# *KOCHIA SCOPARIA* RESPONSE TO DICAMBA AND EFFECTIVE MANAGEMENT PRACTICES FOR SOYBEANS

by

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# Abstract

Kochia [*Kochia scoparia* (L.) Schrad.] is an invasive weed that is common in cropland, pastures and rangeland, rights-of-way, and disturbed areas throughout the western and northern United States and southern Canada. This species aggressively competes with crops, especially in no-till cropping systems, and has evolved resistance to multiple herbicide modes of action. Thus, it has become highly problematic and is difficult to manage. Roundup Ready 2 Xtend™ (Monsanto Co.) soybeans with resistance to dicamba herbicide are expected to be commercialized in 2016, and will offer a new management practice for controlling kochia and other susceptible broadleaf weeds in soybeans. Objectives of this research were to (1) determine whether greenhouse-grown plants from various kochia populations from the central Great Plains differ in susceptibility to postemergence-applied dicamba; (2) compare preemergence versus postemergence control of kochia with dicamba in a greenhouse environment; and (3) investigate various management practices in a systems approach to control kochia in soybeans. $GR_{50}$ values (dose required to reduce plant biomass by 50%) indicated at least an 8-fold difference among 11 kochia populations in susceptibility to postemergence-applied dicamba. Additionally, dicamba at 210 g $ha^{-1}$ applied preemergence caused 95, 88 and 84% mortality and reduced plant biomass (fresh wt.) of the most susceptible and two least susceptible kochia populations from a previous dicamba dose-response study by 99, 68 and 60%, respectively. In comparison, <10% of kochia plants from those populations died and biomass was reduced only 39, 15 and 7%, respectively, when dicamba was applied postemergence. Field experiments demonstrated that preplant conventional tillage followed by nine different in-crop herbicide treatments, and shallow early-spring tillage followed by preplant herbicides (reduced-till) along with the same in-crop herbicides provided greater kochia control than three no-till systems involving early preplant

herbicide treatments followed by the same in-crop herbicides. However, despite greater kochia control with the tillage-based systems in 2013, soybean yields were less compared to the three no-till systems. Consequently, in some years the most effective kochia control practices may not result in the highest soybean yields.

# Table of Contents

# List of Figures

# List of Tables

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# Chapter 1 - Susceptibility of Multiple Kochia Populations to Dicamba

## Abstract

Kochia [*Kochia scoparia* (L.) Schrad.] has become highly problematic throughout the Great Plains of North America as a result of evolving resistance to multiple herbicide mechanisms of action. Commercialization of soybeans and cotton with resistance to dicamba is anticipated in 2016, pending final regulatory approval. Widespread adoption of this technology likely will increase dicamba use and selection pressure on weed populations. The objective of this research was to determine whether various kochia populations from the central Great Plains differ in susceptibility to postemergence-applied dicamba. Greenhouse-grown plants from 34 populations were sprayed with 420 g ae ha$^{-1}$ of dicamba and the populations were categorized from least to most susceptible based on aboveground biomass and plant mortality ratings 5 wk after treatment (WAT). Eleven populations representing the least susceptible, moderately susceptible, and most susceptible populations from the initial screening were selected for a dicamba dose-response experiment. Visual growth reduction estimates, plant mortality, and aboveground biomass (both fresh and dry matter) were recorded 4 WAT. Rankings of the populations based on fresh and dry biomass were similar and $GR_{50}$ values (doses required to reduce biomass by 50%) indicated at least an 8-fold difference among the populations in susceptibility to dicamba applied postemergence. The $GR_{50}$ dose for the least susceptible population was approximately 820 g ae ha$^{-1}$ and plant mortality of that population was less than 20% at 2240 g ae ha$^{-1}$. Evidence of differential susceptibility to dicamba in the kochia

populations tested suggests the need for strong stewardship recommendations for dicamba use and diverse management practices to prevent further evolution of kochia resistance to dicamba.

# Introduction

Kochia is an annual broadleaf weed with early season emergence due to its ability to germinate at low soil temperatures (Friesen et al. 2009). The species native to Eurasia, was introduced to North America as an ornamental, and has naturalized to arid and semiarid environments throughout the Great Plains and Canadian Prairies. Kochia holds economic importance as a result of its impact on crop production systems. It can self-pollinated but produces protogynous flowers where the stigmas usually emerge approximately 1 wk before anthesis, which encourages outcrossing (Friesen et al. 2009). Flowering is initiated when the light period is less than a critical period ranging from 13 to 15 h and generally occurs 8 to 10 wk after emergence (Friesen et al. 2009). If exposed to a short photoperiod of less than 12 h of light, kochia will initiate flowering no matter its growth stage (Eberlein and Fore 1984). A fully-mature kochia plant develops an abscission at the base of the plant after senescence and the architecture of the plant allows it to tumble with the prevailing winds. This key morphological feature is a mechanism for dispersing seed over long distances, which contributes to its ability to persist from one season to the next. Seed production is highly variable, often ranging from 15,000 to more than 150,000 seeds per plant depending upon intra- and interspecific competition (Kumar and Jha 2015; Mulugeta 1991; Stallings et al. 1995). However, Esser (2014) reported kochia plants grown without competition produced >330,000 seeds per plant. Seed viability in the soil is relatively short-lived, 1 to 2 years (Friesen et al. 2009; Schwinghamer and Van Acker 2008). Currently, kochia biotypes have been documented to be resistant to ALS-inhibitors (chlorsulfuron), EPSPS inhibitors (glyphosate), PSII inhibitors (atrazine), and auxinic herbicides (dicamba) (Heap 2015).

Dicamba (3, 6-dichloro-2-methoxybenzoic acid) is an auxinic herbicide used primarily for broadleaf weed control. It is absorbed through roots, shoots, and foliage and translocation occurs systemically through the xylem and phloem to meristematic cells. Dicamba is classified as an auxinic herbicide because of the way it mimics the action of the natural plant hormone auxin. Symptoms of susceptible plants include epinasty and stem tissue proliferation, evidence that plant death may result from uncontrolled cell division. The specific mechanism of action is unknown, though binding to indole-3-acetic acid (IAA) receptor(s) is likely due to a wide array of genetic and physiological responses (Cranston et al. 2001). Thirty-two species are known to have developed resistance to auxinic herbicides, a relatively low number considering their extensive use over the past 70 years (Heap 2015). There have been reports of kochia biotypes resistant to dicamba in Idaho, Kansas, Montana, Nebraska, and North Dakota (Heap 2015). The mechanism of dicamba resistance in kochia has not been determined but studies have shown little or no differences in dicamba absorption, translocation, or metabolism between resistant and susceptible biotypes (Cranston et al. 2001; Ou et al. 2015). Though resistance to auxinic herbicides is slow to develop relative to other herbicide modes of action, it is extremely important to incorporate preventative steps to preserve the effectiveness of herbicides.

Recent approval of Roundup Ready 2 Xtend™ (Monsanto Co.) soybeans with resistance to dicamba is expected to be available in 2016. Development of dicamba resistant technology in crops was accomplished by genetically engineering a bacterial gene, *DMO* (dicamba monooxygenase), that encodes a Rieske non-heme monooxygenase capable of inactivating dicamba when expressed from either the nuclear genome or chloroplast genome of transgenic plants (Behrens et al. 2007). In transgenic plants, the *DMO* enzyme acts to destroy the herbicidal activity of dicamba before toxic levels are achieved. The formulated dicamba to be used in Roundup Ready 2 Xtend™ soybeans is pending regulatory approval; expected in the near future. Widespread adoption of the technology is likely, consequently leading to increased use of dicamba and exerting greater selection pressure on susceptible weed species. Increased selection pressure could cause the possible evolution of dicamba-resistant kochia, as demonstrated following widespread use of sulfonylurea and glyphosate herbicides (Powles 2008). Heavy selection pressure results from herbicides with low soil activity applied repeatedly or from highly effective herbicides with long soil activity (Beckie et al. 2011). To prevent the loss in efficacy of dicamba it is essential to develop baseline profiles of kochia susceptibility to help develop management strategies. The objective of this research was to determine the level of susceptibility to dicamba in multiple kochia populations via a dose-response experiment.

## Materials and Methods

Kochia seed was collected in the fall of 2012 from 34 locations throughout the Great Plains that included western Kansas (29), the Oklahoma Panhandle (3), and South Dakota (2) (Table 1.1). Seed collected from each site in Kansas was a composite of 10-20 mature plants hand-harvested from crop fields with unknown cropping and herbicide usage history. The Oklahoma and South Dakota seed collections were composites of fewer plants but harvested using the same method from non-cropland sites or fields with unknown cropping and herbicide usage history. After thrashing and cleaning, all composite samples were placed in a -18 C freezer to preserve viability.

### *Kochia Population Response to Dicamba Experiment*

Plants from seed of all 34 populations were grown in the Weed Science Greenhouse at Kansas State University in Manhattan, KS in April 2013 and April 2014, where greenhouse conditions were maintained at 25/20 C day/night with 15 h photoperiod. Natural sunlight was supplemented with 250 µmol $m^{-2}$ $s^{-1}$ illumination from sodium vapor lamps when natural sunlight was <750 µmol $m^{-2}$ $s^{-1}$. Seeds of each population were sown in a single 35x12x6 cm plastic tray filled with 565 g of commercial potting mix (Miracle-Gro® Moisture Control® Potting Mix 0.21-0.11-0.16). No additional fertilizer was added and trays were watered from above twice daily using a hand-wand. Approximately 5 days after seedling emergence, the trays were hand-thinned to 12 plants per tray. Once 8-12 cm tall, plants were sprayed with formulated dicamba (Clarity®, BASF) at a rate of 420 g ae $ha^{-1}$ without added adjuvant using a bench-type sprayer chamber calibrated to deliver 187 L $ha^{-1}$ at 220 kPa and 3 km $hr^{-1}$. At 5 wk after treatment (WAT), plant mortality was determined by counting plants, control was estimated visually, and dry aboveground biomass was measured by counting and cutting plants at soil level, placing individual plants in paper bags and drying in an oven at 60 C for 72 h. The experiment was repeated in 2014 and the data was combined to categorize population response to dicamba into most susceptible, moderately susceptible and least susceptible groups.

### *Dicamba Dose-Response Experiment*

Based on the initial assessment of all 34 populations, 11 populations were selected for a dicamba dose-response experiment conducted in the Weed Science Greenhouse at Kansas State University Agricultural Research Center at Hays, KS. Populations were selected based on susceptibility category (most susceptible 3, moderately susceptible 3, and least susceptible 5), county of origin, and seed germination estimates (Figure 1.1, 1.2 and Table 1.1). Seed was planted using a Blackmore Can-Duit Seeder in 4.5x2.3x2.3 cm pots containing 4.7 g of the same commercial potting mix as in the previous experiment. Pots were initially sub-irrigated to achieve full water capacity, then watered from above as needed with a hand-wand to maintain a moist surface. Greenhouse conditions were 30/20 C day/night with 15 h photoperiod. Natural sunlight was supplemented with 250 µmol $m^{-2}$ $s^{-1}$ illumination from sodium vapor lamps for 2 h in the morning and evening. Seedlings 1-3 cm tall were transplanted into sub-irrigated 12x10x10 cm square plastic pots containing 220 g of the same commercial potting mix. After transplanting, plants were watered from above using a hand-wand. No supplemental fertilizer was added. Once 8-15 cm tall, plants were sprayed with dicamba, without added adjuvant, at doses of 0, 70, 140, 280, 560, 1120 and 2240 g ae $ha^{-1}$ using a bench-type spray chamber delivering 77 L $ha^{-1}$ at 207 kPa and 4.8 km $hr^{-1}$. Four WAT plant mortality was visually determined, visual growth reduction estimates were made based on percentage of control ranging from 0 to 100, and fresh and dry biomass was measured by harvesting and weighing aboveground plant material before and after drying in an oven at 60 C for 72 h. The experiment was a completely randomized design with treatments replicated six times. The experiment was conducted in April 2014 and repeated in July 2014.

Data analysis was performed in R (v3.1.1) using a three-parameter non-linear log-logistic model (Equation 1.1) wherein all data showed good fit allowing for data to be combined. The relationship between herbicide dose and aboveground biomass was defined as

**Equation 1.1**

$$f(x) = 0 + \frac{d - 0}{1 + \exp\big(b(\log(x) - \log(e))\big)}$$

where f (x) is aboveground biomass as a percentage of the control, d is the response of the upper limit, b represents the relative slope around e, x denotes herbicide dose, e is the dicamba dose causing a 50% response, ($GR_{50}$) and the response of the lower limit was set equal to 0.

## Results and Discussion

### *Kochia Population Response to Dicamba Experiment*

Plant dry weights at 5 WAT for the 34 populations treated with 420 g $ha^{-1}$ of dicamba ranged from an average of 0.25 to 2.04 g $plant^{-1}$. The most susceptible and moderately susceptible categories collectively included 23 of the 34 populations with dry weights of less than 1 g $plant^{-1}$. Plant dry weights of the other 11 populations ranged from approximately 1 to 2 g $plant^{-1}$, placing them in the least susceptible category (Figure 1.1). Plant mortality for those 11 populations was less than 50%, whereas plant mortality of the other 23 populations ranged from 50 to 96% (Figure 1.2). Distribution of the populations into least susceptible, moderately susceptible, and most susceptible categories for mortality are shown in Figure 1.2.

