Emergence Timing and Persistence of Kochia (*Kochia scoparia*) in Manitoba Fields

BY

TIMOTHY DAMIAN SCHWINGHAMER

A Thesis

Submitted to the Faculty of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Plant Science

University of Manitoba

Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

Emergence Timing and Persistence of Kochia (*Kochia scoparia*) in Manitoba Fields

BY

TIMOTHY DAMIAN SCHWINGHAMER

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

MASTER OF SCIENCE

ACKNOWLEDGEMENTS

I must acknowledge gratefully Rene Van Acker, my thesis advisor; Lyle Friesen, who guided me through the process of statistical analysis; Arvel Lawson, who identified established kochia populations in rural southwestern Manitoba, and established contact with our co-operating farmers; our co-operating farmers; Dr. Jane Froese and Dr. Mario Tenuta; the Department of Plant Science at the University of Manitoba; NSERC and DuPont Canada for providing me with an IPS grant; Andrea Bartlinski, who provided technical support; the summer students; and the land and organisms of Manitoba, without which none of this would have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Schwinghamer, Timothy Damian. M.Sc. The University of Manitoba, April 2007. Emergence timing and persistence of kochia (*Kochia scoparia*) in Manitoba fields. Major Professor: Rene Van Acker.

This research addresses the ecological niche of *Kochia scoparia* (L.) Schrader (family: Chenopodiaceae), and how growers can close the ecological niche of *K. scoparia* in prairie cropland. The predictability of the spring emergence period of *K. scoparia* is a potentially exploitable attribute that may be applied to weed management. The emergence timing of *K. scoparia* was monitored, during the spring and summer of 2005 and 2006, in 12 fields (including high and low disturbance fields, a no-till alfalfa field and fields seeded to barley, beans, canola, corn, and wheat) in southern Manitoba, Canada. *K. scoparia* begins to emerge prolifically at only 50 cumulative growing degree days (GDD T_{base} 0 C) and *K. scoparia* continues to emerge throughout the growing season into late summer. Soil samples taken in the fall from quadrats in which emergence was monitored reveal a very limited *K. scoparia* seedbank. This data supports other research which shows that *K. scoparia* seeds have little or no dormancy and a limited ability to persist in a seedbank. The effects of seeding depth (2, 10, 20, 40, and 80 mm) on emergence was observed, under controlled growth room conditions. *K. scoparia* seeds placed at the soil surface (2 mm) had the greatest emergence. Seeding depth reduced *K. scoparia* emergence significantly. The results from this study show that *K. scoparia* is a very early emerging seed-limited weed species with seed that cannot emerge from great depths. This information will facilitate *K. scoparia* control timing decisions and management for farmers and the data from this study can be used to create an emergence model for *K. scoparia*.

Chapter 1 – Introduction

According to the Prairie Weed Survey (Leeson et al. 2005), kochia was ranked 10th among weeds for the 2000s, up from a rank of 20th in the 1990s, with a frequency of 13.3 percent in fields surveyed and a relative abundance of seven percent. The relative abundance of a species is a measure of species abundance that combines frequency, field uniformity, and field density. The proliferation of kochia is in part due to both its salt tolerance and there being few good control strategies to manage this weed. Reduced soil disturbance provides a niche for kochia establishment and growth, such as is associated with perennial forage production.

Kochia is an annual species that reproduces and spreads by seed. A greater understanding of the biology and ecology of kochia and the herbicidal management of this weed species, especially under western Canadian environmental and agricultural conditions, will aid in devising more effective management strategies and approaches that are based on an understanding of the population dynamics of established kochia. Investigating the emergence period of kochia plants may allow for more informed management decisions and provide some further explanation of herbicide-resistance among kochia accessions, and the persistence of kochia in some cropping system scenarios (and not in others).

This text will begin with a thorough review of the scientific literature, the biology and relationships of kochia to the agricultural ecosystem. This text proceeds to a more specific discussion of experimental results.

There are chemical controls available for use on kochia. With the adoption of reduced tillage farming a rise in kochia populations in western Canada has been observed. Manitoban lands have been and are managed increasingly by the cultivation of large areas with single crops (i.e. monoculture) and herbicides. The herbicides in annual cropping systems have provided selection pressures sufficient to evolve some populations to be herbicide-resistant. The appropriate time to target kochia populations will be identified by the assessment of the percent of kochia emerged of the total emergent population. The presence of kochia influences allelopathically the germination of crop seeds, radical development, etc. Herbicide resistance is an additional complication for crop production, which includes new limitations to only certain crops and herbicides, the dispersal (via pollen) of resistance genes, and the contamination of alfalfa and other forage seed.

Until now, the period of kochia emergence has not been well documented, particularly in southwestern Manitoba, where the weed is relatively new and increasingly problematic to farmers. Information on the emergence period of kochia plants would be valuable because farmers want to control weed infestations and limit its spread.

Chapter 2 - Literature Review

2.0.0. General Nature and Distinction of Species

Kochia scoparia (L.) Schrader (family: Chenopodiaceae) is an herbaceous, annual, warm-season, cosmopolitan dicot that reproduces and spreads by seed (Gates 1941, Frankton and Mulligan 1970, Milchunas et al. 1991, Pyankov et al. 2001). Kochia is also known as *Bassia scoparia* (L.) A. J. Scott, belvedere, summer cypress, and broom toad-flax. It is the Osyris described in *De Materia Medica* by Dioscorides in the first century A. D. (Gunther 1968). It has been marketed commercially as *Kochia trichophylla* (Schmeiss) Schinz and Thell. In Canada, the most typical common name for this species is kochia.

Kochia cotyledons are atriplicoid with hypoderma (Pyankov et al. 2001). All leaves use NADP-ME type C_4 photosynthesis. Young foliage is dark green (Mulugeta 1991). The leaves of kochia are numerous, alternate, hairy, sessile, and linear to narrowly lanceolate in shape (Gates 1941, Eberlein and Fore 1984, Mulugeta 1991). Leaf length on a mature plant (1.8-7.6 cm, 0.8-8.0 mm wide) is a function of branch number and length (Weiner and Fishman 1994). Mature foliage turns yellowish-green, then brownish red, and sometimes purplish in the autumn (Fernald and Kinsey 1958).

The growth of kochia is indeterminate (Mulugeta 1991) and highly variable. In open stands, high light intensities suppress apical dominance. Vigorous lateral growth results in bushy plants, 30 cm (Archibold 1980) to 120 cm tall (Eberlein and Fore 1984), with oval to ovate growth forms, and weaker stem bases (Becker 1978). In dense stands, the primary axis grows vigorously, but lateral growth is poor, resulting in open-branched plants with linear to lanceolate growth forms. Kochia can grow up to 3 m tall (Durham and Durham 1979). Soil degree-days base 10 C, amount of rain, and irrigation all correlate highly to kochia height (Nussbuam 1985). Kochia produces a main stem with abundant top growth (Davis et al. 1967). Kochia stems are smooth but pubescent (Mulugeta 1991) and green, yellowish green, or green with red streaks during the growing season, and purplish red in the fall. Gates (1941) described kochia as "freely branching." Kochia branches are very leafy and either erect or ascending (Everitt et al. 1983). The branches are arranged in a $\frac{2}{5}$ spiral phyllotaxis (Franco and Harper 1988). That is, each leaf stands singly, their points of insertion forming a spiral around the stem (Bennett and Murray 1889). There are 5 leaves in every 2 turns of the spiral. The 6th member stands over the 1st, the 7th over the 2nd, and so on. Ultraviolet-B radiation (280-320 nm) stimulates axillary shoot production and branch fraction (Barnes et al. 1990). Kochia has a taproot system (Mulugeta 1991) with a large root profile. Phillips and Launshbaugh (1958) found kochia roots 5 m deep. However, kochia had the smallest root system of ten weeds in Davis et al.'s (1965) experiment. Kochia flowers are small, stalkless, inconspicuous, green (because they are apetalous) (Gates 1941, Frankton and Mulligan 1970, Eberlein and Fore 1984), and proterogynous (discussed further below) (Stallings et al. 1995). Sometimes clusters of long hairs surround the flowers (Frankton and Mulligan 1970).

The flowers of kochia appear as the stem elongates (Williams 1932). One, to several flowers clustered in narrow spikes (Gates 1941) may be found in the axils of: the leaves (Frankton and Mulligan 1970), the upper leaves (Gates 1941, Eberlein and Fore 1984), or the leaflike but reduced bracts (Everitt et al. 1983), and in terminal panicles or spikes (Gates 1941, Eberlein and Fore 1984). Kochia is a short day plant (Bell et al. 1972a) which flowers indeterminately (Stallings et al. 1995). Critical day-lengths required for flowering range from 13 h 12 min to 15 h 20 min (Bell et al. 1972a). During the peak flowering period, kochia can release pollen in such large quantities that the soil beneath the plants becomes yellow (Becker 1968).

Kochia pollen grains are spheroidal, with a median diameter of 20 to 40 µ, periporate with 100 to 130 pores uniformly distributed over the surface, and have granular particles over their entire surface (Stallings et al. 1995). The circular polypantoporate morphology of kochia pollen may facilitate long distance wind dispersion (Mulugeta et al. 1994*).* Kochia has nonobligate allogamous mating behaviour (Guttieri et al. 1998), i.e., kochia is partially self-fertile (Bell et al. 1972a), but predominantly open pollinated (Thill et al. 1991). Kochia is capable of permanent autoreproduction (Holec et al. 2004). In most kochia plants, stigmas emerge up to one week before anthers (Mulugeta 1991, Stallings et al. 1995). The stigma is receptive to foreign pollen for a few days, or for more than a week, prior to pollen shedding from the anthers of the same flower (Mulugeta 1991). By the time the anther sheds pollen, the stigma may be aged and unreceptive to pollen from the same flower. Steyermark (1962) blames kochia's abundant pollen for "quite a number of hay fever cases".

Kochia is diploid (Cooper 1935 in Mulugeta 1991), the somatic chromosome number in all kochia biotypes is 2n = 18 (Májovský 1974, Thompson 1993). Kochia populations undergo a high degree of outbreeding (Mengistu and Messersmith 2002) and mating patterns approximate random mating (Guttieri et al. 1998). Therefore, unlinked alleles sort independently in field populations. Despite generations of herbicide selection, kochia maintains high genetic diversity through substantial levels of gene flow within and among populations (Mengistu and Messersmith 2002).

Williams (1932) found mature kochia seeds on the same branches as unfertilized ovules. Each kochia flower contains a single seed (Frankton and Mulligan 1970, Mulugeta 1991). Kochia fruit is a reddish utricle (Gates 1941). Kochia seeds are finely granular, dull grayish black to brown with yellow markings, ovate, rough, flat, and with a groove on both sides (Gates 1941, Frankton and Mulligan 1970, Eberlein and Fore 1984, Mulugeta 1991). A transparent (Williams 1932), thin, fragile, star-shaped, hull (calyx) (Mulugeta 1991) encloses the seed (Frankton and Mulligan 1970, Eberlein and Fore 1984). The seed is 1.8 mm (Gates 1941) to 3 mm (Mulugeta 1991) long and about 1.0 mm in diameter (Everitt et al. 1983). The weight of 100 seeds can vary from 38 to 107 mg (70 mg average) (Morton and Manthy 1995). A kochia plant typically produces over 14,000 seeds (Thill et al. 1991). Iverson and Wali (1981) found 50,000 seeds on kochia plants in favourable conditions.

2.0.1. Herbivory

Kochia can be grazed by cattle (*Bos taurus* L.) in range and pasturelands (Thilsted et al. 1986). Signs of kochia toxicosis in cattle include photosensitization, malnutrition, muscular weakness, excessive salivation, and skin lesions (Thistled et al. 1986; Rankins et al. 1991b). Clinical problems range from impaired performance and weight loss to photosensitization, icterus and death in cattle, sheep (*Ovis aries* L.), and horses (*Equus caballus* L.) (Sprowls 1981). Mild chronic toxicosis was associated with kochia hay fed as 50 percent of the diet fed to fine-wool lambs (Rankins and Smith 1991). Wether (i.e., castrated ram) lambs fed kochia hay exhibited hepatoxicosis, altered metabolic hormones, and impaired nitrogen retention (Rankins *et al.* 1991a). The severity of toxicosis in rats (*Rattus rattus*) relates to the contents of substances reactive to Dragendorff's reagent, presumably alkaloids (Rankins 1987). However, dry kochia was not toxic when force-fed to rabbits (Leporidae) (Galitzer and Oehme 1978). Although kochia may produce allelochemics as a defense mechanism for herbivory, the compounds seem to produce ionic imbalances (P, Mn, Zn) in the soil which hasten the demise of kochia stands through autotoxicity (Wali 1999).

Untreated kochia seed caused high mortality and poor performance in turkey poults (*Meleagris gallopavo* L.) (Coxworth and Salmon 1972 in Durham and Durham 1979). Fed seed washed in one percent sodium hydroxide solution, the controls performed slightly better or no better than did the poults on a diet containing 15 percent kochia seeds. Kochia may be lower in cystine content than the requirement for early growth of chicks.

Owing to disturbance, soil near prairie dog (*Cynomys ludovicianus* Ord.) burrows favours the establishment of kochia (Koford 1958). In spring and early summer, prairie dogs seek out and feed heavily on green forbs such as kochia. Kochia also provides food for prairie dogs in winter. Prairie dogs have little net effect on seed abundance, but by cutting kochia, they prevent the growth of infestations.

Insect pests do not damage kochia seriously (Olfert 1990). Kochia hosts western tarnished plant bugs (*Lygus hesperus* Knight), pale legume bugs (*Lygus elisus* Van Duzee), and *Polymerus basalis* Reuter (Armstrong and De Azevedo Camelo 2003). On kochia in Alberta, pale legume bugs formed only 9 percent and *Lygus borealis* Kelton 90 percent of *Lygus* total abundance (Schwartz and Footit 1992). However, kochia in concentrated stands is an excellent host for lygus bugs (Moore et al. 1982). Most mirid adults appear during the flowering period. Lygus nymphs feed on the tender leaves, pass through their nymphal instars, and become mature when the plant is in bloom (Knight 1968). Kochia plants are "well suited" for migratory grasshopper (*Melanoplus sanguinipes*) aggregation and basking (Olfert 1990). Kochia is resistant to feeding by grasshoppers (Erickson and Moxon 1947), and also appears to be a nutrient-poor diet for them (Hinks and Erlandson 1995). Migratory grasshoppers feeding on kochia have high egg viability but low biotic potential (including survival, development and reproduction) (Hinks et al. 1990). The apple pest noctuid moth (*Laconobia subjuncta* Grote and Robinson) larvae develop to pupation and adult emergence on kochia (Landolt 2002), although kochia yields low noctuid moth pupal weights.

False root-knot nematodes (*Nacobbus aberrans* Thorne and Allen) "sugarbeet" race, collected in Nebraska, reproduce on kochia (Inserra et al. 1984). False root-knot nematodes parasitize kochia roots producing root galls (Gray 1997). Among seven weeds grown with fieldbeans, Gast et al. (1983) ranked kochia sixth for total lesion nematodes (*Pratylenchus* sp.) per gram of dry root. Observations made at IARI, New Delhi, indicate that kochia can also host the root-knot nematode (*Meloidogyne incognita*) (Mishra et al. 2002).

Kochia is not always toxic to livestock (Galitzer and Oehme 1978). Kochia contains saponin (Pammel 1911 and Hurst 1942 in Durham and Durham 1979), potentially toxic concentrations of nitrates (Kingsbury 1964), oxalates, and alkaloids (Boerboom 1993). Kochia hay causes photosensitization (Kingsbury 1964), and impairs liver function and suppresses serum prolactin concentrations in cattle (Rankins et al. 1991c). Coxworth (1970 in Durham and Durham 1979) fed untreated kochia meal to mice (*Mus musculus* L.), and observed high mortality. Oxalate is the primary toxicant in drought-stricken, mature, or overgrazed kochia (Rankins et al. 1991c). Curtin and Wen (2004) found a linear relationship between kochia's water-soluble oxalate content and soil excess cation content. Kochia can contain a large quantity of water-extractable oxalate [195-225 cmol kg^{-1} of dry matter (86 to 99 g kg^{-1})]. Kochia balances excess cations over inorganic anions largely by the synthesis of oxalate.

2.0.2. Diseases Affecting Kochia

During senescence, soil-inhabiting fungal mycelium can infect the basal tissues of kochia plants (Becker 1968). Infection typically proceeds at the origins of the branches, at ground level peridermal lesions. Cell wall component degradation by fungi may facilitate stem rigidity and abscission zone tissue brashness. Blackish wood, characteristic of the abscission zone tissues of the senescing plant, indicate decay owing to *Rhizoctonia solani* (Becker 1978). *Rhizoctonia* reduces breaking strength in the abscission zone by about 40 percent during the decay period. Kochia tissue chemistry is favourable to microbial decomposition (Vinton and Burke 1995). The release of nitrogen maintains high nitrogen availability in soils beneath kochia plants. High nitrogen mineralization rates beneath the plant canopy are related to low root lignin : nitrogen and carbon : nitrogen ratios. *Rhizopus* sp. mycelial density appeared to increase with germinating kochia seed density (Wiley et al. 1985). Germinated and dead kochia seeds are subject to degradation by soil fungi (Zorner et al. 1984).

Kochia is a host of black root disease *Aphanomyces cochliodes* (Hall 1998). The damping-off organism *Phythium debaryanum* attacks kochia seedlings (Erickson and Moxon 1947). During and after emergence *P. debaryanum* causes discoloration, collapse of the axis tissues, and eventual seedling death. Symptoms appear more pronounced at 26 to 29 C, and when soils are wet. During cool and rainy periods, leaf spot disease can attack kochia seedlings, causing stunting and eventual seedling death. Herbicide resistant kochia encourages the proliferation of microorganisms (which degrade wastes such as $[^{14}C]$ atrazine on pesticide-contaminated sites, discussed further below) (Perkovich et al. 1996).

2.0.3. Proliferation in North America

Kochia is native to middle- and eastern-Asia steppes (Holá et al. 2004). It was introduced involuntarily (for the most part) into Europe and North America. Artificial and large water and nitrogen fertilizer increases to the soil resource regimes of ecosystems resulted in the repeated reintroduction of kochia in North America (Vinton and Burke 1995). Under new conditions, significant ecological adaptability and plasticity are prominent features of kochia, that lead to its spread into new synantrophic ecotypes, near transportation routes and urban centres (Holec et al. 2004).

