Enhancing Integrated Roadside Vegetation Management Along North Carolina Roadsides through Characterizing Herbicide Fate

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16. Abstract

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Field research revealed Oust (active ingredient: sulfometuron) applied ≥ 6 wk prior to planting poses increased risk to corn, cotton, and tobacco compared other evaluated herbicides. Whereas with appropriate spray drift-prevention practices, all herbicides may be safely applied near soybean production fields ≥ 6 wk prior to planting.

Lastly, research evaluating dormant-stem herbicide efficacy indicate applications conducted March and April suppress maple, oak, and sweetgum growth more than applications occurring from December through February; although it should be noted application performed in March and April present increased risk to neighboring sensitive crops.

This information can be used by the NC DOT Roadside Environmental Unit to aid decision making and ensure all appropriate precautions are implemented to minimize off-target movement with respect to sprayer setup, product selection, and application timing.

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SUMMARY

Research experiments were designed and conducted to characterize herbicide fate after broadcast or dormant-stem applications conducted along North Carolina roadsides as well as assess crop sensitivity to herbicides routinely used by the North Carolina Department of Transportation (NC DOT) for vegetation management. Results from this project suggest that all spray heads currently used by the NC DOT provide acceptable coverage in the treated spray swath. A notable difference between spray heads was observed in drift potential with drift increasing as application volume decreased.

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INTRODUCTION

Managing roadside vegetation is essential for providing motorists with safe travel routes and preserving the integrity of road system infrastructure as unmanaged vegetation can impede motorist sightlines, obscure signage, and result in damage to the physical road structure (NCHRP, 2005). The North Carolina Department of Transportation (NC DOT) manages the second largest state-supported transportation network in the nation with greater than 15,000 miles of primary roads (interstate and highways) and 60,000 miles of secondary roads under its purview (Anonymous 2020). Biological and climatic diversity in North Carolina is enormous (USEPA ecoregion map) and demonstrates the necessity for integrated roadside vegetation management (IRVM) approaches on a regional basis as a generic statewide strategy can lead to effective results in one part of the state but render inadequate results in another (Martin et al. 2017). Synthetic herbicides are an integral component of IRVM, as these products can extend vegetation suppression and are economically favorable compared to mechanical approaches (Pellegrini et al. 2016); however, due to wide-ranging climatic conditions in North Carolina and throughout the southeastern United States, conditions can arise during or following a herbicide application that can lead to off-target movement and can adversely affect adjacent crops (USEPA 2020), human health (Aylward and Hays 2015), or wildlife (Bohnenblust et al. 2013; Bohnenblust et al. 2016).

Off-target herbicide movement can occur via spray particle drift or volatilization, among other pathways (Behrens and Lueschen 1979; Bish et al. 2019; Egan et al. 2014). Although herbicide label verbiage and supplemental information pertaining to practices to mitigate off-target pesticide movement are available (Felsot et al. 2010), small amounts of spray drift are inevitable (USEPA 2011). Arvidsson et al. (2011) evaluated the effect of boom height (1- to 3-ft) on spray drift and reported average total drift was 5%, which may lead to crop losses if herbicide residue is deposited on bordering agricultural fields. Previous researchers have demonstrated crop injury can occur as a result of herbicide exposure via soil and/or foliar pathways (Jeffries et al. 2014; Kelley et al. 2005; Marple et al. 2007; Pfleeger et al. 2011; Yelverton et al. 1992), suggesting the risk of off-target herbicide movement to sensitive crop species exists when applied prior to or following crop establishment. This is concerning, as the NC DOT warm-season release (WSR) program, which is intended to control undesirable winter weeds and annual grasses in turf species such as bermudagrass (*Cynodon dactylon* L.), occurs from February through July (Figure 6; KC Clemmer, personal communication 2019). Herbicides used in the NC DOT WSR program include (but are not limited to): Confront, Escort, and Oust (KC Clemmer, personal communication 2019). Further, the NC DOT apply Plateau and Oust from May through August and Confront from April through September to suppress problematic weeds such as vaseygrass (*Paspalum urvillei*), Johnsongrass (*Sorghum halepense*), and marestail (*Conyza canadensis*), among others, which can obscure signage, guardrails, and impair motorist sightlines (Anonymous 2017a; KC Clemmer, personal communication 2019; NCHRP, 2005). Finally, the NC DOT apply Garlon 4 and Patron 170 from December through March for dormant-stem brush control, while Arsenal is used to control actively growing brush from August through October (KC Clemmer, personal communication 2019).

In North Carolina, corn, and cotton planting as well as tobacco transplanting usually occur from April through May, while soybean planting is most active from late-May through June (Figure 7; NCDA&CS, 2020). Traditional harvest dates for corn and final harvest for tobacco occur in September through early-October, while cotton and soybean harvest may occur from September through mid-December (Figure 7; NCDA&CS, 2020). Pairing these crop production dates with NC DOT herbicide programs suggest roadside herbicide applications may occur prior to or during a majority of corn, cotton, soybean, and tobacco production stages. Further, North Carolina is among the most agriculturally diverse states in the US, producing more than 80 different commodities (USDA&NASS 2019). Pimentel (2005) reported crop injury and subsequent loss resulting from herbicide spray drift are more prevalent in regions with high crop diversity. Crop losses associated with pesticide spray drift are difficult to quantify due to underreporting of incidents to regulatory authorities and private settlements (US EPA 2020); however, estimated annual crop losses due to off-target pesticide movement in the US range from $35 to $136 million USD annually (Pimentel 2005) and recent reports suggest this figure may be much higher. Specifically, in 2020 a Missouri peach farmer was awarded $265 million USD after alleging his 1000-acre orchard was irreparably damaged as a result of dicamba spray drift from applications made to neighboring agricultural fields; however, punitive damages were later reduced to $60 million USD (USDCEDM 2020).

The NC DOT manages approximately 600,000 acres of maintained rights-of-way, which encompasses highways, secondary roads, and railway lines (Lewis et al. 2011). One of many challenges of roadside vegetation management on rights-of-way is the expeditious growth and leaf production of woody plants. Dormant-stem herbicide applications are commonly used by the NC DOT and are described as an herbicide treatment applied to the branches and trunks of deciduous woody/brush vegetation in order to suppress growth. In order to prevent brown-out or senescence of the tree leaves, these herbicide applications are conducted when the woody plants are dormant. In North Carolina, dormant-stem applications are employed December through March. The Garlon 4® has shown to provide excellent control of numerous hardwood species (Hall and Hendler 1986; Pancake and Miller 1990). Garlon 4 and Patron 170® tank-mixed are commonly used by the NC DOT for dormant-stem applications. This research was conducted to evaluate the of Garlon 4 + Patron 170 on woody vegetation as affected by application timing and spray volume.

MATERIALS AND METHODS

Characterize Herbicide Fate and Transport from Application via Passive Air Samplers. Field research was conducted in 2020 and 2021 on a roadside (Interstate 540; Figure 1) in Wake County, NC (Lat. 35.85°N, Long. 78.86°W) to evaluate spray particle drift and subsequent volatility of Garlon 3A (128 fl oz A^{-1}). Research evaluated three boomless spray heads routinely used by NC DOT for roadside herbicide applications. Spray heads included nutating (Figure 2; Model NSC-20108-V2; Norstar Industries, Inc., Auburn, WA), air induction (Figure 3; Model RSI-2870-V2; Roadside, Inc., Auburn, AL), and Boominator® (Figure 4; Model 2650FM; Udor USA, Lino Lakes, MN). All spray heads were fixed at a 45-degree angle to the ground. Experiments were initiated on July 28, 2020, October 20, 2020, February 24, 2021, and April 21, 2021, which correspond to summer, fall, winter, and spring seasonal application timings, respectively.

Garlon 3A (active ingredient: triclopyr) residue in air was quantified using passive air sampler devices. The passive air sampler housing, often referred to as the 'flying saucer', (Tuduri et al. 2005) consists of two stainless-steel bowls with the upper bowl (facing downward), measuring 9.75 in diam. and the lower bowl (facing upwards), measuring 7.75 in diam. (Figure 4). One hole was drilled (1/4 in diam.) into the center of each bowl and they were fastened together with a threaded stainless-steel rod (1/4 in diam. x 8 in length). When fastened, the two bowls create a 27.5 in^2 opening inside the housing perimeter to facilitate air circulation inside the housing and to promote additional air circulation, eight holes (3/8 in diam.) were drilled into the base (around the parameter) of the lower bowl. Average sampling rate was estimated to be 1.5 to 3.5 ft^3 per hr. Passive air samplers housed a polyurethane foam (PUF) disk (5.5 in diam. x 0.5 in width) (TE-1014; Tisch Environmental, Inc., Cleves, OH), which is a uniformly porous substrate to allow very fine droplets and/or gaseous substances to penetrate and be absorbed.

Unique plots measuring 150 ft in length were used and divided into a 100 ft center section, which would be treated with Garlon 3A as well as 25 ft sections on each side of the treated area to minimize lateral herbicide movement from adjacent plots. One day prior to trial initiation, steel fence posts measuring 72 in height (utilized for mounting air samplers) were driven into the ground (approximately 8 to 12 in depth) in the center of each plot, which allowed the PUF disk to be at a height of 60 in from the soil surface. Within each plot, air samplers were deployed at three distances (3, 9, and 30 ft) from the treated spray swath. Next, each air sampler was loaded with a PUF disk, then covered with a 2-gal Ziploc bag until trial initiation.

On the morning of trial initiation, 48.98 gallons of water were added to the truck mounted spray tank and measured with a water flow meter (01N Digital Water Meter, Great Plains Industries, Inc., Wichita, KS). Then it was driven to the experimental site and the spray volume level was marked on the tank. Once on site, Garlon 3A (131 fl oz) was added to the spray tank, which corresponded to a Garlon 3A rate of 1 gal A^{-1} for the first deployed spray head (nutating) and calibrated to deliver a spray volume of 49 gal A^{-1} at 38 psi with a travel speed of 7 MPH (Table 1). Across application timings, nutating spray head was the first spray head to be used, followed by air induction and finally the Boominator. This order was essential, as preliminary efforts revealed differing spray application volumes between the three evaluated spray heads when operated at the standard pressure employed by the NC DOT when using each spray head (KC Clemmer, personal communication). The spray application procedure consisted of charging the sprayer for 10 sec (> 3000 ft upwind of nearest plot), and then applying Garlon 3A to three plots measuring 100 ft in length. Following nutating spray head application, the truck mounted sprayer was driven back to the exact location where the spray volume level had been marked on the tank and water was added to the tank to reach the initial 48.98 gal of solution. The amount of water needed to replenish the spray tank to initial fill level was calculated and an appropriate amount of Garlon 3A was then added in order to achieve the necessary concentration in the tank to deliver Garlon 3A at a rate of 1 gal A^{-1} with the next spray head. The nutating spray head was swapped with air induction spray head. The application procedure for air induction spray head was identical to nutating head and following application water was added to the tank to reach the initial 48.98 gal of spray solution. Solution concentration in the spray tank was once again adjusted for the next evaluated spray head and air induction spray head was replaced with Boominator spray head. The application and refilling procedures were essential for ensuring the Garlon 3A rate (1 gal A^{-1}) was the same when applied across spray heads as differing spray volumes between spray heads required varying herbicide concentrations in the spray tank. After mixing but prior to charging the spray boom a 2 fl oz sample of the spray solution was collected (referred to as “tank-dip”) to be analyzed to ensure the herbicide concentration in the spray tank aligned with the calculated nominal application rate for each respective spray head.