### *Dicamba Dose-Response Experiment*

Fresh weight aboveground biomass as a percentage of the control indicated $GR_{50}$ values ranged from 820 g $ha^{-1}$ for the least susceptible population (227) to 102 g $ha^{-1}$ for the most susceptible population (251) (Table 1.2), representing at least an 8-fold difference among the populations (Figure 1.3). In comparison, dry weight aboveground biomass as a percentage of the control ranged from 57 g $ha^{-1}$ for the most susceptible population (251) to 532 g $ha^{-1}$ for the least susceptible population (227), representing at least a 9-fold difference among the populations (Table 1.2). The fresh and dry biomass illustrated marginally different results though differences among populations remained reasonably large. The range in differences are likely due to the area in which the populations were collected. Origin of population 227, having the highest $GR_{50}$ value of 532 g $ha^{-1}$, is an area in southwestern Kansas where kochia is highly problematic and where dicamba has been commonly used for weed management for many years. Though herbicide use history is not known, it is reasonable to assume extensive use of dicamba in prior years. Dicamba field rates commonly range from 70 to 280 g $ha^{-1}$, which in this experiment proved inadequate to achieve $GR_{50}$ for multiple populations. At 2240 g $ha^{-1}$, less than 20% mortality was observed for the least susceptible population (227), whereas 100% mortality was achieved for the most susceptible population (251) indicating that the populations were segregating for resistance (Figure 1.4). Visual growth reduction estimates were calculated for each treatment and results indicated less than 90% control of all populations at 560 g $ha^{-1}$ (Figure 1.5).

This experiment determined there was a wide range of susceptibility to postemergence dicamba among the 11 populations tested, elucidating the fact that continued evolution of dicamba resistance in kochia is highly likely without proper herbicide stewardship. In order to prevent further evolution, there is need to implement more diversified management plans. The key factors to a more diversified management system include incorporating herbicides with different or multiple modes of action, utilizing preemergence herbicides, limiting dicamba use as a stand-alone herbicide to control kochia, and using tillage, if necessary, to prevent seed soil bank renewal. To preserve the level of control required for herbicides to be economically effective in the future, procedures must be implemented to reduce the number and level of herbicide resistant weeds.

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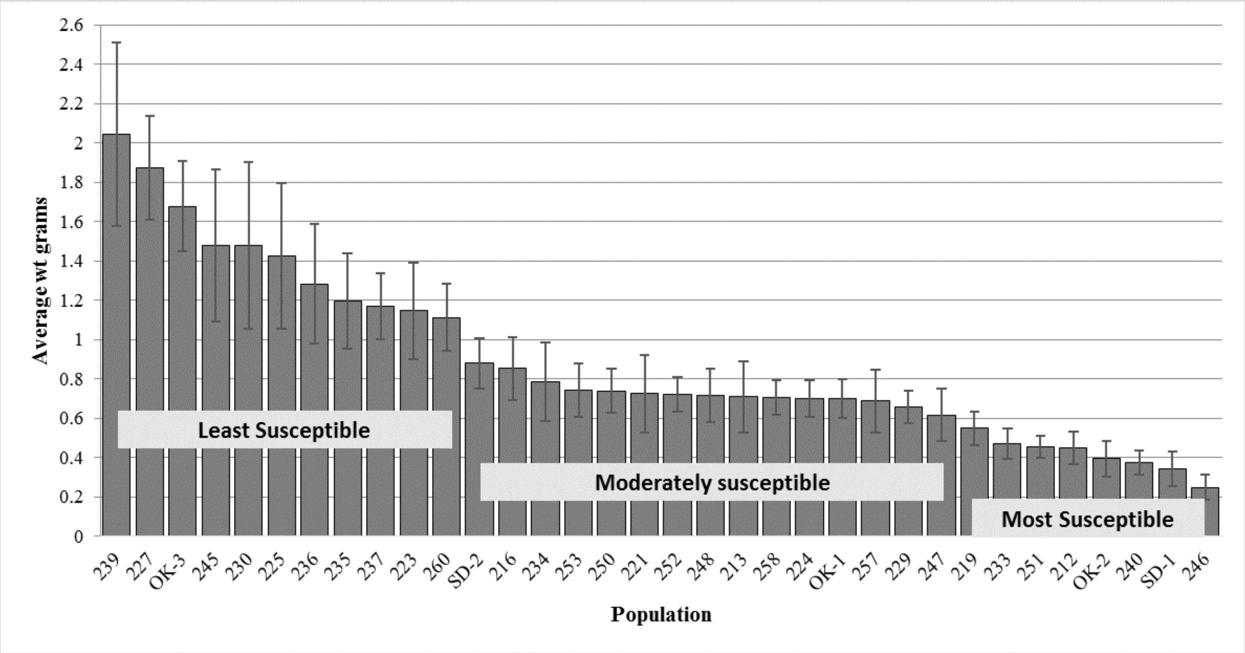

**Figure 1.1 Aboveground dry biomass per plant for 34 kochia populations in response to postemergence-applied dicamba at 420 g ha$^{-1}$.**

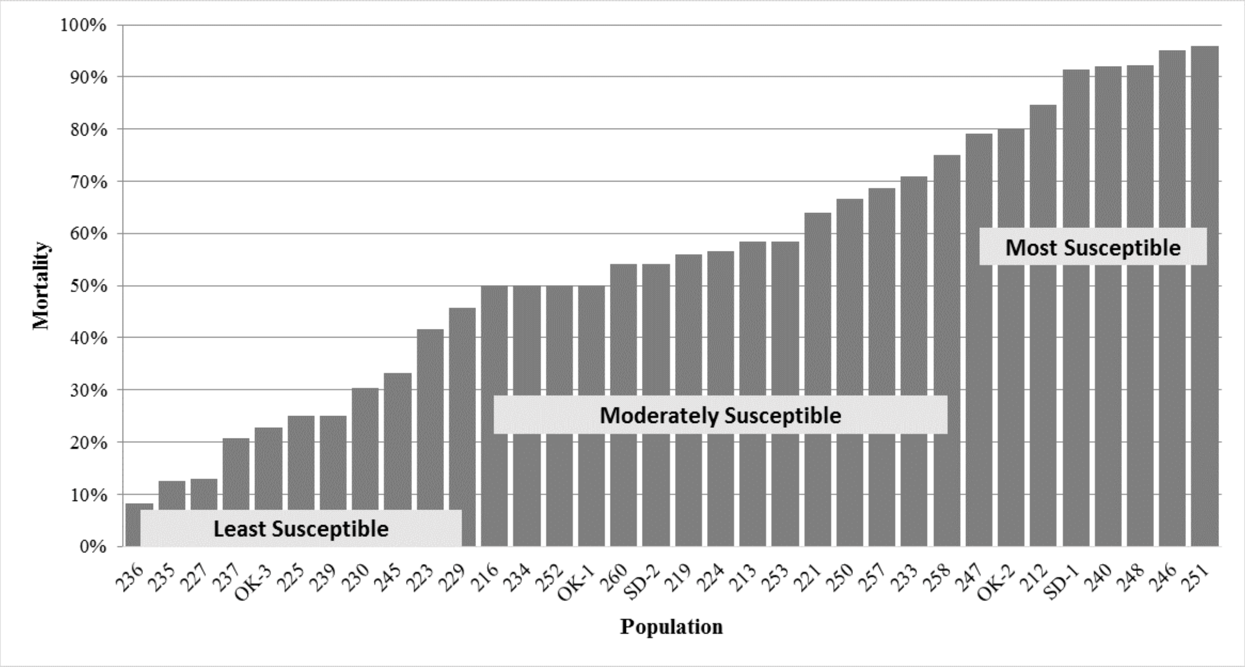

**Figure 1.2 Plant mortality of 34 kochia populations in response to postemergence-applied dicamba at 420 g ha$^{-1}$.**

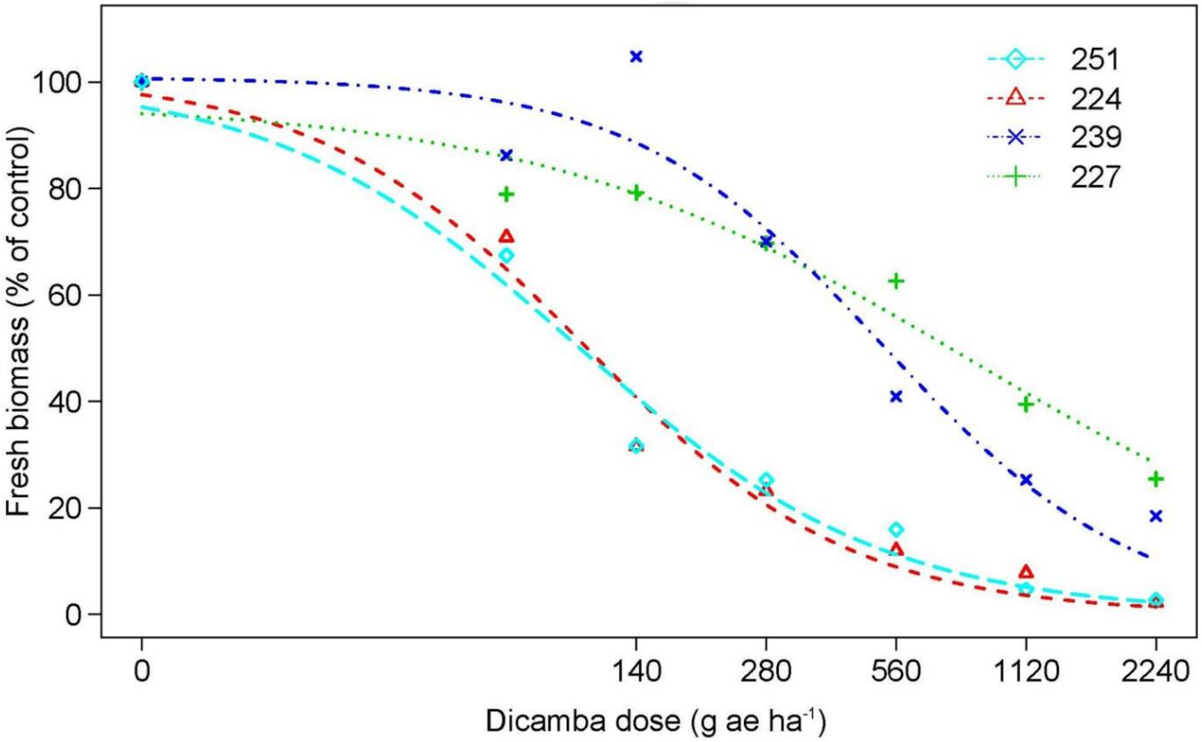

**Figure 1.3 Dicamba dose-response of four kochia populations as aboveground fresh biomass expressed as percent of control.**

