The Effect of Dicamba on Peanut When Applied during Vegetative Growth Stages

B.H. Blanchett, T.L. Grey*[1], E.P. Prostko, and T.M. Webster[2]

ABSTRACT

The development of dicamba-resistant cotton and soybean cultivars has created great concern about the potential off-target movement of dicamba onto sensitive species, including broadleaf crops. Peanut is often grown in close proximity to cotton and soybean. Therefore, field studies were conducted during 2012 and 2013 at Plains, Ty Ty, and Attapulgus, GA to evaluate peanut response to rates of dicamba (35, 70, 140, 280, and 560 g ae ha^{-1}) applied at preemergence (PRE), 10, 20, or 30 d after planting (DAP) corresponding to PRE, V2, V3, and V5 peanut growth stages, respectively. Nontreated controls were included for comparison. As dicamba rate increased, both peanut injury and peanut yield loss increased. Peanut response to dicamba was fit to log-logistic regression models for injury and linear regression models for yield loss. Peanut injury increased with rate of dicamba, but was variable among the locations. A general trend was that peanut plants became more sensitive to dicamba injury as plants approached reproductive stage, as evidenced through a declining linear relationship between I_{50} values (i.e. rate of dicamba that elicits a 50% crop response) and timing of application. PRE applications of dicamba had I_{50} values that ranged from 125 to 323 g ha^{-1} of dicamba, while I_{50} values were 44 to 48 g ha^{-1} of dicamba at the V5 peanut growth stage. There was a linear relationship between peanut yield and dicamba rate, with 560 g ha^{-1} causing maximum yield losses ranging from 0 to 86% when applied PRE, 24 to 82% when applied at V2 growth stage, 30 to 95% when applied at V3 growth stage, and 45 to 88% when applied at V5 growth stage. Across all treatments and locations, there was also a negative linear relationship between peanut yield and peanut crop injury, with a decline of 8.5% yield for every 10% increase in crop injury. Growers and their consultants/extension agents can use this peanut injury data to predict potential peanut yield loss from sprayer contamination or off-target movement of dicamba.

Key Words: *Arachis hypogaea,* peanut, dicamba, crop injury, sprayer contamination, vegetative growth stages, dose response.

Since 1964, dicamba has been an active ingredient on herbicide registered for topical use in grass crops and preplant in other agronomic crops (Keller, 2014). Dicamba is currently registered for use in soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), pasture, and small grains. Cotton and soybean require 15 to 30 d between preemergence (PRE) dicamba application and planting, along with 2.5 cm of irrigation/rainfall to reduce the chance of significant injury to the crop. Currently only monocot crops tolerate topical applications of dicamba. Dicamba has proven performance for control of numerous annual broadleaf weeds, and is very helpful in controlling problematic glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Edwards *et al*., 2013).

Herbicide-resistant weeds, especially with resistance to acetolactate synthase (ALS) inhibiting (Wise *et al*., 2009) and glyphosate herbicides (Culpepper *et al*., 2006), have lessened the effectiveness of numerous weed management systems. Therefore, there is an interest in engineering other types of herbicide-resistant crops (Johnson *et al*., 2012b; Subramanian *et al*., 1997). Monsanto Company and BASF Corporation, major agricultural seed and chemical companies, have responded by developing alternative weed management systems that use dicamba preemergence (PRE) and postemergence (POST) on dicamba-resistant crops including cotton and soybean (Behrens *et al*., 2007; Griffin *et al*., 2013; Johnson *et al*., 2012b). Dicamba-resistant crops have been genetically altered so that they metabolize the dicamba herbicide more readily, thus no injury occurs from application (Subramanian *et al*., 1997). The proposed dicamba-resistant crops will also include herbicide-resistance technology for other herbicide mechanisms of action (MOA) (Griffin *et al*., 2013). This advantage will allow the use of several MOA as an approach to reducing the selection pressure on a single MOA (Vencill *et al*., 2012), as well as assist in controlling current herbicide-resistant weeds.

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Georgia leads the US with 239,271 ha of peanut (*Arachis hypogaea* L.) harvested in 2014. Peanut is commonly grown in the proximity of cotton and soybean across the southeast (Lassiter *et al.*, 2007; Prostko *et al.*, 2011; Prostko *et al.*, 2013). Herbicide resistance technology is used in most cotton and soybean cultivars for weed management solutions, and the increased use of glyphosate and glufosinate herbicides throughout the growing season increased the occurrence of accidental injury to sensitive crops like peanut (Grey and Prostko, 2010; Johnson *et al.*, 2012a; Lassiter *et al.*, 2007). Peanut foliage injury can occur from herbicide residue remaining in the spray system when it is not properly cleaned prior to the next application in peanut (Grey and Prostko, 2010; Prostko *et al.*, 2011).

Herbicide drift occurs when the herbicide becomes suspended in air, never reaching the target site, then moving onto a sensitive species nearby (Auch and Arnold, 1978; Grey and Prostko, 2010). Herbicide drift can be linked to many different factors: nozzle type, boom height, wind speed, pressure, spray formulation, sprayer speed, volume per area, and other environmental variables (Wolf *et al.*, 1993). Grover *et al.* (1978) reported that herbicide drift amounts can range from 1 to 8%, and Wolf *et al.* (1993) indicated drift, without spray nozzle shielding, can reach 16% off target.

Research has indicated that peanut injury from glyphosate at 240, 320, and 470 g ai ha^{-1} caused significant yield reduction of 12 to 36% when applications were made 75, 90, and 105 days after planting (DAP) (Grey and Prostko, 2010). In another study, glyphosate applied to peanut at 560 g ai ha^{-1}, 4 weeks after planting, resulted in yield loss greater than 50% and visual estimates of injury correlated with yield loss (Lassiter *et al.*, 2007). Glufosinate also caused yield loss to peanut when applied less than a normal rate of 538 g ai ha^{-1}. Glufosinate at 135 and 269 g ai ha^{-1} applied three weeks after emergence (WAE) caused yield loss of 14 and 51% respectively in North Carolina (Jordan *et al.*, 2011). Visual estimates of peanut injury and peanut yield indicated a significant negative correlation.

