

Corn Plant Density Effects on Grain Yield and Palmer Amaranth Response to Dicamba

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Abstract

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is primarily found in fallow and cultivated fields throughout Kansas (KS). Previously, we reported that the effective dose of dicamba for 50% control (ED₅₀) of a 10-30 cm tall *A. palmeri* accession from KS (KSP) during the fallow-year of a wheat-corn-fallow rotation (WCF) ranged between 40.4 to 283.5 g ae ha⁻¹. Here, we investigated corn (*Zea mays* L.) plant density effects on grain yield and the KSP response to dicamba in the corn-year of the WCF rotation. The experiments used a randomized complete block design with four replicates and a split-plot arrangement of treatments. Main plots consisted of corn planted at five densities (49,400; 61,700; 74,100; 86,400 and 98,800 plants ha⁻¹) and sub-plots consisted of six doses of dicamba [(70, 140, 210, 280, 420, and 560 g ae ha⁻¹) applied near V6], a weedy-check, and a weed-free check. In general, acceptable grain yield and KSP control with dicamba doses < 560 g ae ha⁻¹ were only achieved when corn was planted at a density ≥ 74,100 plants ha⁻¹. Based on the ED₅₀ estimates, the KSP required 4.4-8.2% less dicamba for height and biomass reduction as corn plant density increased from 49,400 to 98,800 plants ha⁻¹. Conversely, the amount of dicamba required for 50% reduction of KSP density increased 45.1% from 144.4 to 209.6 g ae ha⁻¹ as corn plant density increased from 49,400 to 98,800 plants ha⁻¹, respectively. Taken together, this study shows that integration of high-density corn planting with dicamba is a cost-effective tool for controlling *A. palmeri*. However, resistance mitigation and a season-long control of this species cannot be achieved without the integration of other more diversified and robust strategies that include the use of preemergence fb postemergence herbicide programs that overlap residuals with cultural, biological, and mechanical weed control tactics.

Keywords: corn, high-density planting, dicamba, Palmer amaranth

1. Introduction

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is native to Northern Mexico and the Southwest U.S., and has invaded portions of Africa, Europe, and South America (Kistner & Hatfield, 2018). This amaranth species is a major constraint to crop production in Kansas (Rule, 2007; Nakka, 2016; McCall, 2018) where corn (*Zea mays* L.) acreage is second only to wheat (Kansas Department of Agriculture, 2019). Due to widespread irrigation, the western part of the state accounts for most (44.9%) of the land under corn production (Kansas Department of Agriculture, 2016). Irrigated corn is usually planted at a population ranging from 61,700 to 74,100 or 86,400 plants ha⁻¹ (depending on irrigation capacity) and wheat-corn-fallow rotation (WCF) is a common practice. Palmer amaranth has been reported to interfere with corn production in Kansas (Massinga et al., 2001). Its deep and extensive root system allows the weed to use resources particularly water and nutrients more efficiently than most crops (Sosnoskie et al., 2011). Palmer amaranth's competitive ability is further complemented by its high photosynthetic activity which is higher than other C4 species (Ward et al., 2013) including corn (Steckel, 2007). Massinga et al. (2001) reported up to 91% reduction in corn grain yield because of *A. palmeri* interference. Others have reported similar yield reductions in corn and other crops commonly grown in the state (Brooks, 2013; Putman, 2013; Chahal, 2015).

Farmers have effectively controlled *A. palmeri* in crop fields in the past; however, current weed control options are limited by its high fecundity, growth rate, resource use efficiency, adaptability, and propensity to evolve resistance to herbicides. Dicamba (3,6-dichloro-2-methoxybenzoic acid) has proven effective for control of several broadleaf weeds in corn and soybean (Soltani et al., 2016; Ganie & Jhala, 2017) including difficult-to-control species (Norsworthy et al., 2011) such as *A. palmeri* (Inman et al., 2016; Underwood et al., 2017). However, dicamba use (pattern) is limited by its susceptibility to drift which remains a major concern even with the availability of low-volatility formulations (Osipitan et al., 2019). This is especially relevant because both corn and soybean are often planted in fields that are adjacent to one another. Consequently, off-target injury to sensitive soybeans can result from dicamba applications in corn.