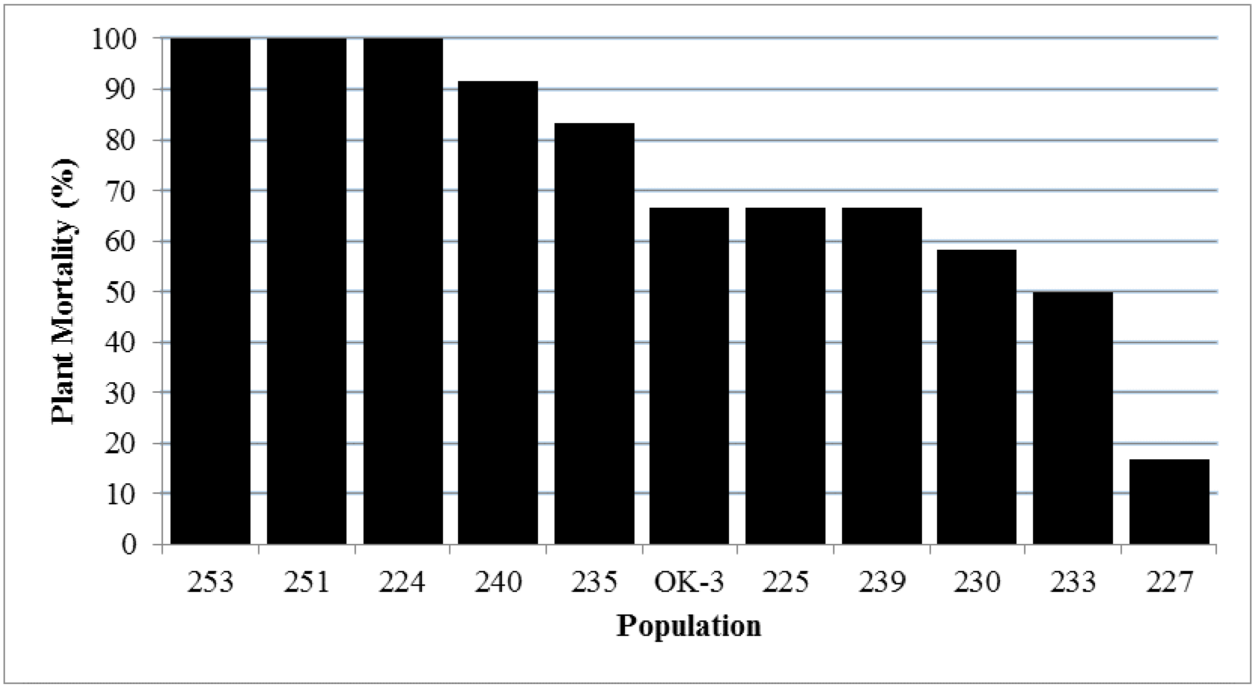

**Figure 1.4 Plant mortality of 11 kochia populations to postemergence-applied dicamba at 2240 g ha$^{-1}$.**

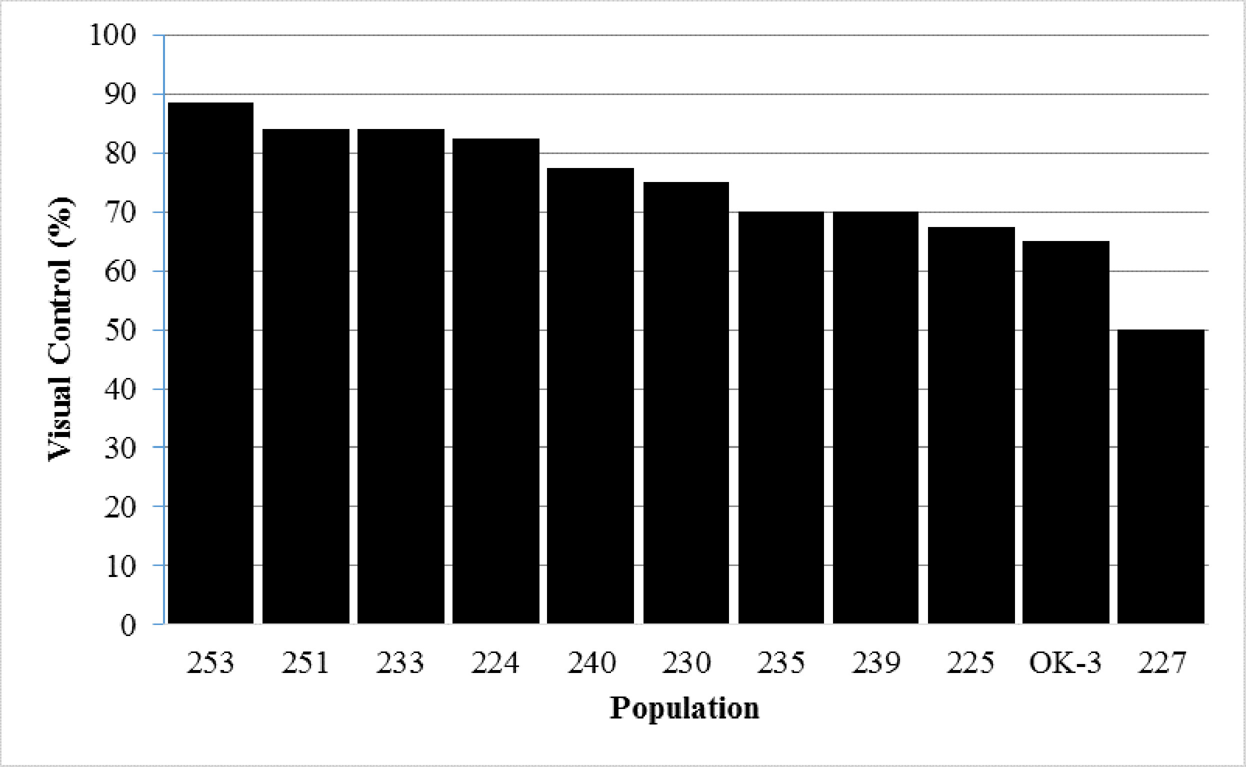

**Figure 1.5 Visual of control of 11 kochia populations with postemergence-applied dicamba at 560 g ha$^{-1}$.**

**Table 1.1 Populations listed by county and state of origin, GPS coordinates, and population identification number.**

| Location- County, State | GPS coordinates- Decimal degrees | | Population no. |
|---|---|---|---|
| Brookings, SD | 44.31765 | -96.84949 | SD-1 |
| Brookings, SD | 44.30289 | -96.92589 | SD-2 |
| Texas, OK | 36.80917 | -101.35222 | OK-1 |
| Texas, OK | 36.58974 | -101.59868 | OK-2 |
| Cimarron, OK | 36.85 | -102.22778 | OK-3 |
| Russell, KS | 38.8606 | -98.81682 | 212 |
| Barton, KS | 38.5068 | -98.8492 | 213 |
| Pawnee, KS | 37.99992 | -99.22053 | 216 |
| Pawnee, KS | 37.99582 | -99.2184 | 219 |
| Pawnee, KS | 37.99582 | -99.21838 | 221 |
| Decatur, KS | 39.92002 | -100.59547 | 223 |
| Rawlins, KS | 39.81738 | -101.33527 | 224 |
| Thomas, KS | 39.4669 | -100.98363 | 225 |
| Gray, KS | 37.91783 | -100.50075 | 227 |
| Haskell, KS | 37.4968 | -100.78138 | 229 |
| Stevens, KS | 37.34417 | -101.17578 | 230 |
| Logan, KS | 39.10241 | -101.03488 | 233 |
| Wallace, KS | 38.89318 | -101.79656 | 234 |
| Greeley, KS | 38.38432 | -101.78977 | 235 |
| Wichita, KS | 38.4809 | -101.41388 | 236 |
| Scott, KS | 38.48417 | -100.88888 | 237 |
| Lane, KS | 38.61 | -100.51512 | 239 |
| Ness, KS | 38.64025 | -99.778117 | 240 |
| Sheridan, KS | 39.16923 | -100.23905 | 245 |
| Ellis, KS | 38.94335 | -99.48083 | 246 |
| Phillips, KS | 39.68388 | -99.23903 | 247 |
| Osborne, KS | 39.54537 | -98.54327 | 248 |
| Russell, KS | 39.0522 | -98.51295 | 250 |
| Pratt, KS | 37.60052 | -98.64797 | 251 |
| Rice, KS | 38.39137 | -98.2052 | 252 |
| Russell, KS | 38.8121 | -98.79245 | 253 |
| Ness, KS | 38.33558 | -99.89812 | 257 |
| Ford, KS | 37.91337 | -99.89365 | 258 |
| Meade, KS | 37.28577 | -100.18552 | 260 |

**Table 1.2 Whole-plant dicamba dose-response of 11 kochia populations presented as dose required to achieve 50% reduction of fresh and dry aboveground biomass.**

| Susceptibility | Population | GR$_{50}$ (SE) Fresh Biomass | Population | GR$_{50}$ (SE) Dry Biomass |
|---|---|---|---|---|
| **Most** | 251 | 102 (23) | 251 | 57 (27) |
| ↓ | 224 | 106 (21) | 224 | 74 (28) |
|  | 240 | 130 (31) | 240 | 90 (33) |
|  | 253 | 155 (20) | 253 | 142 (26) |
|  | 233 | 174 (21) | 233 | 238 (56) |
|  | 230 | 208 (44) | 230 | 274 (76) |
|  | OK-3 | 400 (89) | 235 | 404 (108) |
|  | 235 | 461 (97) | 225 | 485 (152) |
|  | 225 | 467 (116) | 239 | 495 (107) |
|  | 239 | 532 (90) | OK-3 | 516 (151) |
| **Least** | 227 | 820 (268) | 227 | 532 (280) |

# Chapter 2 - Preemergence versus Postemergence Kochia Control with Dicamba

## Abstract

Since its introduction in 1967, dicamba has been used primarily for postemergence herbicidal control of annual and perennial broadleaf weeds. Recent developments have intensified interest in preemergence use of dicamba to control kochia [*Kochia scoparia* (L.) Schrad.], especially populations resistant to glyphosate. This greenhouse research compared the susceptibility of three kochia populations to dicamba applied preemergence versus postemergence. The three populations represented one of the most (251) and two of the least (235 and 227) susceptible populations from an earlier dose-response experiment that included several populations (Chapter 1). At 10 WAT-Pre, preemergence-applied dicamba at 210 g $ha^{-1}$ provided 95, 88 and 84% mortality of kochia populations 251, 235 and 227, respectively. Increasing dicamba dosage to 280 g $ha^{-1}$ resulted in slight increases in mortality in all three populations. In comparison, postemergence-applied dicamba at 210 g $ha^{-1}$ injured each population differently, but at 4 WAT-Post fewer than 10% of plants in any of the populations were dead. Differences in population mortality compared to untreated controls were not significant. Aboveground fresh weight biomass for the 210 g $ha^{-1}$ preemergence dicamba treatment was reduced by 99, 68 and 60% for populations 251, 235 and 227, respectively, compared to 39, 15 and 7% biomass reductions for the postemergence-applied dicamba treatment. The effectiveness of preemergence-applied dicamba observed in this experiment suggests that it can be used to effectively control susceptible kochia populations. A higher rate than used those tested would be required to achieve complete control of populations resistant to postemergence-applied dicamba.

# Introduction

Implementing appropriate and effective weed control practices are systematically reliant on the timing and duration of weed emergence (Dille et al. 2012). The adaptive characteristic of kochia to germinate in early spring prior to summer crop planting provides a distinct competitive advantage in cropping systems and enhances kochia's ability to persist from one season to the next. Early-season emergence provides kochia the ability to capture nutrients and extract soil moisture (often limited in semiarid and arid environments) without competition from crops. Studies have shown that kochia seedlings begin emerging at approximately 50 accumulative growing degree days (GDD) (Schwinghamer and Acker 2008). Dille et al. (2012) reported that kochia seedlings in Kansas emerged soon after March 15 in 2010 and 2011, though kochia has been observed emerging in the state as early as mid-February when conditions are favorable. Most emergence occurs in early season, then emergence slows but continues later into the growing season (Schwinghamer and Acker 2008). In the central Great Plains, 80% of seedlings emerged in early season, indicating the importance of incorporating an early weed control practice (Dille et al. 2012).

Dicamba was registered as a commercial herbicide in 1967 (Erickson et al. 2006). It is most commonly used as a foliar-applied herbicide, though it can remain active in the soil for an extended period to control susceptible species. Dicamba has a half-life of <14 d under conditions favoring rapid microbial metabolism, but it may persist longer in environments with low soil moisture and precipitation (Shaner 2014). Dicamba photodegradation occurs slowly, thus longevity of dicamba is influenced primarily by soil and other environmental factors. Dicamba is soluble in water and has a net negative charge, thus it is weakly adsorbed to soil colloids and is mobile in soil (Shaner 2014). However, adsorption was found to be marginally higher in soils with higher organic matter content (Burnside and Lavy 1966). Microbial degradation is the primary factor that affects dicamba persistence in soil (Fogarty and Tuovinen 1995; Smith 1974). Only three pure bacterial cultures (two *Pseudomonas* spp. and a *Moraxella* sp.) are known capable of degrading dicamba (Krueger 1989). Fogarty and Tuovinen (1995) reported optimal conditions for microbial degradation were 30 C at pH 6.5 to 7.0 by a pure culture of *Pseudomonas paucimobilis* and a consortium of bacteria from soil previously treated with dicamba.

Recent regulatory approval and anticipated launch of Roundup Ready 2 Xtend™ soybeans (Monsanto Co.) and pending regulatory approval of a new, less-volatile formulation of dicamba has raised questions on how the new technology should be utilized. The ability to apply dicamba in soybeans offers a new weed control tactic that needs to be fully investigated. The efficacy of dicamba applied preemergence versus postemergence for kochia control is a dynamic yet to be fully elucidated, but it could possibly be an effective management tactic to control kochia. This study was undertaken to investigate the response of three kochia populations to dicamba applied preemergence versus postemergence in greenhouse conditions.

## Materials and Methods

Kochia populations used in this study were selected from the dicamba dose-response experiment reported in Chapter 1. Populations selected included one of the most susceptible and two of the least susceptible to postemergence dicamba from Pratt (251), Greeley (235) and Gray (227) Counties in Kansas, respectively. The experiment was a completely randomized design with treatments replicated twelve times and repeated by location in the Weed Science Greenhouse at Kansas State University Agricultural Research Center at Hays, KS and the Weed Science Greenhouse at Kansas State University in Manhattan, KS. Greenhouse conditions for both locations were maintained at 25/20 C day/night with a 15 h photoperiod. Natural sunlight was supplemented with 250 μmol $m^{-2}$ $s^{-1}$ illumination from sodium vapor lamps. At the Hays greenhouse natural sunlight was supplemented from 7:00 am to 10:00 pm and at the Manhattan greenhouse it was supplemented until natural sunlight reached 750 μmol $m^{-2}$ $s^{-1}$. To achieve adequate density and similar number of plants across populations and replications, approximately 25 viable seeds were allocated for each pot. In December 2014, seed was planted in 12x10x10 cm square plastic pots (2,500 seeds per $m^2$) containing 1190 g of air-dried Roxbury silt loam soil collected from the Kansas State University Agricultural Research Center at Hays, KS (Table 2.1). The soil was sifted through a mesh sieve with 2.80 mm openings to remove large particles prior to use to achieve a consistent profile. After seeds were distributed by hand onto the soil surface of each pot, a thin layer (1-2 mm) of soil was sifted overtop using a mesh sieve with 2.00 mm openings to ensure good soil-to-seed contact. After planting, dicamba (Clarity®, BASF) at rates of 210 g $ha^{-1}$ and 280 g $ha^{-1}$, without added adjuvant was applied preemergence using a single moving nozzle in a bench-type spray chamber delivering 77 L $ha^{-1}$ at 207 kPa and 4.8 km $hr^{-1}$ at the Hays location and 187 L $ha^{-1}$ at 220 kPa and 3 km $hr^{-1}$ at the Manhattan location. Additional pots for postemergence treatments were sown on the same day but left untreated until targeted kochia growth stage. To avoid leaching dicamba, pots were watered (misted) twice daily using a hand-wand until the soil surface was wet. Eventually the entire soil profile was moist. At 1, 2, 3 and 10 wk after preemergence dicamba treatment (WAT-Pre), plants with live tissue in each pot were counted for the two preemergence treatments and untreated controls for each population. Plant counts determined mortality by comparing treated to untreated controls for each population. Approximately 6 wk after germination, when plant height ranged from 5-10 cm, dicamba at 210 g $ha^{-1}$ without adjuvant was applied to appropriate pots postemergence using the same sprayer calibrations as previously mentioned for each location. At 4 wk after postemergence treatment (4 WAT-Post), final plant counts were determined for all treatments and fresh and dry biomass (g) was measured by weighing all aboveground plant material in each pot before and after drying for 72 h in an oven at 60 C. Data were combined over locations for average number of plants per pot and plant weight per pot to determine plant mortality and biomass reduction differences between treatment means by comparing standard deviations.