Dicamba is known to cause significant injury to sensitive broadleaf crops when off-target exposure occurs as a result of tank contamination, herbicide drift, and movement due to volatilization (Behrens and Lueschen, 1979; Egan *et al.*, 2014; Sciumbato *et al.*, 2004). There is great concern with the introduction of dicamba-resistant crops, as the use of dicamba in amplified quantities throughout the growing season would likely increase the occurrence of accidental crop injury to sensitive broadleaf species grown in the same vicinity, including peanut (Egan *et al.*, 2014; Egan and Mortensen, 2012; Johnson *et al.*, 2012b; Leon *et al.*, 2014; Prostko *et al.*, 2011). The dicamba registration for use in common crops of the southeast can be approximately 560 g ae ha^{-1}, and 16% of that rate is 90 g ha^{-1}. If 90 g ha^{-1} of dicamba can move off-target in a controlled experiment, higher rates of dicamba could drift off-target if applicators did not follow all herbicide label directions. Dicamba exposure rates from tank contamination could range considerably.

Research conducted in 2008 with dicamba treatments applied 30, 60, and 90 days after planting (DAP) indicated peanuts to be more sensitive at the 30 and 60 DAP treatments (during the early reproductive stages of growth) when compared to 90 DAP treatments. Overall, yield loss was 2% to 100% with rates of dicamba at 40 to 560 g ai ha^{-1} (Prostko *et al.*, 2011). Another study conducted in 2009 and 2010 included dicamba treatments at 0.6 to 140 g ae ha $^{-1}$ applied three weeks after emergence (WAE) to peanut field plots. Visual estimates of injury were 30 to 80% at 2 weeks after treatment (WAT), and regression analysis indicated significant responses for yield when plotted against herbicide rate at three of the four locations (Johnson *et al.*, 2012a). Leon *et al.* (2014) indicated that dicamba at 35 to 560 g ae ha^{-1} caused 20 to 78% injury to peanut from applications made 21 and 42 DAP, and the highest rate reduced peanut yield by 65%.

These studies are of great benefit to growers that face the possibility of peanut crop injury from off-target dicamba exposure, because in such an unfortunate situation the grower, extension agents, and crop consultants would be able to make an informed decision about the appropriate plan of action (Leon *et al.*, 2014; Prostko *et al.*, 2011). In an effort to link current data, it is necessary to quantify the injury and yield response of peanut after dicamba applications across various rates at preemergence up to beginning bloom (R1). Therefore, research was conducted to determine the sensitivity of peanut, in terms of plant injury and crop yield, to six rates of dicamba at four early-season application timings during the vegetative growth stages.

Materials and Methods

Field trials were conducted during 2012 and 2013 at three locations that represent the peanut growing regions in Georgia. The first location was the University of Georgia (UGA) Southwest

Table 1. Rainfall and irrigation received monthly with planting, digging, and harvest date for each experiment.[a]

	Rainfall and irrigation per month (cm)												
	May		June		July		August		September		October		Total
Site year	R[b]	I	R	I	R	I	R	I	R	I	R	I	H_2O
Plains 2012	2.4	3.2	6.8	1.0	10.2	2.7	4.7	1.0	10.1	0	1.5	0	43.6
Plains 2013	1.1	1.0	13.3	0	19.7	0	15.0	0	5.5	2.0	0.9	0	58.5
Ty Ty 2012	5.8	1.0	9.9	1.0	15.4	2.0	26.7	0	8.3	0	6.1	0	76.2
Ty Ty 2013	4.4	1.6	29.7	0.4	15.2	0	18.3	0	5.9	1	0.6	0	77.1
Attapulgus 2013	0.1	3.0	11.0	2.5	29.5	0.5	15.8	1.5	8.3	2.0	0.4	0	74.6

	Planting date	Digging date	Harvest date
Plains 2012	May 7	Sept. 27	October 7
Plains 2013	May 20	October 18	October 24
Ty Ty 2012	May 9	Sept. 27	October 8
Ty Ty 2013	May 13	Sept. 25	--------- [c]
Attapulgus 2013	May 10	October 3	October 8

[a]Rainfall and irrigation are reported in centimeters from planting date to harvest date.
[b]Abbreviations: rainfall, R; irrigation, I
[c]Peanut not harvested due to late season stand loss.

Georgia Research and Education Center in Plains, GA, which had a Greenville sandy loam (fine, kaolinitic, thermic Rhodic Kandiudult) soil with 3.8% organic matter (OM), 60% sand, 10% silt, and 30% clay; the second location was the UGA Tifton Campus Ponder Farm in Ty Ty, GA, which had a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudult) soil with 1% OM, 90% sand, 6% silt, and 4% clay; and the third location was the UGA Attapulgus Research and Education Center in Attapulgus, GA, which had an Orangeburg loamy sand (fine-loamy, kaolinitic, thermic typic kandiudult) soil with 1.5% OM, 86% sand, 6% silt, and 8% clay. Soil pH was 5.56, 5.63, and 6.0, respectively. The soil was prepared using a tillovator to loosen the soil and make it more suitable for planting. Peanut cultivar 'Georgia-06G' (Branch, 2007) was planted when soil conditions were warm enough for proper germination (around the 2nd week of May in Georgia). Specific planting dates are shown in Table 1. Peanuts were planted into rows spaced 91cm apart, two rows per plot, using vacuum style planters adjusted to 20 seed m^{-1} row^{-1}. Plots were 1.8 m wide and 7.6 m or 9.1 m long with the same size boarder on either side of each plot.

Preemergence herbicides were applied to suppress weeds early in the season, which included 1066 g ai ha^{-1} of pendimethalin (Prowl H_2O®, 456 g ai L^{-1}, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC), 71.4 g ai ha^{-1} of flumioxazin (Valor®, 51% ai w/w, granule, Valent U.S.A. Corporation, P.O. Box 8025, Walnut Creek, CA), and 26.5 g ai ha^{-1} of diclosulam (Strongarm®, 84% ai granule, Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN). PRE treatments were applied within three d of planting. Irrigation was applied to incorporate the herbicide into the soil and to firm up the soil around the peanut seed. Applications of POST herbicides were used as needed throughout the season which included acifluorfen (Ultra Blazer®, 240 g ai L^{-1}, United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA), clethodim (Select *Max*®, 116 g ai L^{-1}, Valent U.S.A. Corporation), and imazapic (Cadre®, 240 g ai L^{-1}, BASF Corporation). Hand-weeding was used as necessary. Supplemental irrigation was applied throughout the growing season as needed, which is shown in Table 1 with monthly rainfall received. Fertilizer, fungicides, and insecticides were applied by on-site farm management for the duration of the trials based on University of Georgia recommendations (UGA, 2013).

Trials were conducted using a randomized complete block design with 4 treatment timings and 6 herbicide rates, which included a non-treated control. Dicamba (Clarity® 4SC, 480 g ae L^{-1}, BASF Corporation) at rates of 0, 35, 70, 140, 280, and 560 g ae ha^{-1} was applied preemergence (PRE) immediately following crop planting, 10, 20, and 30 DAP. Treatments were replicated 4 times at Plains and Ty Ty and 3 times at Attapulgus. All treatments were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 152 kPa using TeeJet® XR8002VS nozzles (TeeJet® Technologies, Spraying Systems Company, Wheaton facility, P.O. Box 7900, Wheaton, IL).