Fernald (1950 in Becker 1968) stated that kochia was originally cultivated as an ornamental in northeastern North America and from there spread to the west and south. By 1887 it was common in waste places in Ontario, Vermont, and northern New York (Becker 1968). Kochia was collected during botanical surveys in southeastern Wyoming from 1891-1900 (Forcella 1985).

Kochia has grown in the Czech Republic since the first half of nineteenth century (Holec et al. 2004). It was introduced accidentally from its Eastern range of natural occurrence, and from North America, as a contaminant of imported feedstuff and other materials. The railway is the main vector of this species' spread, and it grows mostly around the rails and train stations. From these locations, kochia colonizes the surrounding habitats.

In the early 1900s, in the United States, kochia was grown as an ornamental (Durham and Durham 1979). However, data on herbarium specimens (North Dakota State University and University of North Dakota) indicate that only small populations existed on the northern Great Plains at that time. Stevens's (1946) earliest specimen is from Kulm, LaMoure County, North Dakota, in 1905. Kochia was introduced to Bahia Blanca, Argentina, from central Europe in 1921 (Galitzer and Oehme 1978). Stevens (1946) identified kochia as "the chief instance of a plant which was grown originally as an ornamental and later became a troublesome weed." Kochia seems to have escaped gradually (Becker 1978).

Kochia was rather uncommon until about 1930 when it became recognized as troublesome in South Dakota, Iowa, and Kansas (Stevens 1946, Durham and Durham 1979). It was growing in Colorado in the late 1930s. An explosive population growth was documented during the 30s drought cycle in Kansas (Gates, 1941) and in North Dakota (Stevens 1946). Owing to the frequent droughts in the years between 1926 and 1941, kochia spread throughout marginal areas and the drought-stricken, overgrazed pastures of Kansas (Gates 1941). In North Dakota, by the particularly dry years of 1934 and 1936, it had become common and was attracting much attention by its abundance and evident ability to grow under dry conditions (Becker 1968). In 1935 it was reportedly widespread and common in the middle western states (Muenscher 1935 in Becker 1968). The spread may have been hastened by its contamination of commercial alfalfa seed (Iseley 1960). Kochia was collected in central Wyoming and eastern Idaho in the 1930s (Forcella 1985).

By 1943, kochia was a constituent of the weedy flora in a plowed low prairie in Nebraska (Weaver 1948 in Becker 1968), and it was utilized by cattle in Nebraska pastures at least by 1945 (Darland 1945 in Becker 1968). In the late 1940s it came into the Texas Panhandle in carloads of grain, as it was first observed growing along railroad tracks (Durham and Durham 1979). A Texas A&M popular bulletin in 1947 lists kochia as an annual ornamental. Booth (1941 in Becker 1968) and Costello (1944 in Becker 1968) studied the vegetation of abandoned fields in Kansas, Oklahoma, and NE Colorado, but did not list kochia as a component of the weedy vegetation.

During the drought of 1952-55, kochia was common on overgrazed ranges in southeast Colorado and western Kansas (Becker 1968). Love and Love (1954) observed kochia in the Manitoban prairie. An explosive population growth occurred in the mid 50s in Kansas, Colorado, and North Dakota. Hitchcock (1955 in Forcella 1985) stated that kochia had established in Washington, east of the Cascades. Breitung (1957) recorded kochia in Swift Current, Saskatchewan, commonly escaped in waste places. Kochia was widespread in southern Idaho since the 1960s (Beorboom 1993). It was one of the most common synanthropes discovered on the St. Louis, Missouri, railroad network, based on Mühlenbach's (1979) excursions from 1954 to 1971.

By 1970, kochia was present in Nova Scotia, Quebec, Ontario, Manitoba (Table 2.1), Saskatchewan, Alberta, and British Columbia. It was becoming a problem in cultivated fields in the prairie provinces and the Okanagan Valley of British Columbia (Frankton and Mulligan 1970). Due to the rapid proliferation of the plant, the 1970 Alberta Weed Survey considered kochia the most important species at that time (Leeson et al. 2005). In the early 70s, Oregon had scattered kochia populations (Boerboom 1993).

During the summer drought of 1976 in North and South Dakota, there was further, explosive population growth (Becker 1978). Durham and Durham (1979) observed kochia growing profusely in the Grand Canyon area of Arizona.

Table 2.1 Frequency of Kochia in Manitoba Fields by Ecoregion (Leeson et al. 2005)

Ecoregion (number of fields)	Boreal Transition (482)	Aspen Parkland (1377)	Fescue Grassland (76)	Moist Mixed Grassland (810)	Mixed Grassland (606)	Lake Manitoba Plain (222)	Interlake Plain (62)	Total (3806)
% Frequency	0.6	6.1	6.7	23.9	33.9	3.6	1.6	13.3

Until 1985, there were no reports of kochia influencing cereal crop production in Idaho, Oregon or Washington. However, it affected production of irrigated crops in some locations in Idaho (Forcella 1985). Kochia is extremely competitive, and it infests about 25 percent of North Dakota cropland (Dahl et al. 1982). It has naturalized in the central and western states (Everitt et al. 1983). On the Canadian prairies, kochia occurs in 45 percent of all survey sites: 80, 44, 29, and 78 percent of sites in central Alberta, southern Alberta, central Saskatchewan, and southern Saskatchewan, respectively (Braidek et al. 1984).

2.0.4. Emergence Time of Kochia

Kochia emergence is said to begin immediately following the last night frost (Nussbaum et al. 1985). Kochia emergence extends for a relatively long period following the onset of spring (Smith in Mulugeta 1991). The average heat units (soil base 10) necessary for emergence of kochia is 1 (Alam and Wiese 1985). Kochia emerged April 25 to May 9 at a semiarid site in Colorado (Anderson 1994). Weatherspoon and Schweitzer (1969) observed very few kochia emerging after July 1, even when there was no shading by the crop.

A minimum rainfall rate is required to emerge and sustain kochia, and this minimum seems to increase in a saline seedbed. Stepphun and Wall (1993) observed a 13 day emergence lag, likely related to the time required to leach excess salts, or autotoxins, out of the seedbed.

Some sulfonylurea-resistant mutants possess acetolactate synthase (ALS) enzymes with altered feedback inhibition properties (Subramanian et al. 1991), which may lead to overproduction of branched chain amino acids, such as isoleucine and possibly valine, which are required for DNA synthesis and cell division (Rost et al. 1990 and Shaner 1991 in Dyer et al. 1993). Elevated levels of these amino acids in resistant kochia seeds may allow cell division and growth to proceed more rapidly during germination at low temperatures than in susceptible types, in which levels may be limiting. That is, mutations conferring resistance to sulfonylurea herbicides in kochia accessions may concomitantly reduce or abolish ALS sensitivity to normal feedback inhibition patterns, resulting in elevated levels of branched chain amino acids available for cell division and growth during early germination (Dyer et al. 1993).

2.0.5. Ability of Kochia to Emerge from Depth

Kochia's ability to rapidly germinate, grow, and emerge generally favours its establishment within shallow seedbeds. This may be taken into consideration when kochia is grown as a forage, in which case the appropriate seeding depth is about 1 cm or less (Everitt et al. 1983 in Stepphun and Wall 1993). Al-Khatib et al. (1997) covered kochia seeds to a depth of 2 mm. Krishnan et al. (1998) covered kochia seeds to a depth of 5 mm. Seeds germinating in this shallow layer interact with soil solutions of widely variable salinity, which decrease with influxes of water from precipitation, and increase with loss by evaporation (Stepphun and Wall 1993).

Johnson (1990) found that kochia emergence decreased from seeds buried to a depth of 30 mm, and there was no kochia emergence from seeds buried at 90 mm. Zorner et al. (1984) buried kochia seeds in subplots with depth increments of 1, 3, 5, 10, 15, and 30 cm. Prior to burial, Zorner et al. (1984) placed each group of 400 seeds in 7.5 by 7.5 cm, 113-mesh polypropylene cloth packets that were permeable to water. Successful seedling emergence following germination was restricted by a 5 cm depth limit (Zorner et al. 1984).

For tillage depths to 30, 10, 5, or 1 cm, Zorner et al. (1984) predicted total emergence of the seeds produced the previous fall to be 12, 40, 84, or 92 percent, respectively. The lower emergence percentages resulted from burial of seeds at or below a level from which they could not emerge easily following germination, and from conservation of seed dormancy with deeper burial. Tillage depth can be utilized to limit the quantity of seedlings that result from seed germination. The predicted drop in emergence with deep cultivation is desirable, because it reduces the probability of seedlings escaping control and developing into a problem.

The number of kochia plants increases in no-till systems (Anderson and Nielsen 1996), which favour the proliferation of small-seeded species (Koskinen and McWhorter 1986 in Anderson and Nielsen 1996), but do not affect the weed community emergence pattern (Anderson 1994). Knowledge of weed community emergence patterns could be used to suggest cultural practices such as optimal planting dates that favour a crop over weeds, and possibly reduce herbicide use for within crop weed control.

2.0.6. Recruitment Biology

Most kochia seeds start to germinate within 2 to 3 h (Lodhi 1979), almost complete germination within 24 h, and either germinate or decay within one year (Boerboom 1993). The seeds germinate readily at shallow depths after the first winter of burial (Zorner et al. 1984), when the upper 5 to 10 cm of soil becomes frost-free (Becker 1968). The germination rate decreases as temperature moves higher or lower than 16 C (Lacher et al. 1963). Germination rate may be highest at 5 to 25 C (Everitt et al. 1983) or 25 to 35 C (Khan et al. 2001) and lowest at 5 to 15 C. In any case, light is not required for recruitment (Maguire and Overland 1959, Everitt et al. 1983, and Thompson et al. 1994), but may have a favourable effect (Everson 1949). Germination rates decrease as salinity increases (Khan et al. 2001), but seeds are highly salt tolerant and tolerance increases as temperature increases. Seed germination is tolerant to high solute concentrations (Evetts and Burnside 1972 and Khan et al. 2001), moisture stress, and extreme acid or alkaline conditions (Everitt et al. 1983). Germination rates reduce slightly at pH 2 and pH 10 (Evetts and Burnside 1972) or pH 12 (Everitt et al. 1983). Germination tests showed 80 and 50 percent germination for heavy (60 percent by count) and light seeds (separated by blowing), respectively (Stevens 1960).

Fuerhing (1980) found the highest levels of emergence at seeding depths of 0.64 cm and very little emergence at seeding depths of 1.9 cm. Everitt et al. (1983) found the seedling emergence percentage for kochia seeds left exposed on the soil surface (74%) was significantly higher than for those planted at a depth of 3 mm (57%). Inhibited emergence is probably due to the small size of the seed, since absence of light has no detrimental effect on germination.

2.0.7. Seed Production

Kochia seed seems to have very little dormancy (Zorner et al. 1984), therefore, the number of germinable seeds represents an accurate estimate of viable seed production (Table 2.2) (Mickelson et al. 2004). Owing to widely variable flowering timing, kochia can produce viable seed before the harvest of small grains (Bell et al. 1972a). Seed production per plant is strongly dependent upon population density (Mulugeta 1991). Lirussi et al. (2004) obtained 16.3 g seed (74 percent viability) per 100 g of plant. Comparable yields, in order to obtain protein yields similar to those obtained with kochia (29 percent protein dry basis) would be: flaxseed (*Linum usitatissimum* L.) (27 percent protein): 2300-2700 kg ha^{-1}, rapeseed (*Brassica campestris*) (29 percent protein): 2200-2400 kg ha^{-1}, alfalfa forage (20 percent protein): 3150-3500 kg ha^{-1} (Coxworth et al. 1969). Grazed kochia produces more seed than ungrazed plants (Durham and Durham 1979).

Table 2.2 Seed Production Potential for Kochia

Seeds $plant^{-1}$	Conditions	Source
5	Stressed	Iverson and Wali 1981
84	Kochia cut at the soil surface twelve weeks after emergence	Mulugeta 1991
1968	(not stated)	Mulugeta 1991
4 100	Field locations	Mickelson et al. 2004
5108	Plants were cut early and grew in plots which had low kochia densities	Mulugeta 1991
>14 000	(not stated)	Thill et al. 1991
14 600	(not stated)	Stevens 1932
>20 000	(not stated)	Nussubaum 1985
50 000	Favourable conditions	Iverson and Wali 1981

2.0.8. Seed Dispersal

Fay et al. (1992) measured kochia seedling populations, beneath mother plants, as high as 30 000 plants m^{-2}. However, efficient long distance seed spread over large barren areas occurs due to stem abscission and subsequent dispersion by wind and human activities (Iverson and Wali 1981, Holec et al. 2004). Wind is a very important means of dispersal for kochia seeds (Mulugeta 1991). Dissemination occurs during plant tumbling and decreases exponentially with distance from the original site (Fay et al. 1992). Some seeds remain attached to the desiccated plant skeleton when it finally rests, most fall off during tumbling.

2.0.9. Stem Abscission

The stem of kochia directs stress owing to wind loads, as generated by velocities of only 40 to 48 km h^{-1}, toward the basal abscission zone (Becker 1978). The kochia plant axis acts as a moment arm to induce brash abscission zone tissue failure. Plant desiccation reduces the levels of capillary water and affects its internal distribution, leading to tissue shrinkage, and the concomitant development of brashness within the abscission zone and rigidity in the stem (Becker 1978). Usually, the mycelium of at least one species of soil-inhabiting fungus (*Rhizoctonia solani*) invades the abscission zone (Becker 1968). Infection facilitates abscission by decreasing the force required to rupture the abscission zone tissue. During *R. solani* decay breaking strength can be reduced 40 percent (Becker 1978).

2.1.0. Seed Dormancy

It is often said that kochia seeds have no innate dormancy (Everitt et al. 1983, Dyer 1993, and Thompson et al. 1994). However, portions of dormant and nondormant kochia seed populations can remain viable for at least 36 months (Zorner et al. 1984), and kochia may be detected 4 or 5 years after nil detection at eradication sites (Dodd and Randall 2002 in Panetta and Lawes 2005). Forcella et al. (1997) found no obvious microclimate thresholds that may induce dormancy in kochia. Persistence increases with burial depth, apparently. In Zorner et al.'s (1984) study, the effect of depth on seed persistence was not evident until after 6 months burial, when depth increased seed conservation. The depth effect was evident to 15 cm burial but became less pronounced with time, since no significant differences due to depth were observable beyond 18 months burial. Seed populations at all depths appeared to stabilize with respect to depletion rate after 18 months of burial (Table 2.3). Seed loss from the initially nondormant population included significant viability loss at burial depths of 10 cm or less. During the first four months of burial, nondormant seed population persistence generally decreased with depth, but the effect reversed by 6 months after burial. The effect of depth diminished over time. Secondary dormancy may not be relevant for this hard-seeded species (Taylorson 1987 in Forcella et al. 1997).

Table 2.3 The Effect of Depth and Duration of Seed Burial on Soil Persistence of Initially Dormant Kochia (Zorner et al. 1984)

	Burial depth (cm)					
Burial duration	1	3	5	10	15	30
(months following Oct. 20, 1978)	(% of initially buried seeds remaining)					
1	93	95	95	94	94	93
2	94	97	94	94	94	95
4	93	94	95	94	95	95
6	58	33	42	49	55	53
9	4	6	30	33	40	41
12	2	4	24	28	35	35
18	1	2	3	9	13	13
24	<1	2	2	3	4	4
30	<1	1	1	2	3	3
36	<1	1	1	2	3	2

2.1.1. Practical Usefulness of Kochia

Kochia can be grown as a potherb and for the abundant seeds which can be used as a cereal or in bread (Fernald and Kinsey 1958 and Steyermark 1962). This suggests no serious toxicity problems associated with the human consumption of kochia (Coxworth et al. 1969). The young tips of kochia are cooked as a vegetable (Steyermark 1962). Kochia could be heavily grazed and still produce seed for human food (Durham and Durham 1979). The entire plant, when dried, has been used as a broom for sweeping (Fernald and Kinsey 1958 and Steyermark 1962).

Momordin Ic is the active compound of Kochiae Fructus, an anti-pruritogenic agent, with anti-allergic activity, and a treatment of skin disease, which is originated from the dried kochia fruit (Matsuda et al. 1997). The methanol extract of kochia blocks the activation of nuclear transcription factor kappa-B, which regulates gene expressions involved in cellular proliferation, inflammatory responses, and cell adhesion (Shin et al. 2004). Infusions of the herb are reputed to have anti-rheumatic and cardiac activity (Drost-Karbowska et al. 1978). Momordin Ic and its aglycone, oleanic acid, could be active principles for rheumatoid arthritis (Choi et al. 2002). Kochia saponins have anti-ulcer activity and gastro-protective properties (Borrelli and Izzo 2000). Kochia showed effects with inhibition activity of 47 percent against the epimastigote form of *Trypanosoma cruzi*, the etiologic agent of Chagas disease, the third most prevalent vector-borne illness in the world (Lirussi et al. 2004). The finding of small amounts of (monoamine oxidase inhibitors, serotonin antagonists, and central nervous system stimulants) harmane and harmine (previously known as "telepathine") in kochia is consistent with the presence of tetrahydro-β-carboline alkaloids in Chenopodiaceae

(Drost-Karbowska et al. 1978). Flowering tops contain 2.2 percent betaine, which is important to cardiovascular health. Kochia is a source of anti-inflammatory furonaphthoquinones.

2.1.2. Allelopathy

Several allelopathic compounds, injurious to crop growth, can leach from kochia residue and debris (Einhellig and Schon 1982). Allelochemicals from kochia reduce seedling growth by altering the water balance in growing seedlings. Inhibitors identified from aqueous extracts of kochia leaves are betalains, alkaloids, flavonid quercetin, myricetin, and the phenolics chlorogenic acid, caffeic acid, and (from alkaline hydrolysis of kochia leaves) ferulic acid (Lodhi 1979). Martem (1973 in Karachi and Pieper 1987) groups these compounds into antiquality and unpalatability components of kochia forage. They reduce both the germination of cultivated radish (*Raphanus sativus*) seeds (Lodhi 1979) and the growth of sorghum [*Sorghum bicolor* (L.) Moench], soybean [*Glycine max* (L.) Merr.], and kochia seedlings (Boerboom 1993), but do not inhibit kochia seed germination, regardless of the concentrations applied (Lodhi 1979). Chlorogenic acid from kochia interferes with ^{32}P and ^{86}Rb uptake in sunflower seedlings (and likely non-radioactive P and Rb as well).