## Results and Discussion

Plant mortality and biomass reduction of all three kochia populations were considerably greater when dicamba was applied preemergence compared to postemergence application. Plant counts at 1, 2, 3 and 10 WAT-Pre exhibited different responses in plants per pot in each population (Figures 2.1-2.4). Control (mortality) of each kochia population increased over time, as observed at each rating interval. Among the three populations exposed to preemergence-applied dicamba at 210 g $ha^{-1}$, population 251 was the most susceptible with 95% mortality compared to 88 and 84% mortality for populations 235 and 227, respectively, at 10 WAT-Pre (Figure 2.4); differences between populations 235 and 227 were not significantly different. Mortality of all three populations increased by 4 to 7% with increased dicamba dosage but comparative rankings remained the same (Figure 2.4).

Fewer than 10% of plants treated with dicamba postemergence had died at 4 WAT-Post when compared to number of live plants immediately before application (Figure 2.5). Differences between populations were not significant. Reductions in fresh and dry weight biomass at 4 WAT-Post were similar within populations, differing by $\leq$ 11% (Figures 2.6 and 2.7). The postemergence dicamba treatment reduced fresh and dry biomass of population 251 by 39 and 34%, respectively, compared to 14 and 16% reductions for population 235 and 7 and 8% reductions for population 227. The biomass differences between populations 235 and 227 were not significant, but both populations were more than twice as tolerant to postemergence-applied dicamba than was population 251. Furthermore, biomass reductions indicated substantial differences in kochia susceptibility between preemergence and postemergence applications of dicamba at 210 g ha$^{-1}$. Preemergence-applied dicamba reduced fresh kochia biomass by 99, 68 and 60% compared to reductions of 39, 14 and 7% for postemergence-applied dicamba, respectively, for populations 251, 235 and 227 (Figure 2.6). Except for population 251, fresh biomass production was reduced by at least 21% when preemergence-applied dicamba dosage was increased to 280 g ha$^{-1}$.

This experiment demonstrated that dicamba was considerably more effective in controlling kochia when applied preemergence versus postemergence and that effectiveness varied among the kochia populations tested. Greater effectiveness of preemergence-applied dicamba is perhaps a result of seedling plants absorbing more dicamba through roots and shoots than uptake of dicamba through foliage of emerged plants. Kochia population response to dicamba in terms of plant mortality and biomass reduction were consistent and indicated population 251 was more susceptible to both preemergence- and postemergence-applied dicamba than were populations 235 or 227, which responded similarly. These results also are consistent with results of the dicamba-response experiment reported in Chapter 1. Despite the greater effectiveness in controlling kochia with preemergence-applied dicamba, control of the two more tolerant populations was not complete. The implications are that preemergence-applied dicamba should only be used in conjunction with another herbicide mode of action to prevent increased selection pressure on kochia for evolved resistance to dicamba.

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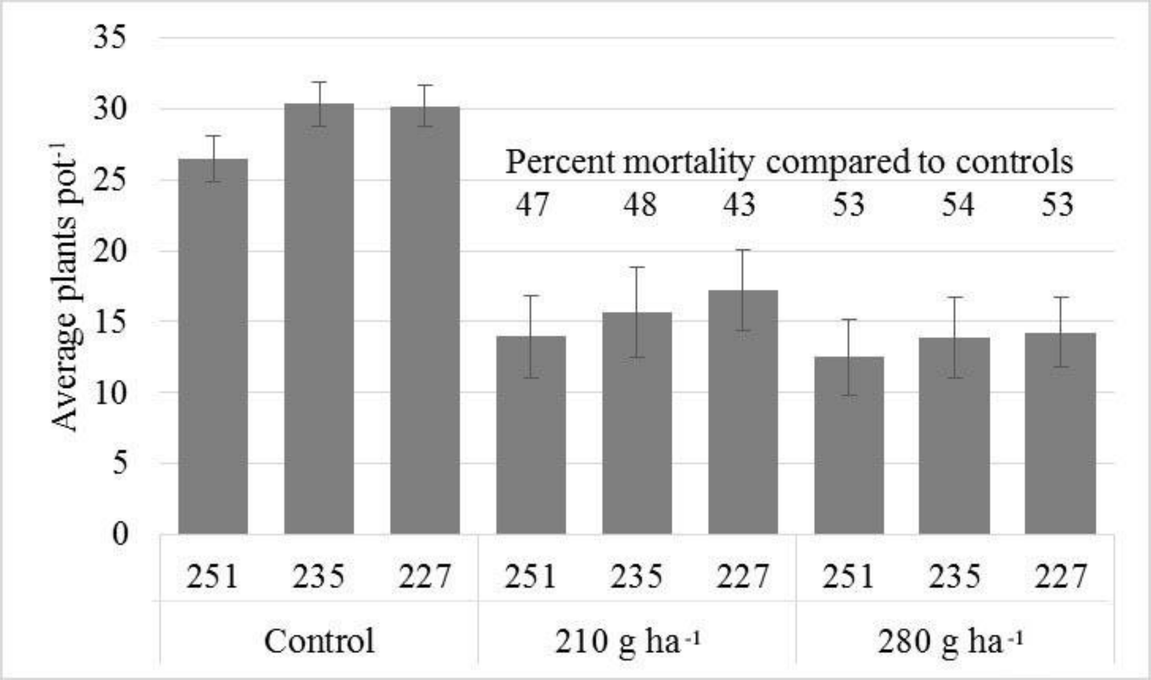