It is important to note, however, that crop injury is not only limited to soybeans and or drift. In corn, for example, the dimethylamine salt of dicamba [e.g., Banvel (Arysta LifeScience, Cary, NC, USA) and Clarity (BASF Corporation, Research Triangle Park, NC, USA)] can be applied at 1,120 g ae ha⁻¹ (higher rate). However, while the use of reduced rates of dicamba products registered for use in soybean is not allowed, Banvel and Clarity rates in corn are usually lowered significantly since they are often tank-mixed with other herbicides or due to injury concerns. The degree of injury, however, can vary depending on; for example, soil organic matter content and or texture, application timing, corn growth stage at time of herbicide application and the amount of product applied. The latter can also be adjusted for weed type and growth stage at time of application.

Previously, we investigated an *A. palmeri* accession from Kansas (KSP) response to dicamba during the fallow-year of a WCF rotation (Cuvaca et al., 2020). This KSP was treated with dicamba applied at increasing doses from 0 up to 560 g ae ha⁻¹ (lower rate), which was significantly greater than the effective dose of the herbicide required to achieve 50% control of the same KSP accession in a greenhouse study conducted in Manhattan, KS (Cuvaca et al., 2020). Cuvaca et al. (2020) determined that only a fraction (40.4 to 283.5 g ae ha⁻¹) of the lower rate (560 g ae ha⁻¹) of dicamba was required to control the KSP (10-30 cm tall) during the fallow-year of the WCF rotation. Here, we investigated corn plant density effects on grain yield and the KSP response to dicamba in the corn-year of the WCF rotation. Our hypothesis was that high-density corn planting will require less dicamba to achieve acceptable KSP control while maintaining grain yield. The use of lower herbicide rates doesn't necessarily mean less weed control but rather, some of the control provided by a particular herbicide is replaced with another chemical or nonchemical weed control tactic (Trower et al., 2001). Therefore, label directions should be followed precisely when making herbicide applications.

2. Materials and Methods

2.1 Experimental Site

Field experiments were conducted at the Kansas State University Southwest Research- Extension Center near Garden City, KS (37°59'38.4" N, 100°49'04.8" W) in 2017 and 2018 growing seasons. The climate at the site is semi-arid, and the soils are predominantly Richfield silt loam (fine, montmorillonitic, mesic Aridic Argiustoll) with a pH of 8 and 1.4% organic matter. The site had been in a fully irrigated WCF rotation since 2004. To ensure that water never limited yield throughout the growing season, the experiments were irrigated using an overhead sprinkler irrigation system with not more than two irrigation events weekly, with each supplying 25 mm of water.

2.2 Experimental Design and Management

Fields were disked and then the final seedbed was prepared with a field cultivator before corn 'DKC62-97RIB' (Monsanto Co., St. Louis, MO, USA) was planted on May 23 in 2017 and May 6 in 2018. The studies used a randomized complete block experimental design (RCBD) with four replicates and a split-plot arrangement of treatments. Main plots consisted of corn planted at five densities (49,400; 61,700; 74,100; 86,400 and 98,800 plants ha⁻¹) while subplots consisted of six dicamba doses [(70, 140, 210, 280, 420, and 560 g ae ha⁻¹) applied near the V6 developmental stage of corn with 0.25% (v/v) nonionic surfactant], a weedy-check, and weed-free check. All experimental units were broadcast-seeded with *A. palmeri* at 535 g ha⁻¹ (~1,078,293 seeds per ha) before corn planting to ensure a uniform infestation across all experimental units. The main plots were 61 m-long with six rows spaced 76 cm apart. The subplots were 7.62 m-long with six rows spaced 76 cm apart. Dicamba application was made using a tractor-mounted plot sprayer equipped with four 11004-VP flat spray nozzles (Turbo TeeJet Induction, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60139) calibrated to deliver 140 L ha⁻¹ at 276 kPa. Wind speed at the time of treatment applications was between 3 and 6 km h⁻¹. Weed-free plots were hand-hoed bi-weekly until harvest. All other weed species were removed by hand from weedy plots and those treated with dicamba. Irrigation water was supplied (with no more than two 25-mm irrigation events weekly) as required throughout the growing seasons at non- yield-limiting rates based on locally