The 10, 20, and 30 DAP treatments coincided with V2, V3, and V5 peanut vegetative growth

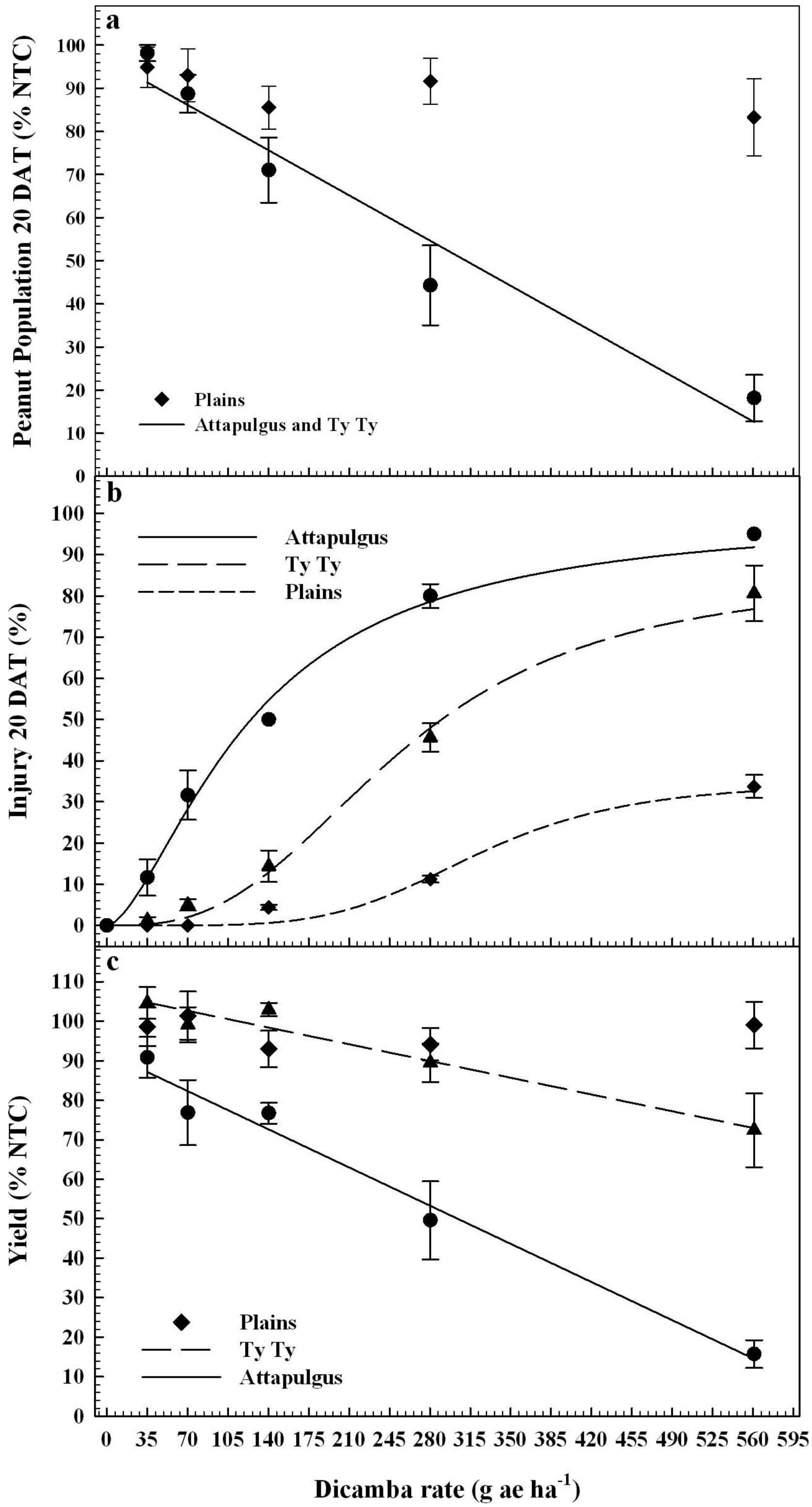

Fig. 1. Peanut plant population 20 days after treatment, DAT (1a), crop injury 20 DAT (1b), and crop yield (1c) as a percentage of the nontreated control (NTC), all regressed on rate of dicamba applied at planting (PRE). Data points represent the observed means with standard error.

stages respectively (Boote, 1982). The treatments will be discussed as the PRE, V2, V3, and V5 treatments. When the V5 treatments were applied, 25% of the peanut plants had blooms, making them very close to what is considered beginning bloom for a population of peanut plants or the first reproductive stage (R1) (Boote, 1982).

Peanut populations were recorded 20 d after planting. Visual estimates of injury were determined based on a combination of plant chlorosis, necrosis, stem epinasty, stem swelling, leaf strapping, leaf cupping, plant stunting, and lack of emergence with a scale of 0 (no injury relative to NTC) to 100% (plant death). Crop injury was evalauted throughout the growing season every 10 d until 80 DAP. At 130 DAP, non-dicamba-treated sections of peanut were checked for maturity using the hull-scrape method (Williams and Drexler, 1981) and the Peanut Profile Board (Developed by Jay Williams). Based on maturity tests, peanuts were dug and inverted. Digging dates and harvest dates are presented in Table 1. Peanuts were partially dried in bright sunlight for 5 to 10 d, and then each peanut plot crop was harvested with a two-row peanut harvester, bagged, and weighed. Moisture content was recorded and adjusted to 10% for final yield determination. Yield data were not collected for the Ty Ty 2013 site year due to late season stand loss. Peanut pod samples (500 g) from each plot were stored in small paper or mesh bags. Within three weeks, each plot sample was shelled with a mechanical peanut sheller, and then kernel weight of 100 random whole seed was measured from each sample.

Data were subjected to ANOVA using PROC GLMMIX (SAS Institute, Inc. 2012) to determine interactions between main factors (α = 0.05). Application timing and herbicide rate were considered fixed effects, whereas random effects included locations, years, replications and the associated interactions. Peanut injury estimates, crop population density, peanut canopy diameter, and peanut yield were each regressed on dicamba rate and fit to linear and nonlinear models.

