economically beneficial to apply control measures. However, economic threshold weed densities will fluctuate because the calculation is dependent on weed control costs, which may include herbicide cost, herbicide application cost, or the cost of mechanical weed control measures, such as inter-row cultivation.

For farmers who practice inter-row cultivation, the results of this research can also be used to determine whether mechanical weed control would be economically beneficial. Utilizing thresholds for kochia and biennial wormwood will allow farmers to avoid unnecessary weed control measures that may reduce profit margins and harm the environment.

5.4 Future Research

Sunflower research has been limited in the Northern Great Plains region. This research project studied only two weeds that are commonly found in sunflower fields, but numerous other problem weed species are present in sunflower fields that need to be studied to determine the potential to cause yield loss in sunflowers either individually, or in mixed populations. Additional measurements focusing on competition for moisture, nutrients and light between weeds and sunflowers early in the growing season would provide insight into the mechanism of yield loss in sunflowers due to weed interference.

In western Manitoba, sunflowers are grown at narrow or wide row spacing, but there is no information available about the effect of row spacing on competitive ability of sunflowers. Narrow row sunflowers may be more competitive with weeds than wide row sunflowers because the large inter-row space is eliminated in narrow row sunflowers. The slow early season growth of sunflowers combined with the low planting density of sunflowers may make them more susceptible to yield loss due to weed interference than other crops when planted in wide row spacing, especially when weeds are not controlled with inter-row cultivation. In a previous study, sunflowers planted in narrow rows had improved radiation interception, earlier canopy closure and increased water use efficiency compared to sunflowers planted in wide rows (Angadi and Entz 2002b). Improved radiation interception, earlier canopy closure and increased water use efficiency also may increase the competitive ability of sunflowers with weeds. In a previous study, soybeans grown in weedy conditions yielded greater when grown in 19 cm wide rows compared to 76 cm wide rows (Harder et al. 2007). Future research should investigate if the same trend occurs in sunflowers.

Yield loss models based on weed densities, as in the present research, are useful because weed densities are easy to communicate to farmers and agronomists and easy to determine in the field without specialized equipment. This is important, because for action thresholds to be adopted by farmers and agronomists, the measurements must not be cumbersome. The limitation to using only weed density as the independent variable in a yield loss model is that it does not account for weed size. The size of the weed will affect competitive ability. This was evident in these experiments, where high densities of late recruiting kochia plants had no effect on sunflower yield because the kochia plants were small and uncompetitive. In contrast, relatively low densities of early recruiting kochia seedlings reduced sunflower yield because the kochia plants were large relative to the kochia seedlings that recruited later in the season. Future research should investigate the relationship between early season weed biomass and sunflower yield loss. There may be a clear relationship between weed biomass and sunflower yield loss.

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7.0 Appendix

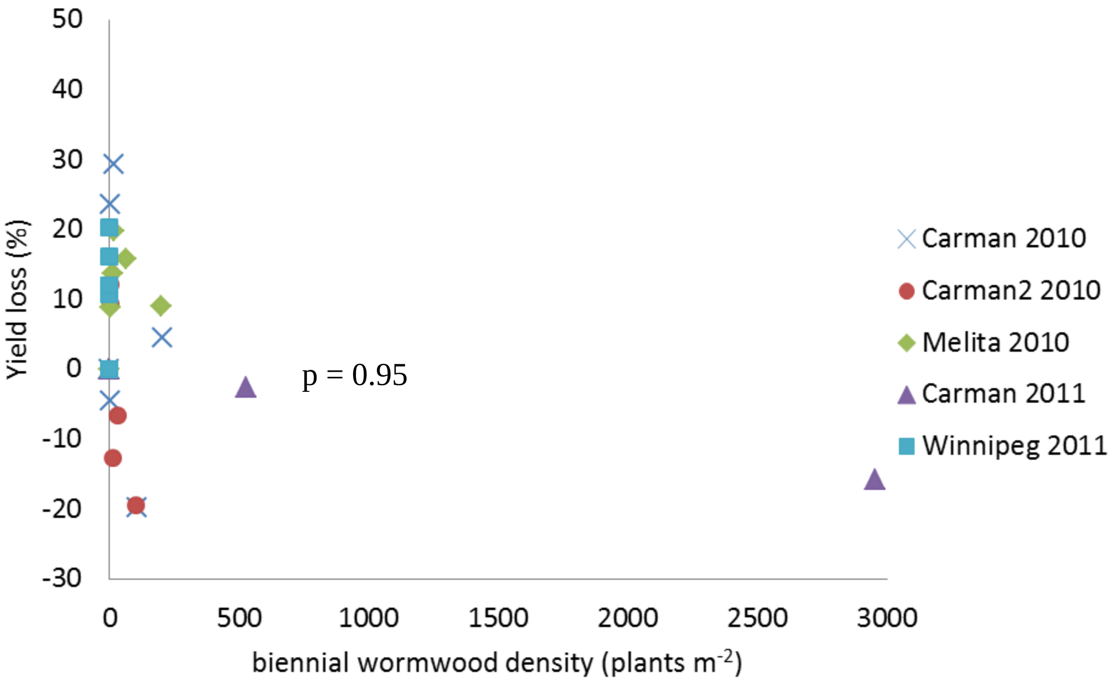

Figure 7.1 Sunflower yield loss as a function of kochia density when the kochia seedlings recruited after the 4-leaf stage of the sunflowers (all experiments combined). Data was tested using the rectangular hyperbola yield loss model (Cousens 1985).

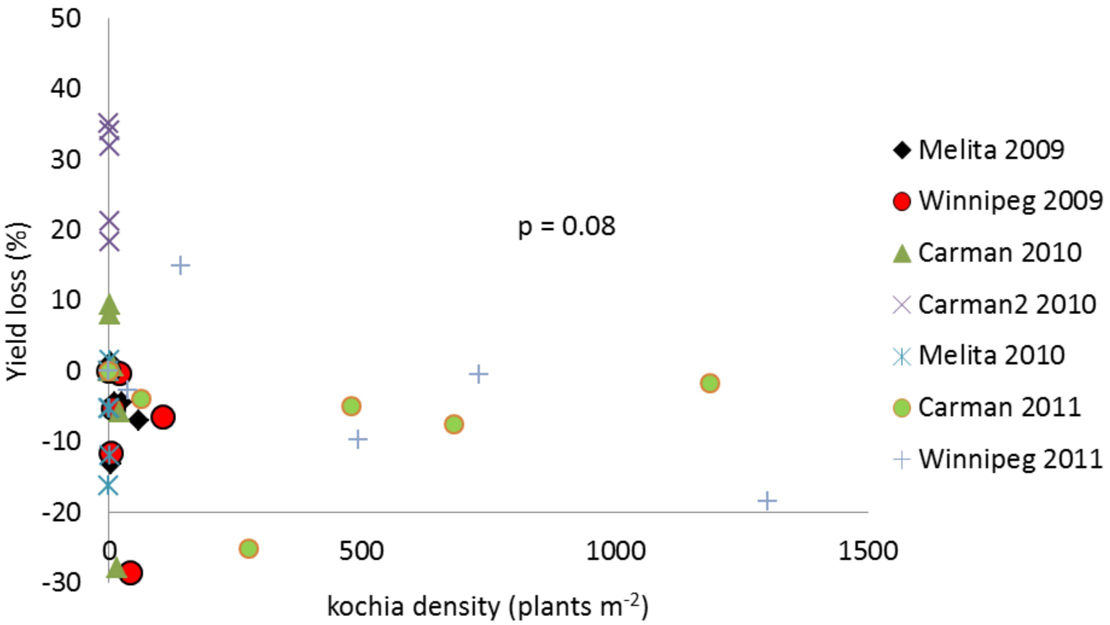

Figure 7.2 Sunflower yield loss as a function of biennial wormwood density when the biennial wormwood seedlings recruited after the 4-leaf stage of the sunflowers (all experiments combined). Data was tested using the rectangular hyperbola yield loss model (Cousens 1985).