Kochia seed lipids accumulate $16{:}1\Delta^5$, an unusual C_{16} monounsaturated fatty acid, at around 5% of total seed fatty acids (Kleiman et al. 1972 in Whitney et al. 2004). This fatty acid can produce 6-acetoxy-5-hexadecanolide, i.e., mosquito (*Culex quinquefasciatus*) ovipositioning pheromone, which stimulates gravid female egg-laying (Olagbemiro et al. 1999 and 2004, Whitney et al. 2000). With the goal of using the gene to direct heterologously the synthesis of the monoenoic fatty acid, to provide chemical feedstocks to facilitate mosquito pheromone synthesis, Whitney et al. (2004) found the genes encoding the variant kochia Δ^5-palmitoyl-ACP desaturase.

Longevity of kochia site dominance does not exceed 3 years (Iverson and Wali 1978), after which there is patchiness and ingress of other plant species into formerly kochia-dominated vegetation. Lodhi (1979) attributes successional patterns to phytotoxins produced by decaying kochia foliage, which induce autotoxicity. Soil treatment with kochia leaves (7.5g kg^{-1} soil) reduced kochia biomass (Wali 1978), while the biomass of slender wheatgrass (*Agropyron trachycaulum*) and yellow sweet clover (*Melilotus officinalis* Lam.) was unaffected. Treatment with kochia leaves causes significant changes in the nutrient composition of soils and plants, including P : Mn and P : Zn ratios in plants. Kochia radicals showed a significant reduction in length at all concentrations of various autotoxins applied. Initial rapid germination and radical growth rapidly decrease. Several growth chamber experiments showed the decaying kochia leaves and roots inhibit kochia growth but not the growth of wild rye (*Agropyron caninum*) and yellow sweet clover (Iverson and Wali 1981). Extracts from mature foliage and the stem fraction are less inhibitory to growth, as compared to those from regrowth or leaves. Hot water facilitates the release of kochia autotoxins into the soil (Karachi and Pieper 1987).

2.1.3. Drought Tolerance

Kochia employs the C_4 metabolic pathway (Black et al. 1969), which allows for greater biomass production under drought conditions (Iverson and Wali 1981). Kochia produces more dry matter under dry soil moisture conditions than under medium or wet conditions (Wiese 1970). Evetts (1972) found a significant increase in kochia height at 9-day watering intervals compared to 3- and 6-day watering intervals. Kochia has shorter, narrower, and less vulnerable xylem vessels compared to its C_3 counterparts, e.g., common lamb's quarters (*Chenopodium album*) (Kocacinar and Sage 2003). Kochia stand densities increase during years of low moisture and high temperatures (Blackshaw et al. 2001b). The water use efficiency of kochia, at a plant density of $5\ m^{-2}$, has been calculated to be 107 (Nussbaum et al. 1985). Kochia has one-half to one-third the water requirement of cereal crops (Coxworth et al. 1969).

Phillips (1958) assumed that the kochia roots extended to at least 3.00 m. The plants attained this depth during a 115-day growing period. Kochia tolerates drought, remains green, and continues limited growth while sorghum or native grasses die or become dormant.

2.1.4. Extensive Roots

Kochia's taproot system extends mainly downward along steep slopes, roadsides, gravel pits, or other xeric sites, but may extend laterally, depending upon substrate water relations (Becker 1968). Kochia roots can elongate 76.2 cm within 15 days after transplanting (Wiese 1968). The rate of root elongation exceeds increases in plant height. Kochia has a top : root ratio of 1 or less (Table 2.4). (Kochia roots weigh the same amount or more than the tops.) Becker (1968) traced the root system of a plant 1 m tall to a depth of 1.5 m into the substratum, in which case the lateral roots extended to about 1 m from the main axis. Such a plant could remove water from 4.5 to 5.0 m^3 of soil. On a bottom-land site with somewhat atypical soil and moisture, Phillips and Launchbaugh (1958) observed extensive kochia root systems obtained from a 15 by 30 cm profile. They obtained kochia roots from 5 m below the surface. A single plant had roots reaching a soil diameter of 2.5 m at the 5 m depth. In salt-affected, moist soils with more or less permanently saturated subsoils, lateral roots of a plant 1.5 m tall were traced in excess of 1.2 m on either sides of the plant axis (Becker 1968). Vertical penetration of roots was less than 0.6 m. Such a plant is capable of removing water from 2.5 to 3.0 m^3 of soil.

Table 2.4 Height, Root Weight, Top Weight, Top/Root Ratio, and Seed Weight of Seed to Start Transplants of Kochia Grown in Glass Faced Boxes (Weise 1968)

	Height (cm)	Top weight (g)	Root weight (g)	Top/root ratio	Weight 100 seed (g)
Kochia	60.5	9.3	10.3	0.9	1.1

2.1.5. Productivity and Competitiveness

Kochia is a very competitive weed. Owing to its fast growth and efficient utilization of water, it grows tall, and accumulates a lot of biomass, e.g, the bushy plants found at the edge of plots (Mulugeta 1991). Davis et al. (1967) measured a dry matter weight of 771 g per plant. Therefore, kochia has potential not only as a forage crop, but also for the production of biomass for energy (Nussbaum et al. 1985). At Texas Tech University Research Center, dry matter yields of 3 548.4, 8 708.0, and 11 326.7 kg ha^{-1} were harvested May 29, June 20, and July 15, respectively (Sherrod 1971). Growth in kochia is indeterminate so biomass accumulation occurs during the whole season (Mulugeta 1991), especially in dry soil (Wiese and Vanidiver 1970).

Kochia does not play a dominant role in non-agricultural, native ecosystems in North America (Vinton and Burke 1995), but it is a highly competitive weed in agricultural ecosystems. Cyclical trends in kochia populations relate to soil moisture stress and subsequent reduced competition from mesic crop plants (Becker 1978). Kochia has the capacity to shade short crop plants (Nussbaum et al. 1985), and it is a problem in late-harvested crops (Wolf et al. 2000).

Kochia habitats include waste places and roadsides (Frankton and Mulligan 1970). Under dryland farming conditions in semi-arid or arid areas (where moisture stress is common) kochia has especially distinct survival and competitive advantages (Wiese and Vanidiver 1970, Evetts and Burnside 1972, Nussbaum et al. 1985). Kochia uses water very efficiently compared to other weeds and dry soil does not reduce growth.

Kochia is a problem in a wide range of crops (Mulugeta 1991), particularly early-planted crops. Kochia's distinct survival and competitive advantages are due to early emergence and establishment and rapid growth (Evetts and Burnside 1972), which continue during the entire growing season (Nussbaum et al. 1985). High variation in earliness of flowering among northern Great Plains populations of kochia is a problem within cool-seasoned cereal crops (Bell et al. 1972a, Forcella 1985).

Kochia accounted for 21 percent of the total weed yield in irrigated sweet Spanish onions (*Allium cepa* L.) (Wicks et al. 1973). On a dry matter production basis, kochia was the predominant weed in unweeded plots and was present in the plots until 4 weeks after onion emergence, or approximately 7 weeks after planting.

Kochia that competed with sugarbeet (*Beta vulgaris*) for the entire season reduced yields more than 95 percent (Weatherspoon and Schweizer 1969, 1971). Sugarbeet root yield was reduced according to the density of kochia plants. In Colorado, one kochia plant per 3.0 m of sugarbeet row reduced yields 24 percent (Boerboom 1993). The minimum density of kochia that results in an economic loss in sugarbeet yield is approximately 0.06 plants m^{-1} of row (Mesbah et al. 1994). Kochia is particularly difficult to control in sugarbeet, because both belong to the Chenopodiaceae family (Weatherspoon and Schweizer 1969). However, early season control eliminates kochia's competitive advantage.

Kochia was present in over 22 percent of the sunflower fields in North Dakota in 1979, and increased in severity and acreage infested as farmers shifted to reduced and no-till cropping systems (Durgan and Dexter 1984). Season-long competition by kochia densities of 0.3, 1, 3, and 6 plants m^{-1} of row decreased sunflower achene yield 7, 10, 20, and 27 percent, respectively (Durgan et al. 1990). Sunflower achene yield was reduced 6 and 10 percent by 2 and 4 weeks of kochia competition, respectively (Durgan and Dexter 1984 and Durgan et al. 1990).

Kochia densities may exceed 2 100 seedlings m^{-2} and reduce soybean yield more than 30 percent (Wolf et al. 2000). Biochemical interference from kochia weeds in soybean fields can contribute to production losses (Einhellig and Schon 1982). Reductions in soybean growth with kochia extracts accompany the development of water stress.

Intraspecific competition is more important than interspecific competition at any density for wheat (*Triticum aestivum*), and the reverse is true for kochia (Christoffoleti and Westra 1994). One wheat plant reduced herbicide-resistant kochia yield per plant equal to the effect of 4.8 herbicide-resistant or 5.4 herbicide-susceptible kochia plants.

Kochia is one of the most troublesome weeds in small grains (Mengistu and Messersmith 2002), including barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), and flax (Dexter 1982 in Mulugeta 1991). In barley, the interference ability of kochia was affected adversely by cool temperatures (Fischer et al. 2000).

Yellow sweet clover grown as a green manure fallow replacement crop controlled kochia (Blackshaw et al. 2001a). Whether harvested as hay, or incorporated, or left it on the surface, weed suppression was similar. Yellow sweet clover reduced kochia densities 96 to 99 percent. Allelopathic compounds from decomposing yellow sweet clover may contribute to the weed suppression effect.

Under drought conditions, kochia continues limited growth while sorghum dies or becomes dormant (Phillips and Launchbaugh 1958). In seedling sorghum, kochia effects increase diffusive resistance and oxygen uptake, lower water potential and reduce chlorophyll content (Einhellig and Rasmussen 1976). Extracts from the dried kochia stalks, and debris incorporation, inhibits sorghum growth and development (Einhellig and Schon 1982).

Haderlie and Poulson (1991) rate kochia as the third most difficult weed to control, of weeds most troublesome to potato (*Solanum tuberosum*) growers in Idaho.

Competition among kochia plants curtails girth increase sharply (Weiner and Fishman 1994). The mass distribution of crowded plants is skewed and unequal. The latter is characteristic of size hierarchies observed in crowded populations (before extensive self-thinning). As a kochia individual grows among neighbours, it develops fewer and shorter branches than it would without interference. The influence of one herbicide-resistant plant, expressed relative to the influence of one herbicide-susceptible plant, is smaller for herbicide-resistant biotypes than for herbicide-susceptible biotypes (Christoffoleti and Westra 1994). Interbiotype competition is greater than intrabiotype competition. There is no evidence that larger individuals have a disproportionate effect on smaller individuals; the effect of a small neighbor on the growth rate of a plant is similar for large and small plants, as is the effect of a large neighbor (Weiner et al. 1997). Competition for resources below ground can be symmetric. When competition is symmetric, it will not exacerbate initial size differences.

2.1.6. Saline Soils

Kochia is a facultative halophyte and an alternative salt-tolerant crop for the saline soils on the Canadian prairies (Stepphun et al. 1994). Saline soils express their salinity at the surface only under certain conditions of soil moisture and surface evaporation (Braidek et al. 1984). These conditions tend to develop when the site has been disturbed. Better recovery response from the effects of salt, at cooler temperatures, confers the advantage of pre-empting sites before other species germinate. This gives kochia many excellent opportunities to colonize successfully (Khan et al. 2001). Kochia grows in sites with soluble salts ranging between 0.16 to 8.2 mmhos cm^{-1} (Morton and Manthy 1995). Soluble salt levels do not differentiate the kochia biotypes. In valley bottoms of the Great Basin in Utah, elevated salinities (>1000 mg NaCl L^{-1}) can eliminate competition from annual kochia (Ewing and Dobrowolski 1992). Annual kochia cover and dominance (in valley bottoms of the Great Basin) fluctuate considerably. As NaCl concentrations increase, seed germination is inhibited progressively (Khan et al. 2001). Few kochia seeds germinate at 1000 mM NaCl. Seeds transferred from salt solutions, after 20 days, to distilled water recovered quickly at warmer temperature regimes. Exposure to high NaCl concentrations does not inhibit germination permanently.

Kochia was introduced into Western Australia in mid-1990 for use as a forage plant and as a component of a mixture of species designed to rehabilitate salt-affected agricultural land (Dodd 1996 in Panetta and Lawes 2005). Plantings were initially made at a small number of farms, mainly for the production of commercial quantities of seed, but by late 1991 kochia had been planted at 68 sites in southwestern Western Australia, mostly in salt scalds (Dodd and Moore 1993 in Panetta and Lawes 2005). Its weed potential was investigated after it was observed to spread beyond the sites where it had been planted.

2.1.7. Mining Spoil Banks

Kochia pioneers on freshly exposed spoils after surface mining for coal in the northern Great Plains. Kochia pioneers in denuded areas of the southwestern U.S. and on mine spoil materials (Sprowles 1981). Wali and Freedman (1973) found kochia growing in the group of spoil banks at the Kincaid sites in northwest North Dakota. The spoil banks showed many bare areas with plants showing reduced growth forms. Kochia tolerated the high salt conditions of the Beulah sites, in west central North Dakota. Of the plants Wali and Freedman (1973) observed, kochia contained the highest levels of Na and Li. Kochia was the only plant that seemed to dominate the entire Glenharold sites, in central North Dakota. Growth form and vigor showed all perceivable gradations.

2.1.8. Hydrocarbon Contamination

Kochia was the most abundant annual forb species on hydrocarbon-contaminated soils in Robson et al.'s (2004) study in southern Saskatchewan. Forbs comprised significantly more cover on contaminated than uncontaminated plots, with kochia making up 13 percent of the total vegetation cover, slightly more than the amount contributed by all forbs on uncontaminated plots. The second most frequent plant on contaminated plots was kochia. The frequency and abundance of kochia was significantly different between contaminated and uncontaminated plots.

2.1.9. Pesticide Contaminated Soil

Significantly less atrazine was extractable from soils vegetated with kochia than from soils vegetated with rapeseed (*Brassica napus*) or unvegetated soils in Iowa (Arthur et al. 2000). That is, more ^{14}C-atrazine was taken up by kochia (9.9 percent of the applied ^{14}C) than by rapeseed. While it would not be in the best interest to introduce the hardy, noxious weed kochia to remediate a contaminated soil, kochia plants already present on a site could be managed.

2.2.0. Non-Herbicidal Management of Kochia

The Canadian Organic Growers (2001) recommend delayed tillage to manage kochia. Shallow tillage removes kochia easily, kills pre-bud stage kochia, and forces kochia seed to sprout or decay (Becker 1968, Thill et al. 1991, and Boerboom 1993). Compared to conventional-tillage, kochia populations can be 2 and 3 times higher under no- and reduced-tillage, respectively (Miller 1984). However, tillage may pull buried viable seed to the surface. Where cultivation or mowing before pollination is impractical (Erickson and Moxon 1947), kochia pollen and seed dispersal can be reduced by cutting, pulling or hoeing (Gates 1941, Mulugeta 1991, and Boerboom 1993). Likewise, mature plants ought to be cut and burnt.

Light interception by a leafy and cold tolerant crop, grown early in the season to develop an advantage for light capture, could help suppress the establishment and early interference of kochia (Fischer et al. 2000). Kochia is less abundant and competitive in winter wheat than spring cereals. Competitive perennial grasses or crops (such as alfalfa) can prevent kochia establishment and suppress growth (Boerboom 1993). Harvested as hay, whether the residues are incorporated or left on the soil surface, yellow clover controls kochia (Blackshaw et al. 2001a). In greenhouse experiments, white mustard (*Brassica hirta*) added to the soil at 20 g per 400 g air dry soil reduced emergence of kochia by 54 percent (Al-Khatib et al. 1997). Rapeseed suppressed emergence of kochia by 25 percent. The emergence and growth of kochia were inhibited more by white mustard than by rapeseed when equal amounts of foliage were incorporated into the soil. Krishnan et al. (1998) found green manure rapeseed, Indian mustard (*Brassica juncea*), and both Martigena and Salvo white mustard crops reduced emergence, height, and fresh weight of kochia.

In areas surveyed by Forcella (1985), plots within forests were devoid of kochia, and pastures (associated with potential forest vegetation) supported few kochia plants. Factors associated with current or previous forest vegetation inhibit establishment of kochia.

2.2.0. Weed Emergence Time and Relevance to Weed Management

Everitt et al. (1983) found the seedling emergence percentage for kochia seeds left exposed on the soil surface (74%) was significantly higher than for those planted at a depth of 3 mm (57%). Early emergence and establishment coupled with rapid growth offers kochia distinct survival and competitive advantages (Evetts and Burnside 1972). Since kochia emerges from cool soil early in the growing season, it is a troublesome weed in crops that are planted early (Mulugeta 1991). Kochia can also be a problem in a wide range of crops because emergence extends for a relatively long period following the onset of spring (Smith 1975 in Mulugeta 1991). Kochia also may emerge after postemergence herbicides are applied, resulting in substantial, uncontrolled populations (Mickelson et al. 2004). Dyer et al. (1993) showed that temperatures less than 10 C cause the greatest differences in germination between sulfonylurea-resistant (R) and -susceptible (S) biotypes. Earlier spring emergence of the R cohorts may allow some selective control with spring seedbed preparation (tillage or herbicides) or by early spring frosts and decrease the proportion of R plants in the population (Thompson et al. 1994). Delaying spring control, when possible, also may control the R population more completely. In no-till systems kochia emergence increased almost 4-fold compared to tilled systems (Anderson and Nielsen 1996).

2.2.1. Herbicidal Management

Physiological differences can explain herbicide response differences (Bell et al. 1972b). Plant size and physiological maturity can affect the susceptibility of kochia to herbicide treatment. Usually, small plants are more susceptible to the herbicides than large plants due to the increased opportunity for coverage of all foliage. Developing plants are more susceptible to herbicide treatment than more mature plants. In greenhouse experiments, herbicides with different modes of action, including atrazine, bromoxynil, MCPA, and diuron, effectively controlled a resistant biotype of kochia from near Liberal, Kansas (Primiani et al. 1990).