Following application, PUF sample collection occurred at the end of each of four time intervals corresponding to 0 to 4, 4 to 24, 24 to 48, and 48 to 96 hr after treatment (HAT). At each sample collection timing, the PUF sample was removed from the air sampler placed in a glass jar (16 fl oz) then the interior air sampler walls were wiped with a moistened wipes (Kimwipes®, Kimberly-Clark Corp., Roswell, GA), which were placed inside a separate 8 fl oz glass jar and both stored temporarily on ice in the field then transferred to a freezer (-10 F) within 2 h. Following sample collection, a new PUF disk was inserted into the air sampler for the subsequent sample collection timing through 96 HAT. In addition to PUF samples, recovery pads (62 in^2, Fisher™ Pure Cellulose Chromatography Paper; Thermo Fisher Scientific, Inc., Pittsburgh, PA) were positioned 11 ft from the pavement (center of spray swath) in the center of each plot at a height of 0.5 ft from the soil surface and collected within 15 mins of application to ensure Garlon 3A was applied at the intended rate. Further, recovery pads were placed at the base of each air sampler located 3 ft from the treated area to collect spray particle drift deposited at application and were collected within 15 min of application and these along with recovery pads located in the treated area were placed in unique glass jars (16 fl oz).

Three replications of a 4 by 3 factorial treatment arrangement were evaluated. Factorial levels included four seasonal application timings (winter, spring, summer, or fall), three spray heads (nutating, air induction, or Boominator) with nontreated plots and samples included within each application timing and experimental block. Statistical analysis was performed by subjecting data to ANOVA ($P \leq 0.05$) using MIXED procedures in SAS® (Version 9.4, SAS Institute, Inc., Cary, NC). Spray head, seasonal application timing, and sample collection timing were analyzed as fixed effects, while replicate was considered a random effect. Mean separation occurred according to Fisher's protected LSD ($P = 0.05$). Finally, date, time, and climatic conditions (relative humidity, air temperature, wind direction, and wind speed) at application were recorded using a weather station (WatchDog 2000 Weather Station; Spectrum Technologies, Inc., Plainfield, IL) positioned in the center of the research area (55 ft from road surface) for each spray head and seasonal application timing (Table 2).

Characterize Drift and Volatility of Herbicides to Adjacent Crops and Off-Target Species.
Field Experiment. Field research was initiated on January 17, 2019, and January 23, 2020, at Sandhills Research Station in Jackson Springs, NC (35.18°N, 79.68°W) on a Candor sand (sandy, kaolinitic, thermic Grossarenic Kandiudults; 92, 4, 4% sand, silt, and clay, respectively) with a pH ranging from 5.6 to 5.9 and matter content of ≤1.5% (wt/wt). Evaluated crop species included corn 'DK C62-08', cotton 'DP 1646B2XF', soybean 'S43XS27', and tobacco 'NC 196' which were seeded (corn, cotton, and soybean) or transplanted (tobacco) on 13 May 2019 and 11 May 2020. Corn, cotton, and soybean were seeded at 28,000, 40,000, and 123,000 seeds A^{-1}, respectively, while tobacco was transplanted at a planting density of 6,000 plants A^{-1} and all crops planted on a row width of 38 in. Seeding was performed with a four-row vacuum planter (John Deere, Moline, IL) equipped with a GPS guidance system and was utilized prior to trial initiation for mapping the location of to-be planted crop rows. By doing so, this ensured the center of plots treated prior to planting would be the area where crops would be seeded. Evaluated crops species were selected as they are widely grown in North Carolina and throughout the southeastern United States based on their prevalence in North Carolina. In 2019, > 900,000 acres of corn, > 500,000 acres of cotton, > 1,500,000 acres of soybean, and > 115,000 acres of tobacco were harvested in North Carolina generating > $1.65 billion USD in combined production value, positioning these crops as the four most economically valuable crops in the state (NCDA&CS, 2020).

Experimental plots measured 10 ft in length and consisted of a single herbicide-treated row with nontreated border rows on either side to reduce the risk of damage to adjacent plots caused by lateral herbicide movement. Corn and soybean cultivars were glyphosate-resistant, and weeds were controlled prior to planting and in season with three applications of Roundup PowerMax® (1.1 lb glyphosate A^{-1}; 20 gal A^{-1}) within each year. Crops were managed following recommendations provided by the North Carolina Cooperative Extension Service for corn (Weisz 2013), cotton (Edmisten et al. 2021), soybean (Stowe et al., 2017) and tobacco (Fisher, 2018) production regarding fertilization, irrigation, and pest control, among other production practices. Specific to pesticides, Prowl® 3.3EC (0.7 lb pendimethalin A^{-1}; 20 gal A^{-1}) and Coragen® (0.1 lb chlorantraniliprole A^{-1}; 20 gal A^{-1}) were applied at planting.

Evaluated herbicide rates included 100, 10, 5, or 1% of a typical North Carolina roadside vegetation management rate (NCRVM) (KC Clemmer, personal communication 2019). Evaluated herbicide treatments included four acetolactate synthase inhibitors (ALS) (also called acetohydroxy acid synthase) and three synthetic auxins. ALS herbicides included: Plateau® (100, 10, 5, or 1% drift of a 6 fl oz A^{-1} application rate: active ingredient: imazapic; BASF Corp., Research Triangle Park, NC), Arsenal® (100, 10, 5, or 1% drift of a 1 pt A^{-1} application rate; active ingredient: imazapyr; BASF Corp., Research Triangle Park, NC), Escort® (100, 10, 5, or 1% drift of a 1 oz A^{-1} application rate; active ingredient: metsulfuron-methyl; Bayer Environmental Science, Research Triangle Park, NC), and Oust® (100, 10, 5, or 1% drift of a 1.5 oz A^{-1}; application rate; active ingredient: sulfometuron-methyl; Bayer Environmental Science, Research Triangle Park, NC). Synthetic auxin herbicides included: Confront® (100, 10, 5, or 1% drift of a 1 pt A^{-1} application rate; active ingredients: clopyralid + triclopyr triethylamine salt; Dow AgroSciences, Indianapolis, IN), Garlon 4® (100, 10, 5, or 1% drift of a 2 gal A^{-1} application rate; active ingredient: triclopyr butoxyethyl ester; Dow AgroSciences, Indianapolis, IN), and Patron 170® (100, 10, 5, or 1% drift of a 1 gal A^{-1} application rate; active ingredients: 2,4-D + 2,4-DP-p; Nufarm Americas Inc., Burr Ridge, IL). A nonionic surfactant (Induce®, Helena Chemical Co., Collerville, TN) was applied at 0.25% (vol./vol.) for all herbicide applications. Herbicides were applied using a hand-held CO_2-pressurized sprayer equipped with a three-nozzle boom. Plots treated with Confront, Arsenal, Plateau, Escort XP, and Oust XP were applied using 80015 DG VS flat-fan nozzles (TeeJet Flat-Fan Nozzles, Spraying Systems Company, Wheaton, IL) calibrated to deliver 15 gal A^{-1} at 20 psi to simulate a broadcast roadside application. Whereas plots treated with Garlon 4 and Patron 170 were applied at 100 gal A^{-1} using 8006 XR VS flat-fan nozzles at 26 psi to simulate a dormant-stem herbicide application. Simulated drift rates of 10, 5, or 1% were selected as previous researchers have reported comparable percentages of a ground-applied herbicides lost via drift (Hall 1991; Maybank et al. 1978; Snoo and Witt 1998; Vieira et al. 2018), while the 100% (i.e., typical NCRVM rate) was evaluated to replicate a direct spray, misapplication, or mixing error. Herbicide treatments were evaluated at four PRE timings (18, 12, 6, or 0 wk before planting [WBP]) and at two POST timings (4, or 8 wk after planting [WAP]). Calendar dates for PRE and POST application timings, harvest timings, cumulative precipitation, average air- and soil-temperature are provided (Table 10). Additionally, it should be noted, crops were planted ≤ 8 h after herbicide applications conducted 0 WBP across years. Finally, the trial area was irrigated following planting to supplement precipitation when needed to achieve 1.5 in H_2O wk^{-1}; however, irrigation was withheld for 1 wk following herbicide treatments applied 0 WBP, 4 and 8 WAP.

Plant injury was visually estimated on a scale of 0 (no injury) to 100% (complete plant death) 2, 4, and 6 WAP for PRE timings and 2, 4, or 6 wk after treatment (WAT) for POST timings. Following the final visual rating, plant heights (3 random plants per plot) were measured from the plant base to the uppermost growing point and then the center 6 ft of each plot was harvested at the soil surface using a Stihl powerhead (KM 111 R; Stihl Inc., Virginia Beach, VA) fitted with a scythe attachment (FH-KM 145° Adjustable Power Scythe; Stihl Inc., Virginia Beach, VA) and aboveground fresh biomass recorded. Although, the presented research did not quantify crop yield, previous researchers have reported these evaluated parameters and crop yield are correlated (Everitt and Keeling 2009; Grey et al. 2005; Grichar et al. 2012; Marple et al. 2007). Plant fresh biomass and plant height data were converted to a percent reduction relative to the nontreated within a replicate using the equation:

$$\%\ reduction = \{[(NT - T)/NT] \times 100\}$$

where *NT* and *T* represent harvest data from a nontreated pot and treated plot, respectively.

The experiment was arranged as a split-split plot randomized complete block design. Whole-plot factor was crop species and subplots were split by application timings with sub-subplots combinations of herbicide and herbicide rates. Three replications of a 4 by 6 by 7 by 4 factorial treatment arrangement were evaluated. Factorial levels included four crop species (corn, cotton, soybean, or tobacco), six application timings (18, 12, 6, or 0 WBP; 4 or 8 WAP), seven herbicides (Arsenal, Confront, Escort, Garlon 4, Oust, Patron, or Plateau), and four herbicide rates (100, 10, 5, or 1% of a typical NCRVM rate). Application timing, herbicide, and herbicide rate were analyzed as fixed effects, while experimental run and replication were considered random. Data were subjected to ANOVA ($P \leq 0.05$) using MIXED procedures in SAS® (Version 9.4, SAS institute, Inc., Cary, NC) and means separated according to Fisher's Protected LSD ($P = 0.05$).