**Figure 2.1 Kochia mortality in response to preemergence-applied dicamba at 210 and 280 g ha$^{-1}$ at 1 WAT-Pre.**

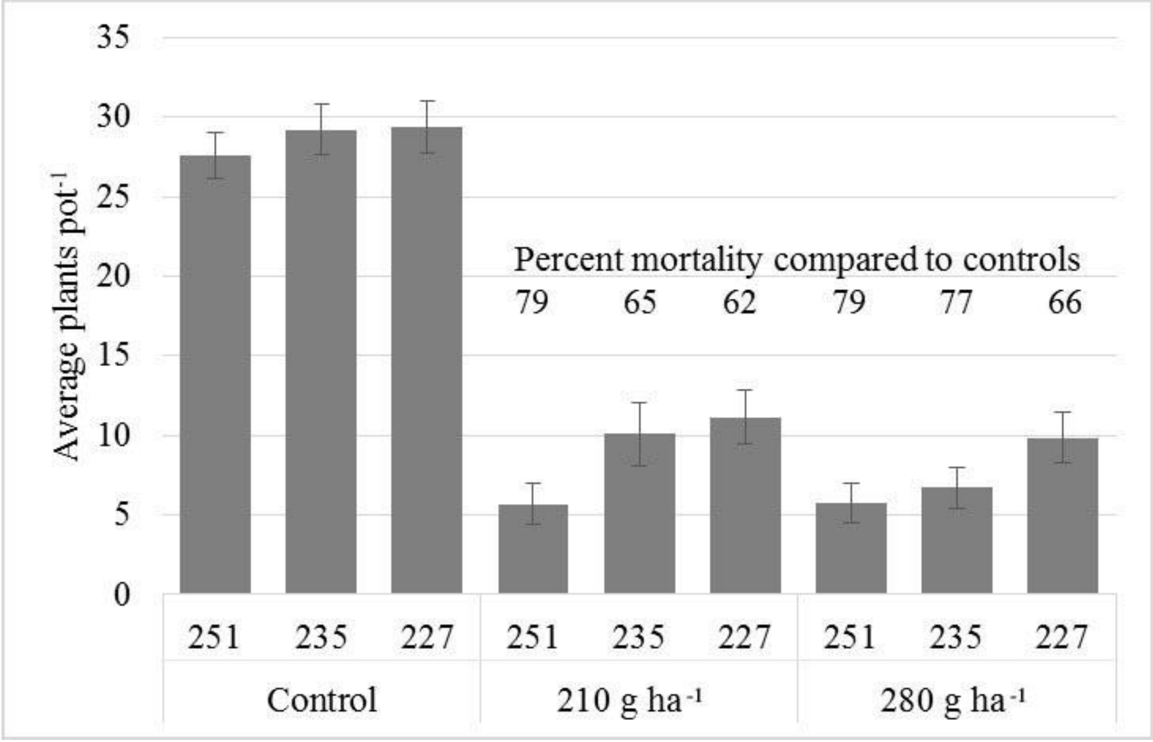

**Figure 2.2 Kochia mortality in response to preemergence-applied dicamba at 210 and 280 g ha$^{-1}$ at 2 WAT-Pre.**

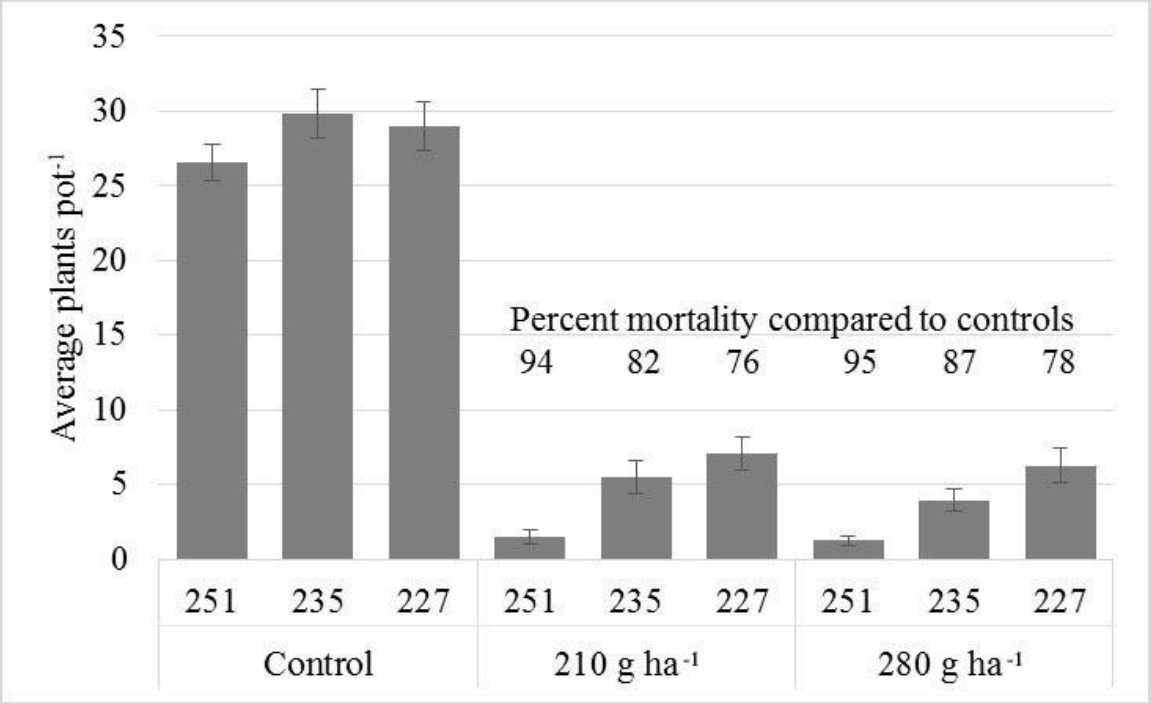

**Figure 2.3 Kochia mortality in response to preemergence-applied dicamba at 210 and 280 g ha$^{-1}$ at 3 WAT-Pre.**

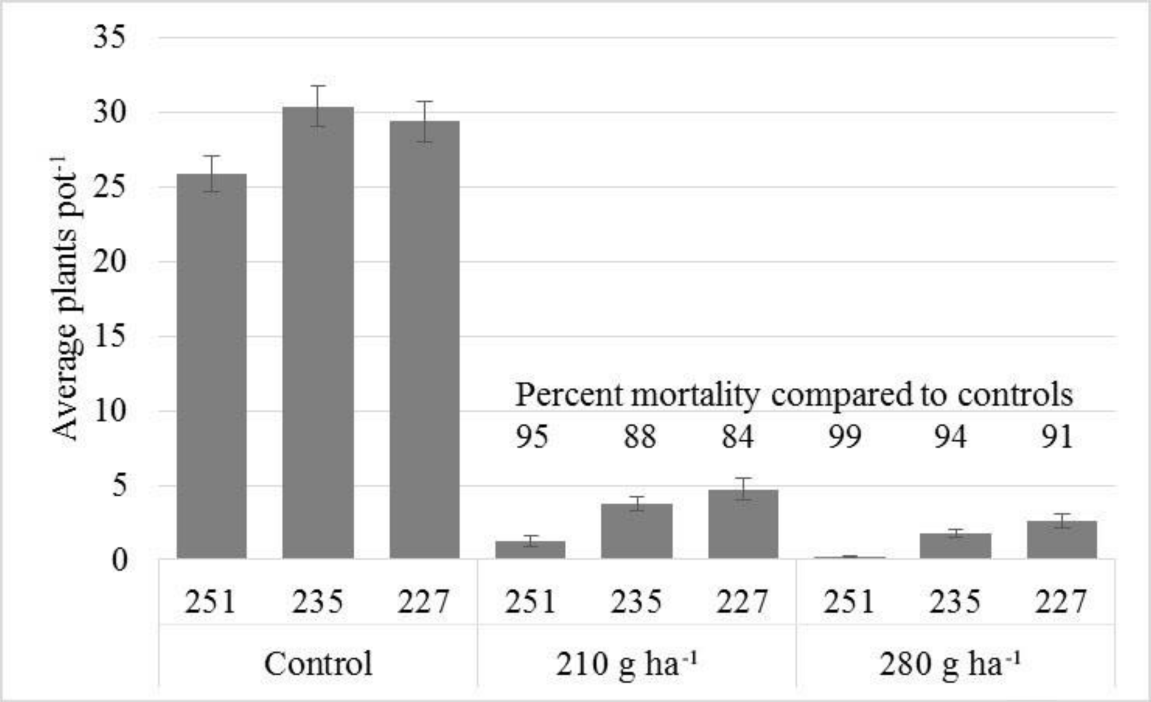

**Figure 2.4 Kochia mortality in response to preemergence-applied dicamba at 210 and 280 g ha$^{-1}$ at 10 WAT-Pre.**

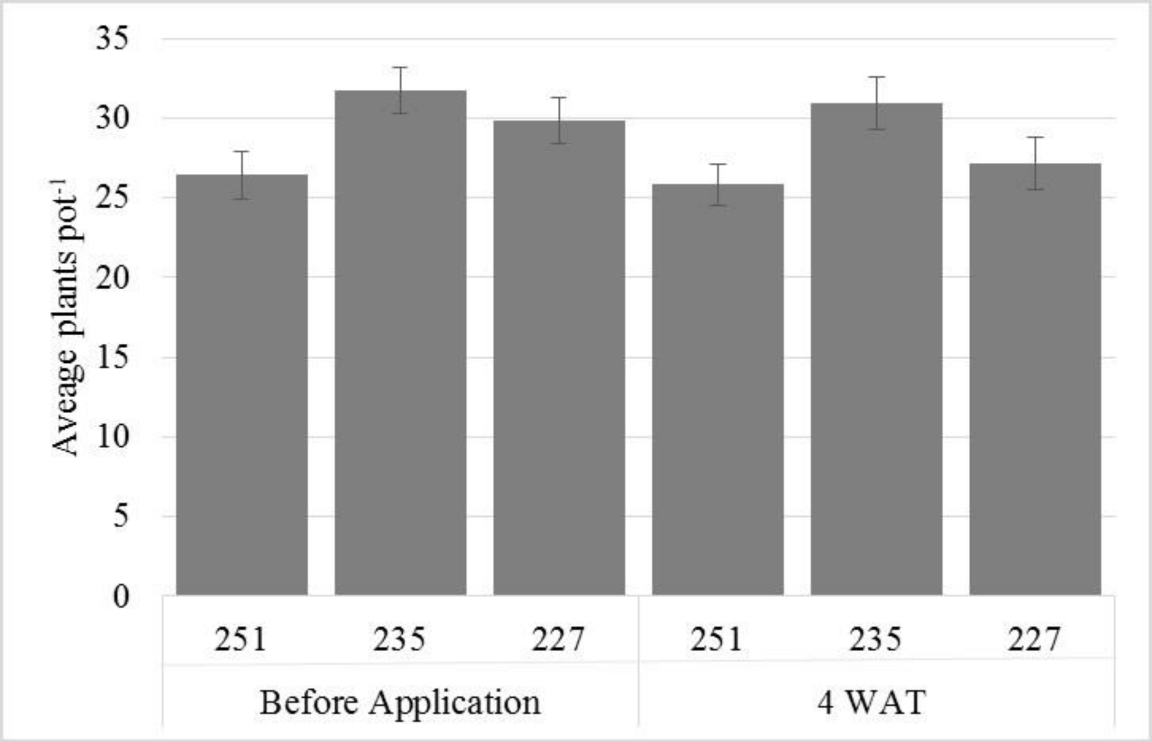

**Figure 2.5 Kochia mortality in response to postemergence-applied dicamba at 210 g ha$^{-1}$ at 4 WAT-Post.**

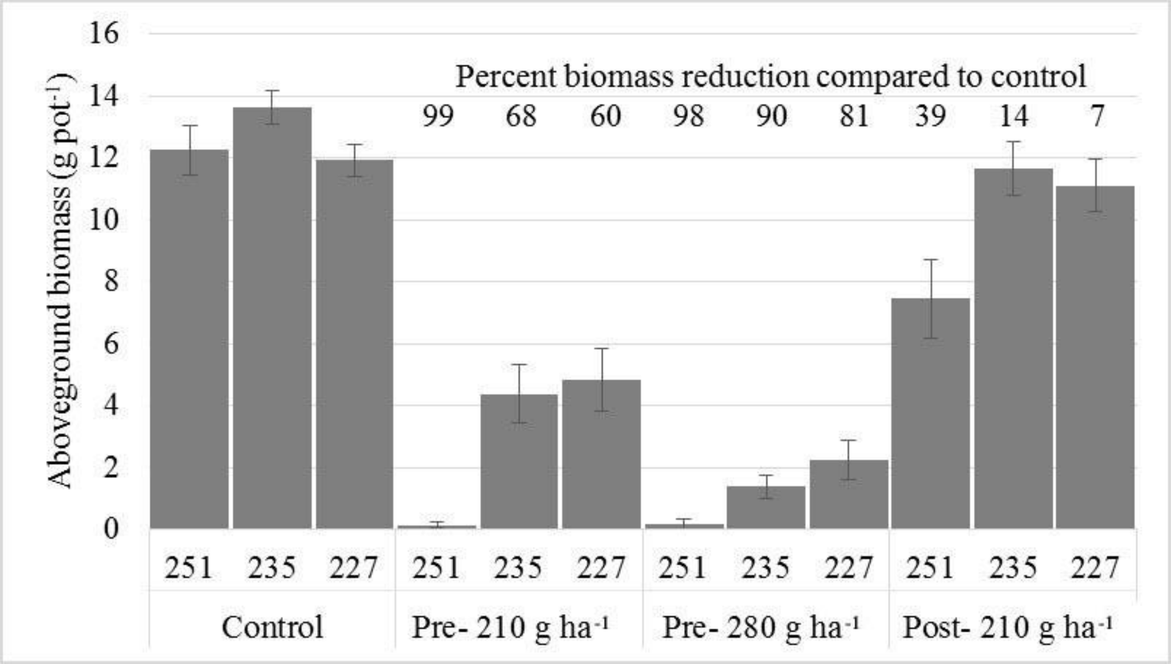

**Figure 2.6 Kochia fresh biomass in response to preemergence and postemergence-applied dicamba at 4 WAT-Post.**

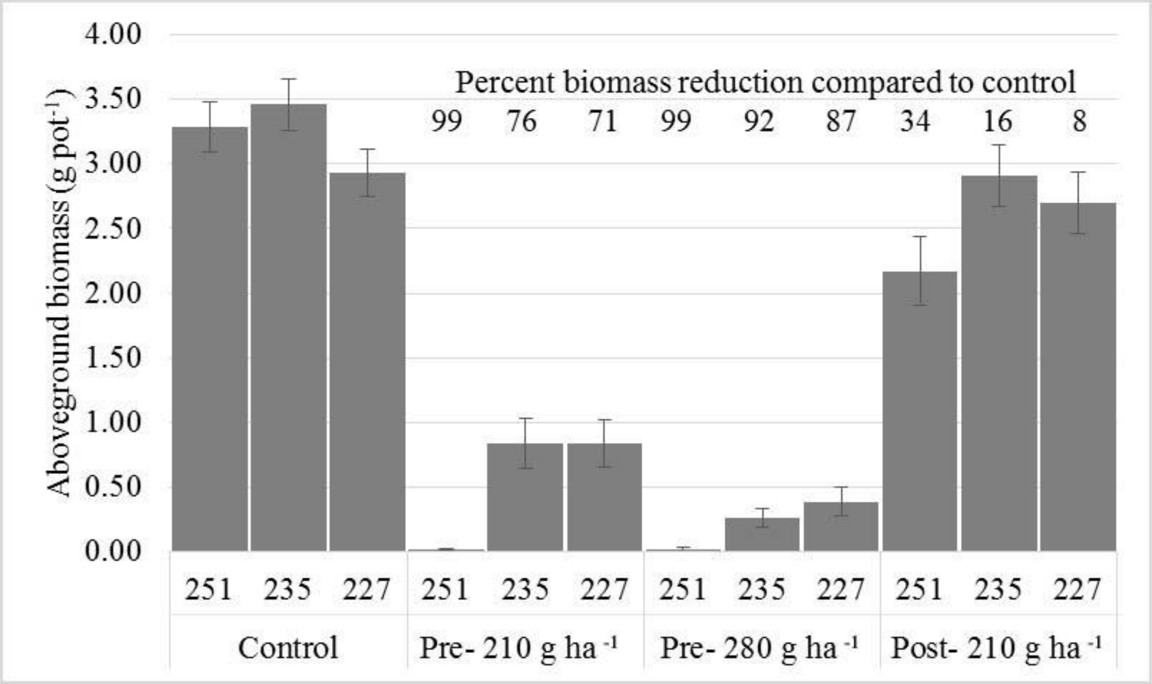

**Figure 2.7 Kochia dry biomass in response to preemergence and postemergence-applied dicamba at 4 WAT-Post.**

**Table 2.1 Soil characteristics of soil used in experiment.**

|  |  |
|---|---|
| Soil Type | Roxbury silt loam |
| Soil Classification | Fine-silty, mixed, superactive, mesic Cumulic Haplustolls |
| Sample Depth | 0-35 cm |

|  |  |  |  | MWB |  | Texture |  |
|---|---|---|---|---|---|---|---|
| pH | $NO_3$-N | Mehlich P | K | OM | Sand | Silt | Clay |
|  | ppm | ppm | ppm | % | % | % | % |
| 7.99 | 15.8 | 34.1 | 683.4 | 1.8 | 26 | 56 | 18 |

# Chapter 3 - Assessment of Soybean Management Practices for Kochia Control

## Abstract

Soybean [*Glycine max* (L.) Merr.] is a major agronomic crop and the leading oilseed crop in the United States. Effective weed management systems in soybeans are continuously challenged by the evolution of herbicide-resistant weeds. The objective of this experiment was to evaluate multiple combinations of early-spring preplant and in-crop weed management practices in a systems approach to control kochia. Field experiments at the Kansas State University Agricultural Research Center at Hays, KS in 2013 and 2014 compared three no-till early-spring preplant herbicide treatments with reduced-till plus preplant herbicide and conventional till treatments followed by no in-crop herbicide or eight different in-crop preemergence and preemergence plus postemergence herbicide treatments. Early preplant conventional till and the reduced-till plus preplant herbicide treatments, consistently provided greater kochia control than the three no-till herbicide treatments when no in-crop herbicides were applied. However, tillage-based systems in 2013 produced the shortest and lowest yielding soybeans, indicating the most effective control practices may not result in the highest soybean yields. Among the three no-till early preplant herbicide treatments with the same in-crop treatments, plots receiving saflufenacil + dimethenamid-P + metribuzin + glyphosate had the greatest kochia control and highest soybean yield. In-crop preemergence imazethapyr + glyphosate + dimethenamid-P with postemergence glyphosate exhibited the most consistently effective treatment for kochia control and soybean yields within preplant treatments. Generally, decreased kochia control and soybean yields were observed for in-crop preemergence glyphosate

and untreated treatment within preplant treatments, suggesting necessity for an in-crop treatment with soil activity.

## Introduction

The United States is the world's largest producer and exporter of soybean, which is the second most-planted field crop in the U.S. behind corn, with nearly 31.4 million soybean hectares planted in 2009 (USDA 2012). In Kansas in 2014, soybean production ranked fourth behind corn, wheat and grain sorghum (USDA-NASS 2014). Soybean production has grown rapidly in the United States as a result of low production costs, planting flexibility, yield improvements, and crop rotation benefits (USDA 2012). As a major crop in the United States, soybean production is challenged by the evolution of several weed species resistant to multiple herbicide mechanisms of action; examples include species resistant to glyphosate and ALS-inhibiting herbicides.