derived models. Palmer amaranth was hand pulled from all experimental plots near corn physiological maturity to prevent replenishment of the soil seedbank.

2.3 Data Collection and Analysis

Palmer amaranth height (m), density (number of plants m^{-2}) and shoot biomass (kg m^{-2} ; on a dry weight basis) were collected from the two central rows near corn physiological maturity. Corn grain was combine-harvested from the two central rows of each subplot in October of each year, and yield was adjusted to 15.5% moisture.

Data (yield) were subjected to the PORC MIXED procedure for analysis of variance (ANOVA) in SAS 9.3 (SAS Institute, Inc., Cary, NC) and means were separated using Fisher's Protected Least Significant Difference test at $\alpha = 0.05$ when the ANOVA indicated treatment effects were significant. Year effect and the significance of interaction between year, corn plant population and dicamba dose also were tested at $\alpha = 0.05$. If the year effect and or interaction of year with treatment were not significant, data were pooled. A three- or four-parameter log-logistic regression model was used to estimate the effective doses of dicamba required to reduce *A. palmeri* height, density and shoot biomass by 50% (ED_{50}) in R 3.4.1 (R Core Team, 2017) (Knezevic et al., 2007). The lack-of-fit test ($P > 0.05$) indicated that the chosen model accurately described the data.

3. Results and Discussion

3.1 Palmer Amaranth Height

There was a significant reduction in *A. palmeri* height with increasing corn plant density in conjunction with dicamba dose (Figure 1). However, increasing either corn planting density or dicamba dose alone was also beneficial. Previous studies have shown that high-density planting speeds up canopy closure thus giving the crop a competitive advantage over weeds (Nice et al., 2001, Arce et al., 2009). For example, Norris et al. (2001) found that tomato planted at higher densities significantly reduced the height of barnyard grass (*Echinochloa crus-galli*). Similarly, in our study, increasing corn plant density alone (from 49,400 to 98,800 plants ha^{-1}) significantly reduced Palmer amaranth height. Evidently, the greatest reduction in *A. palmeri* height was observed when a 560 g ae ha^{-1} dose of dicamba was applied to corn planted at the highest density, 98,800 plants ha^{-1} .