Greenhouse Experiment. Greenhouse research (Method Road Greenhouse; Raleigh, NC) was conducted to evaluate the effect of simulated IRVM program herbicide drift applied at PRE plant, AT plant or POST plant/transplant timing on various agricultural plant species. Herbicides were applied at 1, 5, or 10% of a typical North Carolina roadside vegetation management rate (KC Clemmer, personal communication). Evaluated herbicides included Patron 170 (10, 5, or 1% drift of a 1 gal A^{-1} application rate), Confront (10, 5, or 1% drift of a 1 pt A^{-1} application rate), Plateau (10, 5, or 1% drift of a 1 pt A^{-1} application rate), Arsenal (10, 5, or 1% drift of a 1 pt A^{-1} application rate), Escort (10, 5, or 1% drift of a 1 oz A^{-1} application rate), Oust (10, 5, or 1% drift of a 1.5 oz A^{-1} application rate) and Garlon 4 (10, 5, or 1% drift of a 2 gal A^{-1} application rate). A nonionic surfactant (Induce, Helena Chemical Co., Collerville, TN) was included at 0.25% (vol/vol) for all herbicide applications. Herbicides were applied using a hand-held CO_2-pressurized sprayer equipped with a single nozzle boom. Pots treated with Arsenal, Confront, Plateau, Escort, or Oust were applied using an 80015 DG VS flat-fan nozzle (TeeJet Flat-Fan Nozzles, Spraying Systems Company, Wheaton, IL) calibrated to deliver 15 gal A^{-1} at 20 psi to simulate a broadcast roadside application. Whereas pots treated with Garlon 4 or Patron 170 were applied at 100 gal A^{-1} using an 8006 XR VS flat-fan nozzle at 24 psi to simulate a dormant-stem herbicide application. A 1X rate was not evaluated due to concern of drift or volatility in the greenhouse setting. Herbicides were evaluated at a two PRE-plant timing (6 and 0 WBP), and at one POST-plant timing (6 WAP).

Six total evaluated crop species were chosen for the greenhouse experiment and included cotton 'DP1646B2XF', soybean 'S43XS27', peanut (*Arachis hypogaea* L.), tobacco 'NC 196', bell pepper (Capsicum annuum L.) 'California Wonder', and tomato, (*Solanum lycopersicum* L.) 'Homestead 24'. Cotton, soybean, and peanut were grown from seed in plastic pots filled with a sand medium (pH 6.2) amended to increase soil organic matter to 5% w w^{-1} (Metro-Mix® 820, Sun Gro Horticulture, Agawam, MA). Tobacco, bell pepper and tomato were grown from seed in float tray cells, before being transplanted into the plastic pots. Plastic pots surface area measured 50 in^2 (300 in^3) and were used for all crop species. Plants were irrigated daily with a combination of hand-watering and overhead light irrigation. Plants were grown under 95/70°F day/night temperatures with supplemental lighting (350 µmol m^{-2} s^{-1}) to provide a 14 h day. Excluding a 2 wk period prior to and after herbicide treatment, plants were fertilized every 2 wk following emergence at 0.25 lb N 1,000 ft^{-2} (Peters Professional 20-20-20 Water Soluble Fertilizer, Scotts-Sierra Horticultural Products Company, Marysville, OH). To mimic common agricultural practices, plants for AT-Planting treatment were seeded (cotton, soybean, and peanut) or transplanted (tobacco, bell pepper and tomato) 48 h prior to treatment. To ensure uniform plant populations within pots, three seeds were sewn into each pot and the first seed to germinate was allowed to remain, while the others were selectively removed.

Plant injury was visually estimated on a 0-100% scale (0 = no effect on plant, 100 = complete plant death) at 2, 4, and 6 weeks after the plant's initial herbicide exposure. At 6 weeks after initial herbicide exposure, plant height was measured, and aboveground biomasses were harvested, and fresh weights were recorded. Additionally, plant material was dried for 7 d at 160 °F and aboveground dry biomass was recorded. Plant harvest data were converted to percent reduction relative to the nontreated within a replicate using the following equation:

$$\%\ reduction = \{[(NT - T) / (NT)] \times 100\}$$

where *NT* and *T* equaled harvest data from a nontreated and treated plant, respectively.

Four replications of a 3 by 6 by 7 by 3 factorial treatment arrangement were evaluated in a randomized complete block design in each of two experimental runs. Factorial levels included three application timings (6, 0 WBP or 6 WAP), six plant species (cotton, soybean, peanut, tobacco, bell pepper, or tomato), seven herbicides (Arsenal, Confront, Escort, Garlon 4, Oust, Patron, or Plateau), and three herbicide rates (10, 5, or 1% of a typical NCRVM rate). Data were subjected to ANOVA ($P = 0.05$). Plant species, herbicide, application timing, and experimental run were considered fixed effects. Data were subjected to ANOVA ($P \leq 0.05$) using MIXED procedures in SAS® (Version 9.4, SAS institute, Inc., Cary, NC) and means were separated according to Fisher's Protected LSD ($P = 0.05$).

Assess Residual of Roadside Treatments from Dormant-Stem Applications. Field research was initiated 12 Dec. 2019 on a roadside interchange in Franklin County, NC (Lat. 35.86°N, Long. 78.27°W) to evaluate the effect of herbicide, application timing, and spray volume on dormant stem application efficacy for three tree species. Evaluated tree species included oak (*Quercus* spp.), maple (*Acer* spp.), and sweetgum (*Liquidambar* spp.) ranging from 3 to 8 ft in height and each unique plot contained 4 trees of the same species.

Herbicide treatments included Garlon 4 (2.0 gal A^{-1}) tank-mixed with Patron 170 (6.9 pt A^{-1}) (Garlon 4 + Patron 170) as well as Arsenal (12 fl oz A^{-1}) applied alone. Garlon 4 + Patron 170 was evaluated on three tree species, while Arsenal was evaluated on oak. A crop oil concentrate (Crop Oil Concentrate, Helena Chemical Co., Collerville, TN) was included at 2.5% (vol/vol) for all herbicide treatments. Herbicide applications were administered with a CO_2-pressurized hand sprayer calibrated to deliver 50- or 100-gal A^{-1}. Treatments applied at 50 gal A^{-1} were delivered with a single air induction 9503 EVS flat fan nozzle (TeeJet® flat-fan nozzles, Spraying Systems Company, Wheaton, IL) at 30 psi. Treatments applied at 100 gal A^{-1} were delivered with a single air induction 9508 EVS flat fan nozzle at 13 psi. Herbicide applications were applied from the base of the tree to the uppermost growing point. Applications were performed on December 12, 2019, January 16, 2020, February 13, 2020, March 20, 2020, and April 16, 2020.

Leaf-out was visually estimated on a scale of 0 (no canopy cover) to 100% (complete canopy cover). Following visual rating, tree height was measured from the soil surface to uppermost growing point. Additionally, soil was collected for each herbicide treatment, tree species, and application timing combination to assess residual herbicide activity. Soil was potted in 4 x 4 in pots and seeded with two mustard seeds (a bioindicator plant species) in the greenhouse. Mustard injury was recorded 14 and 28 d after emergence (DAE) and at 28 DAE, aboveground biomass was harvested and fresh mass recorded. Tree height and mustard data were converted to a percent reduction relative to the nontreated within an application timing and tree species using the equation:

$$\%\ reduction = \{[(NT - T) / (NT)] \times 100\}$$

where *NT* and *T* equaled height or harvest data from a nontreated and treated plants, respectively. Leaf-out and tree height data collection occurred on May 6, 2021, while soil was collected on April 3, 2021.

Garlon 4 + Patron 170 evaluation included three replications of a 2 by 5 by 3 factorial treatment arrangement evaluating two spray volumes (50 or 100 gal A^{-1}), five application timings (December, January, February, March, or April), and three tree species (oak, maple, or sweetgum) and evaluated in a randomized block design. Arsenal evaluation included three replications of a 2 by 5 factorial treatment arrangement evaluating two spray volumes (50 or 100 gal A^{-1}) and five application timings (December, January, February, March, or April). Data were subjected to ANOVA ($P \leq 0.05$) using MIXED procedures in SAS® (Version 9.4, SAS institute, Inc., Cary, NC) and means separated according to Fisher's Protected LSD ($P = 0.05$).

FINDINGS AND CONCLUSIONS

Characterize Herbicide Fate and Transport from Application via Passive Air Samplers. Across seasonal application timings, tank-dip samples ranged from 90 to 112%, 99 to 112%, and 98 to 113% of applied for nutating, air induction and Boominator spray heads, respectively (Table 3). These data confirm mixing procedures aligned with calculations across seasonal application timings and spray heads. Across seasonal application timings, no differences were detected between spray heads for recovery pads placed inside the treated area and ranged from 87 to 106%, 88 to 106%, and 86 to 110% of applied for nutating, air induction and Boominator spray heads, respectively (Table 4). These data suggest, regardless of spray head or seasonal application timing, spray coverage in the treated area was within the acceptable range (80 to 120% of applied) required by the US EPA for assessing pesticide application spray drift (US EPA, 2016). ANOVA identified a significant spray head-by-seasonal application timing interaction ($P = 0.03$) for spray recovery pads placed 3 ft from the treated area. It should be noted that these samples were not produced during the summer application as this was the first seasonal application timing evaluated. A decision was made to include these samples in subsequent timings to more accurately assess drift potential of evaluated spray heads. Within the winter application timing, Garlon 3A residue on spray pads placed 3 ft from treated area ranked: Boominator (1.57% of applied) > air induction (1.23%) > nutating (0.83%), although, no differences were identified between spray heads when applied in the fall (0.75 to 0.83% of applied) or spring (0.75 to 1.00%) (Table 5). Within air induction or Boominator spray heads greater residue was detected in these samples when applied in the winter (1.23 to 1.57% of applied) compared to fall (0.81 to 0.83%) or spring (0.75 to 1.00% of applied). Increased residue when applied in winter timing is likely due to wind parameters as average wind speed was ≥ 9 MPH and the wind direction was south/southeast (i.e., blowing towards samplers) during applications performed during this timing (Table 2; Figure 1). Interestingly, no differences between seasonal application timings were detected when applied with nutating spray head (0.75 to 0.89%) suggesting, this spray head may be less susceptible to spray drift compared to air induction or Boominator, although additional research is needed to confirm.