The relationships between peanut injury and dicamba rate using raw replicate data were fit to log-logistic regression models,

$$y = \left(\frac{d}{1+\exp[b(\log(x) - \log(I_{50}))]}\right) \qquad [1]$$

where y is the estimate of peanut injury (%), d is the upper limit of the regression, x is the rate of dicamba (g ae ha^{-1}), I_{50} is the rate of dicamba that resulted in 50% of the maximum injury, and b is the slope of the regression at I_{50} (Ritz et al., 2013; Seefeldt et al., 1995). Differences among parameters between regression models were evaluated using t-test (Glantz and Slinker, 2001).

Results and Discussion

Significant effects were observed for location by dicamba rate (P $<$ 0.0002) and location by dicamba application timing (P $<$ 0.004). Based on those findings, peanut population, crop injury, and peanut yield were analyzed by location and treatment timing by herbicide rate.

Preemergence Treatments. Peanut response varied by location, possibly due to differences in edaphic characteristics (e.g. soil characteristics, microbial activity, temperature, etc.) or other environmental factors. PRE dicamba treatments caused a reduction in peanut emergence relative to the nontreated control (NTC), with a linear relationship between crop population and dicamba rate at Attapulgus and TyTy (Figure 1a). Peanut populations at Attapulgus and TyTy were reduced 15% for every 100 g/ha of dicamba, up to a maximum of 81% reduction at the highest tested dicamba rate (560 g ha^{-1}). However, there was no peanut population response to rate of dicamba at Plains.

←

Population, Attapulgus and Ty Ty,	$y = -0.15x + 97$	$R^2 = 0.75$
Injury, Attapulgus,	$y=\left(\frac{100}{1+exp[-3.7(log(x)-log(125))]}\right)$	$R^2 = 0.98$
Injury, Ty Ty,	$y=\left(\frac{85}{1+exp[-6.6(log(x)-log(256))]}\right)$	$R^2 = 0.90$
Injury, Plains,	$y=\left(\frac{35}{+exp[-11(log(x)-log(323))]}\right)$	$R^2 = 0.92$
Yield, Attapulgus,	$y = -0.14x + 92$	$R^2 = 0.87$
Yield, Ty Ty,	$y = -0.06x + 107$	$R^2 = 0.58$

Previous research demonstrated that dicamba has limited adsorption to soil particles, but studies have shown it moves with the farthest penetration of water through soil profile in an 18 hr period, suggesting some adsorption (Friesen, 1965). Dicamba is degraded under warm and moist aerobic conditions with half-lives of 1 to 6 wk, depending on soil microbial activity and soil texture (Taylor, 1983). In the present study, the Greenville soil (Plains) had a finer texture with 60% sand, 30% clay, and higher organic matter (OM) of 3.8 %; compared to the Tifton soil (Ty Ty) with 90% sand, 4% clay, and 1.0% OM; and the Orangeburg soil (Attapulgus) with 86% sand, 8% clay, and 1.5% OM.

Data analysis indicated that 20 DAT was the ideal post-application interval to evaluate peanut injury. This coincides with the timing of decisions that a grower must make concerning the future of an injured peanut crop (i.e. replant or continue with existing crop), and supports the conclusions of Leon *et al.* (2014). Visual estimates of peanut injury at 20 DAT were regressed on dicamba rate and fit to log-logistic regression models (Figure 1b). Maximum peanut injury (parameter *d* of the log-logistic regression model) occurred at the highest dicamba rate in the study (560 g ha^{-1}) and was 35% at Plains, 85% at TyTy and 100% at Attapulgus. The log-logistic regression model estimated an I_{50} of 125 g ha^{-1} of dicamba for Attapulgus peanut injury, which was a lower (P = 0.0003) dicamba rate than the I_{50} of 256 g ha^{-1} at TyTy and 323 g ha^{-1} at Plains (P = 0.00044). Prostko *et al.* (2003) reported peanut was injured 10 to 30% at 2 WAT when 300 g ha^{-1} of dicamba was applied 0 or 7 days before planting (DBP) of peanut. They concluded that peanut requires a 15 d planting interval when applying dicamba preplant to minimize the potential for peanut injury (Prostko *et al.*, 2003); dicamba in the current experiment was applied PRE immediately after peanut planting.

Peanut yield data were regressed on dicamba rate and fit to linear regression models for TyTy and Attapulgus (Figure 1c). Maximum peanut yield loss at TyTy was 28% from 560 g ha^{-1} dicamba, with a 6% rate of yield loss with each 100 g ha^{-1} dicamba. The rate of peanut yield loss at Attapulgus was more than double that at TyTy, with 14% yield loss for each 100 g ha^{-1} dicamba, with maximum yield loss of 84%. In contrast to the other locations, there were no detectable differences in peanut yield losses at Plains related to PRE dicamba treatments. We hypothesize that this lack of yield response at Plains can be attributed, in part, to the consistent peanut populations at this location across all rates of dicamba (Figure 1a). Prostko *et al.* (2003) determined that 300 g ha^{-1} dicamba reduced peanut yield when applied at planting in Texas in 2000 and Attapulgus, GA in 2001, however other site-years did not have yield loss.

V2 Growth Stage Treatments. Dicamba treatments were applied at the V2 vegetative growth stage of peanut, approximately 10 DAP. Peanut injury data were regressed on dicamba rates and fit to log-logistic regression models (Figure 2a). At Plains, maximum peanut injury at 20 DAT from V2 applications of dicamba was nearly double the injury from PRE applications ($P < 0.0003$). At TyTy and Attapulgus, maximum peanut injury from V2 dicamba treatments was >75%, consistent ($P > 0.44$) with injury from PRE dicamba treatments at both of the locations. Attapulgus and Plains peanut injury I_{50} estimates of 52 and 124 g ha^{-1} of dicamba, respectively, were significantly different (P = 0.001) from one another, whereas Ty Ty peanut injury I_{50} estimate of 92 g ha^{-1} of dicamba was no different from Attapulgus or Plains ($P > 0.24$). This demonstrates the greater sensitivity of emerged peanut to dicamba, as I_{50} values from V2 applications were less than half those from PRE applications, indicating a lower rate of dicamba was sufficient to elicit 50% injury.

Peanut yield declined in a linear manner as rate of dicamba applied at V2 growth stage increased (Figure 2b). Maximum yield loss varied among locations, with 560 g ha^{-1} causing 24% yield loss at Plains, 54% at TyTy, and 82% at Attapulgus. The rate of yield loss varied among locations, with 4, 8, and 11% peanut yield loss for each 100 g ha^{-1} of dicamba at Plains, TyTy, and Attapulgus, respectively.