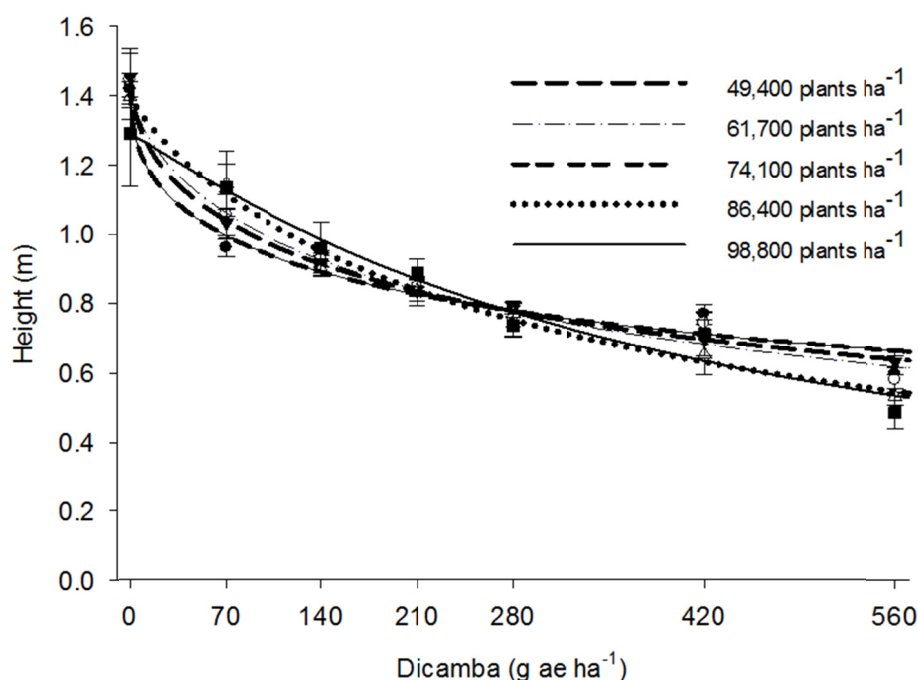


Figure 1. Corn plant density effects on Palmer amaranth (height) response to dicamba

Based on the fitted log-logistic model, less dicamba was required to reduce *A. palmeri* height by 50% (ED_{50}) as corn plant density increased (Table 1). The ED_{50} value for corn planted at 49,400 and 98,800 plants ha^{-1} was 423.3 and 404.7 g ae ha^{-1} dicamba, respectively. Previously, we showed that a similar dose of dicamba or greater

(≥ 397.7 g ae ha⁻¹) was required to control the same *A. palmeri* accession during the fallow-year of the same WCF rotation. Interestingly, however, at intermediate corn plant densities (61,000 to 86,400 plants ha⁻¹), the estimated ED₅₀ values were relatively smaller, ≤ 357.5 g ae ha⁻¹ (Table 1). Furthermore, corn planted at 86,400 plants ha⁻¹ had the smallest ED₅₀ value (331.1 g ae ha⁻¹), suggesting *A. palmeri* height reduction with postemergence application of dicamba could be maximized at this plant density, presumably because of increased herbicide interception (Arce et al., 2009).

Table 1. Effective dicamba doses (ED₅₀) required for 50% *A. palmeri* height, density, and shoot-biomass reduction in various corn plant densities

Palmer amaranth attribute	Corn (plants ha ⁻¹)	ED ₅₀ (SE) (g ae ha ⁻¹)
Height (m)	49,400	423.2 (95.5)
	61,700	349.9 (55.5)
	74,100	357.5 (63.7)
	86,400	331.0 (39.5)
	98,800	404.6 (43.2)
Density (m ⁻²)	49,400	144.4 (27.4)
	61,700	153.5 (32.1)
	74,100	223.9 (54.1)
	86,400	241.9 (64.0)
	98,800	209.6 (35.7)
Biomass (kg m ⁻²)	49,400	126.6 (23.3)
	61,700	253.4 (87.9)
	74,100	212.9 (37.0)
	86,400	112.4 (36.1)
	98,800	116.2 (60.0)

Note. ED₅₀ values were estimated using *A. palmeri* height, density, and shoot-biomass (dry weight basis). SE is standard error of the mean.

3.2 Palmer Amaranth Density

Increasing corn plant density in conjunction with dicamba dose significantly reduced *A. palmeri* density (Figure 2). However, the benefit of increasing either corn plant density or dicamba dose alone was also evident. For example, when left uncontrolled, increasing corn plant density from 49,400 to 98,800 plants ha⁻¹ reduced *A. palmeri* density by 37.5% from 13.6 to 8.5 plants m⁻². Similarly, applying dicamba at the label recommended dose (560 g ae ha⁻¹) reduced *A. palmeri* density at least 67% relative to non-treated, weedy corn regardless of corn plant density. Besançon et al. (2017) and Donovan (1994) reported significant reduction in *A. palmeri* density when sorghum and canola, respectively, were planted at a higher density. The former also reported excellent *A. palmeri* control (> 90%) when sorghum plant density was increased from 99,000 to $\geq 297,000$ plants ha⁻¹ in conjunction with 2,4-D applied postemergence. In contrast, Schultz et al. (2015) did not observe any reduction in waterhemp (*Amaranthus rudis* Sauer) density with increasing soybean seeding rate from 165,000 to 315,000 plant ha⁻¹ except when either a preemergence fb postemergence or two-pass postemergence herbicide program was included.