Garlon 3A residue was not detected in PUF samples collected 24 to 48 or 48 to 96 HAT; therefore, these data were excluded from statistical analysis. No detection at these timings implies negligible Garlon 3A volatility after 24 HAT and aligns with the US EPA classification of the salt in Garlon 3A as exhibiting low volatility with a vapor pressure of 1.6×10^{-4} Pa (77 F) (US EPA, 1998). ANOVA determined the main effect of sampling time interval ($P < 0.0001$) and sampling distance ($P < 0.0001$) were significant. Pooled over seasonal application timings, spray heads, and sampling distances, 0.0677% of applied was detected in PUF samples collected 0 to 4 HAT and decreased > 30-fold compared to samples collected 4 to 24 HAT (0.0020% of applied) (Table 6). Pooled over seasonal application timings, spray heads, and sampling time intervals, greater residue was detected in PUF samples positioned 3 ft from the treated area (0.1006% of applied) and declined > 25-fold compared to 9 ft (0.0036%), which was > 10-fold more than at 30 ft (0.0003%) (Table 7). Further, ANOVA detected a significant spray head-by-sampling time interval-by-sampling distance interaction ($P = 0.004$) for Garlon 3A residue detected in PUF samples. Pooled over seasonal application timings, Garlon 3A residue in 0 to 4 HAT samples positioned 3 ft from the treated area ranked: Boominator (0.2104% of applied) > nutating (0.1950%) > air induction (0.1831%) and declined by > 20-fold compared to samples positioned 9 ft (0.0042 to 0.0080%) or 30 ft (≤ 0.0009%) from the treated area (Table 8). No differences were detected between spray heads or sampling distances from samples exposed 4 to 24 HAT. Finally, ANOVA revealed a significant seasonal application timing-by-sampling time interval-by sampling distance interaction ($P < 0.0001$) for Garlon 3A residue detected in PUF samples. Pooled over spray heads, greater Garlon 3A residue was detected in PUF samples exposed 0 to 4 HAT and positioned 3 ft from the treated area when applied in winter (0.2185% of applied) compared to spring (0.2060%), which were both greater than fall (0.1973%) and further declined when applied in summer (0.1627%) (Table 9). Lastly, no differences were detected between seasonal application timing for samples exposed 0 to 4 HAT and positioned 9 (0.0051 to 0.0072% of applied) or 30 ft (≤ 0.0009%) from the treated area as well as across sampling distances when exposed 4 to 24 HAT (≤ 0.0055%). Finally, it should be noted, the Garlon 3A label states that applications should be avoided when wind speed is below 2 MPH due to variable wind direction and high inversion potential (Anonymous 2021) and inversion conditions were not detected during any application performed across seasonal timings (Table 2).

Research Implications. These results indicate drift from spray heads used by the NC DOT are on the low-end of potential spray drift produced by ground sprayers as recovery pads and PUF samples collected 3 ft from treated area were ≤ 1.57% and ≤ 0.2185% of applied, respectively (Table 5, 9). In comparison, Snoo and Wit (1998) reported 0.5 to 25.1% of the applied spray volume may be lost to drift with a wind speed of ≤ 10 MPH using ground sprayers. Although statistical comparisons between spray recovery pads and PUF samples are not permissible, the large numerical difference in Garlon 3A residue detected between these sample types placed 3 ft from the treated area is likely due to the height relative to the ground where these samples were positioned. Specifically, spray recovery pads were positioned at a height of 0.5 ft from the soil surface while PUF samples were positioned at 5 ft. Despite low spray drift across spray heads, data suggest that the tested Boominator spray head possesses greater drift potential compared to the air induction or nutating spray heads as Garlon 3A residue levels were consistently higher in spray recovery pads and PUF samples positioned 3 ft from the treated area and collected ≤ 4 HAT in plots treated with the Boominator spray head. Furthermore, data suggest wind direction and/or speed may be better indicators of potential spray drift compared to seasonal application timing as greater Garlon 3A residue was detected in recovery pads positioned 3 ft from the treated area during the winter application timing in plots treated with air induction or Boominator spray heads. This result aligns with Arvidsson et al. (2011) who evaluated numerous combinations of spray nozzles, working pressures, release heights, ground speeds, wind speeds, and air temperatures and reported the most decisive factors influencing spray drift were wind speed and release height, followed by driving speed and air temperature. Interestingly, within this research Boominator was deployed at the lowest release height of all evaluated spray heads; however, this spray head also required the lowest spray volume, thus may have generated the least coarse droplet size spectrum (Table 1). Nevertheless, applicators should be mindful that applications performed in spring and summer may present additional risk as the likelihood of sensitive crops being present in neighboring fields during these seasons are greater compared to applications conducted in late-fall or winter (Figure 7; NCDA&CS, 2020).

Characterize Drift and Volatility of Herbicides to Adjacent Crops and Off-Target Species.
Field Experiment. Differences between years were not detected for corn, cotton, soybean, or tobacco visual injury ($P \leq 0.81$), fresh mass reduction ($P \leq 0.19$) or plant height reduction data ($P \leq 0.07$); therefore, data were pooled over experimental runs. Within each crop and across evaluated parameters the main effect of application timing ($P < 0.0001$) was significant; therefore, data were sorted by application timing and presented accordingly. Within each application timing, maximum plant injury was observed 6 WAP for PRE- and 6 WAT for POST-application timings; therefore, data from 2 and 4 WAP for PRE- and 2 and 4 WAT for POST-application timings are not presented. Additionally, interpretation of results should be done, whilst remembering Patron 170 and Garlon 4 were included to simulate drift from a dormant-stem herbicide application, while other products were evaluated to simulate drift from a broadcast herbicide application. Specifically, evaluated Patron 170 and Garlon 4 rates exceeded the single maximum allowable rate for broadcast applications (Anonymous 2015a, b).

Corn Injury. ANOVA identified a significant herbicide-by-rate interaction for corn injury applied 18 WBP ($P < 0.0001$), 12 WBP ($P < 0.0001$), 6 WBP ($P < 0.0001$), 0 WBP ($P < 0.0001$), 4 WAP ($P < 0.0001$) or 8 WAP ($P = 0.046$). In general, across herbicide rates, Oust applied at PRE timings (18, 12, 6, and 0, WBP) consistently resulted in greater corn injury compared to all other evaluated treatments. Specifically, Oust (100% drift) injured corn 80, 88, and 90% applied 18, 12 or 6 WBP, respectively, which was greater injury compared to Oust (10% drift) applied 18 (39% injury), 12 (42%), and 6 WBP (39%) within each application timing (Table 11).

Similarly, Oust applied at 5% drift rate injured corn 13, 23, and 18% applied 18, 12, and 6 WBP. Excluding Oust, visual injury never exceeded 3% applied 18 WBP or 15% at 12 or 6 WBP across herbicides and drift rates. Oust applied 0 WBP at 100% drift rate, caused 100% injury, which was similar to Arsenal or Escort applied at 100% drift rate (89 to 97%). Plateau and Garlon 4 (100% drift) injured corn 76 and 65%, respectively, which were greater than Patron 170 (27%) or Confront (23%) applied 0 WBP at 100% drift rate. However, Oust applied at 5 and 1% drift rate 0 WBP injured corn 80 and 47%, respectively, while injury from other herbicide treatments applied 0 WBP at the same drift rate was ≤ 21%. Oust applied 4 WAP at 100, 10, 5, and 1% drift rates injured corn 100, 99, 93, and 83%, respectively (Table 12). Significant corn injury treated 4 WAP with Oust (1% drift) aligns with Felisberto et al. (2017) who reported Oust (≤ 2.5% drift rate) applied 3 WAP injured corn ≤ 89%. Arsenal and Escort (≥ 5% drift rate) applied 4 WAP injured corn 63 to 100% and 67 to 97%, respectively. Plateau (100% drift) applied 4 WAP caused 82% injury; however, Plateau ≤ 10% drift rate injured corn ≤ 27%. Garlon 4 (100% drift) injured corn 76%, which was greater than applied at ≤ 10% drift rate (10 to 39% injury). Excluding Oust, no differences were observed between herbicide treatments applied at 1% drift rate (≤ 20%) 4 WAP. Herbicides applied 8 WAP, caused ≤ 56% injury across herbicide treatments. Although statistical comparisons between application timings is not permissible, the numerical reduction in visual injury between treatments applied 4 compared to 8 WAP, is likely due to corn plants being near physiological maturity when treated 8 WAP.

Corn Aboveground Biomass Reduction. Oust applied to corn 18, 12, or 6 WBP at 100% drift rate caused 97, 99 and 99% aboveground biomass reductions, respectively (Table 13). Oust (10% drift) caused aboveground biomass reductions ranging from 43 to 49% applied 18, 12, or 6 WBP. Further, Oust (5% drift rate) caused 15, 30, 20% aboveground biomass reductions applied 18, 12, or 6 WBP. Excluding Oust, herbicide treatments applied 18, 12, or 6 WBP timings, reduced corn aboveground biomass ≤ 19%. ALS herbicides (i.e., Oust, Arsenal, Escort, and Plateau) applied 0 WBP at 100% drift rate caused aboveground biomass reductions ranging from 76 to 100%. Oust applied 0 WBP at 10, 5, and 1% drift rate caused 73, 82, and 46% aboveground biomass reduction, respectively, which were greater reductions compared to other herbicide treatments applied at the same drift rate (≤ 29%). Oust aboveground biomass data align with Devlin and Zbiec (1990) who evaluated corn response to Oust applied to soil 0 WBP at 14, 7, and 3.5% drift rates and reported aboveground biomass reductions ranging from 81 to 92%. Garlon 4 (100% drift) reduced aboveground biomass 69%, while drift rates of ≤ 10% caused corn aboveground biomass reductions ranging from 2 to 16% applied 0 WBP. Finally, across drift rates applied 0 WBP, Confront and Patron 170 caused ≤ 18% aboveground biomass reductions. Oust or Arsenal at ≥ 10% drift rate applied 4 WAP resulted in ≥ 88% aboveground biomass reductions (Table 14). Escort applied 4 WAP at 100, 10, 5, and 1% drift rate caused 92, 64, 52 and 13% aboveground biomass reductions, respectively. Plateau and Garlon 4 applied at 100% drift rate caused 76% and 67% aboveground biomass reductions, respectively, which were greater reductions than Plateau at ≤ 10% drift rate (≤ 38%) or Garlon 4 at ≤ 10% drift rate (≤ 30%). Further, Oust applied 4 WAP at 5 or 1% drift rate caused 84 and 71% aboveground biomass reductions, respectively, which were greater reductions compared to other herbicides applied at the same drift rate (≤ 52%). Excluding Oust, no differences were detected between herbicides applied 4 WAP at 1% drift rate (≤ 18% aboveground biomass reductions). No differences were detected between herbicide treatments applied to corn 8 WAP ($P = 0.47$), with biomass reductions ranging from 2 to 39% across herbicides and drift rates.