V3 Growth Stage Treatments. Dicamba treatments were applied at the V3 vegetative growth stage of peanut, approximately 20 DAP. Peanut injury data evaluated 20 DAT were regressed on dicamba rate and fit to log-logistic regression models (Figure 3a). Maximum peanut injury 20 DAT (parameter *d*) from V3 applications of dicamba was 45% at Plains, 72% at Ty Ty, and 100% at Attapulgus; this maintained the trend of greater injury (P = 0.0037) at Attapulgus relative to Plains, with Ty Ty as intermediate and similar to both ($P > 0.14$). There were no differences ($P > 0.85$) in peanut injury I_{50} estimates among the locations (78 to 85 g ha^{-1} dicamba). Griffin *et al.* (2013) determined that soybean, another legume, is sensitive to dicamba during the V3 and V4 growth stages. By 7 DAT, they estimated soybean injury was 20 to 89% from 4 to 280 g ha^{-1} of dicamba, and by 14 DAT the predicted soybean injury for 140 g ha^{-1} had increased an additional 19%, and the 280 g ha^{-1} had increased to 97% injury (Griffin *et al.*, 2013). Leon *et al.* (2014), reported 20 to 78% injury to

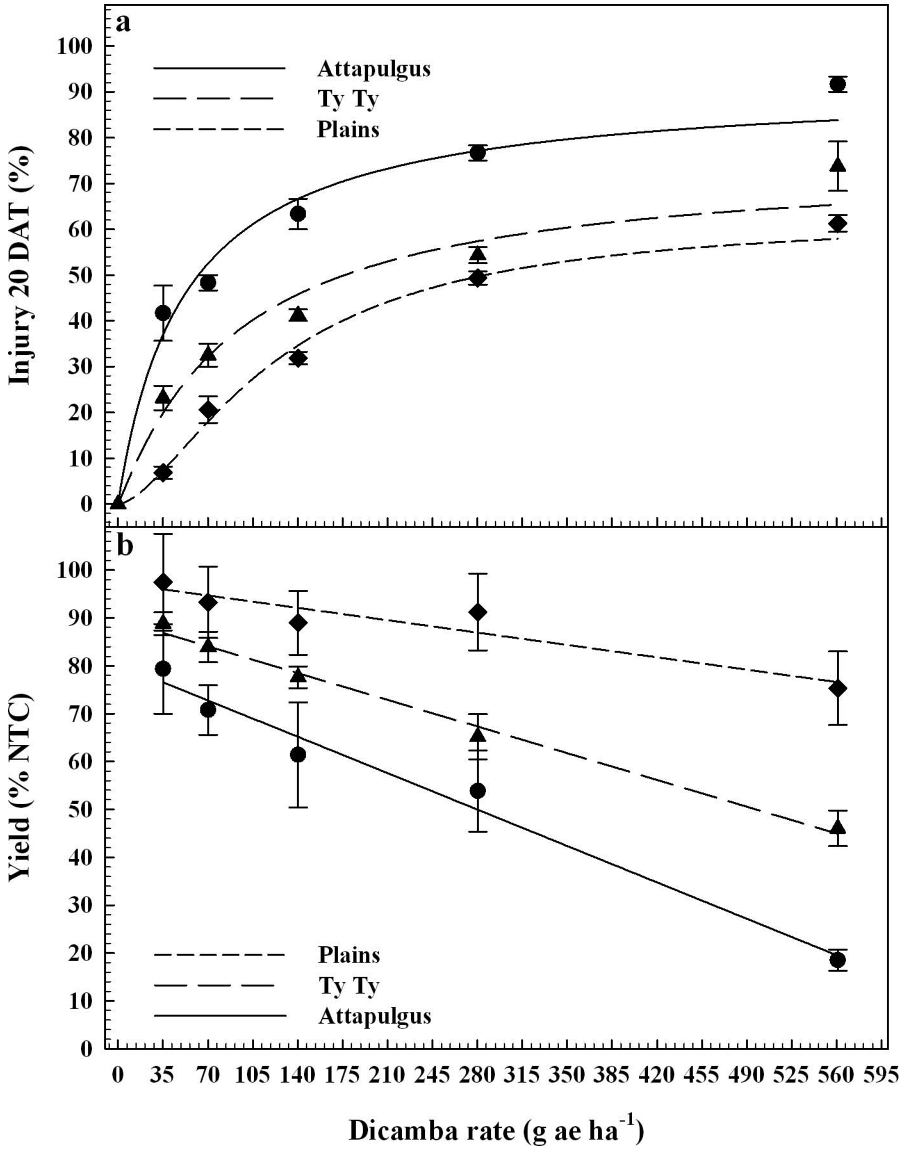

Fig. 2. Peanut injury 20 days after treatment, DAT (2a) and crop yield (2b) as a percentage of the nontreated control (NTC) regressed on rate of dicamba applied at the V2 peanut growth stage. Data points represent the observed means with standard error.

Injury, Attapulgus,	$y=\left(\frac{92}{1+exp[-2.3(log(x)-log(52))]}\right)$	$R^2 = 0.93$
Injury, Ty Ty,	$y=\left(\frac{75}{1+exp[-2.4(log(x)-log(92))]}\right)$	$R^2 = 0.88$
Injury, Plains,	$y=\left(\frac{63}{1+exp[-3.7(log(x)-log(124))]}\right)$	$R^2 = 0.95$
Yield, Attapulgus,	$y = -0.11x + 80$	$R^2 = 0.76$
Yield, Ty Ty,	$y = -0.08x + 90$	$R^2 = 0.86$
Yield, Plains,	$y = -0.04x + 97$	$R^2 = 0.10$

peanut from 35 to 560 g ha^{-1} of dicamba, when applications were made at 21 and 42 d after planting.

Peanut yield data was regressed on rate of dicamba and fit to linear models by location (Figure 3b). There were differences ($P < 0.004$) in the rate of yield reduction per unit of dicamba between Plains (5% yield loss for each additional 100 g ha^{-1} of dicamba) and both Ty Ty and Attapulgus (10 and 13% yield loss for each additional 100 g ha^{-1}, respectively). The maximum yield loss ranged from 30% at Plains to 94% at Attapulugus. Griffin *et al.* (2013) reported soybean yield loss of