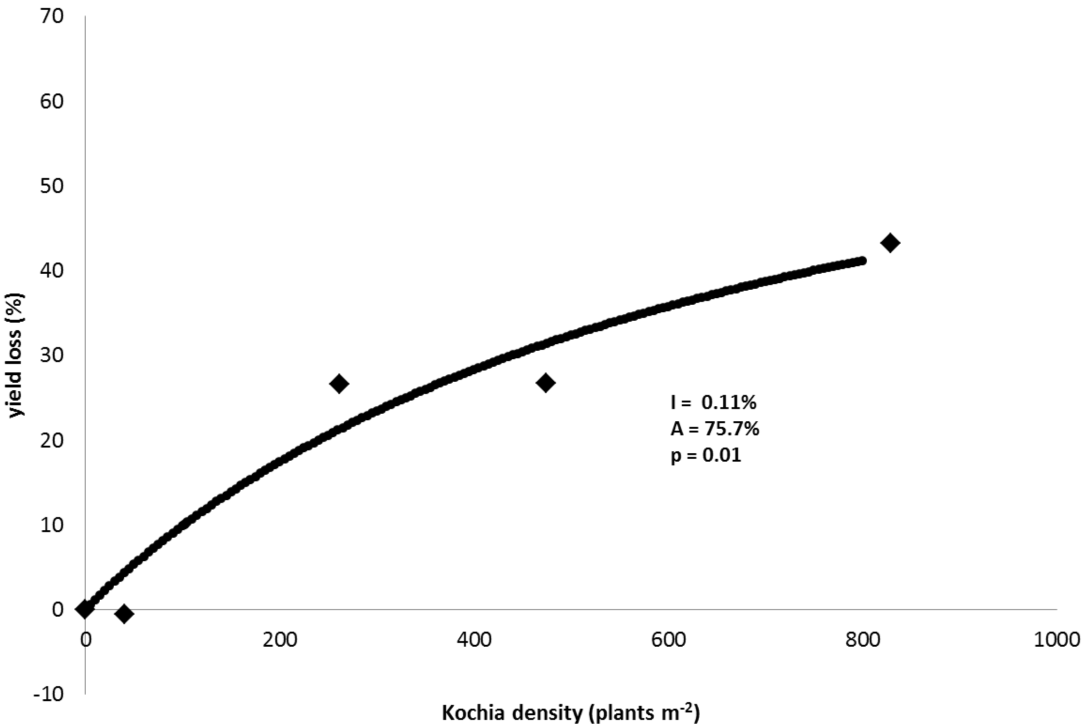

Figure 7.3. Sunflower yield loss as a function of kochia density when the kochia seedlings recruited at about the same time as the sunflowers at Carman 2011. Data was tested using the rectangular hyperbola yield loss model (Cousens 1985).

Table 7.1. Summary of sunflower yields for experiments examining the effect of kochia interference in sunflowers.

Experiment	Weed emergence time	Kochia density treatment											
		0x		1x		5x		10x		20x		40x	
		Sunflower yield											
		kg/ha	SEM	kg/ha	SEM	kg/ha	SEM	kg/ha	SEM	kg/ha	SEM	kg/ha	SEM
Melita 2009	Early	3126	150	2986	178	1982	331	2712	214	2420	263	2467	358
Winnipeg 2009		2355	277	2641	164	2268	219	1834	323	1792	166	1771	303
Carman 2010		3217	253	2766	335	3125	361	2820	569	3210	146	2397	252
Carman (2) 2010		2410	284	2236	92	1658	152	2161	267	1776	370	1664	161
Melita 2010		2536	216	2316	381	2559	397	2822	239	2611	244	2767	203
Carman 2011		3360	232	3379	260	3515	250	2469	310	2462	369	1910	168
Winnipeg 2011		3167	489	1217	245	610	168	560	209	327	101	151	47
Melita 2009	Late	3126	150	3087	390	3536	400	3267	309	3265	268	3342	156
Winnipeg 2009		2355	277	2630	254	2478	316	2363	401	3030	257	2506	433
Carman 2010		3121	337	2824	176	2869	129	3097	335	3990	334	3303	227
Carman (2) 2010		2410	284	1562	488	1587	169	1968	191	1643	313	1896	269
Melita 2010		2536	216	2761	209	2947	261	2762	241	2496	147	2838	118
Carman 2011		3360	232	3493	356	4204	383	3527	522	3611	201	3418	608
Winnipeg 2011		3167	489	3250	349	2696	237	3476	422	3180	254	3751	266

Table 7.2. Summary of sunflower yields for experiments examining the effect of biennial wormwood interference in sunflowers.

Experiment	Weed emergence time	Biennial wormwood density treatment											
		0x		1x		5x		10x		20x		40x	
		Sunflower yield											
		kg/ha	SEM	kg/ha	SEM	kg/ha	SEM	kg/ha	SEM	kg/ha	SEM	kg/ha	SEM
Carman 2010	Early	2393	427	2745	172	1811	246	2517	413	2313	418	1692	189
Carman (2) 2010		1639	98	1615	297	1873	348	1813	256	1846	322	1536	169
Melita 2010		2263	210	2015	164	2049	256	1873	384	1763	265	1403	313
Carman 2011		2716	174	2421	224	2083	313	2018	275	2414	80	2222	148
Winnipeg 2011		4414	180	3632	342	3327	85	3431	293	3008	486	2858	761
Carman 2010	Late	2150	329	1643	442	2246	376	1519	282	2576	274	2053	149
Carman (2) 2010		1639	98	1486	171	1439	197	1848	319	1958	248	1747	302
Melita 2010		2263	210	2062	240	1816	201	1951	283	1907	175	2060	399
Carman 2011		2716	174	2787	99	3688	272	3144	218	3572	181	3403	192
Winnipeg 2011		4414	180	3705	184	3942	130	3517	315	3882	222	3886	160

Table 7.3. Summary of linear regression equations describing the effect of early emerging kochia plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.15	-	-	0.11	-	-	0.4	-	-	0.82	y = 16.9 - 0.036x	0.65	0.05
Winnipeg 2009	y = 21.3 - 0.02x	0.65	0.05	y = 27.9 - 0.03x	0.68	0.04	y = 140.1 - 0.24x	0.77	0.02	y = 3.6 - 0.02x	0.82	0.01	y = 16.1 - 0.01x	0.83	0.01
Carman 2010	-	-	0.08	-	-	0.81	-	-	0.20	-	-	0.56	-	-	0.73
Carman2 2010	-	-	0.58	y = 30.3 - 0.072x	0.73	0.03	-	-	0.57	-	-	0.58	y = 18.6 - 0.034x	0.7	0.04
Melita 2010	y = 23.7 - .07x	0.94	0.001	y = 25.1 - 0.08x	0.66	0.05	-	-	0.70	-	-	0.59	-	-	0.32
Carman 2011	-	-	0.55	y = 28.9 - .007x	0.77	0.02	-	-	0.06	y = 7.4 - 0.002x	0.91	0.003	y = 18.4 - 0.003x	0.88	0.01
Winnipeg 2011	y = 21.7 - .01x	0.82	0.01	y = 17.5 - 0.011x	0.64	0.05	y = 146.5 - 0.052x	0.74	0.03	-	-	0.12	y = 13.0 - 0.009x	0.72	0.03

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	y = 0.7036 – 0.0014x	0.87	0.01	y = 111.3 – 0.391x	0.86	0.01	-	-	0.29	-	-	0.50
Winnipeg 2009	y = 0.7091 – 0.0003x	0.7	0.04	-	-	0.17	-	-	0.16	-	-	0.80
Carman 2010	-	-	0.18	-	-	0.18	-	-	0.27	-	-	0.13
Carman2 2010	-	-	0.99	-	-	0.70	-	-	0.14	-	-	0.48
Melita 2010	-	-	0.37	-	-	0.45	-	-	0.36	-	-	0.81
Carman 2011	-	-	0.08	y = 115.0 – 0.019	0.65	0.05	y = 2973 - 1.4x	0.85	0.01	-	-	0.67
Winnipeg 2011	-	-	0.33	-	-	0.23	-	-	0.07	y = 50421 - 30.1x	0.95	0.001

Table 7.4. Summary of linear regression equations describing the effect of late emerging kochia plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.83	-	-	0.98	-	-	0.51	-	-	0.29	-	-	0.96
Winnipeg 2009	-	-	0.46	-	-	0.32	-	-	0.46	$y = 3.9 + 0.01x$	0.66	0.05	-	-	0.11
Carman 2010	-	-	0.07	-	-	0.56	-	-	0.76	-	-	0.28	-	-	0.29
Carman2 2010	-	-	0.65	-	-	0.54	-	-	0.18	.	.	.	-	-	0.71
Melita 2010	-	-	0.84	-	-	0.56	-	-	0.62	-	-	0.28	-	-	0.87
Carman 2011	-	-	0.18	-	-	0.60	-	-	0.11	-	-	0.33	-	-	0.87
Winnipeg 2011	-	-	0.96	-	-	0.26	-	-	0.6	-	-	0.10	-	-	0.32

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.92	-	-	0.28	-	-	0.46	-	-	0.58
Winnipeg 2009	-	-	0.18	-	-	0.94	-	-	0.71	-	-	0.88
Carman 2010	-	-	0.99	-	-	0.44	-	-	0.07	-	-	0.71
Carman2 2010	-	-	0.65	-	-	0.33	-	-	0.88	-	-	0.69
Melita 2010	-	-	0.99	-	-	0.70	-	-	0.99	-	-	0.49
Carman 2011	-	-	0.35	-	-	0.33	-	-	0.44	-	-	0.15
Winnipeg 2011	-	-	0.28	-	-	0.08	-	-	0.20	-	-	0.66