Corn Plant Height Reduction. Similar to corn injury and aboveground biomass data, Oust (100% drift rate) caused 74, 89, and 90% height reductions applied 18, 12, and 6 WBP, respectively (Table 15). Oust applied at 10% drift rate caused 21, 28, and 23% height reductions applied 18, 12, and 6 WBP, respectively, and excluding Oust (100% drift), caused greater reductions than all other evaluated herbicide treatments applied 18, 12, and 6 WBP (≤ 9%). Within 100% drift rate applied 0 WBP, height reductions ranked: Oust (100%) = Arsenal (94%) ≥ Escort (77%) > Plateau (57%) = Garlon 4 (56%) > Patron 170 (13%) = Confront (12%). Interestingly, Oust applied 0 WBP at 10, 5, and 1% drift rate caused 64, 67, and 38 height reductions, respectively, which were greater reductions compared to other herbicide applied at the same drift rate (≤ 17%). Similar to injury and aboveground biomass data, no differences in corn height were detected between Oust or Arsenal applied ≥ 10% drift rate (≥ 78%), which were similar to Escort (≥ 59%) applied at 10% drift rate (Table 16). Oust applied at 5 or 1% drift rate caused ≥ 65% height reductions and were greater reductions than Arsenal (≤ 28%) or Escort (≤ 41%), while other herbicide treatments (≤ 5% drift) reduced height ≤ 12% applied 4 WAP.

Cotton Injury. ANOVA identified a significant herbicide-by-herbicide rate interaction for cotton injury 18 WBP applied ($P < 0.0001$), 12 WBP ($P < 0.0001$), 6 WBP ($P < 0.0001$), 0 WBP ($P = 0.0008$), and 4 WAP ($P < 0.0001$). Oust applied 18, 12, and 6 WBP at 100% drift rate caused ≥ 81% injury, which was greater injury than other herbicide treatments within each application timing (Table 17). Similarly, Oust (10% drift rate) applied 18, 12, and 6 WBP resulted in 26, 30, and 43% injury, respectively, which was greater injury compared to other herbicide treatments applied at 10% drift rate, within each application timing. Excluding Oust, injury across herbicide treatments was ≤ 25% applied 18, 12, and 6 WBP at ≤ 10% drift rate. Across herbicide treatments applied 0 WBP at 100% drift rate, ≥ 86% injury was observed, which was similar to Oust applied at 10 or 5% drift rate (≥ 86%). Arsenal and Escort applied 0 WBP at 10% drift rate caused ≥ 80% injury and was greater injury than 10% drift rate of Plateau and Confront (49 and 31%, respectively). Similarly, Arsenal, Escort, and Garlon 4 applied 0 WBP at 5% drift rate resulted in ≥ 53% injury, while injury from other herbicide treatments (5% drift) was ≤ 27% (excluding Oust). Oust (1% drift rate) applied 0 WBP caused 50% injury, which was greater injury than other herbicide treatments (≤ 28% injury) applied at 1% drift rate. Arsenal, Escort, Garlon 4, Patron 170, and Oust applied at 100% drift rate 4 WAP caused ≥ 95% injury, which was greater injury than Confront applied at 100% drift rate (68%) (Table 18). Further, within 10% drift rate, Escort, Arsenal, and Patron 170 applied 4 WAP caused ≥ 75% injury compared to 58% caused by Garlon 4 and Oust while Confront and Plateau were less injurious (≤ 33%). A similar trend was observed within 5% drift rate applied 4 WAP and injury ranked: Patron 170 (77%) = Escort (70%) = Arsenal (69%) > Oust (43%) = Garlon 4 (42%) > Confront (18%) = Plateau (16%). Patron 170 (1% drift) applied 4 WAP caused 61% injury, which was greater injury than other herbicide treatments (≤ 30%) applied at 1% drift rate.

Cotton Aboveground Biomass Reduction. ANOVA revealed a significant herbicide-by-herbicide rate interaction for cotton aboveground biomass reduction applied 18 WBP ($P < 0.0001$), 12 WBP ($P < 0.0001$), 6 WBP ($P = 0.0008$), and 0 WBP ($P = 0.0006$). Similar to cotton injury data, Oust (100% drift) applied 18 or 12 WBP resulted in 88% and 94% aboveground biomass reductions, respectively, which were greater reductions compared to other herbicide treatments (≤ 35%) applied within each application timing (Table 19). This trend continued with Oust applied 18, 12, or 6 WBP at 10% drift rate causing 37%, 34%, and 58% aboveground biomass reductions, respectively, and were greater reductions compared to other herbicide treatments (10% drift rate) applied within each application timing (excluding Patron 170). Excluding Oust, no differences in aboveground biomass reductions were observed between herbicide treatments (≤ 18%) applied 18, 12, or 6 WBP at 5 and 1% drift rate. Oust, Arsenal, and Plateau applied 6 WBP at 100% drift rate caused 97%, 74%, and 59% aboveground biomass reductions respectively, while other herbicide treatments caused ≤ 48% reductions. Within the 100% drift rate Arsenal, Plateau, Escort, and Oust applied 0 WBP caused ≥ 99% aboveground biomass reductions, which were greater reductions compared to Confront (71%). Oust (10% drift) applied 0 WBP reduced aboveground biomass 85% which was similar to Arsenal and Escort applied at 10% drift rate (77 to 89%); however, Oust (5% drift) applied 0 WBP reduced aboveground biomass 84%, which was greater than Arsenal (47%) and Escort (55%) applied at 5% drift rate, respectively. No differences were observed between Garlon 4, Confront, Patron 170, and Plateau applied 0 WBP at 1% drift rate causing ≤ 30% aboveground biomass reductions. Although application timings and herbicide rates were not identical between trials, Jeffries et al. (2014) reported similar cotton aboveground biomass reductions after applying Oust at 5% drift rate (71%) and Confront at 20% drift rate (54%) 48 h prior to planting. Excluding Confront, across herbicides applied 0 WBP at 1% drift rate similar aboveground biomass reductions were observed ranging from 9% to 33%.

Cotton Height Reduction. ANOVA identified a significant herbicide-by-herbicide rate interaction for cotton height reduction applied 18 WBP ($P < 0.0001$), 12 WBP ($P < 0.0001$), 6 WBP ($P < 0.0001$), 4 WAP ($P < 0.0001$), and 8 WAP ($P = 0.0209$). Similar to cotton injury and aboveground biomass reduction data, Oust applied 18 or 12 WBP at 100% drift rate caused greater height reductions (≥ 68%) compared to other herbicide treatments (≤ 20%) applied 18 or 12 WBP at 100% drift rate (Table 21). Further, Oust (10% drift) applied 18 or 12 WBP resulted in ≥ 25% height reductions, whereas other herbicide treatments applied 18 or 12 WBP at 10% drift rate reduced height ≤ 13%. Similarly, Oust (100% drift) applied 6 WBP reduced height 86%, which was greater compared to 100% drift rate of Arsenal (48%) and Plateau (42%). Oust (10% drift rate) applied 6 WBP reduced cotton height 35%, while other herbicide treatments applied 6 WBP caused ≤ 20% when applied at ≤ 10% drift rate. Within 100% drift rate, cotton treated 4 WAP with Garlon 4, Escort, Arsenal, Patron 170, and Oust caused ≥ 86% height reductions and were greater reductions compared to Plateau (59%) or Confront (41%) (Table 22). Within 10% drift rate applied 4 WAP, cotton height reductions ranked: Escort (60%) = Arsenal (59%) > Patron 170 (40%) = Oust (37%) = Garlon 4 (31%) ≥ Plateau (13%) = Confront (5%). Cotton treated with Escort (5% drift) 4 WAP reduced cotton height 50% and was similar to Arsenal at 5% drift rate (38%), while both were greater reductions compared to 5% drift rate of Plateau and Confront (≤ 4%). Across herbicide treatments applied 4 WAP at 1% drift rate, cotton height reductions were ≤ 10% (Patron 170). Finally, cotton treated 8 WAP resulted in ≤ 42% height reductions across herbicide treatments, although it should be noted, height reductions were ≤ 33% across herbicide treatments that the NC DOT would be applying during this cotton production stage (Figure 6, 7; NCDA&CS 2020).

Soybean Injury. ANOVA revealed a significant herbicide-by-rate interaction applied 6 WBP ($P < 0.0001$), 0 WBP ($P < 0.0001$), 4 WAP ($P < 0.0001$), and 8 WAP ($P < 0.0001$). Soybean treated with Garlon 4 (100% drift) 6 WBP resulted in 38% injury, which was greater than Arsenal applied at 100% drift rate (29%), while other herbicide treatments caused ≤ 13% (Table 23). This trend continued 0 WBP with greatest injury observed following Garlon 4 applied at 100% drift rate (100% injury), which was greater than Arsenal or Confront at applied at 100% drift rate (76 to 85%). Garlon 4 (10% drift) applied 0 WBP caused 58% injury, which was similar to Escort applied at 100% drift rate (60%). Excluding Garlon 4, within 5 and 1% drift rate applied 0 WBP, no differences were detected between herbicides which caused ≤ 13% injury. Finally, within each drift rate, Oust resulted in less injury (8 to 21%) compared to other evaluated treatments applied 0 WBP. Within 100% drift rate applied 4 WAP, Garlon 4, Confront, Escort, Patron 170, and Arsenal injured soybean ≥ 92%, which were greater than Oust and Plateau (39 and 29%, respectively) (Table 24). Confront (10% drift) caused 61% injury, which was similar to Escort applied at 10% drift rate (56%), both of which were greater than other treatments (excluding Garlon 4) within 10% drift rate (≤ 33%) applied 4 WAP. This trend continued within 5% drift rate applied 4 WAP with Confront and Escort injuring soybean ≥ 39%, while herbicides applied at 1% drift rate caused 8 to 23% injury (excluding Garlon 4). Garlon 4 applied 8 WAP injured soybean 55 to 100%, across drift rates. Within 100% drift rate applied 8 WAP, Confront injured soybean 96%, which was greater than Escort (68%); however, no differences were detected between these two herbicides within a 10, 5, or 1% drift rate (12 to 59%). Patron 170 (100% drift) applied 8 WAP resulted in 77% injury, which was similar to Arsenal applied at 100% drift rate (67%). Similar to injury data observed 4 WAP, across herbicide treatments, Oust and Plateau (4 to 43% injury) consistently resulted in less injury compared to other herbicide treatments.