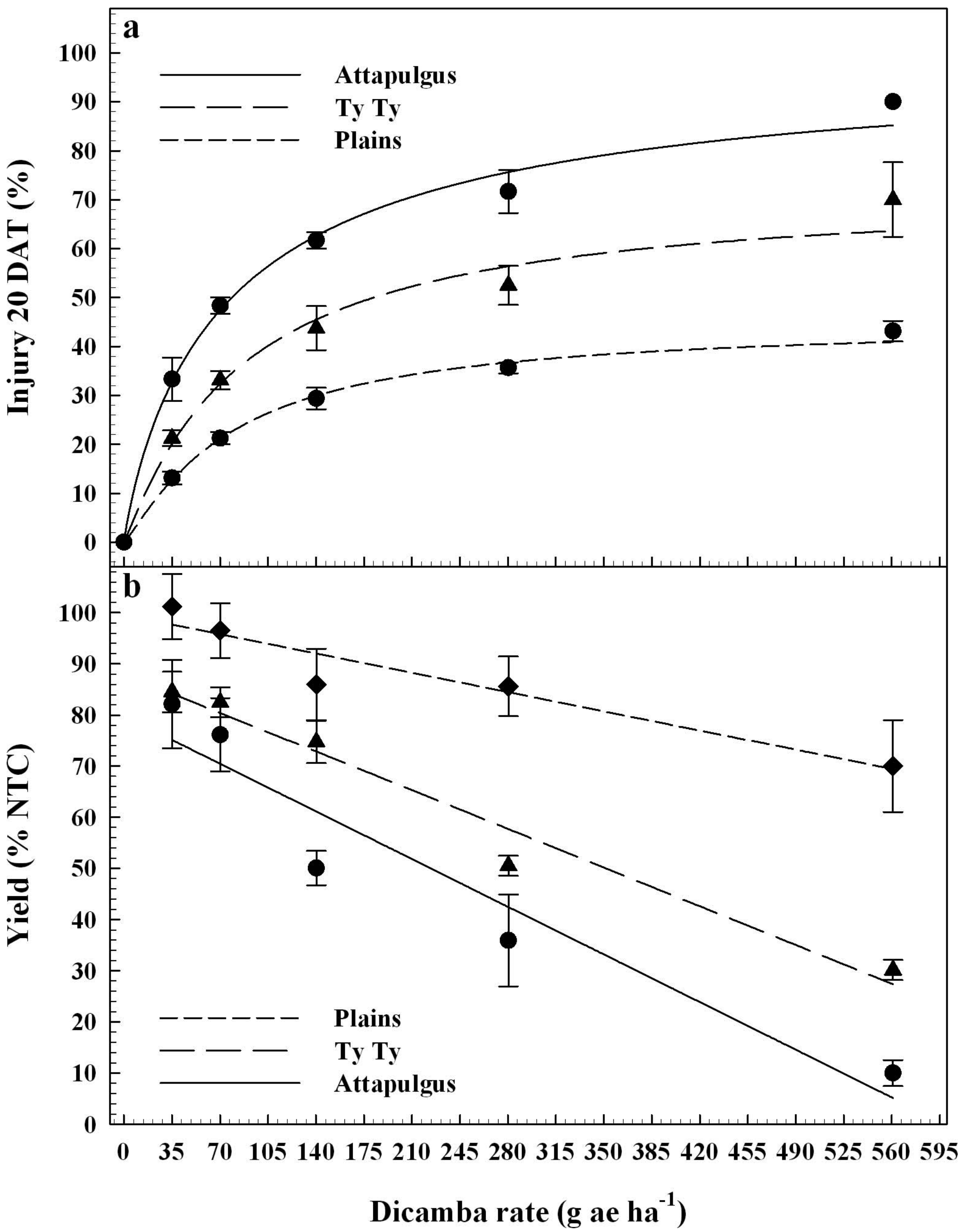

Fig. 3. Peanut injury 20 days after treatment, DAT (3a) and crop yield (3b) as a percentage of the nontreated control (NTC) regressed on rate of dicamba applied at the V3 peanut growth stage. Data points represent the observed means with standard error.

Injury, Attapulgus,	$y=\left(\frac{100}{1+exp[-2.1(log(x)-log(79))]}\right)$	$R^2 = 0.96$
Injury, Ty Ty,	$y=\left(\frac{72}{1+exp[-2.5(log(x)-log(85))]}\right)$	$R^2 = 0.79$
Injury, Plains,	$y=\left(\frac{45}{1+\exp[-2.7(log(x)-log(78))]}\right)$	$R^2 = 0.92$
Yield, Attapulgus,	$y = -0.13x + 80$,	$R^2 = 0.82$
Yield, Ty Ty,	$y = -0.11x + 88$,	$R^2 = 0.91$
Yield, Plains,	$y = -0.05x + 100$,	$R^2 = 0.24$