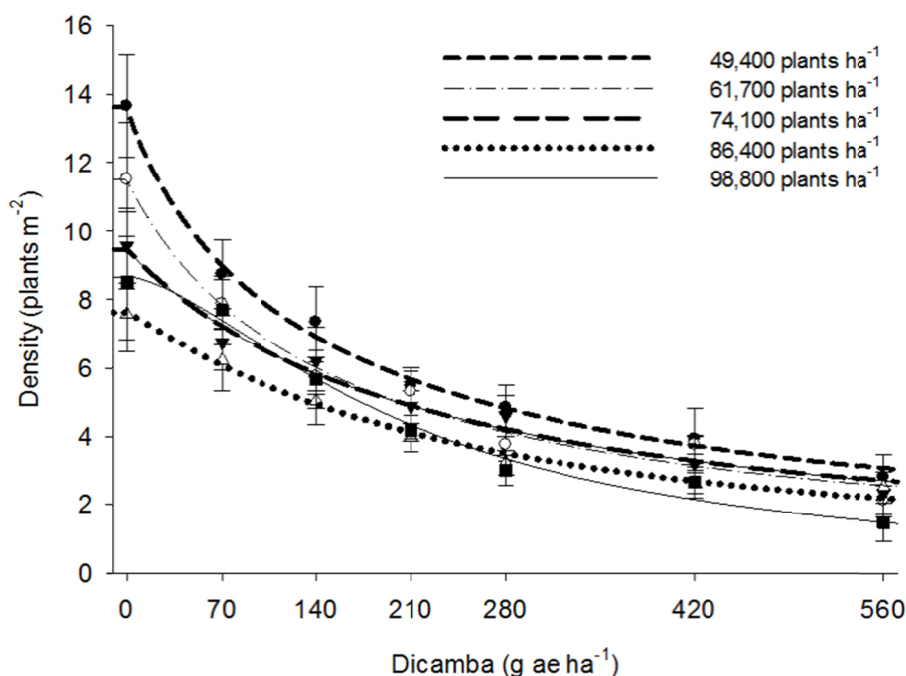


Figure 2. Corn plant density effects on Palmer amaranth (density) response to dicamba

Interestingly, corn planted at the highest density (98,800 plants ha⁻¹) in conjunction with dicamba applied at 560 g ae ha⁻¹ had the lowest *A. palmeri* density (1.49 plants m⁻²). While this may signal potential synergistic interactions, it is worth mentioning, however, that the greatest reduction (79.5%) in *A. palmeri* density was observed when corn was planted at the lowest density (49,400 plants ha⁻¹) in conjunction with dicamba applied at the above dose likely due to a greater canopy opening which ultimately resulted in greater herbicide interception by the weed. Based on the fitted log-logistic model, the effective dose of dicamba required to reduce *A. palmeri* density by 50% (ED₅₀) increased with corn density except at 98,800 plants ha⁻¹. The ED₅₀ values for 49,400; 61,700; 74,100; 86,400 and 98,800 plants ha⁻¹ respectively were 144.4, 153.5, 223.9, 241.9 and 209.7 g ae ha⁻¹ (Table 1). It is possible that the highest corn density had a low ED₅₀ value because it may have reached canopy closure fastest (data not shown). Faster canopy closure means improved crop competition over weeds thus reducing the need for more herbicide.