Soybean Aboveground Biomass Reduction. Within 100% drift rate applied 6 WBP, Garlon 4 (100% drift) caused 45% aboveground biomass reduction, which was greater than Arsenal (22%), Plateau (17%), Confront (12%), Patron 170 (11%), Escort (6%) or Oust (1%) (Table 25). No differences in aboveground biomass reduction were detected within ≤ 10% drift rate applied 6 WBP causing ≤ 14% aboveground biomass reductions across herbicide treatments. Across drift rates, Garlon 4 applied 0 WBP resulted in 8 to 100% aboveground biomass reductions, which were similar to Arsenal (14 to 86%) within each drift rate. Similarly, Confront and Escort caused similar biomass reductions within a drift rate, with reductions ranging from -1 to 70% applied 0 WBP. Patron 170 (100% drift) applied 0 WBP reduced aboveground biomass 48% which was greater than 100% drift rate of Plateau (28%) and Oust (20%); however, no differences were observed between these three herbicides when applied 0 WBP at drift rates of ≤ 10% (≤ 21%). Within 100% drift rate of herbicides applied 4 WAP, Garlon 4, Confront, Escort, Patron 170, and Arsenal caused ≥ 93% aboveground biomass reductions, which were greater reductions compared to Oust or Plateau (38 to 44%) (Table 26). Garlon 4 applied 4 WAP at 1, 5, and 10% drift rate caused 42, 92, and 99% aboveground biomass reductions, respectively, which were greater than all other evaluated herbicide treatments within each drift rate. Confront, Escort, Patron 170, and Arsenal applied at 10% drift rate caused ≤ 44% aboveground biomass reductions, which were greater reductions compared to Oust or Plateau (≤ 14%) applied at the same drift rate. Excluding Garlon 4 and Patron 170, no differences were observed across herbicides applied at 1% drift rate (≤ 8% aboveground biomass reduction). Within 100% drift rate, aboveground biomass reduction 8 WAP ranked: Garlon 4 (95%) = Confront (86%) = Escort (86%) > Patron 170 (60%) > Arsenal (43%) > Oust (23%) = Plateau (21%). Across Garlon 4 drift rates applied 8 WAP, aboveground biomass reduction ranged from 48 to 89%, which were greater reductions compared to all other evaluated herbicide rate combinations, within each drift rate (1 to 41%). At 8 WAP, 10 and 5% drift rate of Confront and Escort were similar ranging from 28 to 41%. Finally, excluding Garlon 4, no differences were observed between herbicides applied 8 WAP at 1 drift rate causing ≤ 10% aboveground biomass reductions.

***Soybean Plant Height Reduction*.** Similar to soybean injury and aboveground biomass reduction data, no differences were detected between soybean height reduction data treated 18 (P

= 0.59) or 12 WBP (P = 0.30). Garlon 4 (100% drift) applied 6 WBP reduced height 33% which was a greater compared to other herbicide treatments (≤ 15% height reduction) (Table 27). Excluding 100% drift rate, no differences were detected between herbicide treatments applied 6 WBP (≤ 9% height reduction). Similarly, within 100% drift rate applied 0 WBP, height reductions ranked: Garlon 4 (100%) > Arsenal (74%) = Confront (61%) > Escort (38%) = Patron 170 (32%) = Plateau (25%) ≥ Oust (19%). Excluding 100% drift rate, height reductions ranged from 0 to 27% across herbicides applied 0 WBP. Within 100% drift rate applied 4 WAP, soybean height reduction ranked: Confront (97%) = Garlon 4 (94%) > Patron 170 (81%) = Escort (80%) = Arsenal (78%) > Oust (22%) = Plateau (12%) (Table 28). Garlon 4 (≥ 10% drift) reduced height ≥ 75% height applied 4 WAP, which were greater reductions compared to other herbicides applied at ≥ 10% drift rate (≥ 29%). Within 1% drift rate, Garlon 4 applied 4 WAP reduced height 21%, while other herbicides caused ≤ 6% height reductions. A similar trend was observed within 100% drift rate applied 8 WAP with Confront and Garlon 4 reducing height 65%, which was greater compared to Escort (47%), Arsenal (43%), and Patron 170 (39%). Excluding 100% drift rate, Confront and Patron 170 height reductions ranged from 15 to 41% and 8 to 27%, respectively while other herbicide treatments (excluding Garlon 4) were ≤ 24%.

*Tobacco Injury***.** ANOVA revealed the herbicide-by-herbicide rate interaction was significant for tobacco injury applied 18 WBP (P < 0.0001), 12 WBP (P = 0.0003), 0 WBP (P = 0.014), 4 WAP (P = 0.0003), and 8 WAP (P = 0.002). Oust (100% drift) applied 18 or 12 WBP injured tobacco ≥ 54%, which was greater injury compared to other herbicide treatments (≤ 28%) applied at 100% drift rate within 18 or 12 WBP timings (Table 29). At 18 WBP, Oust (10% drift) caused 18% injury, while other herbicides injured tobacco ≤ 8% (excluding Oust 100% drift rate). Oust applied at 10 or 5% drift rate caused 25 and 23% injury, respectively, which was greater injury compared to other herbicides applied at the same drift rate (≤ 12%) 12 WBP. Although, ANOVA determined the herbicide-by-herbicide rate interaction was not significant for tobacco injury applied 6 WBP (P = 0.35), within each drift rate, Oust consistently caused greater numerical injury compared to other herbicides. Within synthetic auxin herbicides applied 0 WBP, Garlon 4 (≥ 10% drift) caused ≥ 67% injury, which was greater than Confront (≥ 32%) and Patron (≥ 23%) applied at 10% drift rate, while no differences were detected between these herbicides applied at 5 or 1% drift rate. Within each drift rate, no differences were detected between ALS herbicides applied 0 WBP with Arsenal, Escort, Oust, and Plateau causing injury ranging from 79 to 86% (100% drift) and 36% to 48% (10% drift). Within 5% drift rate applied 0 WBP, Oust caused 42% injury, which was greater injury than Plateau (21%), while no differences were detected between other herbicides applied within this drift rate (23 to 34%). Across herbicides, no differences in injury were detected applied 0 WBP at 1% drift rate (20 to 28%). Injury on tobacco treated 4 WAP at 100% drift rate ranked: Garlon 4 (100%) = Arsenal (100%) = Escort (98%) = Patron 170 (97%) ≥ Oust (83%) ≥ Confront (73%) ≥ Plateau (63%) (Table 30). Within 10% drift rate, injury on tobacco treated 4 WAP with Escort, Garlon 4, Arsenal, Oust, and Patron 170 ranged from 64 to 80%, which was greater injury than Confront (33%) and Plateau (28%). Escort and Garlon 4 applied 4 WAP at 10% drift rate caused 76% and 65% injury, respectively, which was greater than or equal to injury on tobacco treated with Patron 170 (56%), Arsenal (53%), and Oust (47%). Excluding Garlon 4 (42% injury) and Confront (21%), no differences were observed between herbicides applied 1% drift rate 4 WAP (24% to 38%). Similar to tobacco treated 4 WAP, injury 8 WAP ranked: Garlon 4 (100%) = Escort (98%) = Arsenal (96%) = Patron 170 (91%) ≥ Oust (83%) ≥ Confront (80%) = Plateau

(74%). Excluding Garlon 4 (≤ 10% drift rate), Escort applied at 10 and 5% drift rate caused 83 and 71% injury, respectively, which was greater than other herbicides applied 8 WAP at 10 and 5% drift rate. Finally, Garlon 4 (1% drift rate) caused greater injury (60%) compared other herbicides (26% to 41%) applied at 1% drift rate.

Tobacco Aboveground Biomass Reduction. ANOVA identified a significant herbicide-by-herbicide rate interaction for tobacco aboveground biomass reduction applied 18 WBP (P = 0.007), 12 WBP (P < 0.0001), 0 WBP (P = 0.006), 4 WAP (P = 0.006), and 8 WAP (P = 0.0001). Oust applied 18 WBP at 100% drift rate reduced aboveground biomass 71%, which was a greater than other herbicide treatments applied 18 WBP (≤ 16%) (Table 31). Similarly, Oust applied 12 WBP at 100% drift rate reduced aboveground biomass 83%, which was greater than Oust applied at 10% drift rate (30%) and Plateau applied at 100% drift rate (29%), while other herbicides caused ≤ 19% reductions. Pertinent to research objectives, across Garlon 4 and Patron 170 applied at ≤ 100% drift rate reduced aboveground biomass ≤ 11% applied 18 or 12 WBP, which is the timeframe where the NC DOT will apply the majority of these two herbicides for dormant-stem brush control relative to usual tobacco transplanting dates in North Carolina (Figure 6, 7; KC Clemmer, personal communication; NCDA&CS 2020). Garlon 4 applied 0 WBP at 100% drift rate or 10% drift rate caused 98 and 71% aboveground biomass reductions, respectively, which were greater reductions compared Confront (55 and 30%) and Patron 170 (54 and 27%) applied 0 WBP within each rate; however, Arsenal, Plateau, Escort, and Oust applied 0 WBP at 100% drift rate caused aboveground biomass reductions ranging from 80 to 89% and were greater than or equal to 10% drift rate of Oust and Arsenal (61 and 54%, respectively). Tobacco treated 4 WAP with Escort (≥ 5% drift rate) reduced aboveground biomass ≥ 71%, while Arsenal and Oust applied at ≥ 5% drift rate caused ≥ 50% aboveground biomass reductions (Table 32). Confront and Plateau applied at ≤ 10% drift rate reduced aboveground biomass 22 to 27% and 22 to 36%, respectively. Interestingly, Jeffries et al. (2014) treated potted tobacco plants and reported Oust (10% drift rate) reduced tobacco aboveground biomass 23%, which is less than was observed in the presented research; however, authors noted favorable growth conditions in the greenhouse may have mitigated herbicidal effects (Jeffries et al. 2014). Tobacco treated 4 WAP with 10% drift rate of Escort and Oust resulted in 48 and 43% aboveground biomass reductions, respectively. Finally, Escort and Arsenal applied 8 WAP at 100% drift rate reduced aboveground biomass ≥ 60%, which were greater reductions compared to Escort (≤ 10% drift rate), Plateau (≤ 100% drift), Oust (≤ 100% drift), and Confront (≤ 100% drift) (≤ 36%).