Table 7.5. Summary of quadratic regression equations describing the effect of early emerging kochia plants on sunflower. Coefficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves $plant^{-1}$)			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.69	-	-	0.49	-	-	0.47	-	-	0.47	-	-	0.82
Winnipeg 2009	$y = 22.1 - 0.101x + 0.0006x^2$	0.95	0.03	-	-	0.38	$y = 145.4 - 0.708x + 0.00385x^2$	0.95	0.04	-	-	0.13	-	-	0.08
Carman 2010	-	-	0.27	-	-	0.16	-	-	0.76	-	-	0.09	-	-	0.48
Carman2 2010	-	-	0.99	-	-	0.39	-	-	0.2	-	-	.	-	-	0.97
Melita 2010	-	-	0.80	-	-	0.92	-	-	0.93	-	-	0.42	-	-	0.06
Carman 2011	-	-	0.74	-	-	0.32	-	-	0.09	-	-	0.59	-	-	0.07
Winnipeg 2011	$y = 23.0 - 0.024x + 0.00002x^2$	0.99	0.01	-	-	0.16	-	-	0.23	-	-	0.13	-	-	0.19

	seed size (cm^2 $seed^{-1}$)			TKW (g 1000 $seeds^{-1}$)			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.79	-	-	0.61	-	-	0.46	-	-	0.82
Winnipeg 2009	-	-	0.70	-	-	0.25	-	-	0.34	-	-	0.94
Carman 2010	$y = 0.85 - 0.004x + 0.0001x^2$	0.87	0.05	-	-	0.14	-	-	0.50	-	-	0.58
Carman2 2010	-	-	0.28	$y = 104.9 - 0.24x + 0.003x^2$	0.85	0.03	-	-	0.82	-	-	0.56
Melita 2010	-	-	0.34	-	-	0.73	-	-	0.76	-	-	0.38
Carman 2011	-	-	0.88	-	-	0.93	-	-	0.55	-	-	0.16
Winnipeg 2011	-	-	0.44	-	-	0.43	-	-	0.19	-	-	0.94

Table 7.6. Summary of quadratic regression equations describing the effect of late emerging kochia plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.22	-	-	0.09	-	-	0.06	-	-	0.65	-	-	0.27
Winnipeg 2009	-	-	0.29	-	-	0.77	-	-	0.16	-	-	0.73	-	-	0.14
Carman 2010	-	-	0.09	-	-	0.78	-	-	0.22	-	-	0.40	-	-	0.66
Carman2 2010	-	-	0.46	-	-	0.13	-	-	0.58	-	-	.	-	-	0.20
Melita 2010	-	-	0.58	-	-	0.80	-	-	0.60	-	-	0.49	-	-	0.11
Carman 2011	-	-	0.27	-	-	0.70	-	-	0.61	-	-	0.16	-	-	0.46
Winnipeg 2011	-	-	0.38	-	-	0.07	-	-	0.30	-	-	0.16	-	-	0.21

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Melita 2009	-	-	0.13	-	-	0.07	-	-	0.68	-	-	0.06
Winnipeg 2009	-	-	0.51	-	-	0.87	-	-	0.19	-	-	0.69
Carman 2010	-	-	0.67	-	-	0.92	-	-	0.50	-	-	0.58
Carman2 2010	-	-	0.78	-	-	0.82	-	-	0.64	-	-	0.80
Melita 2010	-	-	0.82	-	-	0.16	-	-	0.11	-	-	0.66
Carman 2011	-	-	0.45	-	-	0.39	-	-	0.51	-	-	0.70
Winnipeg 2011	-	-	0.68	-	-	0.32	-	-	0.79	-	-	0.82

Table 7.7. Summary of linear regression equations describing the effect of early emerging biennial wormwood plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.81	-	-	0.13	-	-	0.4	-	-	0.86	y = 17.1 - .007x	0.77	0.02
Carman2 2010	-	-	0.76	-	-	0.12	-	-	0.39	-	-	.	-	-	0.42
Melita 2010	-	-	0.15	-	-	0.24	-	-	0.53	-	-	0.41	-	-	0.35
Carman 2011	-	-	0.11	-	-	0.3	-	-	0.47	-	-	0.36	-	-	0.39
Winnipeg 2011	-	-	0.50	-	-	0.10	-	-	0.20	y = 6.9 - 0.02x	0.95	0.001	y = 17.6 - 0.02x	0.78	0.02

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.60	129.3 - 0.09x	0.71	0.04	-	-	0.66	-	-	0.77
Carman2 2010	-	-	0.79	-	-	0.73	-	-	0.66	-	-	0.55
Melita 2010	y = 0.83 - .0002x	0.64	0.05	-	-	0.99	y = 2156 - 0.85x	0.85	0.01	-	-	0.07
Carman 2011	-	-	0.44	-	-	0.28	-	-	0.92	-	-	0.26
Winnipeg 2011	y = 0.79 - 0.0004x	0.66	0.05	y = 127.9 - 0.09x	0.83	0.01	-	-	0.27	-	-	0.86

Table 7.8. Summary of linear regression equations describing the effect of late emerging biennial wormwood plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.16	-	-	0.07	-	-	0.26	-	-	0.06	-	-	0.8
Carman2 2010	-	-	0.75	-	-	0.39	-	-	0.99	-	-	.	-	-	0.43
Melita 2010	-	-	0.84	-	-	0.31	-	-	0.65	-	-	0.55	-	-	0.26
Carman 2011	-	-	0.99	-	-	0.70	-	-	0.73	-	-	0.88	-	-	0.07

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.66	-	-	0.67	-	-	0.57	-	-	0.74
Carman2 2010	-	-	0.93	-	-	0.91	-	-	0.08	-	-	0.14
Melita 2010	-	-	0.54	-	-	0.17	-	-	0.42	-	-	0.70
Carman 2011	-	-	0.80	-	-	0.72	-	-	0.20	-	-	0.09

Table 7.9. Summary of quadratic regression equations describing the effect of early emerging biennial wormwood plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.44	-	-	0.25	-	-	0.51	-	-	0.98	-	-	0.11
Carman2 2010	-	-	0.95	-	-	0.32	-	-	0.58	-	-	.	-	-	0.71
Melita 2010	-	-	0.30	-	-	0.40	-	-	0.55	-	-	0.43	-	-	0.32
Carman 2011	-	-	0.68	-	-	0.08	-	-	0.53	-	-	0.87	-	-	0.55
Winnipeg 2011	-	-	0.84	-	-	0.19	-	-	0.25	-	-	0.64	-	-	0.11

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.19	-	-	0.12	-	-	0.86	-	-	0.95
Carman2 2010	-	-	0.38	$y = 106.7 - 0.174x + .0008x^2$	0.99	0.001	-	-	0.16	-	-	0.13
Melita 2010	-	-	0.64	-	-	0.84	-	-	0.9	-	-	0.07
Carman 2011	-	-	0.29	-	-	0.16	-	-	0.42	-	-	0.12
Winnipeg 2011	-	-	0.25	-	-	0.11	-	-	0.44	-	-	0.61

Table 7.10. Summary of quadratic regression equations describing the effect of late emerging biennial wormwood plants on sunflower. Co-efficient of regression and regression equations are indicated when the relationship was significant at p 0.05.

	Leaf count (number of leaves plant^{-1})			Stem diameter (mm)			Height (cm)			Anthesis stage (R5.X)			Head diameter (cm)		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.1	-	-	0.75	-	-	0.79	-	-	0.14	-	-	0.64
Carman2 2010	-	-	0.96	$y = 27.79 + 0.12x - 0.0012x^2$	0.99	0.003	-	-	0.62	-	-	.	-	-	0.11
Melita 2010	$y = 24.04 + .07x - 0.0003x^2$	0.94	0.01	-	-	0.68	-	-	0.96	-	-	0.79	-	-	0.74
Carman 2011	-	-	0.28	-	-	0.42	-	-	0.67	-	-	0.93	-	-	0.73

	seed size (cm^2 seed^{-1})			TKW (g 1000 seeds^{-1})			seeds per unit land (seeds m^{-2})			Number heads harvested (# m^{-2})		
	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value	Equation	R^2	p value
Carman 2010	-	-	0.36	-	-	0.47	-	-	0.62	-	-	0.61
Carman2 2010	-	-	0.12	-	-	0.07	-	-	0.61	-	-	0.33
Melita 2010	-	-	0.13	-	-	0.97	-	-	0.24	-	-	0.49
Carman 2011	-	-	0.41	-	-	0.95	-	-	0.61	-	-	0.68