3.3 Palmer Amaranth Shoot Biomass

In general, increasing corn plant density and dicamba dose significantly reduced *A. palmeri* shoot biomass (Figure 3). While there was benefit to increasing either corn plant density or dicamba dose alone, combining the two was more beneficial. For example, increasing corn plant density from 49,400 to 98,800 plants ha⁻¹ reduced *A. palmeri* shoot biomass by almost 7% when corn was left untreated. Applying dicamba at the highest rate (560 g ae ha⁻¹) reduced *A. palmeri* shoot biomass by at least 80% (relative to non-treated, weedy corn) regardless of corn plant density. Similar results were reported elsewhere (Crespo et al., 2016). However, planting corn at the highest density (98,800 plants ha⁻¹) in conjunction with applying dicamba at 560 g ae ha⁻¹ caused the greatest reduction (95.4% relative to non-treated, weedy corn) in *A. palmeri* shoot biomass.

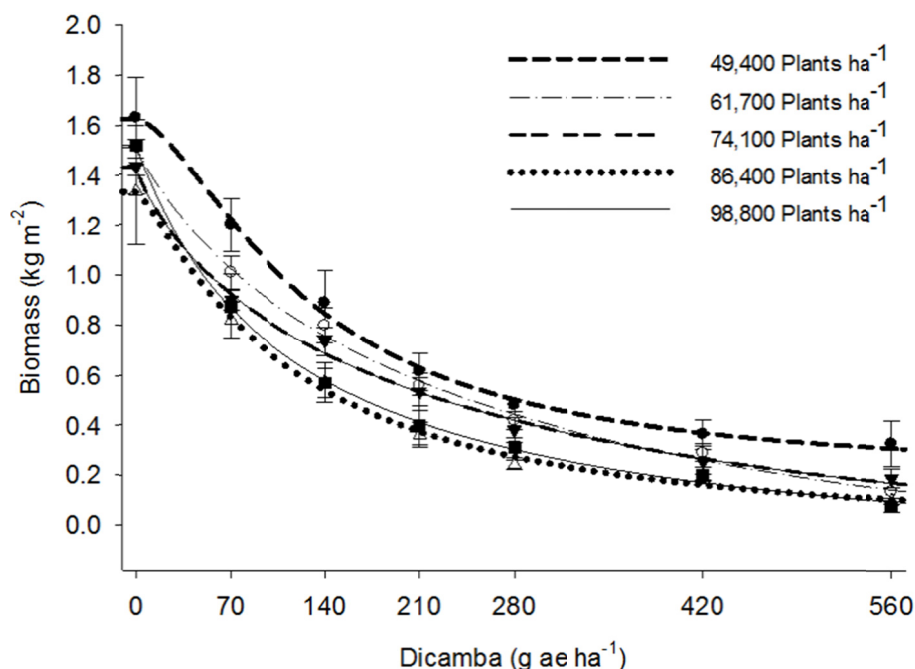


Figure 3. Corn plant density effects on Palmer amaranth (biomass) response to dicamba

Previous studies have discussed the weed biomass reduction benefit of high-density planting in corn (Murphy et al., 1996; Teasdale, 1998; Mohammadi et al., 2012; Marin & Weiner, 2014), as well as other crops like soybean (Norsworthy & Oliver, 2002; Harder et al., 2007), winter wheat (Ona et al., 2018), and sunflower (Mouillon et al., 2020). Based on the fitted log-logistic model, intermediate corn plant densities of 61,700 and 74,100 ha^{-1} required almost twice as much dicamba (212.9-253.4 g ae ha^{-1}) to reduce *A. palmeri* shoot biomass by 50% (ED_{50}) as the lowest (49,400 ha^{-1}) and highest (86,400 and 98,800 ha^{-1}) corn plant densities (Table 1) which is a significantly lower than the dose required to control this same *A. palmeri* accession during the fallow-year of the same WCF rotation (Cuvaca et al., 2020). However, our results suggest that, unlike high-density planting, more herbicide penetration through/into the canopy of the lowest corn density may have contributed to the low ED_{50} value. On the other hand, the dense and early canopy closure (data not shown) of high-density corn planting provided an additional weed suppression thus compensating for the reduced amount of the herbicide penetrating through the crop's canopy.