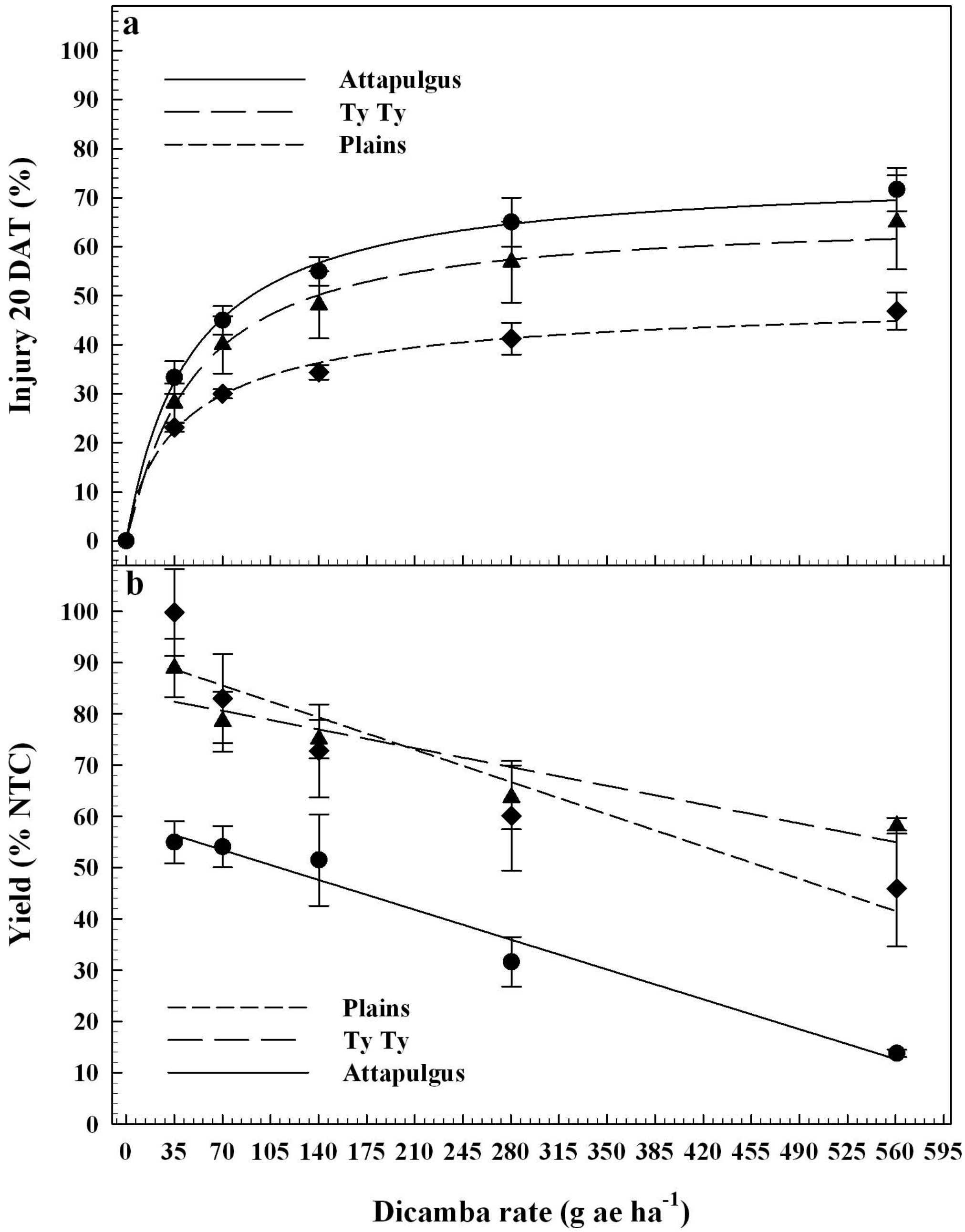

Fig. 4. Peanut injury 20 days after treatment, DAT (4a) and crop yield (4b) as a percentage of the nontreated control (NTC) regressed on rate of dicamba applied at the V5 peanut growth stage. Data points represent the observed means with standard error.

Injury, Attapulgus,	$y=\left(\frac{75}{1+exp[-2.3(log(x)-log(46))]}\right)$	$R^2 = 0.92$
Injury, Ty Ty,	$y=\left(\frac{66}{1+exp[-2.5(log(x)-log(48))]}\right)$	$R^2 = 0.60$
Injury, Plains,	$y=\left(\frac{50}{1+exp[-2.0(log(x)-log(44))]}\right)$	$R^2 = 0.87$
Yield, Attapulgus,	$y = -0.08x + 59$	$R^2 = 0.80$
Yield, Ty Ty,	$y = -0.05x + 84$	$R^2 = 0.52$
Yield, Plains,	$y = -0.09x + 92$	$R^2 = 0.30$

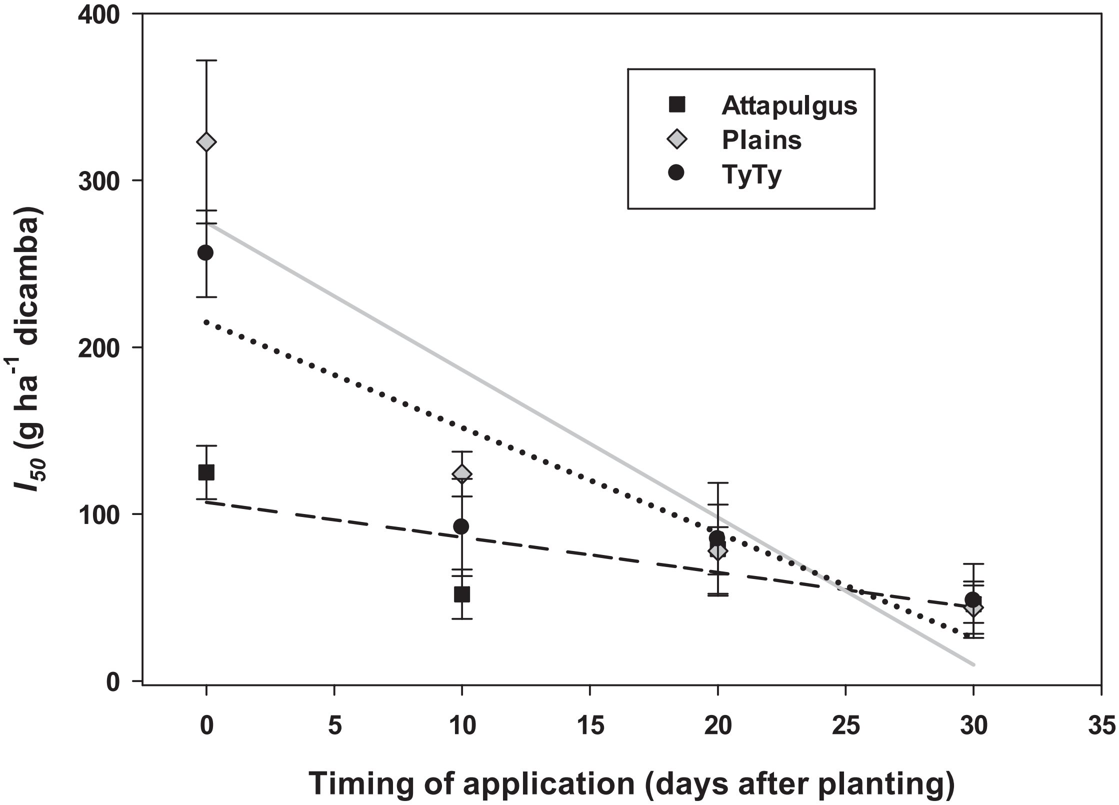

Fig. 5. The linear relationships between estimates of dicamba rate that produces a 50% peanut injury response (I_{50}) and timing of application for each of the three locations.

Attapulgus,	y = − 2.10x + 107	R^2 = 0.57
Ty Ty,	y = − 6.31x + 215	R^2 = 0.78
Plains,	y = − 8.83x + 275	R^2 = 0.83

85% for the 140 g ha^{-1} rate of dicamba. Leon *et al.* (2014) indicated 20% peanut yield loss at 35 g ha^{-1}, and 65% yield loss at 560 g ha^{-1} of dicamba 21 and 45 DAP.

V5 Growth Stage Treatments. The final application of dicamba treatments were applied at the V5 vegetative growth stage of peanut, approximately 30 DAP when 25% of the plants were in the early stages of flowering. According to Boote (1982), the first reproductive growth stage is beginning bloom (R1), which is characterized by 50% of the peanut population with blooms. Therefore, while the peanut trials had not entered the R1 growth stage at the time of dicamba applicaiton, they did just days later. Peanut injury was regressed on dicamba rate and fito to log-logistic models (Figure 4a). Maximum peanut injury from dicamba was lower (P = 0.04) at Plains (50%) relative to Attapulgus (75%), with Ty Ty (66%) similar to both (P > 0.33). There were no differences (P > 0.89) between peanut injury I_{50} estimates (44 to 48 g ha^{-1}) among the locations. A previous study documented that peanut treated with 140 g ha^{-1} of dicamba approximately 3 wk after crop emergence incurred 80% injury 2 WAT (Johnson et al., 2012a).