Table 7.11. Data summary of all site-years.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density	SEM	Kochia density	SEM	Sunflower leaf count	SEM	Sunflower stem diameter	SEM	Sunflower height	SEM	Flower stage	SEM	Sunflower head diameter	SEM
					(plants ha^{-1})		(plants m^{-2})		(# leaves per plant)		(mm)		(cm)		(R 5.X)		(cm)	
bww	Carman 2010	1	early	1x	27900	4600	15	5	21.7	0.7	25.74	1.98	148.1	6.5	3.2	0.9	17.73	1.8
bww	Carman 2010	2	early	5x	32500	5200	38	13	18.5	1.5	22.42	0.53	154.7	4.8	2.7	0.4	16.75	0.9
bww	Carman 2010	3	early	10x	39400	2000	70	20	20.3	2.5	23.41	1.39	160.4	4.7	3.5	0.7	16.40	0.9
bww	Carman 2010	4	early	20x	39100	5900	174	27	20.8	0.6	20.48	2.37	148.4	4.6	2.1	0.4	16.03	0.6
bww	Carman 2010	5	early	40x	33700	3500	258	65	21.2	0.5	21.84	1.29	147.9	3.4	2.9	1.0	15.33	1.2
bww	Carman 2010	6	early	0x	39900	4300	0	0	21.4	0.7	23.46	1.25	152.7	7.9	2.2	0.6	16.75	0.7
bww	Carman 2010	7	late	1x	27800	4600	2	1	21.3	1.4	21.77	2.66	146.8	11.6	1.7	0.4	16.35	1.3
bww	Carman 2010	8	late	5x	37900	7300	3	1	20.8	1.4	23.75	2.68	149.7	5.6	2.2	0.8	16.90	1.3
bww	Carman 2010	9	late	10x	37800	2600	16	6	22.0	1.3	23.18	0.82	153.4	7.3	1.9	0.9	16.73	0.5
bww	Carman 2010	10	late	20x	36600	4300	105	41	24.1	0.6	22.47	2.48	149.5	9.7	2.8	0.5	16.63	1.2
bww	Carman 2010	11	late	40x	27400	4300	205	60	22.9	0.6	20.35	1.57	146.3	4.6	2.6	0.6	16.50	0.9
bww	Carman 2010	12	late	0x	39900	3300	0	0	22.3	0.6	24.83	2.35	155.0	7.8	1.7	0.2	15.83	0.5
bww	Carman2 2010	1	early	1x	37800	1100	7	3	22.7	0.7	26.53	0.90	173.6	5.2	.	.	18.0	1.6
bww	Carman2 2010	2	early	5x	36300	2200	38	7	21.8	1.3	27.63	0.87	177.5	4.9	.	.	18.0	1.3
bww	Carman2 2010	3	early	10x	39100	900	62	16	23.5	0.6	27.61	1.02	177.8	3.0	.	.	19.3	0.8
bww	Carman2 2010	4	early	20x	36500	1300	106	3	21.9	0.8	28.01	1.18	159.6	3.1	.	.	17.7	0.7
bww	Carman2 2010	5	early	40x	37300	1400	219	40	22.4	0.9	28.26	0.45	170.3	2.4	.	.	17.7	0.8
bww	Carman2 2010	6	early	0x	37600	1500	0	0	22.6	0.9	27.72	1.25	174.7	2.1	.	.	18.5	0.9
bww	Carman2 2010	7	late	1x	50800	8900	2	1	21.0	0.7	28.17	0.64	179.7	2.8	.	.	17.1	1.0
bww	Carman2 2010	8	late	5x	39900	4000	4	2	23.5	1.3	28.12	0.85	176.5	2.4	.	.	18.5	0.5
bww	Carman2 2010	9	late	10x	42500	4300	10	6	23.7	0.6	28.84	1.77	174.5	3.0	.	.	19.2	0.6
bww	Carman2 2010	10	late	20x	47400	4900	102	51	22.2	1.0	26.68	1.56	176.6	3.1	.	.	17.1	1.0
bww	Carman2 2010	11	late	40x	33700	4200	31	29	21.9	0.9	30.18	0.54	175.5	1.0	.	.	19.5	1.3
bww	Carman2 2010	12	late	0x	39100	6400	0	0	22.6	0.9	27.72	1.25	174.7	2.1	.	.	18.5	0.9

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested (plants ha^{-1})	SEM	Sunflower yield (kg ha^{-1})	SEM	Sunflower yield loss (%)	Sunflower seed size (cm^2 seed^{-1})	SEM	Sunflower TKW (g 1000 seeds^{-1})	SEM
bww	Carman 2010	1	early	1x	33200	4700	2745	172	-14.7	0.8550	0.0414	136.3	6.2
bww	Carman 2010	2	early	5x	25700	6800	1811	246	24.3	0.8249	0.0430	127.2	10.7
bww	Carman 2010	3	early	10x	37700	2900	2517	413	-20.4	0.8077	0.0143	122.1	3.8
bww	Carman 2010	4	early	20x	32400	5500	2313	418	3.3	0.7992	0.0111	116.4	5.4
bww	Carman 2010	5	early	40x	32400	2800	1692	189	29.3	0.7636	0.0158	102.6	5.5
bww	Carman 2010	6	early	0x	38200	6100	2393	427	0.0	0.8047	0.0325	119.6	7.1
bww	Carman 2010	7	late	1x	22400	3600	1643	442	23.6	0.7959	0.0178	112.5	2.8
bww	Carman 2010	8	late	5x	32400	4100	2246	376	-4.5	0.8776	0.0380	146.9	3.9
bww	Carman 2010	9	late	10x	28200	3900	1519	282	29.4	0.8069	0.0163	118.8	1.6
bww	Carman 2010	10	late	20x	33200	4900	2576	274	-19.8	0.8772	0.0181	142.8	5.7
bww	Carman 2010	11	late	40x	26500	2300	2053	149	4.5	0.8263	0.0199	127.8	5.2
bww	Carman 2010	12	late	0x	36600	6300	2150	329	0.0	0.8020	0.0312	120.6	4.4
bww	Carman2 2010	1	early	1x	31600	4400	1615	297	1.5	0.8098	0.0331	105.8	7.5
bww	Carman2 2010	2	early	5x	30700	3400	1873	348	-14.3	0.8118	0.0064	102.0	3.5
bww	Carman2 2010	3	early	10x	30700	3100	1813	256	-10.6	0.8155	0.0101	99.3	1.3
bww	Carman2 2010	4	early	20x	30800	2500	1846	322	-12.6	0.8078	0.0222	97.1	3.3
bww	Carman2 2010	5	early	40x	25700	4700	1536	169	6.3	0.8230	0.0267	108.9	10.2
bww	Carman2 2010	6	early	0x	24900	2800	1639	98	0.0	0.8277	0.0143	106.1	5.1
bww	Carman2 2010	7	late	1x	27400	5500	1486	171	9.4	0.7849	0.0172	96.9	3.4
bww	Carman2 2010	8	late	5x	24900	2800	1439	197	12.2	0.8050	0.0200	103.4	3.1
bww	Carman2 2010	9	late	10x	29900	4900	1848	319	-12.7	0.8158	0.0107	104.6	2.2
bww	Carman2 2010	10	late	20x	33200	2700	1958	248	-19.4	0.8071	0.0137	100.4	3.7
bww	Carman2 2010	11	late	40x	23300	4000	1747	302	-6.6	0.8607	0.0058	117.0	1.0
bww	Carman2 2010	12	late	0x	24900	2800	1639	98	0.0	0.8277	0.0143	106.1	5.1

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density	SEM	Kochia density	SEM	Sunflower leaf count	SEM	Sunflower stem diameter	SEM	Sunflower height	SEM	Flower stage	SEM	Sunflower head diameter	SEM
					(plants ha^{-1})		(plants m^{-2})		(# leaves per plant)		(mm)		(cm)		(R 5.X)		(cm)	
bww	Melita 2010	1	early	1x	50400	6100	21	6	22.5	1.1	24.90	2.34	164.1	4.4	1.9	0.3	17.5	0.8
bww	Melita 2010	2	early	5x	50800	2500	106	16	22.9	1.0	25.78	0.56	166.3	4.7	1.7	0.5	16.1	0.6
bww	Melita 2010	3	early	10x	45700	5400	230	46	24.4	0.8	26.30	1.28	168.0	5.7	0.7	0.2	16.0	1.5
bww	Melita 2010	4	early	20x	50800	6500	652	182	22.5	0.9	25.72	2.60	166.2	2.9	1.2	0.4	17.2	1.3
bww	Melita 2010	5	early	40x	40400	8600	723	132	20.9	1.0	23.70	0.53	164.7	3.3	1.1	0.3	15.7	0.6
bww	Melita 2010	6	early	0x	44100	1000	0	0	24.3	1.4	26.67	0.44	168.7	3.3	1.2	0.3	18.1	0.8
bww	Melita 2010	7	late	1x	54500	5200	1	1	24.2	1.3	24.29	1.75	170.7	3.9	0.8	0.1	15.9	0.6
bww	Melita 2010	8	late	5x	40300	3200	15	14	24.4	1.5	26.49	1.74	162.2	2.8	1.1	0.4	16.6	0.6
bww	Melita 2010	9	late	10x	43300	2100	11	9	24.8	0.6	24.06	1.15	168.2	3.0	0.7	0.2	16.7	0.9
bww	Melita 2010	10	late	20x	45400	8300	64	59	27.1	0.8	24.12	1.73	170.3	3.5	1.1	0.3	17.0	0.8
bww	Melita 2010	11	late	40x	47900	5700	201	113	23.8	1.4	23.82	1.47	169.5	2.1	1.1	0.4	15.6	1.3
bww	Melita 2010	12	late	0x	44100	1000	0	0	24.3	1.4	26.67	0.44	168.7	3.3	1.2	0.3	18.1	0.8
bww	Carman 2011	1	early	1x	62800	2700	126	49	23.5	0.4	25.29	0.24	184.0	6.9	7.2	0.2	16.9	0.5
bww	Carman 2011	2	early	5x	77500	8700	401	81	23.7	0.4	25.42	0.68	183.1	6.1	7.2	0.3	17.3	0.7
bww	Carman 2011	3	early	10x	76600	7800	817	76	23.6	0.3	23.12	0.59	182.7	6.9	6.7	0.2	15.7	0.6
bww	Carman 2011	4	early	20x	80300	5500	1362	157	23.8	0.6	24.64	1.06	178.1	8.0	7.2	0.2	16.9	0.4
bww	Carman 2011	5	early	40x	63700	4400	1732	153	22.5	0.2	25.01	1.19	189.1	2.9	6.8	0.1	16.4	0.8
bww	Carman 2011	6	early	0x	66200	9600	0	0	24.5	0.5	27.34	0.44	179.5	8.0	7.1	0.2	17.1	0.4
bww	Carman 2011	7	late	1x	67000	5200	528	105	24.6	0.5	27.99	0.50	184.4	5.8	6.9	0.1	17.6	0.2
bww	Carman 2011	8	late	5x	61200	6000	2688	432	24.9	0.3	28.92	1.02	185.7	6.2	6.8	0.2	18.2	0.5
bww	Carman 2011	9	late	10x	54500	6200	2955	319	24.8	0.6	27.38	1.05	188.8	4.6	7.7	0.3	18.2	0.3
bww	Carman 2011	10	late	20x	74100	7500	3232	362	24.1	0.5	27.25	1.02	184.3	8.0	6.6	0.2	17.6	0.5
bww	Carman 2011	11	late	40x	72800	7400	3358	143	24.6	0.2	28.34	0.44	187.6	4.9	7.2	0.2	18.7	0.3
bww	Carman 2011	12	late	0x	66200	9600	0	0	24.5	0.5	27.34	0.44	187.1	3.2	7.1	0.2	17.1	0.4