Tobacco Height Reduction. ANOVA determined the herbicide-by-herbicide rate interaction for tobacco height reduction was significant applied 18 WBP (P = 0.002), 12 WBP (P < 0.0001), 0 WBP (P = 0.01), 4 WAP (P < 0.0001), and 8 WAP (P < 0.0001). Similar to tobacco injury and aboveground biomass data, Oust (100 rate) applied 18 or 12 WBP reduced tobacco height 57% and 68%, respectively, which were greater reductions compared to other herbicide treatments applied 18 (0% to 18%) or 12 WBP (-1% to 27%) (Table 33). Escort (100% drift), Plateau (100% drift), and Oust (≤ 10% drift) applied 12 WBP reduced tobacco height ≤ 27%, whereas other herbicide treatments caused ≤ 17% reductions. When applied 0 WBP at 100% drift rate, Arsenal, Escort, Plateau, and Oust reduced tobacco height ≥ 67%. As previously noted, no known reports exist evaluating tobacco response to simulated drift rates of Arsenal and Plateau; however, Yelverton et al. (1992) reported imazaquin (0.125 lb A^{-1}), which is in the same chemical family (imidazolinone) applied 0 WBP caused height reductions ranging from 67% to 73% and aligns with data from the presented research. Within each rate, no differences were observed in tobacco height reduction when Arsenal, Escort, Plateau, and Oust applied 0 WBP ranging from 67 to 79, 32 to 42, 21 to 40, and 12 to 23%, when applied at 100, 10, 5, and 1% drift rate, respectively. Similarly, Confront and Patron 170 applied 0 WBP at 100% drift rate reduced tobacco height 44% and 36%, respectively, while Confront and Patron 170 applied at 10% drift rate caused ≤ 26% reductions. Within the 5% drift rate, tobacco treated 4 WAP with Escort and Arsenal caused ≥ 53% height reductions, while Plateau and Confront reduced height ≤ 23% and ≤ 16%, respectively (Table 34). Oust applied 4 WAP at 100, 10, 5, and 1% drift rate caused 62, 48, 41, and 26% height reductions, respectively. Tobacco treated 8 WAP with Escort (100% drift) resulted in a 56% height reduction and was greater than Arsenal (100% drift) (44%), while 100% drift rate of Oust, Plateau, and Confront caused ≤ 22% reductions. Within 5 or 1% drift rate, no differences in tobacco height reduction were observed between herbicide applied 8 WAP (≤ 14%) (excluding Garlon 4).

Research Implications. In general, corn, cotton and tobacco injury and growth reductions varied between herbicides with greater injury and growth reductions observed when applied 0 WBP or 4 WAP compared to 18, 12, or 6 WBP. Soybean injury and growth reductions were greater when applied POST (i.e., 4 and 8 WAP) compared to PRE (i.e., 18, 12, 6 and 0 WBP). Interestingly, Oust (≥ 10% drift) applied 18, 12, or 6 WBP, routinely caused greater corn, cotton, and tobacco injury compared to other herbicides within a drift rate; however, when Oust (≥ 5% drift) was applied 4 WAP, this trend was not observed with cotton and tobacco but continued with corn. Excluding Oust, herbicides applied at ≤ 10% drift rate 18, 12, and 6 WBP injured corn (≤ 5%), cotton (≤ 25%), and tobacco (≤ 18%), while soybean injury and growth reductions were ≤ 14% across herbicides, including Oust. These data suggest, Oust poses greater risk to corn, cotton, and tobacco compared to other herbicides when applied in the wk or months prior to crop establishment (i.e., ≥ 6 WBP). Whereas soybean injury and growth reduction data suggest, all evaluated herbicides are relatively safe on soybean applied ≥ 6 WBP. Specific to herbicides used by NC DOT for dormant-stem brush control, Patron 170, and Garlon 4 applied 18 or 12 WBP at 100% drift rate caused ≤ 21% (cotton and tobacco) and ≤ 6% (corn and soybean) aboveground biomass reductions; however, when applied 6 WBP at 100% drift rate, Patron 170 and Garlon 4 caused ≤ 60, 48, 45, and 17% aboveground biomass reductions on tobacco, cotton, soybean, and corn, respectively. These data imply applications for dormant-stem brush control conducted in December or January pose notably less risk to cotton, soybean, and tobacco compared to applications conducted in February or March, while Patron 170 and Garlon 4 are relatively safe on corn when applied December through March.

As previously mentioned, herbicide treatments applied 0 WBP were conducted ≤ 8 h prior to planting, and thus these data provide useful estimates of corn, cotton, soybean, and tobacco sensitivity to evaluated herbicides exposed via soil. Excluding Patron 170 and Garlon 4, numerical increases in plant injury were observed with cotton and tobacco compared to corn (excluding Oust) and soybean treated 0 WBP at 10% drift rate. Applied 0 WBP at 10% drift rate, Arsenal, Escort, and Oust injured cotton more (suggesting increased risk) compared to Confront and Plateau, whereas tobacco injury was similar across herbicides applied 0 WBP at 10% drift rate implying similar risk (excluding Patron 170 and Garlon 4). Specific to corn, Oust poses the greatest risk compared to other herbicides applied 0 WBP across drift rates, while Arsenal and Confront present increased risk to soybean compared to other herbicides applied 0 WBP at 10% drift rate (excluding Patron 170 and Garlon 4).

Excluding Patron 170 and Garlon 4, cotton and tobacco injury was numerically similar when treated 4 WAP at 10% drift rate. Whereas injury on corn was numerically similar to cotton and tobacco treated 4 WAP at 10% drift rate of Arsenal and Escort. Alternatively, soybean injury did not follow trends observed with cotton, soybean, or tobacco with the exception of Plateau consistently resulting in the lowest injury of herbicides applied at 10% drift rate across crop species. This result is important to consider as the NC DOT apply Plateau from mid-March through August, which aligns with corn, cotton, soybean, and tobacco establishment in North Carolina production fields (Figure 6, 7; NCDA&CS 2020). Finally, it should be noted, herbicides applied 8 WAP to cotton and tobacco exhibited wide variability in how injury equated to growth reductions with visual injury routinely exceeding growth reduction percentages, while corn and soybean injury and growth reductions were comparable treated 8 WAP. Therefore, future research should evaluate similar research objectives as the presented research while extending the research period to quantify crop yield when grown and harvested in accordance with current production practices as well as quantify spray drift percentages from application equipment commonly used for roadside vegetation management (i.e., boomless spray heads).

Greenhouse Experiment. *Cotton Injury.* ANOVA revealed a significant herbicide-by-herbicide rate interaction for cotton injury applied 6 WBP and 0 WBP. Within 10% drift rate applied 6 WBP injury ranked: Garlon 4 (81%) = Escort (74%) = Oust (73%) > Patron 170 (46%) = Confront (46%) > Plateau (28%) (Table 35). Within the 1% drift rate, Arsenal and Oust resulted in the greater injury (43%) compared to other herbicides applied 6 WBP. Excluding Confront (58% injury), herbicides applied 0 WBP at 10% drift rate caused ≥ 82% injury. Within the 5% drift rate applied 0 WBP, Oust and Escort (≥ 92% injury) caused greater injury compared to Garlon 4 (79%), Arsenal (74%), and Patron 170 (74%), while Confront and Plateau resulted in 49% and 45%, respectively. Similarly, Escort and Oust applied 0 WBP at 1% drift rate caused ≥ 71% injury and was greater than Arsenal (43%), Garlon 4 (40%), Patron 170 (36%), Confront (31%) and Plateau (21%).

*Cotton Aboveground Fresh Biomass Reduction***.** A significant herbicide-by-herbicide rate interaction was observed for cotton aboveground fresh biomass reduction applied 0 WAP. Within 10% drift rate applied 0 WAP, Arsenal, Escort, Garlon 4, Oust, Patron 170, and Plateau caused similar aboveground fresh biomass reductions ranging from 84% to 98% which were greater than Confront (49%) (Table 36). No differences were detected between 10% and 5% drift rates of Oust, Escort, Garlon 4, Arsenal, Patron 170, and Confront causing 96%, 92%, 82%, 75%, 73%, and 46% aboveground fresh biomass reductions, respectively applied 0 WBP. Similar to visual injury data, Escort and Oust applied 0 WBP at 1% drift rate caused greater aboveground fresh biomass reductions (≥ 78%) compared to Patron 170 (49%), Garlon 4 (43%), Arsenal (29%), Confront (14%), and Plateau (11%).

Cotton Aboveground Dry Biomass Reduction. Similar to cotton aboveground fresh biomass reduction data, a significant herbicide-by-herbicide rate interaction was observed for cotton aboveground dry biomass reduction when applied 0 WAP. Excluding Confront (58%), no differences in aboveground dry biomass reductions were observed between herbicides applied 0 WAP at 10% drift rate ranging from 87% to 99% (Table 37). Within the 5% drift rate applied 0 WBP, cotton aboveground dry biomass reduction ranked: Oust (96%) = Escort (94%) = Garlon 4 (84%) = Arsenal (80%) = Patron 170 (77%) > Confront (50%) = Plateau (50%). When applied 0 WAP, Oust and Escort caused significantly greater dry biomass reduction at the 1% drift rate, 84% and 80% respectively, compared to all other herbicide treatments. Importantly, Escort and

Oust applied 0 WBP at 1% drift rate caused ≥ 80% aboveground dry biomass reductions, which were greater than Patron 170 (56%), Garlon 4 (50%), Arsenal (37%), Confront (19%), and Plateau (10%). Finally, although ANOVA did not identify a significant herbicide-by-herbicide rate interaction 6 WAP, dry aboveground biomass reductions were ≥ 35% across herbicides and drift rates.

*Cotton Height Reduction***.** ANOVA identified a significant herbicide-by-herbicide rate interaction for cotton height reduction when applied 6 WBP. Within 10% drift rate applied 6 WBP at 10% drift rate Garlon 4 (71%), Escort (65%), and Oust (59%) resulted in greater cotton height reductions compared other herbicides (Table 38). Further, no differences in height reductions were detected across drift rates of Arsenal (29% to 43%), Confront (1 to 17%), Patron 170 (9% to 35%), and Plateau (5% to 19%) applied 6 WBP. Interestingly, Garlon 4 (5% drift rate) applied 6 WBP reduced cotton height 70%, which was greater than other herbicides applied at 5% drift rate (≤ 43%); however, Garlon 4 applied at 1% drift rate reduced height 9%, which was similar to other herbicides applied at 1% drift rate (1% to 29%).