Since the late 1980s, growers have used imidazolinone and sulfonylurea herbicides that inhibit acetolactate (ALS) enzyme to control kochia in wheat and soybean (Wolf et al. 2000). At the Garden City Branch, Kansas Agricultural Experiment Station, all chlorsulfuron rates gave good control of kochia (Norwood 1982a) and single applications resulted in the best control (also achieved by sequential applications of atrazine and cyanazine). Metsulfuron was more active on ALS-inhibiting herbicide resistant kochia from an industrial site in Winnipeg, Manitoba, under growth room conditions than in the field (Friesen et al. 1993). In years of high kochia densities, stunting of resistant plants by metsulfuron, triasulfuron, or tribenuron, can result in significant wheat yield increases. At the Aberdeen Research and Extension Center near Aberdeen, Idaho, kochia control ranged from 22 to 96 percent, depending on rimsulfuron rate and adjuvant (Tonks and Eberlein 2001). Rimsulfuron 1MSO at 9 and 18 g a.i. ha^{-1} controlled kochia greater than rimsulfuron 1 NIS at the same rates. Rimsulfuron at 18, 26, or 35 g a.i. ha^{-1} 1 MSO controlled kochia 92 percent, whereas rimsulfuron 1 NIS controlled kochia 89 percent, regardless of rimsulfuron rate. Mixing COC with rimsulfuron did not enhance kochia control relative to rimsulfuron 1 NIS. Kochia control with rimsulfuron 1 SIL was at least 27 percent lower than rimsulfuron with any other additive tested. Imazethapyr at 35 or 70 g a.i. ha^{-1} controlled triazine-resistant kochia better than the standard herbicide treatment of metolachlor plus cyanazine (Wicks et al. 1997).

As a short term residual and a postemergence herbicide, dicamba gave good control of Idaho and Iowa kochia biotypes, in Johnston and Wood's (1976) study. While dicamba was definitely the best systemic when applied preemergence, 2,4-D was nearly equal to dicamba when applied postemergence. These herbicides are far more effective on kochia when applied pre-emergence, in the autumn or early spring, than postemergence. Kochia can be controlled easily with timely application of 2,4-D (Wicks et al. 1984). King et al.'s (1990) field tests, in the western half of the United States, on populations of sulfonylurea resistant kochia, revealed that metasulfuron-methyl in combination with dicamba offered the highest level of efficacy on kochia. Furthermore, Fluroxypyr and tank mixtures containing fluroxypyr, bromoxynil/MCPA ester, and dichlorprop/2,4-D ester can be effective. These mixtures can kill 90 percent or more of ALS-inhibiting herbicide resistant kochia seedlings (Friesen et al. 1993). Surviving kochia plants are severely stunted and set little or no seed. Friesen et al. (1993) concluded, to control ALS-inhibiting herbicide resistant kochia populations, herbicides with alternative modes of action such as fluroxypyr, bromoxynil/MCPA ester, or 2,4-D ester could be applied alone or in tank mixture with sulfonylurea herbicides. Similarly, dicamba plus 2,4-D and bromoxynil plus MCPA controlled north-eastern South Dakota kochia biotypes and increased wheat yields by 15 percent or more (Wolf et al. 2000).

At the Garden City Branch, Kansas Agricultural Experiment Station, kochia averaged 5.4 plants per square meter on June 14, 1982, and ranged in size from 8 to 30 cm tall. Control of kochia with atrazine at 560 g a.i. ha^{-1} applied August 12 was satisfactory (Norwood 1982b). Delaying the application of atrazine until November 10 resulted in improved control of kochia. Control with isouron or isouron plus atrazine was similar to control with the two higher rates of atrazine alone. Control with spring applied cyanazine or metribuzin (on plots previously treated with atrazine) was good also. Martin (1985) killed kochia seedlings with no triazine history (the seeds were collected from fields 1.6 km upwind from Idaho railroad sites) by 2 kg a.i. ha^{-1} atrazine. Miller (1986) established research plots in Chugwater, Wyoming. Broad-spectrum weed control was excellent with atrazine at 695 g a.i. ha^{-1} alone or in combination with other herbicides and good with FMC-57020 alone at 1120 and 1401 g a.i. ha^{-1} or at 841 g a.i. ha^{-1} in combination with metribuzin. Miller (1986) achieved 100 percent kochia kill with any chlorsulfuron + dicamba + X-77 (+ paraquat), FMC-57020 + chlorsulfuron/metribuzin/atrazine, or atrazine (+ paraquat) + X-77 treatment. Chodová and Mikulka (1997) demonstrated very good efficacy of Bladex (active ingredient cyanazine) and the mixture Arsenal (active ingredient imazapyr) + Bladex to control kochia. Both susceptible and resistant populations of kochia were found to show high susceptibility to cyanazine. Postemergence treatments with atrazine, carfentrazone, fluroxypyr, bromoxynil plus MCPA, nicosulfuron plus dicamba, and nicosulfuron plus dicamba plus atrazine, all provided adequate to excellent control of resistant north-central North Dakota kochia biotype inbreds (Nandula and Manthey 2002). Bromoxynil plus MCPA ester, carfentrazone, fluroxypyr, nicosulfuron plus dicamba plus atrazine, nicosulfuron plus dicamba, and atrazine alone, all provided 88 to 99 percent control of kochia.

Diuron was the outstanding residual herbicide in all three of Johnston and Wood's (1976) tests. Buthidazole and fenac also gave outstanding control of kochia from Idaho and Iowa. Atrazine history had no effect on the response of kochia to diuron (Salhoff and Martin 1985). Both diuron at 1.4 kg a.i. ha^{-1} plus prodiamine at 1.4 kg a.i. ha^{-1} or metribuzin at 0.9 kg a.i. ha^{-1} plus norflurazon at 2.0 kg a.i. ha^{-1} controlled kochia well over all tillage levels used by Boydston (1995). A mixture of 3.4 kg a.i. ha-1 of cycloate plus 1.1 kg a.i. ha-1 of R11913 was the most effective preplanting treatment evaluated by Schweizer (1973) for the control of kochia at the time of emergence.

Hutchinson et al. (2003) evaluated a total glyphosate program of single or sequential applications, tank mixtures of glyphosate and residual herbicides applied early postemergence, and residual preemergence herbicides followed by a late postemergence glyphosate application at the University of Idaho Aberdeen Research and Extension Center near Aberdeen, ID. A standard rimsulfuron + metribuzin + nonionic surfactant early postemergence treatment was included for comparison. All herbicide treatments controlled kochia 87 to 99 percent. Similarly, postharvest glyphosate (631 g a.i. ha^{-1}) and paraquat (701 g a.i. ha^{-1}) application in late August to early September reduced kochia seed production by 92 percent or greater at each site at the Agricultural Experiment Station, Fargo, ND (Mickelson et al. 2004). Glyphosate at 1.1 kg a.i. ha^{-1} had close to 100 percent control of kochia in all stages (Beling et al. 1981).

Surfactants can improve spray retention on kochia (Harbour et al. 2003). Seventeen g a.i. ha^{-1} DPX 4189 with 0.25 percent surfactant gave 100 percent control of kochia in the 2.5 cm stage (Beling et al. 1981). Herbicides mixed with allinol 810-60 surfactant are better retained, than with MON 0818, oxysorbic 20, or R-11 surfactant. Bromoxynil phytotoxicity is not affected by surfactants, and all surfactants studied by Harbour et al. (2003) equally enhanced 2,4-D amine phytotoxicity. Glyphosate phytotoxicity to kochia was enhanced only by MON 0818 and oxysorbic 20. 2,4-D amine and glyphosate absorption were greater with surfactants than without. Kochia leaves have crystalline epicuticular wax structure, which influences the absorption of these herbicides.

2.2.2. Herbicide Resistance

Herbicide resistance is making cost effective weed control more difficult, especially with kochia (Derksen et al. 2002). The occurrence of weeds with herbicide-resistant biotypes and crops with herbicide-tolerant cultivars has increased dramatically along with potential for gene flow between these plants and their wild or weedy relatives (Stallings et al. 1995). Kochia may emerge after postemergence herbicides are applied, resulting in substantial, uncontrolled populations (Mickelson et al. 2004). Kochia is difficult to control, possibly because of its leaf characteristics. Kochia leaves are generally pubescent, with crystalline epicuticular wax (Nalewaja 1992 in Harbour et al. 2003), which may suspend spray droplets and herbicide above the cuticle (de Ruiter 1990 and Wirth 1991 in Harbour 2003), thereby preventing contact with the epicuticular surface for absorption.

Chlorsulfuron-resistant kochia was first reported in Manitoba in 1988 (Morrison and Devine 1993). A single nuclear gene controls the dominant or semi-dominant chlorsulfuron resistance trait (Mulugeta 1991 and Stallings et al. 1995). Seven chlorsulfuron resistant kochia biotypes in Guttieri et al.'s (1995) study had point mutations in the codon for the proline residue in Domain A (the DNA sequence of a 196 base pair region of the genes encoding acetolactate synthase in kochia). The point mutations varied and encoded all six possible amino acid substitutions at Pro_{173}. Multiple resistance alleles indicate that widespread resistance of kochia to acetolactate synthase (ALS) inhibiting herbicides is due to multiple founding events. In Friesen et al.'s (1993) field and growth room studies, herbicide resistant kochia was extremely and moderately resistant to thifensulfuron, at the whole plant and enzyme levels, respectively. The herbicide resistant kochia was highly resistant to thifensulfuron under both field and growth room conditions. There was no wheat yield increase in plots treated with thifensulfuron. Field histories indicate that sufficient carryover from high rates of Glean in wheat effectively controlled kochia into the summerfallow year, particularly if conditions were dry and led to the appearance of SU resistant strains. Thus, the resistant biotypes were selected for and reproduced every year, including those years where wheat was produced without using any Glean (Maurice and Billett 1991). Kochia shoot dry matter per plant was somewhat reduced in thifensulfuron-treated plots compared to the untreated control, but this reduction probably was a result of increased kochia densities and intraspecific interference rather than herbicidal activity. The degree of tribenuron resistance may not correlate with kochia botanical traits or site edaphic characteristics (Morton and Manthey 1995). Sulfonylurea resistance in kochia is due to a less sulfonylurea-sensitive ALS enzyme (Saari et al. 1990). ALS coding gene(s) mutations may concomitantly reduce or abolish the enzyme sensitivity to normal feedback inhibition patterns (Dyer 1992). Sulfonylurea resistance appears to be a dominant (Thompson 1993) or semi-dominant trait under the control of a single gene (Mulugeta 1991). However, different mutations of the ALS coding gene(s) may be responsible for varying cross-resistance (Sivakumaran et al. 1991). Germination differences between resistant and wild-type (susceptible) biotypes are greatest at 8 C (Thompson et al. 1994). Resistant biotypes germinate more uniformly than wild-type biotypes. Chlorsulfuron-resistant kochia was cross-resistant at the whole plant level to the imidazolinone herbicide imazethapyr, in Friesen et al.'s (1993) study. Kochia ALS-inhibitor resistance (R) is based on a threonine for proline substitution at amino acid 173 and a C to A transition in the first position of the codon for the proline residue in Domain A (Guttieri et al. 1992 and 1995). However, widespread R do not result from a lone resistance allele. The point mutation of Pro_{197} can result in nine different codons, six of which code different amino acid residues. A mutation at ALS gene codon 574 conferred R in all Czech kochia biotypes (Salava et al. 2004), i.e., leucine for tryptophan.

2,4-D is generally not effective in controlling kochia (Mickelson et al. 2004). Kochia is at least moderately tolerant to 2,4-D (Dahl et al. 1982). The 2,4-D ester, either alone or in a mixture with thifensulfuron, killed less than half the kochia seedlings in Friesen et al.'s (1993) study, and the survivors were stunted. Quinclorac, either alone or in a 2:1 mixture with thifensulfuron or tribenuron, did not reduce kochia densities in Friesen et al.'s (1993) study. However, survivors were stunted, particularly plants treated with the higher rate of quinclorac (or the quinclorac plus thifensulfuron or tribenuron treatment). Owing to the reduced efficacy of 2,4-D and ALS-inhibiting herbicides, dicamba has become the primary selective agent for resistant kochia (Cranston et al. 2001). Dicamba-resistant biotypes demonstrated subtly altered auxin response pathways, e.g. delayed shoot gravitropism (Goss and Dyer 2003). Likewise, altered auxin response delayed apical dominance after decapitation, and enhanced root resistance to natural and synthetic auxin inhibition. Cranston et al. (2001) found kochia produced a maximum of 13 percent dicamba resistant progeny. Dicamba absorption rates are similar in resistant and susceptible plants. Resistance to auxinic herbicides has been slow to develop and spread. There are fluroxypyr resistant kochia populations (Dyer et al. 2001). In 1968, all of Bell et al.'s (1972b) kochia selections were completely tolerant to picloram. Bell et al. (1972b in Bandeen et al. 1982) established the independence of 2,4-D or dicamba responses by kochia. Some selections respond similarly to both (Eberlein and Fore 1984). Manthey et al. (1995) found all the dicamba resistant kochia plants in that study were also 2,4-D resistant, but not all 2,4-D resistant kochia were dicamba resistant. Kochia responses to 2,4-D and dicamba range from complete kill to complete survival (Nandula and Manthey 2002). Manthey et al. (1995) observed kochia resistance to combined dicamba, 2,4-D, and tribenuron. Resistance frequency was 2,4-D > tribenuron > dicamba (Manthey et al. 1997). Sites with frequent resistant plants still contain susceptible plants. 2,4-D, dicamba, and tribenuron herbicide resistance allele frequency is low (Goblirsch et al. 1997), but continual use of a single herbicide or herbicides having the same mode of action lead to an increase in the frequency of herbicide resistance alleles within a population. The kochia line observed by Dyer et al. (2001) was resistant to MCPA, 2,4-DB, picloram, sulfonylurea, and imidazolinone.

Kochia seed survival is meager. Atrazine tolerant seed rapidly supplants susceptible biotypes after a few years of selection pressure (Burnside et al. 1981). Once the selection pressure is removed, viable buried seed continues the occurrence of atrazine-tolerant kochia plant stands. Biological alterations in atrazine resistant plants result from chloroplast alterations and photosynthetic function disorders, evident mainly at higher temperatures (30°C) due to resistant biotype photosensitivity (Chodová and Mikulka 2000). Salhoff and Martin (1980) treated kochia <4 cm with atrazine, prometryn, ametryn, tebutryn, prometon, metribuzin, and cyanazine. The kochia plants with atrazine history survived and those with none were destroyed. After 13 years of triazine herbicide use on Union Pacific Railroad lines in Idaho, kochia developed triazine herbicide resistance (Johnston and Wood 1976). Burnside et al. (1981) reported triazine resistant kochia along several railroad right-of-ways. According to LeBaron and Gressel (1982 in Eberlein and Fore 1984), infestations of triazine resistant kochia extended along several railroad lines in at least 11 states. Triazine resistant kochia biotypes are less competitive for light and nutrients than triazine susceptible biotypes (Eberlein and Fore 1984), but it is a problem in ecofallow corn (Wicks 1986). Salhoff and Martin (1980) found that Group 5 cross-resistance in kochia extends to all commercial *s*-triazines and metribuzin, and that progeny grown from seed taken from locations with an atrazine history were less competitive for light and nutrients and were more easily controlled with other types of herbicides, e.g., 2,4-D. Kochia biotypes showing double resistance to Group 5 PS2 activity inhibitors and Group 2 ALS-inhibitors, were found in three localities in the Czech Republic (Chodová and Mikulka 2000b, 2002 in Holá et al. 2004). Wicks et al. (1997) found kochia density was greatest on their untreated check and metolachlor plus cyanazine plots in 1994.

2.2.3. Summary

Kochia is a short day plant which flowers indeterminately (Stallings et al. 1995). Kochia has nonobligate allogamous mating behaviour (Guttieri et al. 1998). Kochia is capable of permanent autoreproduction (Holec et al. 2004) and reproduces by seed. The kochia seed is 1.8 mm (Gates 1941) to 3 mm (Mulugeta 1991) long and about 1.0 mm in diameter (Everitt et al. 1983). A kochia plant typically produces over 14,000 seeds (Thill et al. 1991). Cattle will graze kochia in range and pasturelands (Thistled et al. 1986). Kochia is native to middle- and eastern-Asia steppes (Holá et al. 2004). It is often said that kochia seeds have no innate dormancy (Everitt et al. 1983, Dyer 1993, and Thompson et al. 1994). Forcella et al. (1997) found no obvious microclimate thresholds that may induce dormancy in kochia.

Soil treatment with kochia leaves (7.5g kg^{-1} soil) reduced kochia biomass (Wali 1978). Kochia has the capacity to shade short crop plants (Nussbaum et al. 1985). (Wicks et al. 1973). Early season control eliminates kochia's competitive advantage. One wheat plant reduced herbicide-resistant kochia yield per plant equal to the effect of 4.8 herbicide-resistant kochia or 5.4 herbicide-susceptible kochia plants. Yellow sweet clover reduced kochia densities 96 to 99 percent.

Shallow tillage removes kochia easily, kills pre-bud stage kochia, and forces kochia seed to sprout or decay (Becker 1968, Thill et al. 1991, and Boerboom 1993). Kochia may emerge after postemergence herbicides are applied, resulting in substantial, uncontrolled populations (Mickelson et al. 2004).

Kochia is a problematic species in field crop production that is hard to manage with herbicides. The latter may be due in part to the emergence pattern of kochia, which has not been adequately characterized in the field. There is an abundance of herbicide resistant kochia also in Western Canada and farmers are concerned about its persistence.

2.2.4. Objectives

The objectives of this thesis were to aid in the management of kochia by determining its time of emergence in the field and its persistence in the seed bank. The research will address the practical usefulness of kochia via the literature review. Two areas of inquiry were investigated with an experimental approach. The areas of inquiry were: the ecological niche of kochia and the method by which growers may close that niche in prairie cropland. The specific research objectives were to determine (in the field) the emergence timing of kochia and also to determine its persistence in the seedbank and ability to emerge from depth in the soil.