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested (plants ha^{-1})	SEM	Sunflower yield (kg ha^{-1})	SEM	Sunflower yield loss (%)	Sunflower seed size (cm^{2} seed^{-1})	SEM	Sunflower TKW (g 1000 seeds^{-1})	SEM
bww	Melita 2010	1	early	1x	39100	3700	2015	164	10.9	0.7797	0.0159	96.5	3.1
bww	Melita 2010	2	early	5x	46600	3000	2049	256	9.4	0.7623	0.0135	93.8	4.9
bww	Melita 2010	3	early	10x	42400	3100	1873	384	17.2	0.7862	0.0151	102.6	2.1
bww	Melita 2010	4	early	20x	32400	3600	1763	265	22.1	0.7960	0.0276	101.2	6.7
bww	Melita 2010	5	early	40x	29000	7100	1403	313	38.0	0.7848	0.0212	96.9	3.8
bww	Melita 2010	6	early	0x	37400	2400	2263	210	0.0	0.8004	0.0164	103.6	1.9
bww	Melita 2010	7	late	1x	47400	4900	2062	240	8.9	0.7604	0.0152	92.8	3.8
bww	Melita 2010	8	late	5x	34900	3200	1816	201	19.7	0.7887	0.0185	97.6	3.9
bww	Melita 2010	9	late	10x	44100	10100	1951	283	13.8	0.7755	0.0236	97.5	3.1
bww	Melita 2010	10	late	20x	38300	5000	1907	175	15.7	0.8158	0.0239	95.8	2.0
bww	Melita 2010	11	late	40x	44100	3700	2060	399	9.0	0.7575	0.0159	90.8	2.2
bww	Melita 2010	12	late	0x	37400	2400	2263	210	0.0	0.8004	0.0164	103.6	1.9
bww	Carman 2011	1	early	1x	53200	2300	2421	224	10.9	0.7506	0.0139	101.2	2.6
bww	Carman 2011	2	early	5x	49100	6400	2083	313	23.3	0.7688	0.0270	97.3	3.7
bww	Carman 2011	3	early	10x	60700	5500	2018	275	25.7	0.7290	0.0271	96.9	1.9
bww	Carman 2011	4	early	20x	57400	3100	2414	80	11.1	0.7650	0.0061	98.8	1.4
bww	Carman 2011	5	early	40x	52400	2800	2222	148	18.2	0.7553	0.0215	99.3	6.0
bww	Carman 2011	6	early	0x	38200	5500	2716	174	0.0	0.8039	0.0263	115.6	8.3
bww	Carman 2011	7	late	1x	47400	4100	2787	99	-2.6	0.7476	0.0113	104.7	3.9
bww	Carman 2011	8	late	5x	47400	6700	3688	272	-35.8	0.7909	0.0247	118.6	5.2
bww	Carman 2011	9	late	10x	47400	5500	3144	218	-15.7	0.7448	0.0061	112.7	4.5
bww	Carman 2011	10	late	20x	54900	7500	3572	181	-31.5	0.7711	0.0140	110.2	4.2
bww	Carman 2011	11	late	40x	48200	3900	3403	192	-25.3	0.7862	0.0161	112.3	3.8
bww	Carman 2011	12	late	0x	38200	5500	2716	174	0.0	0.8039	0.0263	115.6	8.3

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density	SEM	Kochia density	SEM	Sunflower leaf count	SEM	Sunflower stem diameter	SEM	Sunflower height	SEM	Flower stage	SEM	Sunflower head diameter	SEM
					(plants ha^{-1})		(plants m^{-2})		(# leaves per plant)		(mm)		(cm)		(R 5.X)		(cm)	
bww	Winnipeg 2011	1	early	1x	49100	6500	14	8	22.9	0.4	24.87	1.65	172.2	3.5	6.6	0.2	17.9	0.6
bww	Winnipeg 2011	2	early	5x	64500	8400	31	15	23.4	0.2	24.75	0.71	170.7	2.9	6.6	0.3	16.4	1.0
bww	Winnipeg 2011	3	early	10x	70800	7200	81	28	23.3	0.3	23.93	0.32	175.9	4.5	6.0	0.6	15.5	0.3
bww	Winnipeg 2011	4	early	20x	52800	6900	76	27	24.2	0.2	24.63	0.43	166.9	7.1	5.2	0.5	16.3	0.7
bww	Winnipeg 2011	5	early	40x	57900	12400	213	28	23.8	0.4	23.80	0.98	149.3	12.0	3.2	0.8	14.6	0.4
bww	Winnipeg 2011	6	early	0x	50800	4300	0	0	23.8	0.6	26.51	0.93	175.6	6.5	6.7	0.1	18.4	0.7
bww	Winnipeg 2011	7	late	1x	67000	7500	0	0	24.8	0.7	28.02	1.04	180.7	4.9	6.7	0.2	20.1	1.7
bww	Winnipeg 2011	8	late	5x	70800	8600	0	0	24.0	1.0	27.04	0.63	181.7	6.0	7.0	0.2	17.9	1.1
bww	Winnipeg 2011	9	late	10x	62400	10200	0	0	24.8	0.3	27.54	0.68	183.4	3.2	7.2	0.2	18.3	0.7
bww	Winnipeg 2011	10	late	20x	62000	8200	0	0	24.9	0.6	28.46	1.60	177.6	5.7	7.0	0.2	18.3	1.6
bww	Winnipeg 2011	11	late	40x	63300	8000	0	0	24.5	0.5	27.57	1.02	179.2	7.3	7.1	0.3	19.2	0.6
bww	Winnipeg 2011	12	late	0x	50800	4300	0	0	23.8	0.6	26.51	0.93	175.6	6.5	6.7	0.1	18.4	0.7

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested (plants ha^{-1})	SEM	Sunflower yield (kg ha^{-1})	SEM	Sunflower yield loss (%)	Sunflower seed size (cm^{2} seed^{-1})	SEM	Sunflower TKW (g 1000 seeds^{-1})	SEM
bww	Winnipeg 2011	1	early	1x	44300	6900	3632	342	17.7	0.8151	0.0266	128.7	6.8
bww	Winnipeg 2011	2	early	5x	54000	5800	3327	85	24.6	0.7611	0.0150	122.8	3.8
bww	Winnipeg 2011	3	early	10x	59000	3400	3431	293	22.3	0.7249	0.0102	114.9	1.4
bww	Winnipeg 2011	4	early	20x	47400	6200	3008	486	31.9	0.7617	0.0113	121.0	2.4
bww	Winnipeg 2011	5	early	40x	50700	10400	2858	761	35.3	0.7171	0.0187	110.1	7.1
bww	Winnipeg 2011	6	early	0x	52400	9100	4414	180	0.0	0.7953	0.0260	131.1	8.6
bww	Winnipeg 2011	7	late	1x	43200	6900	3705	184	16.1	0.8075	0.0609	135.5	15.3
bww	Winnipeg 2011	8	late	5x	49900	8700	3942	130	10.7	0.7705	0.0227	120.9	5.8
bww	Winnipeg 2011	9	late	10x	42400	4100	3517	315	20.3	0.7780	0.0119	127.1	2.1
bww	Winnipeg 2011	10	late	20x	45700	7200	3882	222	12.1	0.8022	0.0389	134.3	9.5
bww	Winnipeg 2011	11	late	40x	48200	3400	3886	160	12.0	0.7795	0.0244	130.2	4.6
bww	Winnipeg 2011	12	late	0x	52400	9100	4414	180	0.0	0.7953	0.0260	131.1	8.6

