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

BY

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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. Steyernark (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