Chapter 3 - Materials and Methods

3.0.0. Field Selection

Field observation sites were established at seven locations in south central Manitoba in the spring of 2005 and at six locations in the spring of 2006 (Table 3.1). The sites were all on clayey lacustrine black chernozemic soil and, based on contact with farmers managing the fields, all sites were known to have some level of kochia infestation. The sites were uniformly at the edges of fields, near the slight topography of irrigation ditches, and accessible by road.

Table 3.1. Field details.

Field	Land location	Notes
A	SW-02-11-02-W	Between May 31 and June 7, 2005, seeded with an air seeder with 2 or 6" openers, on 7" spacing. Kochia likely group 2 resistant. Canola in 2005. No fall tillage in 2004. Bayer had trials in 2004.
B	NW 30-05-06	May 31, 2005, direct seeded wheat sprayed with glyphosate (Roundup) and phenoxycarboxylic acid (2,4-D). Low disturbance.
C	SW-29-05-06-W	The field was cultivated between 15 and 26 of July, 2005, the low-lying marginal area, and the quadrats, were avoided. Cultivates first, then seeds with disks on 6" spacing. June 15, 2005, quadrats 3 & 4 under water. June 20, 2005, spray trials nearby. July 1, 2005, all quadrats under water.
D	SW-29-05-06-W	The field was cultivated between 15 and 26 of July, 2005, the low-lying marginal area, and the quadrats, were avoided. Cultivates first, then seeds with disks on 6" spacing
E	SW-30-05-06-W	June 16, 2005, simulated canola seeding. Low disturbance - 3" spoons on 7.5" spacing. June 16, 2005, spray trials visibly weaken surrounding plants (observed on June 22, 2005). June 22, 2005, canola emerging in all quadrats. July 1, 2005, quadrat 4 under water, canola in 3 and 4 may be showing signs of herbicide damage.
F	SE-30-05-06-W	June 16, 2005, simulated canola seeding. Low disturbance - 3" spoons on 7.5" spacing. July 26, 2005, field around quadrats tilled. June 22, 2005, spray trials (quadrats 3 & 4 downwind) and canola emerging in quadrats 1 & 2. July 1, 2005, water too murky to count.
G	SE-12-05-06-W	May 4, 2005, corn seeded. Cultivates first, then goes in with knives on 9.5" spacing.
H	SE 25-04-06	May 10, 2006, wheat planted with 1" openers on 30" spacing. Thifensulfuron methyl and tribenuron methyl (Harmony Total) and dicamba (Banvel) and propiconazole (Tilt) sprayed at recommended rates. 2005 crop beans.
I	NE-30-05-06	Cultivated before any emergence. Barley/grass mixture air seeder. No herbicide sprayed. Very wet in the spring. No emergence.
J	NW-15-05-06-W	Cultivated, but avoided quadrats. Beans in 2004. Planted to wheat. Flucarbazone-sodium, 4,5-dihydro-3-methoxy-4-methyl-5-oxo-N-[[2-(trifluoromethoxy)phenyl]sulfonyl]-1H-1,2,4-triazole-1-carboxamide (Everest) and fluroxypyr plus phonoxycarboxylic acid (2,4-D) (Attain) sprayed at recommended rates.
K	SW-22-05-06-W	Alfalfa, no disturbance. Everest and Attain sprayed at recommended rates.
L	NE-15-05-06	May 6, 2006, cultivates and seeds wheat with 1" openers on 7.5" spacing. Everest and Attain sprayed at recommended rates.

3.0.1. Field Observation

Weed seedling emergence was measured at least once per week from mid-April throughout the season in a fashion similar to the methods described in Bullied et al. (2003). Four permanent 0.25 m^2 quadrats were placed in each field in areas generally representative of the field edge, where kochia infestations in this region are typically observed. Quadrats were marked with plastic stakes and pin flags, which seeding operations did not displace. Newly emerged seedlings were counted and removed at each visit. Similar to a previous farm-based study of weed emergence (Bullied et al. 2003), this study was observational and was meant to provide a representation of seedling emergence in production fields. We did not interfere with farm practices conducted on the fields. Seedlings were not protected during pre-sowing tillage or applications of pesticide.

3.0.2. Soil Temperature

In each field, soil temperatures were recorded continuously throughout the observation period with the use of small, self-contained Stow Away® TidbiT™ temperature loggers (Onset Computer Corporation, Pocasset MA) (Bullied et al. 2003). One data logger was placed in each field. Measuring points were 2.5 cm below the soil surface. To install each of these data loggers, a shallow hole was dug in the soil and the data logger was inserted at the 2.5 cm depth into the soil at the side of the hole. This minimized soil disturbance around the data logger to facilitate accurate measurement of soil temperature. Because seeds of many small-seeded annual weeds germinate and emerge primarily from 0 to 2 cm soil depth (Buhler 1995 in Forcella et al. 1997), daily temperatures of these soil layers may be more important in regulating plant behaviour than those at 5 to 10 cm soil depth. Data loggers were removed during tillage and seeding operations and replaced shortly afterwards. Because there is a strong association between soil temperature at shallow depths and air temperature (Marginet 2001 and Reimer and Shaykewich 1980 in Lawson et al. 2006), soil temperature data during these periods were replaced by air-temperature data obtained from a local Environment Canada weather station. In the case of field A, air-temperature data was obtained from the Environment Canada weather station located at the Winnipeg International Airport. For all other fields, air temperature data was obtained from the Environment Canada station located at the University of Manitoba Research Farm in Carman, Manitoba.

Cumulative soil growing degree days (GDD) were calculated for each site. Until soil-temperature data were available from the on-site soil-temperature data loggers, air-temperature data from one local weather station were used for the daily GDD calculation. The following equations were used to calculate GDD:

$$GDD_{daily} = [(T_{max} + T_{min})/2)]-T_{base} \qquad [1]$$

$$\text{Cumulative GDD} = \sum_{i=1}^{n} GDD_{daily} \qquad [2]$$

(McMaster and Wilhelm 1997) where T_{max} is the maximum daily soil temperature, T_{min} is the minimum daily soil temperature, and T_{base} is the base temperature at which plant growth and development was deemed not to occur (0 C), n is the number of days elapsed from January 1, and GDD_{daily} was a non-negative value (daily GDD values that were negative were replaced by 0). A base temperature of 0 C has previously been used as a biologically justifiable base to reflect the germination and emergence of many weed species (Bullied et al. 2003) and anectdotally kochia has been known to emerge early in the season from cool soils (Evetts and Burnside 1972).

3.0.3. Soil Seedbank Analysis

In the early fall of each year (August 22, 2005 and August 30, 2006) soil samples were taken from each field site quadrat using a soil core (8.50 cm diameter, 10.50 cm depth, 596 cm^3 soil core volume). Samples were brought back to the University of Manitoba and a method resembling that of Cardina and Sparrow (1996) was used to determine the seedbank contents. Each sample was placed into an individual plastic tray such that the soil depth did not exceed 2.5 cm. The trays were placed in a growth room and watered regularly. When emergence was complete, the trays were removed from the growth room, bagged, and placed in a walk-in freezer (-20 C). After 6 weeks the trays were placed again in the growth chamber, the soil in each tray was stirred when thawed and then watered regularly, and monitored for kochia emergence. In 2006, the schedule for this experiment included 3 periods of 6 weeks in the growth room alternated with 2 periods of 3 weeks in the freezer.

3.0.4. Emergence from Depth Experiment

A 6 week trial was run as a randomized complete block design replicated 4 times, including 5 seeding depth treatments with 60 seeds placed at each depth in each treatment (similar to method described in Boyd and Van Acker 2003) in pots (10.2 cm diameter, 9.0 cm depth). The seeds were sourced from field populations. In the fall of 2005, kochia plants were collected just prior to their abscission, from 3 distinct field sites. The plants were bagged in cloth bags and allowed to dry for a month. The plants were then hand threshed and the seed collected. The seed was stored at 4 C until it was needed. The experiment was run twice. For the first and second runs of the experiment, metro-mix 220 (contains vermiculite, water, bark and related material, and sphagnum peat moss) and 2 soil : 2 sand : 1 peat were used as potting mixtures, respectively. Seeds were placed on mosquito netting (Mountain Equipment Co-op, Winnipeg, MB) at 2, 10, 20, 40, and 80 mm below the soil surface in each pot. All pots were kept in a growth room (20 C day 15 C night). The pots were watered daily and any emerged kochia seedlings were counted at regular intervals (every 2 to 3 days) and removed after being counted.

3.1. Statistical Analysis

3.1.0. Emergence Timing

Emergence period data were expressed as a cumulative percent of total emergence. Fields 2006 I and J were excluded from emergence-period analyses because of the anomalously low kochia seedling density in these fields as compared to densities in the other fields. Initial statistical analyses of variance (ANOVA) using the PROC GLM procedure in SAS indicated that field site was not a significant factor ($P \leq 0.05$) influencing the emergence period of kochia, but year was, and there was no significant year × site interaction. Therefore, the field data were pooled within year. Emergence-period data were analyzed by nonlinear regression analysis as a function of cumulative soil GDD with the NLIN procedure in SAS (SAS Institute Inc., Cary NC). The logisitic model fitted was

$$y = C + D/(1 + (x/E_{50})^{b}) \qquad [3]$$

where y is cumulative percent emergence of kochia, x is cumulative soil GDD, C is the lower limit (asymptote) of the response curve, $C + D$ is the upper asymptote (maximum emergence), E_{50} is the x value (GDD) at the mid-point or the inflection point of the curve (not necessarily the GDD value at 50% emergence depending upon the values of the fitted C and D parameter estimates and the shape of the curve), and b is the slope (Burke et al. 2005 in Lawson et al. 2006, Seefeldt et al. 1995). The notation used in Equation 3 closely follows that used by Seefeldt et al. (1995). Individual curves were statistically tested systematically for common C and D, common E_{50}, and common b with the use of the lack-of-fit F test at the 0.05 level of significance as outlined by Seefeldt et al. (1995). A single coefficient of determination (R^2) was calculated for the model as described by Kvalseth (1985 in Lawson et al. 2006), with the use of the residual sum-of-squares value from the SAS output.

3.1.1. Seedbank Data

In 2005, the samples from each quadrat were pooled on a per field basis prior to the grow out procedure and so were not able to calculate means and standard errors for this data for each field sample. Therefore, for 2005, absolute values are presented for each field. In 2006, the samples from each quadrat were not pooled but there was no detectable seedling emergence from any of the samples, except 2 samples, and so although we could have calculated means and standard errors for the data from 2006 there was little point given that all the data except 2 were zero values. As a result, the 2006 data were also presented as absolute numbers.

3.1.2. Emergence Depth Data

The data from the growth room experiment was analyzed with SAS GLM procedure. The variability due to subsequent experimental runs was found to be not-significant and the analysis was re-run with data pooled over runs.

Chapter 4 - Results and Discussion

4.0. Emergence Period

The data showed kochia emergence was early and sustained (Figure 4.1). Kochia begins to emerge at about 50 cumulative GDD. Usually, 50 cumulative GDD would occur very early in the spring in southern Manitoba. Environment Canada weather data indicate 50 GDD is reached approximately April 17 (30-year average = 17.23 day of April, standard deviation = 8.79 days). Cold weather, such as is typical to mid-April in Manitoba, can make weed control with herbicides (at that time of year) difficult (B. Murray pers. comm.) and farmers are not usually on the land that early in the season. Kochia emergence is sustained throughout the season, albeit in small numbers after the initial emergence flush. Twenty five percent emergence can occur as early as 108 cumulative GDD (April 13 in 2005) and 75 percent emergence may be complete as early as 298 GDD (May 10 in 2005) (Table 4.2).

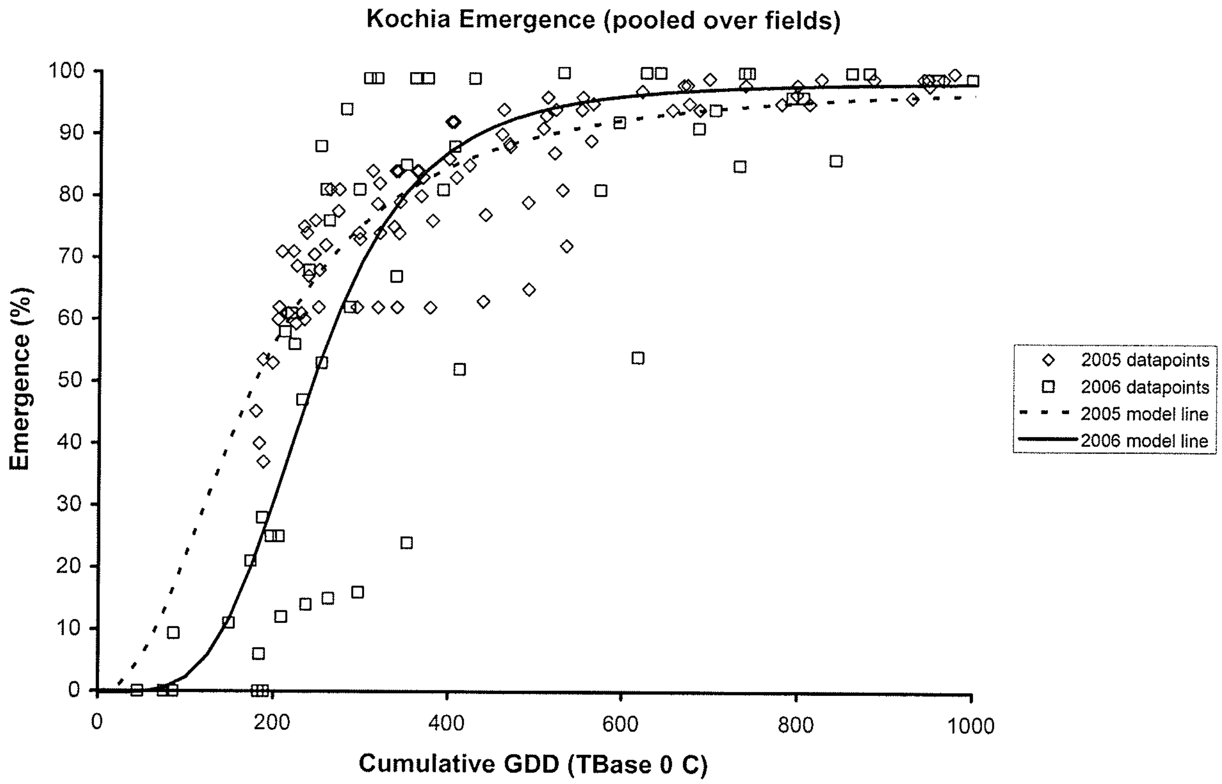

Figure 4.1. Kochia emergence in southwestern Manitoba, Canada in 2005 and 2006 as related to cumulative growing degree days (GDD) T_{base} 0 C. Markers represent field data and lines represent the fitted logistic regression equations. Refer to Table 4.1 for parameter estimates.

Table 4.1 Parameter estimates (standard errors in parentheses) for emergence period response of kochia (T_{base} 0 C) in 2005 and 2006 in southwestern Manitoba, Canada (Figure 4.1). Percentage cumulative kochia emergence was expressed as a function of cumulative growing degree days. A logistic model was fitted to the data (refer to Materials and Methods for a description of the model fitted).

Year	C	Standard Error	D	Standard Error	B	Standard Error	E_{50} (in cumulative GDD)	Standard Error	R^2
2005	-0.29	3.84	98.86	4.23	-2.20	0.28	175.6	10.3	0.83
2006	-0.29	3.84	98.86	4.23	-4.09	0.54	242.7	8.3	

Table 4.2. Emergence percentages of kochia, and cumulative growing degree day (GDD) values, with dates corresponding to 2005 and 2006.

	Cumulative GDD	
Emergence (%)	2005	2006
25	108 (April 13)	187 (April 21)
50	178 (April 19)	245 (April 27)
75	298 (May 10)	322 (May 4)

Kochia is able to germinate quickly under optimum conditions and usually penetrates its seed coat after 24 h (Stepphun and Wall 1993). The kochia seed coat has no effect on its germination (Romo and Haferkamp 1987 in Al-Ahmadi and Kafi 2007). Kochia adjusts its germination over a wide range of temperatures. Kochia seeds collected in Iran germinated at 3.5 to 50 C in dark conditions (Al-Ahmadi and Kafi 2007). At a site in Texas, Nussbaum et al. (1985) calculated kochia could emerge when the daily minimum soil temperature was 3 C and daily maximum was 8 C. In general, kochia emerged immediately following the last night frosts (Nussbaum et al. 1985). Cold to moderate temperatures improve germination (Everitt et al. 1983). Photosystem 1 activity increases in kochia biotypes grown under low-temperature conditions (Hóla et al. 2004). Furthermore, some sulfonylurea-resistant mutant kochia plants possess ALS enzymes with altered feedback inhibition properties (Subramanian et al. 1991), the mutated enzyme can overproduce isoleucine and valine, branched chain amino acids that allow for rapid cell division and growth during early germination at low temperatures (Dyer et al. 1993).

Because kochia often grows in very dry environments, its rapid germination is particularly important for exploiting the often limited near surface soil moisture in spring

(Dyer et al. 1993). Kochia is highly salt tolerant during the germination period. Kochia takes up a large excess of cations over anions and it maintains charge balance by synthesizing oxalate (Curtin and Wen 2004). Exposure to high concentrations of NaCl does not inhibit kochia germination permanently (Khan et al. 2001). Khan et al.'s (2001) data shows almost complete recovery to high NaCl concentrations under a cool temperature (5 to 15 C) regime. Seeds present in the soil are exposed to cooler conditions and low salinity during the late spring and this situation may enhance the germination and recruitment earlier in the season. Although high salinity inhibited kochia germination, germination under high salinity conditions improved at high temperatures (Khan et al. 2001).

The results from this study agree with the assertion made in Mulugeta (1991) that kochia emergence extends for a relatively long period following the onset of spring. We found that although there is sustained emergence over the course of the season, it is generally at a very low level (in proportion to the high level of emergence at the beginning of the season). Anderson (1994) identified a peak in weed emergence due to kochia emergence between April 25 and May 9, near Akron, Colorado.