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density (plants ha^{-1})	SEM	Kochia density (plants m^{-2})	SEM	Sunflower leaf count (# leaves per plant)	SEM	Sunflower stem diameter (mm)	SEM	Sunflower height (cm)	SEM	Flower stage (R 5.X)	SEM	Sunflower head diameter (cm)	SEM
kochia	Melita 2009	1	early	1x	64500	6500	7	4	23.6	1.0	24.71	1.16	162.2	7.0	7.2	0.5	16.2	0.7
kochia	Melita 2009	2	early	5x	50300	3000	13	1	23.6	0.9	24.55	0.48	152.8	6.2	7.8	0.3	16.5	0.8
kochia	Melita 2009	3	early	10x	54100	3800	10	3	22.8	0.3	25.65	0.79	163.2	7.2	7.7	0.3	16.0	0.5
kochia	Melita 2009	4	early	20x	57900	8600	27	6	23.5	0.6	25.05	1.12	158.9	9.4	7.0	0.5	16.3	1.2
kochia	Melita 2009	5	early	40x	62000	7200	44	11	23.8	0.9	24.01	1.52	152.0	10.8	7.6	0.2	15.2	1.4
kochia	Melita 2009	6	early	0x	54900	6300	0	0	22.8	1.0	26.82	1.28	155.2	6.2	7.2	0.5	17.4	1.1
kochia	Melita 2009	7	late	1x	65300	5500	5	4	25.1	0.8	25.62	1.00	164.2	5.1	7.5	0.1	16.7	0.4
kochia	Melita 2009	8	late	5x	63300	4700	3	3	24.7	0.9	25.46	1.01	162.2	1.3	7.9	0.3	17.4	0.5
kochia	Melita 2009	9	late	10x	66600	4100	10	4	23.9	0.7	25.56	0.35	165.4	4.6	7.0	0.5	16.9	0.2
kochia	Melita 2009	10	late	20x	65400	3700	27	12	25.5	0.5	25.00	0.81	166.2	8.3	8.1	0.2	16.9	0.7
kochia	Melita 2009	11	late	40x	60000	2800	59	8	24.0	0.4	26.18	1.20	154.9	10.1	7.9	0.3	17.2	0.7
kochia	Melita 2009	12	late	0x	54900	6300	0	0	22.8	1.0	26.82	1.28	155.2	6.2	7.2	0.5	17.4	1.1
kochia	wpg 2009	1	early	1x	48300	5200	7	1	21.3	0.8	28.47	0.65	144.0	2.0	3.4	0.2	16.3	0.3
kochia	wpg 2009	2	early	5x	44100	4300	14	2	20.3	0.6	26.35	1.06	137.6	1.5	3.2	0.1	16.1	0.5
kochia	wpg 2009	3	early	10x	39100	1900	21	7	20.8	0.6	26.84	0.91	127.8	2.9	3.5	0.2	15.5	0.4
kochia	wpg 2009	4	early	20x	47400	3800	55	12	18.3	0.8	26.38	1.48	119.5	0.9	2.1	0.5	14.9	0.4
kochia	wpg 2009	5	early	40x	49900	2900	120	20	18.7	1.0	25.08	2.29	115.7	1.3	1.9	0.3	14.6	0.7
kochia	wpg 2009	6	early	0x	46600	5300	0	0	22.3	0.3	28.86	0.86	144.2	1.5	3.8	0.3	16.2	0.6
kochia	wpg 2009	7	late	1x	37000	5300	5	2	20.2	0.6	28.03	1.80	141.1	2.5	3.5	0.2	16.7	0.8
kochia	wpg 2009	8	late	5x	37400	3400	10	3	20.3	0.6	28.89	0.57	144.7	4.4	4.5	0.4	17.5	0.2
kochia	wpg 2009	9	late	10x	40400	2500	21	3	21.3	0.2	29.68	0.12	140.9	1.2	4.4	0.4	17.0	0.5
kochia	wpg 2009	10	late	20x	43300	5300	43	5	20.3	0.2	28.29	0.63	138.8	0.8	4.3	0.4	18.0	1.1
kochia	wpg 2009	11	late	40x	34500	1400	107	17	22.2	0.8	29.67	1.33	141.5	5.1	5.1	0.6	17.9	1.2
kochia	wpg 2009	12	late	0x	46600	5300	0	0	22.3	0.3	28.86	0.86	144.2	1.5	3.8	0.3	16.2	0.6

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested	SEM	Sunflower yield	SEM	Sunflower yield loss	Sunflower seed size	SEM	Sunflower TKW	SEM
					(plants ha^{-1})		(kg ha^{-1})		(%)	(cm^2 seed^{-1})		(g 1000 seeds^{-1})	
kochia	Melita 2009	1	early	1x	50700	4300	2986	178	4.5	0.6850	0.0109	106.4	1.9
kochia	Melita 2009	2	early	5x	46600	4800	2982	331	4.6	0.6977	0.0184	107.0	7.1
kochia	Melita 2009	3	early	10x	49900	3000	2712	214	13.2	0.6798	0.0062	103.7	2.5
kochia	Melita 2009	4	early	20x	46600	5400	2420	263	22.6	0.6709	0.0227	102.2	7.2
kochia	Melita 2009	5	early	40x	50700	1600	2467	358	21.1	0.6398	0.0326	94.1	8.0
kochia	Melita 2009	6	early	0x	45700	5300	3126	150	0.0	0.7084	0.0369	114.8	8.2
kochia	Melita 2009	7	late	1x	53200	7500	3087	390	1.2	0.6839	0.0038	105.7	2.1
kochia	Melita 2009	8	late	5x	53200	6500	3536	400	-13.1	0.6954	0.0094	107.0	2.2
kochia	Melita 2009	9	late	10x	54900	6700	3267	309	-4.5	0.6760	0.0042	105.6	2.3
kochia	Melita 2009	10	late	20x	58200	4900	3265	268	-4.5	0.6613	0.0041	102.5	2.4
kochia	Melita 2009	11	late	40x	52400	800	3342	156	-6.9	0.6902	0.0117	105.1	2.0
kochia	Melita 2009	12	late	0x	45700	5300	3126	150	0.0	0.6761	0.0252	107.5	5.3
kochia	wpg 2009	1	early	1x	46600	5600	2641	164	-12.1	0.7066	0.0156	102.1	2.0
kochia	wpg 2009	2	early	5x	41600	2100	2268	219	3.7	0.7032	0.0271	101.2	1.0
kochia	wpg 2009	3	early	10x	35700	5400	1834	323	22.1	0.7179	0.0137	102.0	1.3
kochia	wpg 2009	4	early	20x	39900	2300	1792	166	23.9	0.6803	0.0295	100.1	2.8
kochia	wpg 2009	5	early	40x	39100	1600	1771	303	24.8	0.6759	0.0289	99.6	4.7
kochia	wpg 2009	6	early	0x	36600	2300	2355	277	0.0	0.7051	0.0189	108.0	1.9
kochia	wpg 2009	7	late	1x	39900	3000	2630	254	-11.7	0.6802	0.0125	105.7	3.3
kochia	wpg 2009	8	late	5x	37400	3400	2478	316	-5.2	0.7171	0.0076	106.5	3.0
kochia	wpg 2009	9	late	10x	35700	3100	2363	401	-0.3	0.6847	0.0135	105.1	2.3
kochia	wpg 2009	10	late	20x	37400	2400	3030	257	-28.7	0.7003	0.0190	107.4	2.4
kochia	wpg 2009	11	late	40x	37400	1500	2506	433	-6.4	0.7290	0.0388	106.4	3.0
kochia	wpg 2009	12	late	0x	36600	2300	2355	277	0.0	0.7051	0.0189	108.0	1.9