Similar to each of the other application timings, peanut yield data declined in a linear manner as dicamba rate increased at V5 applications (Figure 4b). There were no detectable differences (P > 0.11) in the rate of yield reduction per unit of dicamba (5 to 9% yield loss for each additional 100 g ha^{-1} of dicamba) among locations. However, there were differences in the y-intercept (representing the response as dicamba dose approached zero) between Attapulgus and both Ty Ty (P = 0.0001) and Plains (P = 0.0005). These differences among locations were maintained at the highest tested dicamba rate (560 g ha^{-1}), with 86% yield loss at Attapulgus, 58% at Plains, and 44% at Ty Ty. At the same Plains location, Prostko *et al.* (2011) reported an estimated peanut yield loss of 7% from 40 g ha^{-1} of dicamba applied 30, 60, and 90 DAP. In the current study, peanut yield loss associated with 40 g ha^{-1} dicamba ranged from 0 to 44% when applied PRE, 10 (V2), 20 (V3), and 30 DAP (V5), with a yield loss of 15% when averaged over locations and application timings (Figures 1c, 2b,

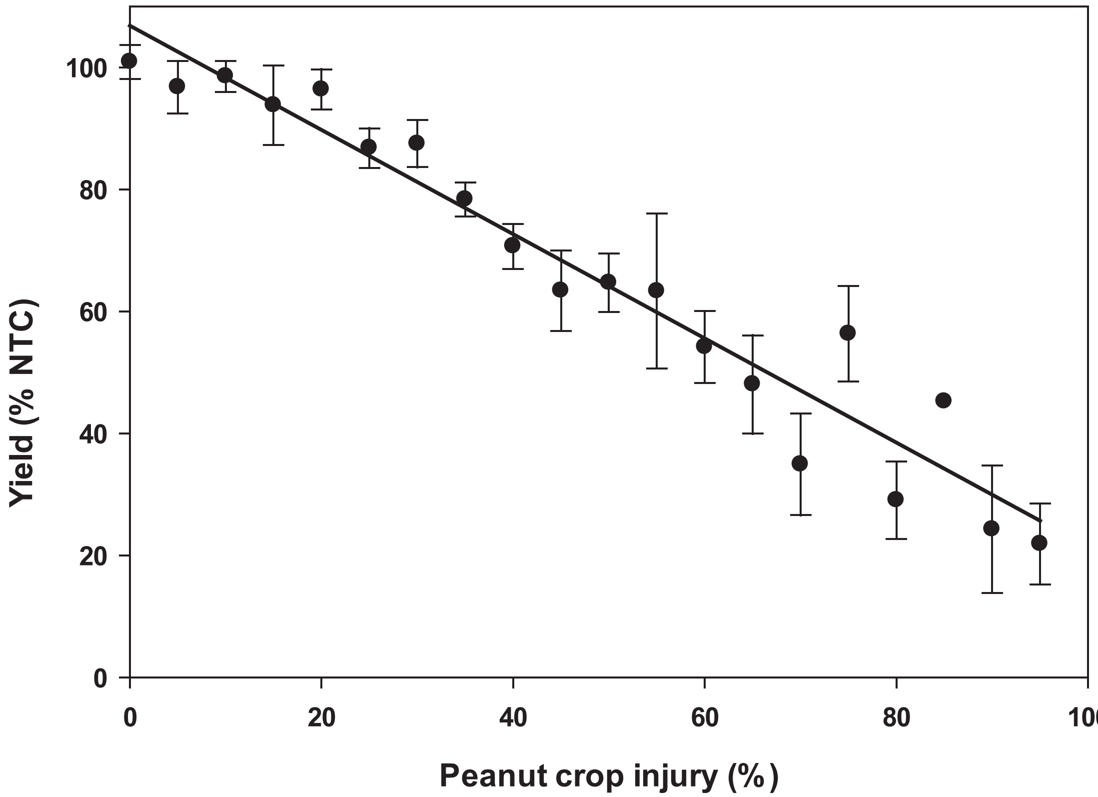

Fig. 6. The linear relationship between peanut yield (expressed as a percentage of the nontreated control, NTC) and peanut crop injury evaluated 20 days after treatment.

y = −0.85x + 107	**R^2 = 0.49**

3b, 4b). In a previous study, peanut at the Ty Ty location had an estimated yield loss of 93% at 560 g ha^{-1} when applied 30 DAP (Prostko *et al.*, 2011). The current study confirms the potential for this level of peanut yield loss from 560 g ha^{-1} when applied PRE (0 to 86% yield loss), 10 DAP (24 to 82%), 20 DAP (30 to 94%), and 30 DAP (45 to 87%). However, the variability among locations in peanut yield loss suggests that additional factors may potentially confound accurate predictions of yield loss from off-target movement or misapplicaitons of dicamba; additional research to further investigate this variability is needed.

Summary and Conclusions

Plant injury increased with dicamba rate when applied to peanut in vegetative growth stages. Due to the detrimental injury (leaf chlorosis, necrosis, stem epinasty, leaf strapping, stem swelling, and plant stunting) peanut plant growth was reduced or stopped, resulting in reduced peanut yield. Peanut injury and yield loss was quite variable among locations. Differences in soil textures and other edaphic conditionspotentially contributed to variable responses by peanut to dicamba. Generally, dicamba was more injurious to peanut as plants approached initial bloom at 30 DAP, the treatment applied to the most mature plants evaluated in this study. There was a linear relationship between I_{50} values for peanut injury and timing of application by location, with a decline in dicamba rate needed to produce a 50% response in peanut injury over time (Figure 5). This demonstrated the greater peanut sensitivity to dicamba as applications were made to older plants. Across all treatments and locations, there was also a negative linear relationship between peanut yield and peanut crop injury, with a decline of 8.5% yield for every 10% increase in crop injury (Figure 6).

Based on the rapid adoption of previous herbicide resistant crop technology (Webster and Sosnoskie 2010), dicamba resistant crops have the potential for widespread use in the near future. Growers utilizing this technology will need to be aware of potential for off-target movement of dicamba to peanut fields, implementing practices to prevent dicamba drift, sprayer contamination, and volatilization. Due to the sensitivity of peanut to dicamba, growers and applicators should take caution when applying dicamba in the proximity of peanut throughout all vegetative and early reproductive growth stages. In the unfortunate situation where peanut injury from accidental dicamba exposure occurs, these data could assist the grower in determining peanut yield loss estimates and a possible plan of action.

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