In 2005 spring precipitation was relatively low (Table 4.3). Kochia recovers from field edge salinity under cooler, early spring temperatures. The particularly high level of precipitation in March of 2006 could have contributed to the delay in kochia emergence that year. Rainfalls in quantities sufficient to leach salts out of the seedbed may give germinating seeds only a temporary advantage as the soil surface dries and salts accumulate again (Roundy et al. 1984 in Stepphun and Wall 1993). Each rainfall that supplies sufficient water will provide a period of time for germination and growth of roots into the more tolerable soil (re: salt) before evaporation dries and re-salinizes the seedbed (Stepphun and Wall 1993).

Table 4.3 Precipitation data for the growing seasons in 2005 and 2006 obtained from the Environment Canada weather station at the University of Manitoba Carman Research Station, during the periods of observation (Environment Canada Climate Data)

	Total Precipitation (mm)			Average Temperature (C)		
Month	2005	2006	30-year average	2005	2006	30-year average (1976-2006)
March	14.1	93.6	23.6	-7.7	-6.3	-5.8
April	19.0	34.3	30.5	7.1	8.5	4.4
May	88.6	28.0	62.5	10.2	12.4	12.4
June	139.8	49.6	86.2	17.4	17.9	17.2
July	89.6	26.2	77.6	19.7	20.4	19.7
August	23.6	37.6	64.4	17.6	18.8	18.1

4.1. Times of Kochia Emergence Relative to Other Species

Table 4.4 shows how quickly kochia emerges by comparison to some other weed species. Eighty percent of kochia populations we observed emerged very early, before even 10 percent of each of the other weed populations would have emerged typically in Manitoba (Bullied et al. 2003). Generally, C4 plants emerge late. Kochia is an exception. Green foxtail and broadleaf redroot pigweed are examples of later emerging C4s. The *E* values for weeds other than kochia were calculated from the data of Bullied et al. (2003) also using a T_{base} 0 C and are based on observations in agroecosystems in southern Manitoba.

Table 4.4. Emergence (E) values (cumulative GDD) for kochia management, averaged over 2005 and 2006, and E values for other common weed species.

Species	E_{10}	E_{25}	E_{80}	E_{90}
Kochia	142*	169	291	353
Canola	380**	446	595	643
Green foxtail	473	552	735	801
Wild oat	342	438	654	724
Wild buckwheat	401	481	661	720
Wild mustard	291	355	505	559
Common lambsquarters	456	530	710	784
Redroot pigweed	530	617	822	901
Field pennycress	346	470	731	799

* E values for kochia were derived from the 4-parameter logistic equation $x = E_{50}\times((D/(y-C)-1)^{1/b})$ to correspond to the Carman Research Station temperature data.

** E values for weeds other than kochia were derived from the equation $x = -\ln((a-y)/yb)/c$ based on data from Bullied et al. (2003).

The difference between kochia emergence timing and the timing of other species may be attributed to the intersection of higher levels of oxalate production (Curtin and Wen 2004), more active Photosystem 1 under low temperature regimes (Hóla et al. 2004), and increased isoleucine and valine production (Dyer et al. 1993). Kochia seed germination is tolerant of high solute concentrations (Evetts and Burnside 1972 and Khan et al. 2001), moisture stress, and extreme acid or alkaline conditions (Everitt et al. 1983) such as may delay the emergence of other weed species. Kochia can emerge and persist in environments inhospitable to other weeds.

Kochia emergence time may be sustained past tillage events by weed tumbling. Kochia skeletons may tumble onto fields and deposit seeds after tillage buries other weed seeds. Kochia seedlings grow from seed disseminated by tumbling, decrease exponentially with distance from the original site, and remain attached to the desiccated plant skeleton when it finally rests (Fay et al. 1992). Furthermore, Everitt et al. (1983) found the seedling emergence percentage for kochia seed left exposed on the soil surface (74%) was significantly higher than for those planted at a depth of 3 mm (57%).

For many of the field sites, we were monitoring for populations in non-cultivated areas, where the kochia seed was likely at or near the soil surface and this would also facilitate early emergence, as Bullied et al. (2003) pointed out. Sustained emergence can include emerging later in the season, e.g., pigweed, or over a longer period of time, e.g., pennycress or wild oat (W. J. Bullied pers. comm.). The very early emergence of kochia may be related to its ability to emerge from the soil surface (Stepphun and Wall 1993) in comparison to other species such as for example, green foxtail where surface emergence is limited by light inhibition (Boyd and Van Acker 2003).

4.2. Emergence Density and Timing of Management Events

The field density for all fields is a measure of the number of plants of species counted in a square metre (Leeson et al. 2005). When density values were averaged over all fields surveyed it was 2 292.2 (standard deviation ± 3 226.2) m^{-2} and the average field density minus fields I and J was 2 672.3 (standard deviation ± 3 346.3) m^{-2} (Table 4.5). The high standard deviation indicates the high variability of kochia field densities in this study. There was a lot of variation in density.

The average field density of kochia seedlings in this study was particularly high because quadrats were located on sites of established kochia populations. The high density of kochia seedlings in field K may have been due to the presence of established kochia patches in this perennial alfalfa field. Field K provides an illustration for Iseley's (1960) hypothesis that kochia can be spread by the contamination of commercial alfalfa seed. This study does not support Boerboom's (1993) hypothesis that alfalfa can prevent kochia establishment and suppress growth.

Table 4.5 Cumulative emergence of kochia in 2005 and 2006, as related to management period, in southwestern Manitoba, Canada (standard deviations in parentheses).

		Emerged kochia seedlings			
Year-field designation	Crop	Total (m^{-2})	Prior to crop seeding (m^{-2})	Prior to in-crop herbicide application (m^{-2})	After in-crop herbicide application (m^{-2})
2005-A	Canola	2794 (1656.4)			
2005-B	NA[2]	1207 (973.8)	1120 (927.8)	No Data[1]	87 (72.7)
2005-C	NA	2379 (2520.5)			
2005-D	NA	2550 (1350.9)			
2005-E	Canola	152 (84.0)	134 (79.0)		18 (6.9)
2005-F	Canola	973 (706.2)	966 (713.6)	No Data[1]	7 (11.5)
2005-G	Corn	536 (235.2)	266 (204.0)	No Data[1]	270 (33.4)
2006-B	NA	3073 (2038.9)			
2006-C	NA	3397 (1847.7)			
2006-H	Wheat	177 (120.4)		177 (120.4)	0 (0)
2006-I	Barley/grass	2 (2.3)			
2006-J	Wheat	21 (17.4)	11 (16.8)		10 (17.4)
2006-K	Alfalfa	12669 (8089.3)	12634 (8088.6)*	24 (40.1)**	11 (19.4)***
2006-L	Wheat	2161 (2670.4)	2146 (2686.1)		15 (20.8)

* prior to first cut of alfalfa, **prior to second cut of alfalfa, *** after second cut of alfalfa

[1] The farmer both seeded and applied herbicides in the time between field visits.

[2] No crop, quadrats located in uncropped area

Kochia seedling densities on the sites of established populations are much higher than would be observed typically in cultivated fields after crop seeding and herbicide application. Weatherspoon and Schweizer (1971) observed only 59 kochia plants m^{-2} in "severely infested" sugarbeet fields. Nussbaum et al. (1985) observed kochia to produce over 20000 seeds per plant (equivalent to over 2 million seeds m^{-2}) but only 110 kochia plants m^{-2}. Although kochia was the predominant weed in an untreated control, Wicks et al. (1997) recorded 25 m^{-2} at most, in a study in Nebraska. Leeson et al.'s (2005) "high" value for kochia field density in mid-season (post-control) in-field surveys in the 2000s, in Manitoba, was 197.0 m^{-2}.

4.3. Persistence of Kochia Seeds in the Soil Seed Bank

Soil samples from field sites showed a low level of kochia seed persistence in the seed bank (Table 4.6). In almost half of the field sites there was no detectable persistant seed at all, and in 10 out of 12 sites more than 90% of the viable seedbank had emerged during the year. The flooding of field E, during the growing season of 2005, affected the results from that field. The lack of persistence is consistent with Everitt et al. (1983), Dyer (1993), and Thompson et al. (1994).

Table 4.6. Kochia seed persistence at end of season in southern Manitoba fields.

Soil sample (year-field)	Seedbank seedlings (m^{-2})[1]	Seedbank population as proportion of total seedling population for given site (%)	Seedling population emerging from quadrats as proportion of total seedling population for given site (%)
2005-A	264	8.6	91.4
2005-B	88	6.8	93.2
2005-C	132	5.3	94.7
2005-D	220	8.0	92.0
2005-E	44	22.5	77.5
2005-F	132	12.0	88.0
2005-G	0	0	100
2006-B	44	1.4	98.6
2006-C	0	0	100
2006-J	0	0	100
2006-K	44	0.35	99.7
2006-L	0	0	100

[1]Based on growouts from soil samples

4.4. Growth Room Emergence

Seeding depth has a significant effect (Table 4.7) on kochia emergence. Even shallow seed burial (40 mm) reduced emergence significantly. This result agrees with the results of Johnson (1990) who found that emergence decreased when kochia seeds were buried to a depth of 30 mm. Johnson (1990) found no emergence from kochia seeds buried to a depth of 90 mm. Similarly, in an emergence study by Zorner et al. (1984), a 50 mm depth limit restricted successful kochia germination. Other researchers have attributed the inability of kochia to emerge from depth to the small size of the seed (Gates 1941, Everitt et al. 1983, Mulugeta 1991).

Table 4.7 Emergence percentage of kochia seed planted at increasing depths in a growth room based experiment. Emergence represents total final emergence as a percentage of seeds used. Results are pooled over both experimental runs.

Seeding Depth (mm)	Emergence mean (%) (standard error)
2	52.25 (1.47)^a
10	41.00 (3.28)^b
20	26.75 (3.17)^c
40	7.25 (2.57)^d
80	0.00 (0.00)^e
LSD (0.05)	4.58

These results indicate that kochia has very specific depth requirements for recruitment. Boyd and Van Acker (2003) identified specific depth requirements for recruitment in the case of cleavers (*Galium* spp). As Boyd and Van Acker (2003) established, there is a practical link between growth room recruitment site and field management. Localized inversion tillage may be employed for management of kochia, owing to the key biological characteristics of its recruitment being limited to surface recruitment and its possessing little seed dormancy or persistence.

In the process of investigating emergence from depth, suicidal germination was observed. While the influence of depth was significant upon kochia emergence, kochia seeds germinated regardless of depth. Radicals emerged at depths from which the seedling could never have emerged. Perhaps this is not surprising, as many researchers have asserted that kochia seed seems to not posses dormancy typically, and light is not required for the germination of kochia seed (Macguire and Overland 1959, Everitt et al. 1983, Thompson et al. 1994). Further research is necessary to identify whether kochia accessions are subject to suicidal germination outside of the growth room environment.

4.5. Conclusion

Kochia emergence was early (50 cumulative GDD, i.e., the second to third week of April in southwestern Manitoba) and sustained. One of the reasons that kochia emerges so early is that it adjusts its germination over a wide range of temperatures, e.g., kochia seeds collected in Iran germinated in temperatures from 3.5 to 50 C (Al-Ahmadi and Kafi 2007). Another reason why kochia emerges so early may be that Photosystem 1 activity increases in biotypes grown under low-temperature conditions (Hóla et al. 2004). Early germination with respect to GDD found in this study agree with Everitt et al.'s (1983) assertion that cold to moderate temperatures improve kochia germination. The emergence time of kochia may be sustained past tillage events by weed tumbling. Kochia skeletons may tumble on to fields and deposit seeds after tillage buries other weed seeds.

The results of this study indicate that kochia density in established patches at the edges of fields is much higher than the residual field densities observed by other researchers. Nussbaum et al. (1985) observed only 110 kochia plants m^{-2}. Leeson et al. (2005) observed only 197.0 kochia plants m^{-2}.

Soil samples from field sites showed a low level of kochia seed persistence in the seed bank (Table 4.6). The lack of persistence is consistent with Everitt et al. (1983), Dyer (1993), and Thompson et al. (1994). Even a very shallow seeding depth (40 mm) significantly and drastically (Table 4.7) reduces kochia emergence. This result is similar to the emergence study by Zorner et al. (1984). Other researchers have attributed the inability of kochia to emerge from depth to the small size of the seed (Gates 1941, Everitt et al. 1983, Mulugeta 1991). While the influence of depth was significant on kochia emergence, kochia seeds germinated regardless of depth in the growth room experiment.

Chapter 5 – General Discussion

The objectives of this thesis project were to aid in the management of kochia by determining its time of emergence in the field and its persistence in the seed bank. This general discussion will address these objectives and the two areas of inquiry: What is the ecological niche of kochia? And how can growers close the ecological niche of kochia in prairie cropland?

5.0.0. Time of Emergence

Early emergence subjects kochia seedlings to the risk of late frost, but may allow for development during short growing seasons. It is worth noting that climate models predict less variable temperatures and earlier springs for southern Manitoba in the coming decade (Anderson 2006). The earlier and more uniform emergence of resistant biotypes (Thompson et al. 1994) may make them easier to control than the variable and sustained emergence of the wild type, via, for example, shallow tillage early in the growing season. Early emergence combined with earlier springs may result in increased proliferation of this plant, and the establishment of kochia populations in zones where successful colonization would have been impossible previously. The expansion of agricultural operations into the Boreal zone due to climate change (Ryan Brook, personal communication), and the salinization of Boreal soil regimes due to tillage, may push the limit of kochia populations in Manitoba further north.

5.0.1. Persistance

Kochia seeds have a very low level of persistence in the soil seedbank. Although one plant may produce 50,000 tiny seeds (Iverson and Wali 1981), most would either germinate or decay within one year (Boerboom 1993). However, there is some evidence from other studies that portions of dormant and nondormant kochia seed populations can remain viable for at least 36 months (Zorner et al. 1984). Our results indicate only very slight persistence, among the given accessions we investigated. However, even slight persistence may be biologically significant due to the enormous volume of seeds that a kochia plant can produce and disseminate while tumbling. These results indicate most seeds are recruited after the first winter to command spaces within the saline field environment. Kochia at the edge of a field can branch freely and grow ovate, which may allow for more successful tumbling.

5.0.2. The Ecological Niche of Kochia

As extreme wind events become more frequent, and as economic factors drive increasing monoculture agricultural production across the rural landscape, more herbicides will become necessary for fewer farmers to manage more land per farmer. Soil salinization, which has been a characteristic of tillage agriculture since the dawn of civilization, will only increase the area suitable to kochia establishment across Manitoba and the prairie provinces.

With respect to the economic threshold of kochia, Schweizer (1970) characterized the reduction in root yield of sugarbeets due to in-row interference using a linear model.

Christoffoleti and Westra (1994) described mixture yields of wheat and sulfonylurea-resistant and –susceptible kochia by a natural log transformation. Other examples of competition are cited in the literature review. The economic thresholds for crops other than sugarbeets and wheat remain uncharacterized. Usually, the saline soils inhabited by kochia are too marginal for crop growth. In which case, soil salinity may be more significant to yield loss than competition with (salt tolerant) kochia.

At the whole plant level, kochia has a variety of characteristics that allow the plant to tolerate drought conditions, for example, the C_4 metabolic pathway and narrow xylem (Kocacinar and Sage 2003). However, wet conditions do not disallow the growth of kochia. In our study we observed that during the wet 2005 growing season, kochia continued to emerge in flooded fields. It appeared to be the case that some kochia emerged while submerged, which supports the idea that kochia can tolerate a wide range of soil moisture regimes.

Kochia balances excess soil cations over inorganic anions by oxalate synthesis. Oxalates, alkaloids, and nitrates can result in horse and livestock toxicosis (Thistled et al. 1986, Rankins and Smith 1991, Rankins et al. 1991a, Rankins et al. 1991b). Low nutrient levels, e.g., low levels of cystine, may also deter herbivory. The alkaloid allelochemical defense mechanism against herbivory allows kochia resistance to insect, e.g., migratory grasshopper, feeding as well. Although autotoxic exudations may compromise the habitats of kochia, the plants avoid negative effects on reproduction by producing even more seeds after being grazed, and moving elsewhere by tumbling (Durham and Durham 1979).

Kochia plays a role in the reclamation of contaminated sites by encouraging the proliferation of microorganisms that degrade wastes, e.g., atrazine. Special relationships with soil fungus, such as *Rhizoctonia solani*, facilitate basal fracture. Kochia also has successful relationships among the macrofauna. Humans and prairie dogs cultivate and propagate the plant, respectively (Koford 1958).

The development of herbicide resistant kochia is problematic. Many localized herbicidal applications have produced enormous, landscape-scale selection pressures. Since (at least some of) the resistance genes are dominant or semi-dominant, they are likely to persist and alter agricultural behaviour for many years to come.

The herbicide-resistant crop industry depends on the vulnerability of weed plants to the herbicides. Research and development of alternative herbicide-resistant crops, to keep ahead of herbicide-resistant weeds, may be prohibitive. In any case, the continued release of herbicide resistant crops, and increasingly large-scale monoculture operations, will only intensify the problem of herbicide resistant weeds. Weed resistance to glyphosate, once thought to be highly unlikely (Bradshaw et al. 1997), has even now become very common for a wide range of weed species worldwide (Heap 2007).

5.0.3. Closing the Ecological Niche of Kochia

To paraphrase Paulo Freire, with respect to the development of a seed, time belongs to human beings (Freire 1970). Closing the ecological niche of kochia may require nothing more than timely (but perhaps relatively deep) tillage to allow the crop to gain advantage. This tactic may be problematic in light of the no-till strategy of agricultural management. Alternatively, to manage established kochia populations with herbicide, the grower may need to seed crops that have in-crop herbicide options that are effective against kochia.

Trifluralin, ethalfluralin, or pre-seed glyphosate followed by an in-crop option such as fluroxypyr plus 2,4-D, may provide residual control for established populations. Either dicamba tank mixes with 2,4-D, or MCPA, or bromoxynil plus 2,4-D when kochia seedlings are small, could provide post-emergence control. However, Group 2 herbicide-resistant kochia generally render these products ineffective (Murray and Friesen, 2004, 2005 MB kochia survey – unpublished). The existence of herbicide resistant kochia provides farmers with a reason to switch from herbicidal management to non-herbicidal management.