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density (plants ha^{-1})	SEM	Kochia density (plants m^{-2})	SEM	Sunflower leaf count (# leaves per plant)	SEM	Sunflower stem diameter (mm)	SEM	Sunflower height (cm)	SEM	Flower stage (R 5.X)	SEM	Sunflower head diameter (cm)	SEM
kochia	Carman 2010	1	early	1x	43700	8300	2	1	21.2	1.3	26.31	2.63	173.4	10.3	2.2	0.5	19.3	2.0
kochia	Carman 2010	2	early	5x	40400	6700	8	2	21.3	2.1	25.48	0.97	157.7	12.6	2.4	0.8	18.6	0.8
kochia	Carman 2010	3	early	10x	35800	5700	14	4	20.5	0.9	24.71	1.32	167.0	7.0	3.2	0.3	17.4	0.2
kochia	Carman 2010	4	early	20x	34900	4900	30	13	20.1	1.8	27.84	0.97	158.8	10.8	2.5	0.1	19.5	0.9
kochia	Carman 2010	5	early	40x	32400	5600	33	13	19.9	0.5	26.02	1.78	160.3	11.3	1.5	0.4	19.5	0.8
kochia	Carman 2010	6	early	0x	39500	6300	0	0	24.3	1.2	28.95	0.70	166.2	7.8	2.3	0.8	19.4	0.7
kochia	Carman 2010	7	late	1x	45800	5300	2	2	24.4	0.7	26.10	0.53	165.4	7.4	2.4	0.6	18.1	0.2
kochia	Carman 2010	8	late	5x	41200	4700	2	2	24.4	1.4	27.99	1.18	171.1	8.1	2.1	0.8	19.0	1.0
kochia	Carman 2010	9	late	10x	31600	4500	9	4	24.3	0.6	28.52	1.08	160.3	5.1	2.1	0.6	18.3	1.0
kochia	Carman 2010	10	late	20x	40800	8700	15	5	22.8	1.6	28.25	1.63	165.6	8.2	2.6	0.6	20.3	1.0
kochia	Carman 2010	11	late	40x	41200	2700	21	7	21.6	1.4	26.74	1.77	167.6	3.4	3.5	0.8	18.9	1.0
kochia	Carman 2010	12	late	0x	38700	5400	0	0	23.2	0.4	29.74	0.83	167.2	4.4	3.0	1.0	18.4	1.1
kochia	Carman2 2010	1	early	1x	37900	6300	7	4	23.4	0.9	30.99	0.45	180.2	2.7	.	.	19.0	0.9
kochia	Carman2 2010	2	early	5x	45300	5900	10	3	23.3	0.8	28.50	1.69	177.4	4.7	.	.	17.3	0.6
kochia	Carman2 2010	3	early	10x	48300	2800	22	9	23.5	1.0	27.22	0.86	180.2	3.6	.	.	18.1	0.5
kochia	Carman2 2010	4	early	20x	42400	3100	37	11	21.8	0.3	28.00	1.07	184.4	3.9	.	.	17.5	0.2
kochia	Carman2 2010	5	early	40x	44900	5800	66	15	23.6	1.2	25.92	1.97	175.3	4.9	.	.	16.4	0.4
kochia	Carman2 2010	6	early	0x	39900	5600	0	0	21.5	1.8	31.07	1.17	180.1	6.4	.	.	18.8	1.0
kochia	Carman2 2010	7	late	1x	36200	4300	0	0	21.4	1.3	31.97	2.17	172.5	3.5	.	.	18.3	0.8
kochia	Carman2 2010	8	late	5x	40300	3400	1	1	22.8	0.6	27.64	0.79	175.6	3.1	.	.	17.6	0.3
kochia	Carman2 2010	9	late	10x	49100	4500	1	1	21.0	0.8	26.86	0.88	179.3	4.1	.	.	17.4	0.5
kochia	Carman2 2010	10	late	20x	42400	6100	1	1	22.7	1.2	30.49	1.03	178.9	2.3	.	.	17.7	0.6
kochia	Carman2 2010	11	late	40x	37900	3500	2	1	21.7	0.8	30.78	0.98	183.2	4.3	.	.	18.6	0.3
kochia	Carman2 2010	12	late	0x	39900	5600	0	0	21.5	1.8	31.07	1.17	180.1	6.4	.	.	18.8	1.0

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested	SEM	Sunflower yield	SEM	Sunflower yield loss	Sunflower seed size	SEM	Sunflower TKW	SEM
					(plants ha^{-1})		(kg ha^{-1})		(%)	(cm^2 seed^{-1})		(g 1000 seeds^{-1})	
kochia	Carman 2010	1	early	1x	39900	7000	2766	335	14.0	0.8390	0.0452	125.7	8.9
kochia	Carman 2010	2	early	5x	38200	5100	3125	361	2.9	0.8126	0.0183	120.3	5.2
kochia	Carman 2010	3	early	10x	31600	6100	2820	569	12.3	0.8334	0.0084	129.1	5.3
kochia	Carman 2010	4	early	20x	34100	4700	3210	146	0.2	0.8591	0.0304	133.6	6.6
kochia	Carman 2010	5	early	40x	22400	4500	2397	252	25.5	0.8889	0.0182	143.3	5.8
kochia	Carman 2010	6	early	0x	33200	3600	3217	253	0.0	0.8557	0.0247	134.6	6.4
kochia	Carman 2010	7	late	1x	39900	1300	2824	176	9.5	0.8410	0.0278	132.6	4.9
kochia	Carman 2010	8	late	5x	36600	4000	2869	129	8.1	0.8259	0.0314	126.8	7.8
kochia	Carman 2010	9	late	10x	32400	4500	3097	335	0.8	0.8369	0.0409	126.9	14.7
kochia	Carman 2010	10	late	20x	35700	3900	3990	334	-27.8	0.8732	0.0380	133.7	8.4
kochia	Carman 2010	11	late	40x	38200	5100	3303	227	-5.9	0.8278	0.0267	125.4	5.8
kochia	Carman 2010	12	late	0x	32400	2500	3121	337	0.0	0.8587	0.0123	133.9	5.7
kochia	Carman2 2010	1	early	1x	33200	1900	2236	92	7.2	0.8292	0.0130	103.2	4.0
kochia	Carman2 2010	2	early	5x	28200	3200	1658	152	31.2	0.8120	0.0174	101.7	4.3
kochia	Carman2 2010	3	early	10x	33200	2300	2161	267	10.3	0.8039	0.0092	101.5	2.0
kochia	Carman2 2010	4	early	20x	32400	5900	1776	370	26.3	0.8144	0.0172	101.1	3.0
kochia	Carman2 2010	5	early	40x	29100	2500	1664	161	30.9	0.8213	0.0309	103.7	6.1
kochia	Carman2 2010	6	early	0x	32400	2000	2410	284	0.0	0.8188	0.0140	105.7	5.0
kochia	Carman2 2010	7	late	1x	21600	3400	1562	488	35.2	0.8443	0.0268	115.7	6.9
kochia	Carman2 2010	8	late	5x	24000	2500	1587	169	34.1	0.8229	0.0275	111.4	5.8
kochia	Carman2 2010	9	late	10x	31600	2100	1968	191	18.3	0.8184	0.0190	105.1	7.8
kochia	Carman2 2010	10	late	20x	24900	3900	1643	313	31.8	0.8564	0.0041	103.5	3.1
kochia	Carman2 2010	11	late	40x	24100	2800	1896	269	21.3	0.8435	0.0209	104.9	6.3
kochia	Carman2 2010	12	late	0x	32400	2000	2410	284	0.0	0.8188	0.0140	105.7	5.0

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density	SEM	Kochia density	SEM	Sunflower leaf count	SEM	Sunflower stem diameter	SEM	Sunflower height	SEM	Flower stage	SEM	Sunflower head diameter	SEM
					(plants ha^{-1})		(plants m^{-2})		(# leaves per plant)		(mm)		(cm)		(R 5.X)		(cm)	
kochia	Melita 2010	1	early	1x	40300	4800	2	1	23.8	0.4	26.21	0.78	166.7	4.0	0.5	0.1	17.8	0.7
kochia	Melita 2010	2	early	5x	37400	2700	7	2	24.5	0.5	26.14	1.39	164.2	1.1	1.0	0.3	19.2	0.6
kochia	Melita 2010	3	early	10x	44500	7200	9	2	24.4	0.8	25.45	2.08	175.0	2.3	0.6	0.2	18.4	0.2
kochia	Melita 2010	4	early	20x	42000	2700	19	3	24.8	1.8	26.52	1.87	168.4	3.5	0.8	0.1	19.1	1.1
kochia	Melita 2010	5	early	40x	39100	4200	28	7	25.7	1.0	27.51	0.76	171.1	6.0	0.7	0.2	18.3	0.6
kochia	Melita 2010	6	early	0x	40800	5800	0	0	23.6	1.5	24.21	1.11	170.6	3.9	0.6	0.1	16.9	0.5
kochia	Melita 2010	7	late	1x	48200	3900	1	1	24.9	1.7	28.30	0.93	172.2	4.1	1.0	0.4	17.1	1.1
kochia	Melita 2010	8	late	5x	47800	4500	0	0	26.0	1.1	25.00	0.50	172.9	6.3	0.4	0.0	18.2	0.6
kochia	Melita 2010	9	late	10x	44900	4900	0	0	24.4	1.3	26.42	1.82	166.3	6.1	0.6	0.1	19.7	0.5
kochia	Melita 2010	10	late	20x	43300	1300	1	1	24.2	1.9	27.05	0.24	161.3	6.0	0.6	0.3	18.1	0.2
kochia	Melita 2010	11	late	40x	47400	1700	3	2	25.4	1.3	26.94	1.77	172.9	5.7	0.8	0.3	18.7	0.8
kochia	Melita 2010	12	late	0x	40800	5800	1	1	25.4	2.2	24.21	1.11	170.6	3.9	0.6	0.1	16.9	0.5
kochia	Carman 2011	1	early	1x	55800	12700	41	7	23.8	0.2	30.13	1.04	190.9	3.0	7.3	0.2	18.1	0.8
kochia	Carman 2011	2	early	5x	63700	5500	141	18	23.2	0.3	27.41	0.93	191.6	3.4	7.0	0.4	18.3	1.1
kochia	Carman 2011	3	early	10x	72000	12500	261	65	22.2	0.6	25.13	1.06	189.5	4.0	7.2	0.3	18.0	1.2
kochia	Carman 2011	4	early	20x	54500	2700	475	62	24.0	0.4	25.84	1.17	187.5	3.1	6.8	0.2	17.1	0.5
kochia	Carman 2011	5	early	40x	61600	8300	829	75	22.9	0.1	23.69	0.90	188.7	1.8	6.0	0.2	15.7	1.1
kochia	Carman 2011	6	early	0x	76600	9600	0	0	23.9	0.2	29.00	0.88	192.9	1.0	7.6	0.3	17.9	0.8
kochia	Carman 2011	7	late	1x	63700	8800	63	11	23.3	0.3	28.53	0.72	196.9	1.8	7.4	0.1	17.4	0.2
kochia	Carman 2011	8	late	5x	70400	6700	276	30	24.1	0.3	30.46	1.58	192.3	4.9	7.4	0.1	18.1	0.3
kochia	Carman 2011	9	late	10x	59500	5300	480	49	24.0	0.8	29.48	1.24	193.4	1.9	7.4	0.1	19.5	0.8
kochia	Carman 2011	10	late	20x	72800	7000	682	29	23.4	0.3	28.11	0.30	193.6	4.5	7.2	0.1	17.3	0.3
kochia	Carman 2011	11	late	40x	63700	5300	1189	175	22.9	0.5	28.68	1.22	189.5	4.6	7.4	0.2	17.6	0.6
kochia	Carman 2011	12	late	0x	76600	9600	0	0	23.9	0.2	29.00	0.88	192.9	1.0	7.6	0.3	17.9	0.8