3.4 Corn Grain Yield

Unlike increasing dicamba dose, there was no benefit to increasing corn plant density alone even when corn was kept weed-free throughout the growing season. However, increasing corn plant density in conjunction with dicamba dose significantly increased corn grain yield (Table 2). The greatest increase in grain yield was observed when dicamba was applied at 560 g ae ha^{-1} in conjunction with corn planted at the highest density of 98,800 plants ha^{-1} . Interestingly, however, achieving grain yield comparable to that of weed-free corn did not always require a 560 g ae ha^{-1} dicamba application. Similarly, significantly increasing grain yield did not always require increasing corn density up to 98,800 plants ha^{-1} except when 560 g ae ha^{-1} dicamba was applied. Previous studies have shown that high-density planting can lead to increased stress among corn plants, presumably because of interplant competition for resources (Sangakkara et al., 2004), which can negatively impact grain yield (Sangoi, 2001) even if other benefits such as quicker canopy closure, greater light interception and lower weed competition are detectable (Abuzar et al., 2011; Robinson & Conley, 2007).

Table 2. Corn plant density effects on grain yield response to dicamba

Corn (Plants ha ⁻¹)	Corn grain yield (SE)							Weed-free
	Dicamba (g ae ha ⁻¹)							
	0	70	140	210	280	420	560	
	----- Mg ha ⁻¹ -----							
49,400	5.1 (0.1) ABb	5.6 (0.5) Cb	6.0 (0.7) Cb	6.7 (0.4) Bab	7.2 (0.5) Bab	8.6 (0.0) Cab	10.0 (0.6) Da	10.1 (0.1) Da
61,700	5.9 (0.0) Ac	6.6 (0.0) BCc	7.5 (0.4) BCbc	8.6 (0.2) Aabc	8.9 (0.4) Aabc	8.9 (0.4) BCabc	10.4 (0.2) Cab	11.1 (0.3) Ca
74,100	6.1 (0.4) Ac	6.8 (0.7) BCbc	8.5 (0.0) ABabc	10.1 (0.8) Aab	10.0 (0.0) Aab	10.9 (0.6) Aa	10.9 (0.2) Ba	11.3 (0.2) Ca
86,400	5.3 (0.3) ABb	8.2 (0.2) Aab	9.5 (0.4) Aa	9.9 (0.3) Aa	9.8 (0.2) Aa	10.2 (0.7) ABa	11.0 (0.6) Ba	11.8 (0.3) Ba
98,800	3.6 (0.0) Bb	7.4 (0.5) ABab	8.6 (0.7) ABab	9.7 (1.0) Aa	10.0 (0.6) Aa	11.0 (0.2) Aa	11.3 (0.3) Aa	12.6 (0.1) Aa

Note. SE is standard error of the mean. Means followed by the same uppercase letter within the same column are equal at $\alpha = 5\%$. Means followed by the same lowercase letter within the same row are equal at $\alpha = 5\%$.

4. Conclusions

Many interlinked factors can affect herbicide efficacy under field conditions and the use of the higher rate may not always be required. Results of this study clearly showed that acceptable *A. palmeri* control and grain yield can be achieved with the integration of high-density corn planting in conjunction with a lower dicamba dose. Previously, we reported that the effective dose of dicamba for 50% control of KSP (10-30 cm tall) during the fallow-year of a WCF rotation ranged from 40.4 to 283.5 g ae ha⁻¹ (Cuvaca et al., 2020). Here we demonstrated that the dose of dicamba required to achieve the same level of KSP control during the corn-year of the same rotation varies with corn plant density with ED₅₀ estimates ranging from 112.4 to 404.6 g ae ha⁻¹. It is possible that these discrepancies in the amount of dicamba required to control KSP were likely influenced by variation in weed sizes and agronomic practices. Nonetheless, considering *A. palmeri* fast growth rate and its propensity to evolve herbicide resistance, integration of other more diversified and robust strategies that include the use of preemergence fb postemergence herbicide programs that overlap residuals with cultural, biological, and mechanical weed control tactics should be considered. Further, more research is needed to investigate corn plant density effects on *A. palmeri* response to other herbicide programs.

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