High genetic diversity through substantial levels of gene flow within and among populations, despite heavy selection pressure due to the herbicidal management of conventional agriculture, is at least in part due to proterogyny, combined with long distance pollen dispersion by wind. Continual use of single herbicides, or herbicides with identical modes of action, leads to increased herbicide resistance alleles in the population (Goblirsch et al. 1997). However, the sulfonylurea-resistant ALS coding gene mutation is thought to be dominant or semi-dominant, so resistance will likely not be managed into extinction. In extreme cases, where resistant populations are dense and large, perhaps small fields of kochia could be grown as a crop (*tonburi*, the seeds of kochia are sold as a condiment in the Asian food market) in rotational agriculture. The autotoxic residues from the kochia foliage could allow for subsequent crop rotations to be free from contamination. If farmers let patches grow patches to harvest, they must still contain the spread. Total seed capture at harvest could aid in containment. Easy basal abscission facilitates manual harvesting.

Kochia seems to be non-persistent, so if a farmer has significant populations and a very intensive management approach (including manual operations before populations set viable seed), it may be a very effective means of longer term management because the species is seed limited and the persistence of given populations relies on re-seeding. Farmers with problematic populations may also want to consider inversion tillage within patches to bury the seed source and thus limit recruitment in subsequent years.

5.1. Recommendations for Future Research

In the process of investigating the emergence of kochia from depth, we observed suicidal germination. While the influence of depth was significant upon kochia emergence, kochia seeds germinated regardless of depth. Further research is necessary to identify whether kochia accessions are subject to suicidal germination, outside of the growth room environment. Whether suicidal germination is a survival strategy, or more particularly the product of ALS enzyme mutation, needs to be addressed. The mechanism of suicidal germination could be of use to the development of genetic restriction technologies.

It has been hypothesized that kochia has been spreading for a century via the contamination of alfalfa and other leguminous seed. Due to the huge number of kochia seedlings in the perennial alfalfa field, these results certainly do not contradict that hypothesis. Further research would be necessary, involving more than one alfalfa field and the in-depth investigation of the contiminants of alfalfa seed samples including certified and common seed, and given the antiquity of the question, the research is long overdue.

There is disagreement in the literature regarding whether or not kochia residue is autotoxic, long-term field trials would be required to address this question.

There seems to be a possibility that shallow tillage after herbicide-resistant cohort emergence may only stimulate further emergence. Further research would be necessary to identify the relationship between shallow tillage and kochia emergence in fields. Further research is necessary to characterize survivorship after particular control methods.

Literature Cited

Al-Ahmadi, M. and M. Kafi. 2007. Cardinal temperatures for germination of *Kochia scoparia* (L.). Journal of Arid Environments 68: 308-314

Alam, L. and A. Wiese. 1985. Efeect of degree days on weed emergence. Proceedings, Southern Weed Science Society, 38th annual meeting: 448

Al-Khatib, K., C. Libbey and R. Boydston. 1997. Weed suppression with *Brassica* green manure crops in green pea. Weed Science 45: 439-445

Anderson, J. 2006. Climate change – is there more variability in the weather? Manitoba Agronomists Conference, University of Manitoba.

Anderson, R. 1994. Characterizing weed community seedling emergence for a semiarid site in Colorado. Weed Technology 8: 245-249

Anderson, R. and D. Nielsen. 1996. Emergence pattern of five weeds in the Central Great Plains. Weed Technology 10: 744-749

Anderson, R. and D. Nielsen. 1996. Emergence pattern of five weeds in the central Great Plains. Weed Technology 10: 744-749

Archibold, O. 1980. Seed input as a factor for the regeneration of strip mine wastes in Saskatchewan. Canadian Journal of Botany 58: 1490-1495

Armstrong, J. and L. De Azevedo Camelo. 2003. Lygus species associated with Texas High Plains cotton, alfalfa and weeds. Southwestern Entomologist 28(3): 197-204

Arthur, E., B. Perkovich, T. Anderson and J. Coats. 2000. Degradation of an atrazine and metolachlor herbicide mixture in pesticide-contaminated soils from two agrochemical dealerships in Iowa. Water, Air, and Soil Pollution 119: 75-90

Bandeen, J., G. Stephenson and E. Cowett. 1982. Discovery and distribution of herbicide-resistant weeds in North America. P 9-30 in H. LeBaron and J. Gressel, ed. Herbicide Resistance in Plants. John Wiley and Sons, New York

Barnes, P., S. Flint and M. Caldwell. 1990. Morphological responses of crop and weed species of different growth forms to ultraviolet-B radiation. Amer. J. Bot. 77(10): 1354-1360

Becker, D. 1968. Tumbleweeds: ecology and abscission. Ph.D. Dissertation. University of North Dakota, Grand Forks, North Dakota

Becker, D. 1978. Stem abscission in tumbleweeds of Chenopodiaceae: Kochia. Amer. J. Bot. 65(4):375-383

Beling, F., L. Wilson and A. Wiese. 1981. Effects of DPX 4189 and DPX 5648 on various sized annual weeds. Proceedings, 34th Annual Meeting Southern Weed Science Society: 96

Bell, A. R., J. D. Nalewaja, and A.B. Schooler. 1972a. Light period, temperature and kochia flowering. Weed Sci. 20(5): 462-464

Bell, A., J. Nalewaja and A. Schooler. 1972b. Response of kochia selections to 2,4-D, dicamba, and picloram. Weed Science. 20(5): 458-462

Bennet, A. and G. Murray. 1889. A Handbook of Cryptogamic Botany. London: Longmans, Guerny and Co.; and New York: 13 East 16th Street. pp viii, 473

Blackshaw, R., F. Larney, C. Lindwall, P. Watson and D. Derksen. 2001. Tillage intensity and crop rotation affect weed community dynamics in a winter wheat cropping system. Canadian Journal of Plant Science: 805-813

Blackshaw, R., J. Moyer, R. Doram and A. Boswell. 2001a. Yellow sweetclover, green manure, and its residues effectively suppress weeds during fallow. Weed Science 49: 406-413

Boerboom, C. 1993. Kochia (*Kochia scoparia* L. Schrad.). Pacific Northwest Cooperative Extension Publication 460: 4 pp

Borrelli, F. and A. Izzo. 2000. The plant kingdom as a source of anti-ulcer remedies. Phytotherapy Research 14: 581-591

Boyd, N. and R. Van Acker. 2003. The effects of depth and fluctuating soil moisture on the emergence of eight annual and six perennial plant species. Weed Science 51: 725-730

Boydston, R. 1995. Effect of tillage level and herbicide on weed control and yield of asparagus (*Asparagus officinalis*) in the Pacific Northwest. Weed Technology 9: 768-772

Bradshaw, L., S. Padgette, S. Kimball, B. Wells. 1997. Perspectives on glyphosate resistance. Weed Technology 11(1): 189-198

Braidek, J., P. Fedec and D. Jones. 1984. Field survey of halophytic plants of disturbed sites on the Canadian Prairies. Canadian J. Plant Sci. 64: 745-751

Breitung, A. 1957. Annotated catalogue of the vascular flora of Saskatchewan. American Midland Naturalist 58(1): 1-72

Bullied, W., A. Marginet and R. Van Acker. 2003. Conventional- and conservation-tillage systems influence emergence periodicity of annual weed species in canola. Weed Science 51: 886-897

Burnside, O.C., C.R. Fenster, L.L. Evetts, and R. F. Mumm. 1981. Germination of exhumed weed seed in Nebraska. Weed Sci. 29(5):577-586

Canadian Organic Growers. 2001. Organic Field Handbook. Second edition. Janice Wallace, ed. Mothersill Printing Inc.

Cardina, J. and D. H. Sparrow. 1996. A comparison of methods to predict weed seedling populations from the soil seedbank. Weed Sci. 44:46-51.

Chodová, D. and J. Mikulka. 1997. Susceptibility of kochia (*Kochia scoparia*) to some herbicides. Ochrana Rostlin. 33(2): 113-123

Chodová, D. and J. Mikulka. 2000. Identification of resistance to imazapyr and cross resistance to selected sulfonylurea herbicides in *Kochia scoparia*. Z. PflKrankh. PflSchutz, Sonderh. 17: 383-388

Choi, J., K. Lee, H. Jung, H. Park and H. Park. 2002. Anti-rheumatoid arthritis effect of the *Kochia scoparia* fruits and activity comparison of momordin Ic, its prosapogenin and sapogenin. Archives of Pharmacal Research 25(3): 336-342

Christoffoleti, P. and P. Westra. 1994. Competition effects with mixed stands of wheat and kochia (*Kochia scoparia*) biotypes resistant and susceptible to acetolactase synthase inhibitor herbicides. Sci. agric., Piracicaba 51(2): 245-251

Coxworth, E., J. Bell and R. Ashford. 1969. Preliminary evaluations of Russian thistle, kochia, and garden atriplex as potential high protein content seed crops for semiarid areas. Can. J. Plant. Sci. 49: 427-434

Cranston, H., A. Kern, J. Hackette, E. Miller B. Maxwell and W. Dyer. 2001. Dicamba resistance in kochia. Weed Sci. 49: 427-434

Curtin, D. and G. Wen. 2004. Plant cation-anion balance as affected by the ionic composition of the growing medium. Plant and Soil 267: 109-115

Dahl, G., A. Dexter and J. Nalewaja. 1982. Kochia competition and control in wheat. P. 15-16. In Proc. N. Cent. Weed Control Conf., 37th, Indianapolis. 7-9 Dec. 1982. N. Cent. Weed Sci. Soc., Manhattan, KS.

Davis, R., A. Wiese and J. Pafford. 1965. Root moisture profiles of various weeds. Weeds 13: 98-100

Davis, R., W. Johnson, and F. Wood. 1967. Weed root profiles. Agron. J. 59:555-556

Derksen, D., R. Anderson, R. Blackshaw and B. Maxwell. 2002. Weed dynamics and management strategies for cropping systems in the Northern Great Plains. Agronomy Journal 94: 174-185

Drost-Karbowska, K., Z. Kowalewski and J. Phillipson. 1978 Isolation of harmane and harmine from *Kochia scoparia*. Lloydia Vol. 41 No. 3:289-290

Durgan, B. and A. Dexter. 1984. Kochia competition in sunflower. Proc. North Cent. Weed Cont. Conf. 39: 120

Durgan, B., A. Dexter and S. Miller. 1990. Kochia (*Kochia scoparia*) interference in sunflower (Helianthus annuus). Weed Technol. 4:52-56

Durham, R. and J. Durham. 1979. Kochia: its potential for forage production. *In* Arid Land Plant Resources, eds. Goodin, J. and D. Northington. International centre for arid land studies. Texas Tech University, Lubbock TX: 440-450

Dyer, W., H. Cranston and A. Kern. 2001. Physiological characteristics of dicamba resistance in kochia. Proc. West. Soc. Weed Sci. 54: 80

Dyer, W., P. Chee and P. Fay. 1993. Rapid germination of sulfonylurea-resistant *Kochia scoparia* L. accessions is associated with elevated seed levels of branched chain amino acids. Weed Science. 41: 18-22

Eberlein, C. and Z. Fore. 1984. Kochia biology. Weeds Today. 15 no 3: 5-6

Einhellig, F. and J. Rasmussen. 1976. Allelopathic effects of *Kochia scoparia* (L.) Schrad. on grain sorghum. Proc. S. D. Acad. Sci. 55: 189

Einhellig, F. and M. Schon. 1982. Noncompetitive effects of *Kochia scoparia* on grain sorghum and soybeans. Can. J. Bot. 60: 2923-2930

Erickson, E. and A. Moxon. 1947. Forage from kochia. Bull. 384 S. Dak. Agr. Exp. Sta. S. Dak., U.S.A.

Everitt, J., M. Alaniz, and J. Lee. 1983. Seed germination characteristics of *Kochia scoparia*. Journal of Range Management. 36 (5): 646-648

Everson, L. 1949. Preliminary studies to establish laboratory methods for the germination of weed seeds. Proc. Assoc. Off. Seed Anal. 39:84-89

Evetts, L.L. and O.C. Burnside. 1972. Germination and seedling development of common milkweed and other species. Weed Sci. 20(4):371-378

Ewing, K. and J. Dobrowolski. 1992. Dynamics of shrub die-off in a salt desert plant community. J. Range Manage. 45: 194-199

Fay, P., D. Mulugeta and W. Dyer. 1992. The role of seed dispersal in the spread of sulfonylurea resistant *Kochia scoparia*. Abstr. Weed Sci. Soc. Am. 32:49

Fernald, M. and A. Kinsey revised by R. Rollins. 1958. Edible wild plants of eastern North America. Harper and Row, New York.

Fischer, A., C. Messersmith, J. Nalewaja and M. Duysen. 2000. Interference between spring cereals and *Kochia scoparia* related to environment and photosynthetic pathways. Agronomy Journal. 92: 173-181

Forcella, F. 1985. Spread of kochia in the northwestern United States. Weeds Today 16 (46): 4-6

Forcella, F., R. Wilson, J. Dekker, R. Kremer, J. Cardina, R. Anderson, D. Alm, K. Renner, R. Harvey, S. Clay and D. Buhler. 1997. Weed seed bank emergence across the Corn Belt. Weed Science 45: 67-76

Franco, M. and J. Harper. 1988. Competition and the formation of spatial pattern in spacing gradients: an example using *Kochia scoparia*. The Journal of Ecology. 76 no 4 (Dec): 959-974

Frankton, C., G. Mulligan. 1970. Weeds of Canada. Publication 948. Canada Department of Agriculture. Ottawa.

Freire, P. 1970. *Pedagogy of the Oppressed*. The Continuum Publishing Company.

Friesen, L., I. Morrison, A. Rashid and M. Devine. 1993. Response of a chlorsulfuron-resistant biotype of *Kochia scoparia* to sulfonylurea and alternative herbicides. Weed Science. 41: 100-106

Fuerhig, H. 1980. Kochia as a forage crop. Proceedings Eighth Annual Texas Beef Conference. Amarillo, TX: 1-3

Galitzer, S. and F. Oehme. 1978. *Kochia scoparia* (L.) Schrad toxicity in cattle: a literature review. Vet. Hum. Toxicology 20: 421-423

Gast, R., R. Wilson and E. Kerr. 1983. The harbouring of the lesion nematode on various weed species and fieldbeans in western Nebraska. Abstracts, 1983 Meeting of the Weed Science Society of America: 26-27

Gates, F. 1941. Weeds of Kansas. Report of the Kansas State Board of Agriculture June, 1941. W.C. Austin, State Printer, Topeka.

Goblirsch, C., F. Manthey and J. Nalewaja. 1997. Possible effect of herbicide treatment on the frequency of resistance alleles in kochia [*Kochia scoparia* (L.) Schrad.] populations. Weed Sci. Soc. Am. Abstr. 37: 50

Goss, G. and W. Dyer. 2003. Physiological characterization of auxinic herbicide-resistant biotypes of kochia (*Kochia scoparia*). Weed Science. 51: 839-844

Gunther, R. 1968. The Greek Herbal of Dioscorides. Hafner Publishing Company. New York. 701 pp

Guttieri, M., C. Eberlein and D. Thill. 1995. Diverse mutations in the acetolactate synthase gene confer chlorsulfuron resistance in kochia (*Kochia scoparia*) biotypes. Weed Science 43: 175-178

Guttieri, M., C. Eberlein and E. Souza. 1998. Inbreeding coefficients of field populations of *Kochia scoparia* using chlorsulfuron resistance as a phenotypic marker. Weed Science 46: 521-525

Guttieri, M., C. Eberlein, C. Mallory Smith, D. Thill and D. Hoffman. 1992. DNA sequence variation in domain A of the acetolactate synthase genes of herbicide-resistant and –susceptible weed biotypes. Weed Science 40: 670-676

Holec, J., J. Soukup, M. Jursík and P. Hamouz. 2004. Invasive weed species on arable land in the Czech Republic. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz. Sp. Iss. 19: 231-236

Hutchinson, P., D. Tonks and B. Beutler. 2003. Efficacy and economics of weed control programs in glyphosate-resistant potato (*Solanum tuberosum*). Weed Technology 17: 854-865

Inserra, R., M. di Vito and H. Ferris. 1984. Influence of Nacobbus aberrans densities on growth of sugarbeet and kochia in pots. Journal of Nematology 16(4): 393-395

Iseley, D. 1960. Weed identification and control in the North Central States. Iowa State University Press. Ames, Iowa.

Iverson, L., and W. Wali. 1981. Ecology of *Kochia scoparia* on surface mined lands. In: Proc. North Dakota Acad. Sci. 35: 7

Johnson, D. J. Krall, R. Delaney and D. Thiel. 1990. Response of seed of 10 weed species to Fresnel-lens-concentrated solar radiation. Weed Technology 4: 109-114

Johnston, D. and W. Wood. 1976. *Kochia scoparia* control on noncropland. Proc. North Cent. Weed Control Conf. 31: 126-128

Karachi, M. and R. Pieper. 1987. Allelopathic effects of kochia on blue grama. Journal of Range Management. 40 (4): 380-381

Khan, M., B. Gul and D. Weber. 2001. Influence of salinity and temperature on the germination of *Kochia scoparia*. Wetlands Ecology and Management. 9: 483-489

Haderlie, L. and M. Poulson. 1991. 1990 weed control survey. Proceedings University of Idaho Winter Commodity Schools 23: 149-154

Hall, G. 1998. Aphanomyces cochliodes. IMI Descriptions of Fungi and Bacteria 98: Sheet 972

Harbour, J., C. Messersmith and B. Ramsdale. 2003. Surfactants affect herbicides on kochia (*Kochia scoparia*) and Russian thistle (*Salsola iberica*). Weed Science 51: 430-434

Heap, I. The International Survey of Herbicide Resistant Weeds. Online. Internet. January 17, 2007. Available www.weedscience.com

Hinks, C. and M. Erlandson. 1995. The accumulation of haemolymph proteins and activity of digestive proteinases of grasshoppers (*Melanoplus sanguinipes*) fed wheat, oats or kochia. J. Insect Physiol. 41(5): 425-433

Hinks, C., O. Olfert, N. Westcott, E. Coxworth and W. Craig. 1990. Preference and performance in grasshopper, *Melanoplus sanguinipes* (Orthoptera: Acrididae), feeding on kochia, oats, and wheat: implications for population dynamics. Journal of Economic Entomology 83: 1338-1343

Holá, D., M Kočová, O. Rothová, D. Chodová and J. Mikulka. 2004. The effect of low growth temperature on Hill reaction and photosystem 1 activities in three biotypes of *Kochia scoparia* (L.) Schrad. with different sensitivity to atrazine and ALS-inhibiting herbicides. Plant Soil Environ. 50(1): 10-17

King, G., W. Schumacher, N. McKinley, J. Saladini and L. Saari. 1990. Sulfonylurea-resistant weeds: An update of distribution and control. Proc. West. Soc. Weed Sci. 43: 79

Kingsbury, J. 1964. Poisonous plants of the United States and Canada. Prentice-Hall, Englewood Cliffs, N.J.