Commercialization of glyphosate tolerant soybean in 1996 proved profitable and extremely popular as a means for weed control. As early as 2006, 89% of planted soybean hectares were glyphosate resistant varieties (USDA-NASS 2014). Glyphosate is a broadspectrum non-selective herbicide that is efficacious, economical, and environmentally benign (Powles 2008). As a result, glyphosate has become the world's most important and widely used herbicide. Its extensive use, however, often exclusive of other herbicide mechanisms of action, has led to heavy selection pressure, consequentially resulting in evolved resistance to glyphosate. Currently, there are 32 known weed species worldwide that have evolved resistance to glyphosate (Heap 2015). Glyphosate resistant crop technology is a primary weed management practice used in soybeans, though the evolution of glyphosate-resistant weeds is challenging its continued effectiveness. Recent approval and anticipated launch in 2016 of

Roundup Ready 2 Xtend ™ soybean (Monsanto Co.) with traits conferring resistance to both glyphosate and dicamba, and pending regulatory approval of dicamba will provide a new weed management option for soybeans. Stacking of glyphosate and dicamba resistant traits will permit the use of dicamba either preemergence or postemergence in soybean for weed control (Johnson et al. 2010). As occurred with the release of glyphosate resistant crops, this new technology is expected to be widely adopted and will increase selection pressure on weed species currently susceptible to dicamba. To avoid similar outcomes as occurred with the evolution of glyphosate-resistant weeds, integrated weed management practices need to be developed and implemented to prevent further evolution of dicamba-resistant weeds.

Kochia has become one of the most troublesome and difficult-to-control weeds in soybean production systems with season-long competition reducing yield up to 30% (Forcella 1985). Kochia is most problematic in no-till cropping systems (Anderson and Nielson 1996) in semiarid regions where producers rely on herbicides for weed management to conserve soil moisture. Currently, there are fewer effective herbicide options than in the past for kochia control as a result of its evolved resistance to multiple herbicide mechanisms of action (Powles 2008). Seed placement in soil and seed viability are known to affect kochia establishment (Schwinghamer and Van Acker 2008). At a shallow seed burial depth of 2 mm, emergence was reduced by approximately 50% and at 40 mm less than 10% emergence was observed compared to emergence on or from just below the soil surface (Schwinghamer and Van Acker 2008). Within the growing season, if seed did not germinate there were either few or no remaining viable seeds, suggesting that kochia has a short seed life (Schwinghamer and Van Acker 2008). Some have attributed small seed size of 1.5 to 2.0 mm long as a probable reason for its short seed viability and inability to emerge from depths more than a few mm (Friesen et al. 2008; Everitt et al. 1983). Kochia's short-lived seed viability and its inability to emerge from more than a few mm soil depth makes tillage an effective control option.

As previously mentioned, there are fewer effective herbicide options than in the past for use in soybean to establish herbicide rotations. Several preemergence herbicides with soil residual applied in late fall or early spring have proven effective in controlling kochia (Stahlman et al. 2012; Kumar and Jha 2015); however, supplemental herbicide or tillage is needed to obtain season-long control. Preemergence herbicides generally have been more cost effective than herbicides applied postemergence. The most feasible herbicide options for controlling kochia in a no-till system is to implement early preplant treatments. Applying herbicides before kochia emergence will relieve selection pressure imposed by using postemergence applications alone. The objective of this experiment was to investigate combinations of early season preplant and in-crop herbicide treatments for kochia control in soybeans.

## Materials and Methods

Field experiments were conducted in 2013 and 2014 at the Kansas State University Agricultural Research Center at Hays, KS. Experimental areas were adjacent research blocks and were covered with standing winter wheat stubble free of weed growth from the previous crop season. Soil characteristics for each experiment are shown in Table 3.1. To ensure presence and achieve uniform kochia density, mature kochia seed was harvested from a larger area (with known presence of glyphosate-resistant biotypes) and broadcast over the experimental area each fall prior to trial initiation to allow seed to overwinter on-site. After few kochia emerged in the spring of 2013, it was discovered the seed broadcast the previous fall had low viability, thus the experimental area was overseeded a second time 2 wk after early preplant treatments were initiated. This was not necessary in 2014.

The experiment was a split-plot arrangement of treatments in a randomized complete block design with four replications.  Main-effect treatments identified and shown in Table 3.2 consisted of three early preplant herbicide treatments (no-till), a combination of early preplant tillage and preplant herbicide (reduced–till), and multiple preplant tillage (conventional till) established in early spring prior to kochia emergence.  Hereafter, these early preplant treatments are referred to as No-till 1, No-till 2, No-till 3, Reduced-till, and Conventional till.  Early preplant treatments were initiated at least 8 wk before soybean planting and herbicide application following tillage in the Reduced-till herbicide treatment was made approximately 2 wk before planting.

Sub-effect treatments shown in Table 3.2 were randomized within each main-effect treatment and included a control in which no herbicide was applied (other than that in main-treatments) for comparisons of sub effects within main effects. The conventional till main-effect and no herbicide sub-effect treatment combination served as the untreated control for all treatment combinations.  Sub-effect treatments consisted of three residual herbicide mixtures and a glyphosate applied preemergence without a mid-season postemergence glyphosate application and the same preemergence treatments followed by glyphosate postemergence 5 and 6 wk after preemergence treatment application in 2013 and 2014, respectively.  Individual sub-effect treatments are identified in Table 3.2 and hereafter are referred to as PRE 1, PRE 1 fb glyp, PRE 2, PRE 2 fb glyp, PRE 3, PRE 3 fb glyp, PRE 4, and PRE 4 fb glyp.  All treatments that contained glyphosate included ammonium sulfate at 2% w/v and all treatments containing imazethapyr included non-ionic surfactant at 0.5%v/v.

Sub-effect plot size was 2.5 x 7 m encompassing four rows of soybeans with a 1.8 m running control at the back of each plot.  Preplant herbicide treatments were applied with a tractor-mounted, $CO_2$ sprayer equipped with AIXR 110015 (TeeJet®) spray nozzles delivering 94 L $ha^{-1}$ at 345 kPa and 6.4 km $hr^{-1}$. Tillage treatments were performed using a V-blade undercutter for the first tillage operation and a field cultivator for the second and third tillage operations on the dates shown in Table 3.2. Preemergence and postemergence treatments were applied with a tractor-mounted, compressed-air sprayer equipped with TTI 110015 (TeeJet®) spray nozzles calibrated to deliver 140 L $ha^{-1}$ at 276 kPa and 4.8 km $hr^{-1}$.

On 3 June 2013 and 22 May 2014, Asgrow® 2933 soybeans were planted 3.8 to 5 cm deep in 76-cm-spaced rows at 387,700 seeds $ha^{-1}$ using a 4-row Monosem no-till planter. Soybeans emerged on 10 June 2013 and 30 May 2014 and flowered on 20 July 2013 and 18 July 2014.

At 7, 14 and 21 days after the postemergence glyphosate application, kochia control was estimated visually from 0 to 100%, where 0 equaled no visible control and 100 equaled no live plants. Soybean plant heights at the R4 growth stage were determined on 20 August 2013 and 13 August 2014 by averaging the distance from the soil surface to tips of the uppermost leaves of three randomly selected plants in the center two rows of each plot. The center two rows of soybeans were mechanically harvested with a plot combine on 26 September 2013 and 9 October 2014. Grain yields were adjusted to 13% moisture.

Kochia control, soybean plant height, and soybean yield data were analyzed using the GLIMMIX procedure in SAS 9.3 (SAS Institute, 2011) for analysis of variance (ANOVA) with means separated using least significant difference (LSD) at $P \leq 0.05$ to determine differences between kochia management systems. Each year was considered an environment and data analysis indicated an interaction between environment and treatments for kochia control, soybean height, and soybean yield. Fixed effects for this experiment were early preplant treatments and in-crop herbicide treatments. Replication was considered a random effect.

## Results and Discussion

Cumulative precipitation from March through September 2013 and 2014 was slightly above normal compared to 30-yr average precipitation for Hays, KS (Figure 3.1). However, the period from March through May was considerably dryer than normal in both years, 56% of normal in 2013 and 26% of normal in 2014. Rainfall during this period (March-May), however, was sufficient in both years to activate early preplant herbicides and rainfall each year within 2 wk after sub-effect herbicides were applied preemergence totaled more than 60 mm (Figure 3.2). This provided adequate moisture for mid-season vegetative growth but low sub-soil moisture and lack of rainfall coupled with high temperatures during reproductive growth in the month of August adversely affected soybean pod-set, seed-fill, and grain yield. Soybean plant heights were highly varied and not discussed here but are included in Appendix B.

### *Kochia Control*

There were interactions in both years between early preplant and in-crop herbicide treatments. Kochia control from postemergence glyphosate had not yet peaked at 7 DAT and control ratings for treatment combinations at 14 and 21 DAT were similar, thus only 21 DAT results are shown and discussed for 2013 and 2014 (Table 3.4 and 3.5). The 7 and 14 DAT control ratings are included in Appendix A.

In 2013, early preplant Conventional till and Reduced-till without in-crop herbicide treatment (in-crop untreated) controlled kochia 99-100%, thus no benefit was gained from any of the in-crop treatments (Table 3.4). In comparison, all three herbicide-based no-till treatments without following in-crop treatments were less effective than the Conventional till and Reduced-till treatments with control effectiveness of the no-till treatments ranking in decreasing order: No-till 2 (88%) = No-till 3 (82%) > No-till 1 (68%). This ranking resulted from most in-crop herbicide treatments providing greater kochia control when applied following early preplant No-till 2 than when following early preplant No-till 1; only in-crop PRE 1 and PRE 1 fb glyp were as effective. In comparison, kochia control differences between combinations of individual in-crop herbicides and the two more effective early preplant herbicide treatments were of smaller magnitude. Five of 8 treatment combination comparisons were not significantly different and two that were significant differed by ≤3%. The remaining in-crop treatment, PRE 3, was 10% more effective when applied following No-till 2.

Compared to the in-crop untreated, most preemergence treatments with or without postemergence glyphosate application in mid-season improved kochia control when following early preplant No-till 2 or No-till 3; only in-crop PRE 3 did not. Among in-crop preemergence herbicide treatments not followed by postemergence glyphosate, with two exceptions, PRE 1 was consistently more effective than other in-crop herbicides in controlling kochia within each of the three early preplant no-till treatments. The two exceptions were PRE 3 and PRE 3 fb glyp following No-till 2 and No-till 3, respectively. For No-till 1, kochia control was only improved when applying PRE 1 among in-crop preemergence treatments without postemergence glyphosate. Applying glyphosate postemergence in mid-season was only beneficial to PRE 3 following early preplant No-till 1 and PRE 2 following either No-till 2 or No-till 3.

In 2014 as in 2013, early preplant Conventional till without in-crop herbicide treatment controlled kochia 99%, thus no benefit was gained from any of the in-crop herbicide treatments (Table 3.5). The other four preplant treatments without following in-crop treatments were less effective at 78, 70, 43 and 38% control with Reduced-till, No-till 2, No-till 3, and No-till 1, respectively.  Compared to the in-crop untreated, most preemergence treatments with or without postemergence glyphosate application, except for PRE 4, improved kochia control when following early preplant no-till treatments.  In-crop treatments PRE 1, PRE 1 fb glyp, PRE 2, PRE 2 fb glyp, and PRE 3 increased kochia control compared to Reduced-till, whereas PRE 2, PRE 3, and PRE 3 fb glyp did not.  Except for No-till 2 followed by PRE 2, PRE 1 was consistently more effective in controlling kochia than other in-crop preemergence herbicide treatments not followed by postemergence glyphosate.  Applying glyphosate postemergence in mid-season only improved kochia control for in-crop treatments PRE 1 and PRE 2 following early preplant No-till 3, in-crop treatment PRE 1 following early preplant Reduced-till, and in-crop treatment PRE 4 following either early preplant No-till 1 or No-till 3.

Among the in-crop treatments, PRE 1 was generally the most effective in controlling kochia and the addition of postemergence glyphosate was typically not beneficial.  In-crop treatments following the three early preplant herbicide-based no-till treatments consistently increased control effectiveness. This suggests the need to include an in-crop herbicide to supplement and extend weed control provided by early preplant herbicides.  Also, PRE 4 generally was less effective than in-crop treatments containing imazethapyr, dimethenamid, or pyroxasulfone, indicating that applying an herbicide at planting with soil activity is more effective than glyphosate for controlling kochia.

Results suggest conventional tillage or a single tillage followed by preplant herbicide implemented in early spring were as or more effective in controlling kochia than any of the three no-till treatments tested when no in-crop herbicide was applied.  Sub-surface tillage with a V-blade undercutter lifts and loosens the soil to the depth of tillage.  This disturbance likely moved kochia seed on the soil surface into the soil profile to depths from which seedlings were unable to emerge (Schwinghamer and Van Acker 2008). Additionally, tillage is more certain of destroying kochia seedlings that may have already emerged compared to an early preplant herbicide in circumstances where emergence occurred earlier than expected.