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested	SEM	Sunflower yield	SEM	Sunflower yield loss	Sunflower seed size	SEM	Sunflower TKW	SEM
					(plants ha^{-1})		(kg ha^{-1})		(%)	(cm^2 seed^{-1})		(g 1000 seeds^{-1})	
kochia	Melita 2010	1	early	1x	42400	4100	2316	381	8.7	0.7966	0.0157	99.3	2.5
kochia	Melita 2010	2	early	5x	35700	3400	2559	397	-0.9	0.8469	0.0115	109.7	4.6
kochia	Melita 2010	3	early	10x	47400	5600	2822	239	-11.3	0.8212	0.0221	102.9	6.0
kochia	Melita 2010	4	early	20x	36500	2300	2611	244	-2.9	0.8361	0.0225	104.8	5.1
kochia	Melita 2010	5	early	40x	44900	2100	2767	203	-9.1	0.8280	0.0055	106.4	1.7
kochia	Melita 2010	6	early	0x	46600	4200	2536	216	0.0	0.8150	0.0200	103.7	3.3
kochia	Melita 2010	7	late	1x	48200	4400	2671	209	-5.3	0.7968	0.0053	100.1	2.6
kochia	Melita 2010	8	late	5x	49900	1300	2947	261	-16.2	0.7928	0.0105	97.8	1.6
kochia	Melita 2010	9	late	10x	39900	6500	2672	241	-5.3	0.8237	0.0291	100.0	1.8
kochia	Melita 2010	10	late	20x	41600	2800	2496	147	1.6	0.8230	0.0149	101.9	1.6
kochia	Melita 2010	11	late	40x	40700	3900	2838	118	-11.9	0.8083	0.0182	100.0	1.8
kochia	Melita 2010	12	late	0x	46600	4200	2536	216	0.0	0.8150	0.0200	103.7	3.3
kochia	Carman 2011	1	early	1x	42400	8400	3379	260	-0.6	0.8160	0.0369	119.6	5.7
kochia	Carman 2011	2	early	5x	48200	4900	3515	250	-4.6	0.7990	0.0167	116.5	3.6
kochia	Carman 2011	3	early	10x	49900	6500	2469	310	26.5	0.7562	0.0288	106.0	5.5
kochia	Carman 2011	4	early	20x	48200	3200	2462	369	26.7	0.7653	0.0216	105.8	4.3
kochia	Carman 2011	5	early	40x	43200	5600	1910	168	43.1	0.7412	0.0153	99.9	4.5
kochia	Carman 2011	6	early	0x	47400	7600	3360	232	0.0	0.7737	0.0133	109.5	4.3
kochia	Carman 2011	7	late	1x	48200	5600	3493	356	-4.0	0.7640	0.0134	111.9	1.7
kochia	Carman 2011	8	late	5x	49100	2500	4204	383	-25.1	0.7847	0.0106	119.4	2.8
kochia	Carman 2011	9	late	10x	43200	8200	3527	522	-5.0	0.8027	0.0173	119.3	4.4
kochia	Carman 2011	10	late	20x	48200	2100	3611	201	-7.5	0.7756	0.0210	113.2	3.1
kochia	Carman 2011	11	late	40x	42400	3100	3418	608	-1.7	0.7881	0.0151	117.5	2.9
kochia	Carman 2011	12	late	0x	47400	7600	3360	232	0.0	0.7737	0.0133	109.5	4.3

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunfower density (plants ha^{-1})	SEM	Kochia density (plants m^{-2})	SEM	Sunflower leaf count (# leaves per plant)	SEM	Sunflower stem diameter (mm)	SEM	Sunflower height (cm)	SEM	Flower stage (R 5.X)	SEM	Sunflower head diameter (cm)	SEM
kochia	Winnipeg 2011	1	early	1x	69100	4600	34	3	21.7	0.8	15.84	0.99	139.1	8.7	3.3	0.9	11.9	1.2
kochia	Winnipeg 2011	2	early	5x	69900	7400	201	34	18.8	1.2	12.42	0.94	125.2	8.4	0.6	0.2	9.4	1.4
kochia	Winnipeg 2011	3	early	10x	65400	4200	340	64	17.3	1.5	12.02	0.79	122.9	6.9	0.5	0.3	9.2	1.0
kochia	Winnipeg 2011	4	early	20x	56200	8600	563	28	14.2	1.1	10.21	0.41	115.5	1.3	0.2	0.1	7.6	0.6
kochia	Winnipeg 2011	5	early	40x	59100	6500	905	78	14.7	0.4	9.48	0.47	105.9	6.1	0.1	0.1	6.5	0.2
kochia	Winnipeg 2011	6	early	0x	64900	5100	0	0	23.5	0.7	22.34	0.72	164.8	6.7	7.1	0.3	16.1	0.3
kochia	Winnipeg 2011	7	late	1x	60300	5500	37	14	23.6	0.4	22.94	0.30	172.9	3.4	7.2	0.1	15.8	0.6
kochia	Winnipeg 2011	8	late	5x	47800	3700	144	15	24.2	0.9	23.67	1.63	167.1	4.7	7.2	0.2	17.1	1.4
kochia	Winnipeg 2011	9	late	10x	82000	3200	493	115	22.9	0.5	23.81	0.95	174.4	3.7	7.1	0.3	16.1	1.7
kochia	Winnipeg 2011	10	late	20x	55800	5800	732	64	26.3	0.5	25.23	0.97	172.1	4.9	7.2	0.2	16.7	1.3
kochia	Winnipeg 2011	11	late	40x	57000	6100	1302	92	23.0	0.4	23.68	0.73	169.7	3.6	6.9	0.4	15.1	0.8
kochia	Winnipeg 2011	12	late	0x	64900	5100	0	0	23.5	0.7	22.34	0.72	164.8	6.7	7.1	0.3	16.1	0.3

Table 7.11. Data summary of all site-years continued.

Weed	Site-year	Trt	Weed emergence time	Weed seed rate	Sunflower heads harvested	SEM	Sunflower yield	SEM	Sunflower yield loss	Sunflower seed size	SEM	Sunflower TKW	SEM
					(plants ha^{-1})		(kg ha^{-1})		(%)	(cm^2 seed^{-1})		(g 1000 seeds^{-1})	
kochia	Winnipeg 2011	1	early	1x	52400	6700	1217	245	61.6	0.5264	0.0275	84.0	6.2
kochia	Winnipeg 2011	2	early	5x	40700	5500	610	168	80.7	0.5341	0.0170	83.6	2.8
kochia	Winnipeg 2011	3	early	10x	42400	5900	560	209	82.3	0.5050	0.0117	78.1	1.5
kochia	Winnipeg 2011	4	early	20x	33200	4500	327	101	89.7	0.5481	0.0292	84.7	4.9
kochia	Winnipeg 2011	5	early	40x	23200	5200	151	47	95.2	0.5162	0.0181	77.8	3.0
kochia	Winnipeg 2011	6	early	0x	49100	5400	3167	489	0.0	0.7010	0.0041	111.7	2.5
kochia	Winnipeg 2011	7	late	1x	57400	4900	3250	349	-2.6	0.6693	0.0182	108.7	4.7
kochia	Winnipeg 2011	8	late	5x	43200	4500	2696	237	14.9	0.7029	0.0362	110.8	7.1
kochia	Winnipeg 2011	9	late	10x	69100	7200	3476	422	-9.8	0.6967	0.0299	109.9	8.7
kochia	Winnipeg 2011	10	late	20x	46600	7100	3180	254	-0.4	0.7092	0.0306	111.6	6.7
kochia	Winnipeg 2011	11	late	40x	57400	6700	3751	266	-18.4	0.7067	0.0228	114.3	5.2
kochia	Winnipeg 2011	12	late	0x	49100	5400	3167	489	0.0	0.7010	0.0041	111.7	2.5

Figure 7.4. Representation of the time of determination of sunflower growth and development parameters.