Kocacinar, F. and R. Sage. 2003. Photosynthetic pathway alters xylem structure and hydraulic function in herbaceous plants. Plant Cell and Environment 26(12): 2015-2026

Koford, K. 1958. Prairie dogs, whitefaces, and blue grama. Wildlife Monographs. No. 3: 76 pp

Krishnan, G., D. Holshouser and S. Nissen. 1998. Weed control in soybean (*Glycine max*) with green manure crops. Weed Technology 12: 97-102

Lacher, J.R., D. Bivens and C. Jones. 1963. Germination of *Kochia scoparia*. Proc. Assoc. Off. Seed Anal. 53:45-50

Landolt, P. 2002. Survival and development of Lacanobia subjuncta (Grote & Robinson) (Lepidoptera: Noctuidae) Larvae on common weeds and crop plants of eastern Washington state. Pan-Pacific Entomologist 78(1): 1-6

Leeson, J., A. Thomas, L. Hall, C. Brenzil, K. Brown and R. Van Acker. 2005. Prairie Weed Survey: Cereal, Oilseed and Pulse Crops 1970s to the 2000s. Weed Survey Series. Publication 05-1. Agriculture and Agri-Food Canada, Saskatoon Research Centre, Saskatoon, Saskatchewan.

Lirussi, D., J. Li, J. Prieto, M. Gennari, H. Buschiazzo, J. Ríos and A. Zaidenberg. 2004. Inhibition of *Trypanosoma cruzi* by plant extracts used in Chinese medicine. Fitoterapia 75: 718-723

Lodhi, M. 1979. Germination and decreased growth of *Kochia scoparia* in relation to its autoallelopathy. Canadian J. Bot. 57:1083-1088

Love, A. and D. Love. 1954. Vegetation of a prairie marsh. Bulletin of the Torrey Botanical Club 81(1): 16-34

Maguire, J., and A. Overland. 1959. Laboratory germination of seeds of weedy and native plants. Wash. Agric. Expt. Sta. Circ. 349

Májovský, J. 1974. Index of chromosome numbers of Slovakian flora part 4. Acta Facultatis Rerum Naturalium Universitatis Comenianae Botanica XXIII: 1-20

Mallory-Smith, C., D. Thill and G. Stallings. 1993. Survey and gene flow in acetolactate synthase resistant kochia and Russian thistle. Brighton Crop Protection Conference, Weeds 2: 555-558

Manthey, F., J. Nalewaja, C. Messersmith. 1995. North Dakota has kochia [*Kochia scoparia* (L.) Schrad.] biotypes that are resistant to dicamba, 2,4-D, and tribenuron. Weed Sci. Soc. Am. Abstr. 35: 87

Manthey, F., R. Roach and J. Nalewaja. 1997. Survey of kochia [*Kochia scoparia* (L.) Schrad.] resistance to tribenuron, dicamba, and 2,4-D in north central North Dakota. Weed Sci. Soc. Am. Abstr. 37: 50

Matsuda, H., Y. Dai, Y. Ido, M. Yoshikawa and M. Kubo. 1997. Studies on Kochiae Fructus IV. Anti-allergic effects of 70% ethanol extract and its component, momordin Ic from dried fruits of *Kochia scoparia* L. Biol. Pharm. Bull. 20(11) 1165-1170

Maurice, D. and D. Billett. 1991. Herbicide resistance. Agri-fax (Edmonton, Alberta) 640-7: 4

McMaster, G. and W. Wilhelm. 1997. Growing degree-days: One equation, two interpretations. Agricultural and Forest Meteorology 87(4): 291-300

Mengistu, L. and C. Messersmith. 2002. Genetic diversity of kochia. Weed Science 50: 498-503

Mesbah, A., S. Miller, K. Fornstrom and D. Legg. 1994. Kochia (*Kochia scoparia*) and green foxtail (*Setaria viridis*) interference in sugarbeets (*Beta vulgaris).* Weed Technology 8: 754-759

Mickelson, J., A. Bussan, E. Davis, A. Hulting and W. Dyer. 2004. Postharvest kochia (*Kochia scoparia*) management with herbicides in small grains. Weed Technology 18: 426-431

Milchunas, D., W. Laurenroth and P. Chapman. 1992. Plant competition, abiotic, and long- and short-term effects of large herbivores on demography of opportunistic species in a semiarid grassland. Oecologia 92: 520-531

Miller, S. 1986. Evaluation of post harvest herbicide treatments for weed control in fallow. Research Progress Report of the Western Society of Weed Science. P 287

Mishra, S., S. Misra and R. Misra. 2002. Occurrence of root-knot nematode infestation in *Kochia.* Journal of Ornamental Horticulture, New Series **5**(2): 62

Moore, T., R. Stevens and E. McArthur. 1982. Preliminary study of some insects associated with rangeland shrubs with emphasis on Kochia prostrata. Journal of Range Management. 35(1): 128-130

Morrison, I. and M. Devine. 1994. Herbicide resistance in the Canadian prairie provinces: Five years after the fact. Phytoprotection 75(suppl.): 5-16

Morton, C. and F. Manthey. 1995. North Dakota Kochia [*Kochia scoparia* (L.) Schrad.] Biotype Characteristics. Weed Sci. Soc. Am. Abstr. 35: 87

Mühlenbach, V. 1979. Contributions to the synanthropic (adventive) flora of the railroads in St. Louis, Missouri, U.S.A. Annals of the Missouri Botanical Garden 66(1): 1-108

Mulugeta, D. 1991. Management, inheritance, and gene flow resistance to chlorsulfuron in *Kochia scoparia* L. (Schrad). M.S. thesis Montana State University. Bozeman MT.

Mulugeta, D., B. Maxwell, P. Fay and W. Dyer. 1994. Kochia (*Kochia scoparia*) pollen dispersion, viability and germination. Weed Science 42: 548-552

Mulugeta, D., P. Fay, W. Dyer and L. Talbert. 1991. Inheritance of resistance to the sulfonylurea herbicides in *Kochia scoparia* L. (Schrad). Proc. West. Soc. Weed. Sci. 44: 81

Nandula, V. and F. Manthey. 2002. Response of kochia (*Kochia scoparia*) inbreds to 2,4-D and dicamba. Weed Technology. 16: 50-54

Norwood, C. 1982a. Extended weed control using chlorsulfuron. In North Central Weed Cont. Conf. Research Report – V.39. Page 79

Norwood, C. 1982b. Fallow weed control with fall and spring applied herbicides. In North Central Weed Cont. Conf. Research Report – V.39. Page 81

Nussbaum, E., A. Wiese, D. Crutchfield, E. Chenault and D. Lavake. 1985. The effect of temperature and rainfall on emergence and growth of eight weeds. Weed Sci. 33: 165-170

Nussbaum, E., A. Wiese, D. Crutchfield, E. Chenault, D. Lavake and J. Green. 1983. Production and water use efficiency of weeds. Proceedings, Southern Weed Science Society, 36th annual meeting: 146

Olagbemiro, T., M. Birkett, A. Mordue and J. Pickett. 1999. Production of (5*R*,6*S*)-6-acetoxy-5-hexadecanolide, the mosquito oviposition pheromone, from the seed oil of the summer cypress plant, *Kochia scoparia* (Chenopodiaceae). J. Agric. Food Chem 47: 3411-3415

Olagbemiro, T., M. Birkett, A. Mordue and J. Pickett. 2004. Laboratory an field responses of the mosquito, *Culex quinquefasciatus*, to plant-derived *Culex* spp. Oviposition pheromone and the oviposition cue skatole. Journal of Chemical Ecology 30(5): 965-976

Olfert, O. 1990. Resistance of *Kochia scoparia* to feeding damage by grasshoppers (Orthoptera: Acrididae). Journal of Economic Entomology 83(6): 2421-2426

Panetta, F. and R. Lawes. 2005. Evaluation of weed eradication programs: the delimitation of extent. Diversity and Distributions 11: 435-442

Perkovich, B., T. Anderson, E. Kruger and J. Coats. 1996. Enhanced mineralization of [^{14}C] atrazine in *Kochia scoparia* rhizospheric soil from a pesticide-contaminated site. Pestic. Sci. 46: 391-396

Phillips, W.M. and J.L. Launchbaugh. 1958. Preliminary studies of the root system of *Kochia scoparia* at Hays, Kansas. Weeds 6:(1)19-23

Primiani, M. M., J. C. Cotterman, and L. L. Saari. 1990 Resistance of kochia (*Kochia scoparia*) to sulfonylurea and imidazolinone herbicides. Weed Technol. 4:169-172

Rankins, D. and G. Smith. 1991. Nutritional and toxicological evaluations of kochia hay (*Kochia scoparia*) fed to lambs. J. Anim. Sci. 69: 2925-2931

Rankins, D., G. Smith and D. Hallford. 1991a. Altered metabolic hormones, impaired nitrogen retention, and hepatoxicosis in lambs fed *Kochia scoparia* hay. J. Anim. Sci. 69: 2932-2940

Rankins, D., G. Smith and D. Hallford. 1991b. Serum constituents and metabolic hormones in sheep and cattle fed *Kochia scoparia* hay. J. Anim. Sci. 69: 2941-2946

Rankins, D., G. Smith and D. Hallford. 1991c. Effects of metoclopramide on steers fed *Kochia scoparia* hay. J. Anim. Sci. 69: 3699-3705

Reimer, A. and C. Shaykewich 1980. Estimation of Manitoba soil temperatures from atmospheric meterological measurements. Canadian Journal of Soil Science 60: 299-309

Robson, D., J. Knight, R. Farrell and J. Germida. 2004. Natural revegetation of hydrocarbon-contaminated soil in semi-arid grasslands. Can. J. Bot. 82: 22-30

Saari, L., J. Cotterman and M. Primiani. 1990. Mechanism of sulfonylurea herbicide resistance in the broadleaf weed, *Kochia scoparia*. Plant Physiol. 93:55-61

Salava, J., D. Chodová and J. Mikulka. 2004. Molecular basis of acetolactate synthase-inhibitor resistance in Czech biotypes of kochia. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz. Sp. Iss. 19: 915-919

Salhoff, C. R. and A. R. Martin. 1980. Kochia biotype competition and response to herbicides. Proc. NCWCC. 35:86

Schwartz, M. and R. Foottit. 1992. *Lygus* species on oilseed rape, mustard, and weeds: a survey across the prairie provinces of Canada. The Canadian Entomologist 124: 151-158

Schweizer, E. 1973. Control of kochia in sugarbeets with 3'-hydroxypropionanilide isopropylcarbamate. Weed Science 21(2): 110-114

Seedfeldt, S. J. Jensen and E. Fuerst. 1995. Log-Logistic analysis of herbicide dose-response relationships. Weed Technology 9: 218-227

Sherrod, L. 1971. Nutritive value of *Kochia scoparia* I. Yield and chemical composition at three stages of maturity. Agronomy Journal 63: 343-344

Shin, K., Y. Kim, W. Park, I. Kang, J. Ha, J. Choi, H. Park and K. Lee. 2004. Inhibition of methanol extract from the fruits of *Kochia scoparia* on lipopolysaccharide-induced nitric oxide, prostaglandin E2, and tumor necrosis factor-α production from murine macrophage RAW 264.7 cells. Biol. Pharm. Bull. 27(4): 538-543

Singh, H. D. Batish and R. Kohli. 2003. Allelopathic interactions and allelochemicals: new possibilities for sustainable weed management. Critical Reviews in Plant Science 22(3&4): 239-311

Sivakumaran, K., D. Mulugeta, S. A. Gerhardt, P. K. Fay, and W. E. Dyer. 1991. Characteristics of diverse sulfonylurea-resistant and susceptible *Kochia scoparia* L. accessions. Proc. West. Soc. Weed Sci. 44:82

Sprowls, R. 1981. Problems observed in horses, cattle and sheep grazing kochia. Amer. Assn. Veterinary Laboratory Diagnosticians. 24th Annual Proceedings: 397-406

Stallings, G. D. Thill, C. Mallory-Smith and B. Shafi. 1995. Pollen-mediated gene flow of sulfonylurea-resistant kochia (*Kochia scoparia*). Weed Science 43: 95-102

Stepphun, H. and K. Wall. 1993. *Kochia scoparia* emergence from saline soil under various water regimes. Journal of Range Management. 46 (6): 533-538

Stepphun, H., E. Coxworth, J. Kernan, D. Green and J. Knipfel. 1994. Response of *Kochia scoparia* to nitrogen fertilization on a saline soil. Canadian Journal of Soil Science. 74: 267-275

Stevens, O. 1932. The number and weight of seeds produced by weeds. Am. J. Bot. 19: 784-794

Stevens, O. 1946. Introduction and spread of weeds and other plants in North Dakota. North Dakota Agricultural Experiment Station Bulletin no. 339

Stevens, O. 1960. North Dakota weed development notes. North Dakota Red. Rep. No. 1: P 8

Steyermark, A. 1962. Flora of Missouri. Iowa State University Press. Ames, Iowa. Pp 602-3

Subramanian, M. V., V. Loney-Gallant, J. M. Dias, and L. C. Mireles. 1991. Acctolactate synthase inhibiting herbicides bind to the regulatory site. Plant Physiol. 96:310-313

Thill, D., C. Mallory-Smith, L. Saari, J. Cotterman, M. Primiani and J. Saladini. 1991. Sulfonylurea herbicide resistant weeds: Discovery, distribution, biology, mechanism, and management. Pages 115-128 in Herbicide Resistance in Weeds and Crops, J. Caseley, G. Cussans, and R. Atkin, eds. Butterworth-Heinemann, Ltd., Oxford, U. K.

Thistled, J., C. Hibbs, H. Kiesling, R. Kirksey, A. Meinenger, J. Tompkins. 1986. Toxicosis in cattle grazing irrigated Kochia. Proceedings of the 14th World Congress on Diseases of Cattle,

Thompson, C. 1993. Biology of Sulfonylurea Herbicide-Resistant and –Susceptible Kochia (*Kochia scoparia*). Ph.D. Dissertation. University of Idaho. Moscow, ID

Thompson, C., D. Thill and B. Shafi. 1994. Germination characteristics of sulfonylurea-resistant and –susceptible kochia (*Kochia scoparia*). Weed Science 42: 50-56

Tonks, D. and C. Eberlein. 2001. Postemergence weed control with rimsulfuron and various adjuvants in potato (*Solanum tuberosum*). Weed Technology 15: 613-616

Vinton, M. and I. Burke. 1995. Interactions between individual plant species and soil nutrient status in shortgrass steppe. Ecology 76: 1116-1133

Wali, M. 1999. Ecological succession and rehabilitation of disturbed terrestrial ecosystems. Plant and Soil 213: 195-220

Wali, M. and P. Freedman. 1973. Ecology of some mined areas in North Dakota. In Some Environmental Aspects of Strip-Mining in North Dakota. Ed. M. Wali. Educ. Ser. 5 ND Geo. Surv. P. 5-47

Weatherspoon, D. and E. Schweitzer. 1969. Competition between kochia and sugarbeets. Weed Sci. 17: 464-467

Weatherspoon, D. and E. Schweizer. 1971. Competition between sugarbeets and five densities of kochia. Weed Science 19: 125-128

Weiner, J. and L. Fishman. 1994. Competition and allometry in *Kochia scoparia.* Annals of Botany 73: 263-271

Weiner, J., D. Wright and S. Castro. 1990. Symmetry of below-ground competition between *Kochia scoparia* individuals. Oikos 79: 85-91

Whitney, H., O. Sayanova, J. Pickett, J. Napier. 2004. Isolation and expression pattern of two putative acyl-ACP desaturase cDNAs from *Bassia scoparia.* Journal of Experimental Botany 55(397): 787-789

Whitney, H., O. Sayanova, M. Lewis, J. Pickett and J. Napier. 2000. Isolation of two putative acyl-acyl protein desaturase enzymes from *Kochia scoparia.* International Symposium on Plant Lipids, 14th. Biochemical Society, Cardiff University: 623-624

Wicks, G. 1986. Triazine resistant kochia in corn. Proceedings, North Central Weed Control Conference 41: 79

Wicks, G., G. Mahnken and G. Hanson. 1997. Weed control and crop injury in ecofallow corn (*Zea mays*) using imazethapyr. Weed Technology 11: 748-754

Wicks, G., R. Klien and C. Fenster. 1984. Survey of western Nebraska wheat farmers on herbicide usage. North Cent. Weed Cont. Conf. 39: 140-141

Wiese, A. 1968. Rate of weed root elongation. Weed Science 16: 11-13

Wiese, A. and C. Vanidiver. 1970. Soil moisture effects on competitive ability of weeds. Weed Science 18: 518-519

Wiley, R., E. Schweizer and E. Ruppel. 1985. Interaction of kochia (*Kochia scoparia*) and *Rhizopus* sp. On sugarbeet (*Beta vulgaris*) germination. Weed Science 33: 275-279

Williams, M. 1932. The development of the embryo of *Kochia scoparia*. Bulletin of the Torrey Botanical Club 59(7): 391-400

Wolf, R., S. Clay and L. Wrage. 2000. Herbicide strategies for managing kochia (*Kochia scoparia*) resistant to ALS-inhibiting herbicides in wheat (*Triticum aestivum*) and soybean (*Glycine max*). Weed Technology 14: 268-273

Zorner, P., R. Zimdahl and E. Schweizer. 1984. Effect of depth and duration of seed burial on kochia (*Kochia scoparia*). Weed Science 32: 602-607