### *Soybean Yield*

Soybean yields within early preplant and in-crop herbicide treatments were not exceedingly variable in 2013 (Table 3.6). Conventional till and No-till 2 were the only early preplant treatments in which in-crop treatments increased yield compared to the in-crop untreated. In-crop PRE 2 was the only treatment that improved yield for Reduced-till and in-crop PRE 1 fb glyp and PRE 4 were the only treatments that improved yield for early preplant No-till 3. With the exception of the in-crop untreated, in-crop treatments were not significantly different for early preplant treatment No-till 1. Applying postemergence glyphosate in mid-season was only beneficial to in-crop treatment PRE 4 following early preplant No-till 2 and in-crop treatment PRE 3 following early preplant Reduced-till.

In 2014, soybean yield for each of the treatments was substantially lower than in 2013 (Table 3.7). Applying glyphosate postemergence in mid-season did not improve yields for any of the early preplant treatments. In-crop treatments PRE 1, PRE 1 fb glyp, and PRE 2 fb glyp were the most consistently highest yielding in-crop treatments when combined with early preplant treatments. Within the preplant no-till treatments, in-crop treatments PRE 2, PRE 3, and PRE 4 did not improve yield compared to the in-crop untreated, except for in-crop treatment PRE 3 fb glyp following early preplant treatment No-till 2.

Low weed density in 2013, low crop yields in both years but especially 2014, and inconsistent results between years for certain treatments limits the number of conclusions that can be drawn with confidence. However, it is concluded that shallow tillage in early spring prior to kochia emergence was highly effective in controlling kochia. Among the three early preplant treatments, No-till 1 (pendimethalin + saflufenacil + glyphosate) was considerably less effective than either No-till 2 (saflufenacil + dimethenamid-P + metribuzin + glyphosate) or No-till 3 (pyroxasulfone + saflufenacil + glyphosate) and further, that No-till 2 was significantly more effective than No-till 1 when no in-crop herbicide was applied. Among the in-crop herbicide treatments, PRE 1 (imazethapyr + glyphosate + dimethenamid-P) consistently provided the greatest kochia control and highest crop yields though not always significantly greater compared with other in-crop treatments that varied between years and early preplant no-till treatments. Applying glyphosate postemergence mid-season often did not improve kochia control (because of glyphosate-resistance) or increase yield within early preplant treatments. However, from a weed management standpoint postemergence glyphosate may have reduced kochia seedbank renewal.

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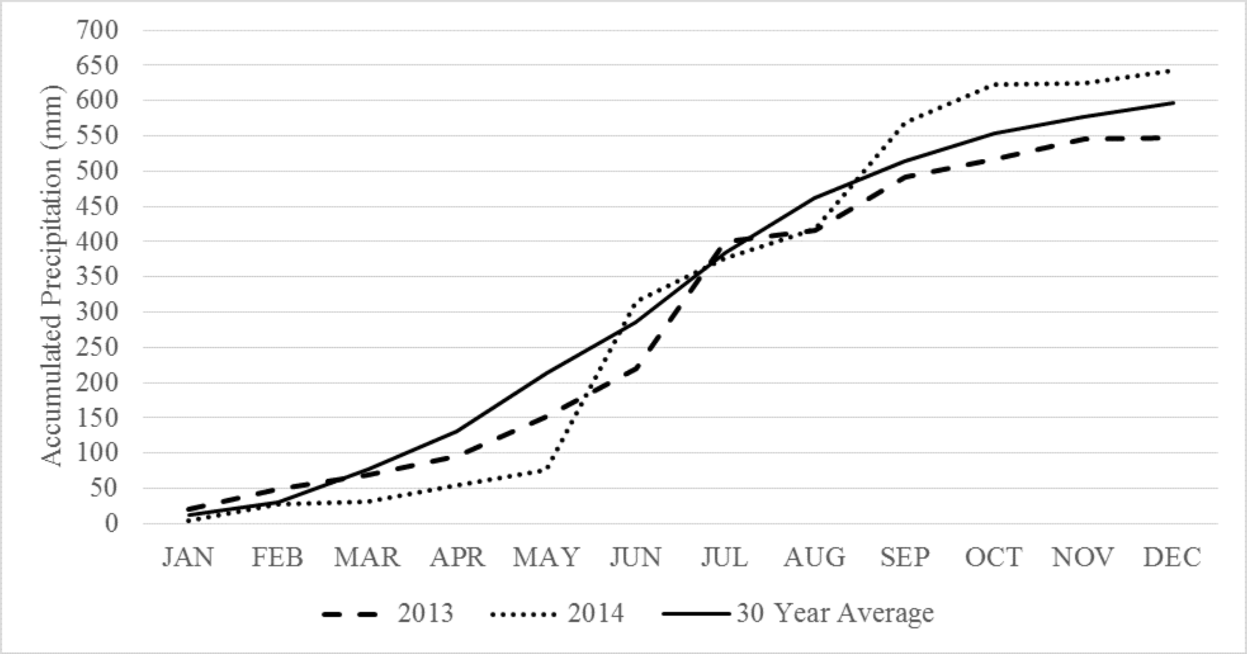

**Figure 3.1 Cumulative precipitation for 2013, 2014, and 30 year average at Hays, KS.**

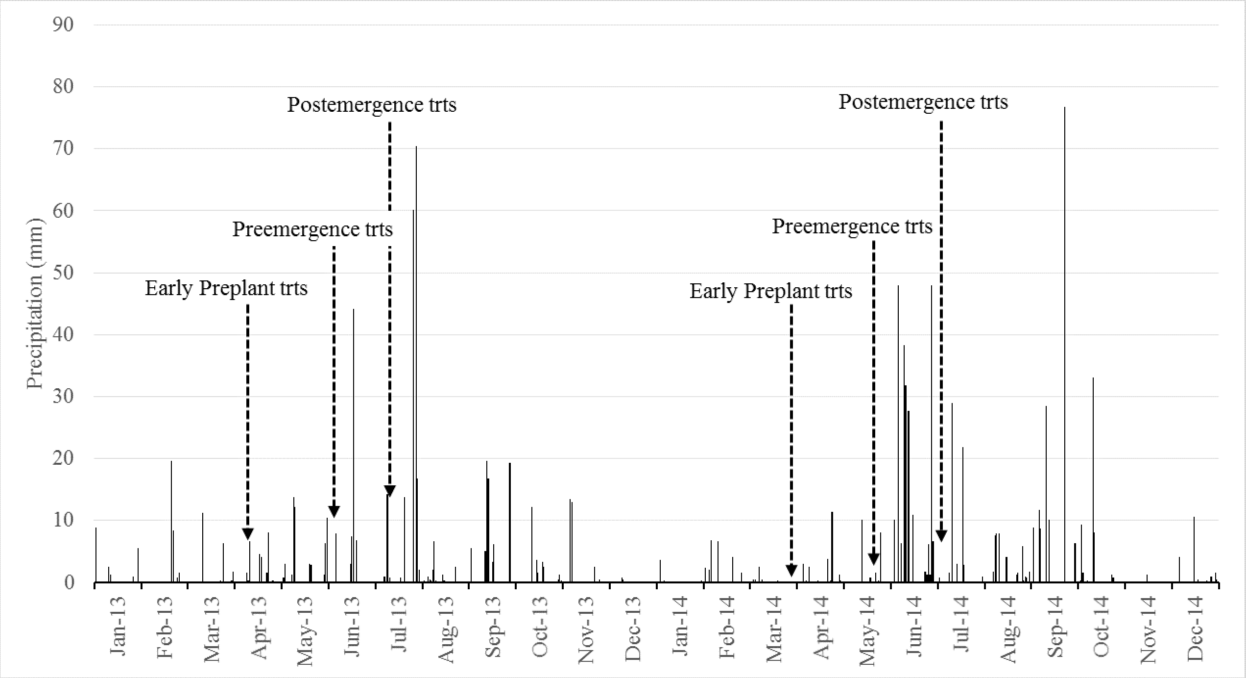

**Figure 3.2 Daily precipitation for 2013 and 2014 at Hays, KS with herbicide application timing shown.**

**Table 3.1 Soil characteristics for both years, KSU Agricultural Research Center, Hays, KS.**

| | |
|---|---|
| Soil Type | Roxbury silt loam |
| Soil Classification | Fine-silty, mixed, superactive, mesic Cumulic Haplustolls |
| Sample Depth | 0-35 cm |

| | | | | | | MWB | Texture | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | pH | $NO_3$-N | Mehlich P | K | CEC | OM | Sand | Silt | Clay |
| | | ppm | ppm | ppm | meq/100g | **%** | **%** | **%** | **%** |
| 2013 | 6.5 | 12.3 | 21.8 | 594 | 21.6 | 1.9 | 10 | 54 | 36 |
| 2014 | 6.9 | 6.2 | 16.4 | 610 | 26.4 | 1.7 | 10 | 54 | 36 |

**Table 3.2 Main-effect and sub-effect treatments, herbicide rates and tillage depths, and date of operations.**

| Treatment ID | Main Effect Treatments[a,b] | Herbicide rates, g ha$^{-1}$ and tillage depth | 2013 | 2014 |
|---|---|---|---|---|
| No-till 1 | Pendimethalin + saflufenacil + glyphosate | 1330 + 50 + 870 | April 8 | March 28 |
| No-till 2 | [Saflufenacil + dimethenamid-P] + metribuzin + glyphosate | [31 + 270] + 210 + 870 | April 8 | March 28 |
| No-till 3 | Pyroxasulfone + saflufenacil + glyphosate | 149 + 50 + 870 | April 8 | March 28 |
| Reduced-till | Tillage (V-blade undercutter) fb<br>[Saflufenacil + imazethapyr] + dimethenamid-P | 7.5-10 cm<br>[7 + 48 ]+ 525 | April 8<br>May 15 | March 31<br>May 8 |
| Conventional till | Tillage (undercutter) fb<br>Tillage (field cultivator) fb<br>Tillage (field cultivator) | 7.5-10 cm<br>6.25-7.5 cm<br>6.25-7.5 cm | April 8<br>May 15<br>May 31 | March 31<br>May 8<br>May 22 |
| | Sub Effect Treatments[c,d] | | | |
| PRE 1 | [Imazethapyr + glyphosate] + dimethenamid-P | [16 + 200] + 630 | June 3 | May 22 |
| PRE 1 fb glyp[d] | [Imazethapyr + glyphosate] + dimethenamid-P | [16 + 200] + 630 | June 3 | May 22 |
| | Glyphosate | 870 | July 11 | July 3 |
| PRE 2 | Dimethenamid-P + glyphosate | 630 + 870 | June 3 | May 22 |
| PRE 2 fb glyp | Dimethenamid-P + glyphosate | 630 + 870 | June 3 | May 22 |
| | Glyphosate | 870 | July 11 | July 3 |
| PRE 3 | Pyroxasulfone + glyphosate | 149 + 870 | June 3 | May 22 |
| PRE 3 fb glyp | Pyroxasulfone + glyphosate | 149 + 870 | June 3 | May 22 |
| | Glyphosate | 870 | July 11 | July 3 |
| PRE 4 | Glyphosate | 870 | June 3 | May 22 |
| PRE 4 fb glyp | Glyphosate<br>Glyphosate | 870<br>870 | June 3<br>July 11 | May 22<br>July 3 |
| Untreated | No herbicide | | | |

[a] All herbicide treatments containing glyphosate included ammonium sulfate at 2 % w/v and all imazethapry treatments included non-ionic surfactant 0.5 % v/v.

[b] Herbicides and rates enclosed by brackets indicate a premix product.

[c] Preemergence and postemergence to the crop. Weeds many have been present either or both times.

[d] glyp, glyphosate.

**Table 3.3 Herbicide common and trade names, abbreviations, rates, and manufacturer.**

| Common name[a] | Trade name | Abbreviations | Rates[b] g ai $ha^{-1}$ | Formulation | Manufacture |
|---|---|---|---|---|---|
| Dimethenamid-P | Outlook | Dime | 630 and 525 | 6 EC | BASF |
| Glyphosate | Roundup PowerMAX | Glyp | 870 | 4.5 SL | Monsanto |
| Imazethapyr + glyphosate | Extreme | Imaz + glyp | 16 + 200 | 2.17 SC | BASF |
| Metribuzin | Metribuzin 75DF | Metr | 210 | 75 WG | BASF |
| Pendimethalin | Prowl $H_2O$ | Pend | 1330 | 3.8 SL | BASF |
| Pyroxasulfone | Zidua | Pyrx | 149 | 85 WG | BASF |
| Saflufenacil | Sharpen | Safl | 50 | 2.85 SC | BASF |
| Saflufenacil + dimethenamid-P | Verdict | Safl + dime | 31 + 270 | 5.57 EC | BASF |
| Saflufenacil + imazethapyr | Optill | Safl + imaz | 17 + 48 | 68 WG | BASF |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v.

[b] Glyphosate rates are g ae $ha^{-1}$.

**Table 3.4 Kochia control 21 days after in-crop postemergence glyphosate treatment, Hays, KS, 2013.**

| | | | Early preplant treatments and herbicide rates, g $\text{ha}^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48]+ 525 | tillage 3 times |
| | | g $\text{ha}^{-1}$ | %[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 93 A b | 98 AB a | 96 AB b | 100 A a | 100 A a |
| PRE 1 fb glyp | [Imaz + glyp] + dime | 16 + 200 + 630 | 98 A a | 99 A a | 97 A a | 100 A a | 100 A a |
| | Glyp | 870 | | | | | |
| PRE 2 | Dime + glyp | 630 + 870 | 69 D c | 94 C ab | 86 D bc | 100 A a | 100 A a |
| PRE 2 fb glyp | Dime + glyp | 630 + 870 | 73 CD b | 97 AB a | 94 ABC b | 100 A a | 100 A a |
| | Glyp | 870 | | | | | |
| PRE 3 | Pyrx + glyp | 149 + 870 | 73 CD c | 98 AB a | 88 CDE b | 100 A a | 100 A a |
| PRE 3 fb glyp | Pyrx + glyp | 149 + 870 | 89 AB b | 98 AB a | 94 ABC ab | 100 A a | 100 A a |
| | Glyp | 870 | | | | | |
| PRE 4 | Glyp | 870 | 74 CD b | 96 BC a | 92 ABC a | 100 A a | 100 A a |
| PRE 4 fb glyp | Glyp | 870 | 82 BC c | 96 BC ab | 89 BCD bc | 100 A a | 100 A a |
| | Glyp | 870 | | | | | |
| Untreated | No herbicide | | 68 D c | 88 D b | 82 E b | 100 A a | 99 B a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

**Table 3.5 Kochia control 21 days after in-crop postemergence glyphosate treatment, Hays, KS, 2014.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | %[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 88 A b | 97 A ab | 89 A b | 91 AB ab | 99 AB a |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 92 A abc | 84 BCD c | 89 A bc | 95 A ab | 100 A a |
| PRE 2 | Dime + glyp | 630 + 870 | 66 B b | 82 CD ab | 80 AB b | 80 CD b | 98 BC a |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 70 B c | 91 AB ab | 80 AB bc | 90 AB ab | 97 C a |
| PRE 3 | Pyrx + glyp | 149 + 870 | 66 B b | 86 BCD ab | 66 B b | 86 BC ab | 99 AB a |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 61 B c | 88 BC ab | 69 B bc | 84 BCD ab | 100 A a |
| PRE 4 | Glyp | 870 | 41 C b | 78 DE a | 48 C b | 82 CD a | 99 AB a |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 67 B b | 79 CD ab | 66 B b | 85 BCD ab | 98 BC a |
| Untreated | No herbicide | | 38 C c | 70 E ab | 43 C bc | 78 D a | 99 AB a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

**Table 3.6 Soybean yield for each treatment, Hays, KS, 2013.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | (kg ha$^{-1}$)[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 1221 A a | 1232 A a | 1126 ABC a | 841 C b | 962 A b |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 1343 A a | 1259 A a | 1232 AB a | 854 BC b | 951 AB b |
| PRE 2 | Dime + glyp | 630 + 870 | 1160 A ab | 1304 A a | 1058 C ab | 990 A ab | 918 AB b |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 1150 AB ab | 1230 A a | 1161 ABC a | 862 BC c | 938 AB bc |
| PRE 3 | Pyrx + glyp | 149 + 870 | 1120 AB a | 1169 A a | 1085 BC ab | 842 C b | 929 AB ab |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 1194 A ab | 1310 A a | 1151 ABC ab | 942 AB c | 1019 A bc |
| PRE 4 | Glyp | 870 | 1035 AB b | 843 B c | 1265 A a | 874 BC bc | 777 C c |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 1090 AB ab | 1261 A a | 1050 C abc | 888 BC bc | 828 BC c |
| Untreated | No herbicide | | 846 B b | 479 C c | 1073 C a | 851 BC b | 510 D c |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

**Table 3.7 Soybean yield for each treatment, Hays, KS, 2014.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | (kg ha$^{-1}$)[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 575 AB ab | 653 A a | 453 AB b | 533 A ab | 555 A ab |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 514 A a | 573 AB a | 547 A a | 543 A a | 549 A a |
| PRE 2 | Dime + glyp | 630 + 870 | 421 ABC a | 520 BC a | 473 AB a | 440 AB a | 491 AB a |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 416 ABC b | 564 ABC a | 419 AB b | 474 A ab | 512 A ab |
| PRE 3 | Pyrx + glyp | 149 + 870 | 389 BC ab | 555 ABC a | 364 B b | 469 AB ab | 519 A a |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 471 ABC ab | 617 AB a | 337 B b | 511 A ab | 589 A ab |
| PRE 4 | Glyp | 870 | 276 C ab | 507 BC a | 283 B b | 449 AB ab | 478 AB ab |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 406 BC ab | 553 ABC a | 344 B b | 436 AB ab | 498 AB ab |
| Untreated | No herbicide | | 322 BC a | 459 C a | 271 B a | 358 B a | 383 B a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

# Appendix A - Kochia Control 7 and 14 DAT in 2013 and 2014, Hays, KS

### Table A.1 Kochia control 7 days after in-crop postemergence glyphosate treatment, Hays, KS, 2013.

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | %[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 97 A b | 99 A ab | 99 A ab | 100 A a | 100 A a |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 99 A a | 99 A a | 98 AB a | 100 A a | 100 A a |
| PRE 2 | Dime + glyp | 630 + 870 | 88 BC b | 98 AB a | 91 BC b | 100 A a | 100 A a |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 84 CD b | 97 ABC a | 97 AB a | 100 A a | 100 A a |
| PRE 3 | Pyrx + glyp | 149 + 870 | 88 BC c | 100 A a | 94 ABC b | 100 A a | 100 A a |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 93 AB b | 99 A a | 93 ABC b | 100 A a | 100 A a |
| PRE 4 | Glyp | 870 | 78 E c | 96 BC b | 95 ABC b | 100 A a | 100 A a |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 84 CD c | 96 BC b | 95 ABC b | 100 A a | 100 A a |
| Untreated | No herbicide | | 79 DE c | 94 C ab | 88 C b | 100 A a | 100 A a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

**Table A.2 Kochia control 7 days after in-crop postemergence glyphosate treatment, Hays, KS, 2014.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | %[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 91 A b | 96 A ab | 91 A b | 96 AB ab | 100 A a |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 92 A ab | 88 BCD b | 92 A ab | 98 A ab | 99 AB a |
| PRE 2 | Dime + glyp | 630 + 870 | 71 B b | 84 CDE ab | 84 AB ab | 90 CD a | 99 AB a |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 72 B b | 95 AB a | 80 AB b | 96 AB a | 98 B a |
| PRE 3 | Pyrx + glyp | 149 + 870 | 73 B b | 88 BCD ab | 72 B b | 92 ABC a | 100 A a |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 67 B c | 90 ABC ab | 71 B bc | 90 CD ab | 100 A a |
| PRE 4 | Glyp | 870 | 44 C b | 78 EF a | 48 C b | 87 CD a | 100 A a |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 71 B b | 82 DE ab | 70 B b | 91 BCD a | 100 A a |
| Untreated | No herbicide | | 43 C c | 74 F ab | 46 C bc | 86 D a | 100 A a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

**Table A.3 Kochia control 14 days after in-crop postemergence glyphosate treatment, Hays, KS, 2013.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | %[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 96 A b | 99 A a | 97 A b | 100 A a | 100 A a |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 98 A a | 99 A a | 98 A a | 100 A a | 100 A a |
| PRE 2 | Dime + glyp | 630 + 870 | 78 B c | 95 CD ab | 89 CD b | 100 A a | 100 A a |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 76 B c | 97 BC ab | 96 AB b | 100 A a | 100 A a |
| PRE 3 | Pyrx + glyp | 149 + 870 | 81 B c | 99 A a | 91 BC b | 100 A a | 100 A a |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 91 A c | 98 AB ab | 95 AB bc | 100 A a | 100 A a |
| PRE 4 | Glyp | 870 | 76 B c | 96 CD ab | 94 ABC b | 100 A a | 100 A a |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 81 B c | 97 BC ab | 93 ABC b | 100 A a | 100 A a |
| Untreated | No herbicide | | 74 B d | 91 D b | 84 D c | 100 A a | 100 A a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

## Table A.4 Kochia control 14 days after in-crop postemergence glyphosate treatment, Hays, KS, 2014.

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | %[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 89 A b | 97 A ab | 91 A b | 95 AB ab | 100 A a |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 91 A ab | 86 BC b | 90 A ab | 96 A ab | 99 AB a |
| PRE 2 | Dime + glyp | 630 + 870 | 71 B b | 83 CD ab | 80 AB b | 87 C ab | 99 AB a |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 70 B b | 94 AB a | 80 AB b | 95 AB a | 98 B a |
| PRE 3 | Pyrx + glyp | 149 + 870 | 69 B b | 85 C ab | 67 B b | 90 ABC a | 99 AB a |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 67 B c | 88 BC ab | 69 B bc | 87 C ab | 100 A a |
| PRE 4 | Glyp | 870 | 41 C b | 77 DE a | 45 C b | 85 C a | 100 A a |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 71 B bc | 81 CD abc | 66 B c | 89 BC ab | 100 A a |
| Untreated | No herbicide | | 38 C c | 71 E ab | 43 C bc | 86 C a | 100 A a |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

# Appendix B - Soybean plant height for each treatment in 2013 and 2014, Hays, KS

**Table B.1 Soybean plant height for each treatment, Hays, KS, 2013.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1$^{c}$ | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates$^{a}$ | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | cm$^{b}$ | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 62 BC a | 65 A a | 64 AB a | 48 CD b | 51 A b |
| PRE 1 fb glyp | [Imaz + glyp] + dime<br>Glyp | 16 + 200 + 630<br>870 | 67 A a | 66 A a | 66 A a | 47 D b | 52 A b |
| PRE 2 | Dime + glyp | 630 + 870 | 62 BC ab | 67 A a | 59 CD bc | 54 A cd | 49 AB d |
| PRE 2 fb glyp | Dime + glyp<br>Glyp | 630 + 870<br>870 | 61 CD a | 61 A a | 61 BCD a | 49 BCD b | 50 A b |
| PRE 3 | Pyrx + glyp | 149 + 870 | 61 CD a | 63 A a | 62 BCD a | 50 A-D b | 51 A b |
| PRE 3 fb glyp | Pyrx + glyp<br>Glyp | 149 + 870<br>870 | 66 AB a | 64 A a | 63 ABC a | 53 AB b | 52 A b |
| PRE 4 | Glyp | 870 | 57 D a | 49 B b | 60 CD a | 49 BCD b | 45 BC b |
| PRE 4 fb glyp | Glyp<br>Glyp | 870<br>870 | 61 CD a | 64 A a | 61 BCD a | 52 ABC b | 49 AB b |
| Untreated | No herbicide | | 57 D a | 45 B b | 58 D a | 48 CD b | 43 C b |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.

**Table B.2 Soybean plant height for each treatment, Hays, KS, 2014.**

| | | | Early preplant treatments and herbicide rates, g ha$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | No-till 1[c] | No-till 2 | No-till 3 | Reduced-till | Conv. till |
| Treatment ID | In-crop herbicides | Rates[a] | 1330 + 50 + 870 | [31 + 270] + 210 + 870 | 149 + 50 + 870 | tillage fb [17 + 48] + 525 | tillage 3 times |
| | | g ha$^{-1}$ | cm[b] | | | | |
| PRE 1 | [Imaz + glyp] + dime | 16 + 200 + 630 | 60 A a | 60 A a | 55 AB a | 59 ABC a | 63 A a |
| PRE 1 fb glyp | [Imaz + glyp] + dime | 16 + 200 + 630 | 61 A a | 61 A a | 58 A a | 62 A a | 60 AB a |
| | Glyp | 870 | | | | | |
| PRE 2 | Dime + glyp | 630 + 870 | 54 AB a | 57 AB a | 55 AB a | 57 ABC a | 59 AB a |
| PRE 2 fb glyp | Dime + glyp | 630 + 870 | 54 AB a | 60 A a | 54 AB a | 55 BCD a | 61 A a |
| | Glyp | 870 | | | | | |
| PRE 3 | Pyrx + glyp | 149 + 870 | 53 B bc | 60 A ab | 50 ABC c | 59 ABC ab | 53 A a |
| PRE 3 fb glyp | Pyrx + glyp | 149 + 870 | 52 B b | 57 AB ab | 51 ABC b | 60 AB a | 60 AB a |
| | Glyp | 870 | | | | | |
| PRE 4 | Glyp | 870 | 51 B a | 55 B a | 49 BC a | 54 CD a | 56 BC a |
| PRE 4 fb glyp | Glyp | 870 | 57 AB a | 59 AB a | 48 BC b | 54 CD ab | 56 BC a |
| | Glyp | 870 | | | | | |
| Untreated | No herbicide | | 51 B ab | 56 AB a | 45 C b | 58 D ab | 54 C ab |

[a] All treatments containing glyphosate (glyp) included ammonium sulfate at 2% w/v and all treatment containing imazethapyr (imaz) included non-ionic surfactant at 0.5 % v/v. Herbicides and rates enclosed by brackets indicate a premix product.

[b] LS means within columns followed by the same uppercase letter and LS means within rows followed by the same lower case letter are not significantly different at $\alpha = 0.05$.

[c] No-till 1, pendimethalin + saflufenacil + glyphosate; No-till 2, [saflufenacil + dimethenamid-P (dime)] + metribuzin + glyphosate; No-till 3, pyroxasulfone (pyrx) + saflufenacil + glyphosate; Reduced till, one V-blade tillage plus preplant [saflufenacil + imazethapyr] + dimethenamid-P; conventional tillage, 3 preplant tillage operations.