Peanut Injury. A significant herbicide-by-herbicide rate interaction for peanut visual injury was observed when treated 6 WBP, 0 WBP, and 6 WAP. Plateau (≤ 10% drift rate) applied 6 WBP caused minimal peanut injury (≤ 5%) across drift rates. This result was expected as Cadre® a product containing the same active ingredient (imazapic) as Plateau is registered for use in peanut production systems (Anonymous 2014). Within 10% drift rate applied 6 WBP, Garlon 4 (93% injury), Escort (84%), and Confront (83%) caused greater injury compared to Arsenal (57%) and Patron 170 (56%), which were similar to Oust (70%) (Table 39). Similarly, Garlon 4, Escort, and Confront applied 6 WBP at 5% drift rate injury peanut 77%, 71%, and 64%, respectively, which was greater than or equate to Arsenal (57%) or Oust (57%), while Patron 170 was 34%. Within 1% drift rate applied 6 WBP, peanut injury ranked: Garlon 4 (58%) = Escort (51%) > Oust (33%) = Patron 170 (28%) = Confront (25%) = Arsenal (23%). Confront, Escort, Garlon 4, Oust, and Patron 170 applied 0 WBP at 10% drift rate resulted in ≥ 91% injury, which was similar injury compared to 5% drift rate within each herbicide and ranged from 84% to 91% (excluding Confront). Within the 1% drift rate applied 0 WBP, peanut visual injury ranked: Escort (70%) = Oust (65%) = Patron 170 (64%) > Confront (44%) = Garlon 4 (44%) > Arsenal (20%) > Plateau (0%). Within each drift rate applied 6 WAP, Garlon 4, caused greater injury (55% to 82%) compared to other herbicides. Notably, Oust (≤ 10% drift rate) applied 6 WAP injury peanuts ≤ 33%, which was less than other herbicides within each drift rate (excluding Arsenal and Plateau). Further Escort, Confront, and Patron 170 applied 6 WAP at 5% drift rate injured peanuts ≥ 45%, which was greater than Arsenal (27%) and Oust (23%) applied at 5% drift rate. A similar trend was observed within 1% drift rate applied 6 WAP with Escort, Confront, Patron causing injury ranging from 26% to 36%, which was greater than Arsenal (15%) and Oust (9%).

*Peanut Aboveground Fresh Biomass Reduction***.** A significant herbicide-by-herbicide rate interaction was observed for peanut aboveground fresh biomass reduction when applied 0 WBP. Within 10% drift rate, Escort, Garlon 4, Oust, and Patron caused ≥ 91% aboveground fresh biomass reductions, which was similar to Confront (80%) but greater than Arsenal (69%) (Table 40). Similarly, Garlon 4, Oust, and Patron 170 applied at 5% drift rate 0 WBP reduced aboveground biomass ≥ 90%, which was similar to Escort (81%) but greater than Arsenal (66%) and Confront (59%) applied at 5% drift rate. Finally, within the 1% drift rate applied 0 WBP, peanut aboveground fresh biomass reduction ranked: Oust (73%) = Patron 170 (71%) = Escort (71%) > Garlon 4 (35%) = Confront (21%) = Arsenal (11%).

Peanut Aboveground Dry Biomass Reduction. A significant herbicide-by-herbicide rate interaction was observed for peanut aboveground dry biomass reduction when applied 6 WBP and 0 WBP. Within 10% drift rate applied 6 WBP, aboveground dry biomass reduction ranked: Garlon 4 (92%) = Escort (88%) = Confront (81%) = Oust (75%) ≥ Arsenal (47%) = Patron 170 (45%) (Table 41). Garlon 4 (5% drift rate) applied 6 WBP reduced peanut dry aboveground biomass 87%, which was greater compared to other herbicides applied at 5% drift rate (≤ 54%) (excluding Escort). At 6 WBP, Garlon 4, Escort, Oust, and Arsenal applied at 1% drift rate caused 51%, 49%, 39%, and 21% aboveground dry biomass reductions, respectively, while Patron 170 and Confront were ≤ 2%. Within 10% drift rate, Escort, Garlon 4, Oust, and Patron 170 reduced aboveground dry biomass ≥ 92%, while Confront and Arsenal caused 82% and 70% reductions respectively. Similarly, within 5% drift rate, Escort, Garlon 4, Oust, and Patron 170 caused ≥ 85% aboveground dry biomass reductions, which greater than or equal to Arsenal (65%) and Confront (61%). Finally, within 1% drift rate, peanut aboveground dry biomass reduction applied 0 WBP ranked: Oust (72%) = Escort (72%) = Patron 170 (70%) > Garlon 4 (39%) = Confront (25%) = Arsenal (14%).

Peanut Height Reduction. ANOVA identified a significant herbicide-by-herbicide rate interaction for peanut height reduction when applied 0 WBP. Within 10% drift rate applied 0 WBP, Garlon 4, Escort, Patron 170, Oust and Confront caused 96%, 82%, 82%, 74%, and 64% height reductions, respectively, which were greater than or equal to Arsenal (46%). The trend continued within 5% drift rate applied 0 WBP with Garlon 4, Escort, Oust and Patron 170 causing ≥ 61% height reductions, while Confront and Arsenal resulted in 43% and 30% reduction, respectively. Finally, Escort, Oust, and Patron 170 applied 0 WBP at 1% drift rate reduced peanut height 49%, 44% and 38%, respectively, while 1% drift rate of Confront, Garlon 4, and Arsenal were ≤ 17%.

Pepper Injury. A significant herbicide-by-herbicide rate interaction was observed for pepper visual injury applied 6 WBP, 0 WBP, and 6 WAP. Within 10% drift rate applied 6 WBP, pepper injury ranked: Garlon 4 (87%) > Escort (69%) ≥ Arsenal (55%) = Oust (51%) = Patron 170 (48%) = Plateau (47%) = Confront (41%) (Table 43). Applied 6 WBP within 5% drift rate, Escort and Garlon 4 caused ≥ 58% injury and was greater than Arsenal, Confront, Oust, Patron 170, and Plateau (≤ 43%). Excluding Garlon 4, no differences in injury were detected within each herbicide applied 6 WBP at 5% and 1% drift rates; however, Escort (1% drift rate) caused 59% injury, which was greater compared to other herbicides within 1% drift rate. Within 10% drift rate applied 0 WBP, pepper injury ranked: Garlon 4 (100%) > Escort (90%) = Arsenal (86%) = Confront (81%) = Plateau (81%) ≥ Oust (74%) > Patron 170 (54%). Within 5% drift rate applied 0 WBP, Escort, Garlon 4, and Plateau caused 74%, 88%, 69% injury, respectively, which was greater injury compared to Arsenal (52%), Confront (59%), Oust (56%), and Patron 170 (31%). Escort and Garlon 4 applied 0 WBP at 1% drift rate injured pepper ≥ 51% and was greater than other 1% drift rate of other herbicides which ranged from 17% to 41%. Overall, all herbicides applied 6 WAP were injurious to pepper with injury ranging from 69% to 100%, 53% to 100%, and 36% to 71% applied at 10%, 5%, and 1% drift rates, respectively.

Pepper Aboveground Fresh Biomass Reduction. A significant herbicide-by-herbicide rate interaction was observed for pepper aboveground fresh biomass reduction applied 0 WBP. Within 10% drift rate applied 0 WBP, pepper aboveground fresh biomass reduction ranked: Garlon 4 (98%) = Escort (92%) = Arsenal (88%) = Confront (86%) ≥ Plateau (78%) = Oust (77%) = Patron 170 (66%) (Table 44). Interestingly, Garlon 4 (≤ 5% drift rate) and Escort (5%

drift rate) caused ≥ 80% aboveground fresh biomass reductions, which were greater than 5% or 1% drift rates of Arsenal (40% to 63%), Confront (33% to 44%), Oust (35% to 61%), and Patron 170 (18% to 33%), although Plateau (5% drift rate) was similar (67%). Although a significant herbicide-by-herbicide rate interaction was not observed when applied 6 WBP or 6 WAP, it should be noted aboveground fresh biomass reductions followed similar trends as visual injury data applied at 6 WBP and 6 WAP. Specifically, Garlon 4 and Escort applied 6 WBP or 6 WAP at ≥ 5% drift rates consistently caused numerical increases in aboveground fresh biomass reductions compared to other herbicides.

Pepper Aboveground Dry Biomass Reduction. Similar to the pepper fresh biomass reduction, ANOVA identified a significant herbicide-by-herbicide rate interaction for pepper aboveground dry biomass reduction applied 0 WBP. Applied 0 WBP at the 10% drift rate, Garlon 4 (98%), Escort (89%), Arsenal (88%), and Confront (87%) resulted in greater aboveground dry biomass reductions compared to Patron 170 (65%) and Plateau (71%) (Table 45). Within 5% drift rate, pepper aboveground dry biomass reduction ranked: Escort (78%) = Garlon 4 (77%) = Arsenal (68%) = Plateau (63%) ≥ Oust (59%) = Confront (45%) ≥ Patron 170 (43%). Finally, within 1% drift rate applied 0 WBP, Garlon 4 reduced aboveground dry biomass 79%, which was greater compared to other herbicides, with no differences detected between Plateau (57%) and Escort (47%) and other herbicides causing ≤ 40% reductions.

Pepper Height Reduction. A significant herbicide-by-herbicide rate interaction was observed for pepper height reduction applied 0 WBP and 6 WAP. Within 10% drift rate applied 0 WBP, pepper height reduction ranked: Garlon 4 (94%) > Escort (66%) = Plateau (58%) = Arsenal (57%) = Confront (57%) = Oust (52%) > Patron 170 (27%) (Table 46). Within 5% drift rate applied 0 WBP, Plateau reduced peanut height 47%, which was greater than Patron 170 (17%), while other herbicides caused similar reductions (29% to 42%). Similarly, within 1% drift rate applied 0 WBP, Garlon 4 and Plateau caused ≥ 27% height reductions and were greater compared to Arsenal and Patron (≤ 9%), while other herbicides caused similar reductions (17% to 23%). Applied 6 WAP at 10% drift rate, Garlon 4 and Escort reduced peanut height ≥ 82%, which was greater than Confront (51%), Oust (62%), Patron 170 (62%), and Plateau (47%). Interestingly, Garlon 4 applied 6 WAP at 5% drift rate reduced peanut height 89%, which was greater than other herbicides applied at 5% drift rate (24% to 64%); however, Garlon 4 (1% drift rate) caused 28% height reductions, which was similar to 1% drift rate of Arsenal (28%), Confront (16%), Oust (26%), Patron 170 (18%), and Plateau (37%), but less than Escort (59%).

Soybean Injury. A significant herbicide-by-herbicide rate interaction was observed for soybean visual injury applied 6 WBP, 0 WBP, and 6 WAP. Garlon 4 applied 6 WBP at 10%, 5%, and 1% drift rates caused 98%, 96%, and 54% injury and was greater than other herbicides applied 6 WBP within each drift rate (Table 47). Similarly, Confront applied 6 WBP at 10% and 5% drift rates injured soybean 77% and 63%, respectively and was greater injury within each drift rate compared to 10% and 5% drift rates of Arsenal (44% and 26%, respectively), Escort (62% and 41%), Oust (38% and 28%), Patron 170 (43% and 38%), and Plateau (41% and 31%). Within 1% drift rate applied 6 WBP, no differences in injury were detected between Arsenal (19%), Confront (31%), Escort (29%), Oust (24%), and Patron 170 (28%) (excluding Garlon 4). Applied 0 WBP at 10% drift rate, soybean injury ranked: Escort (100%) = Garlon 4 (100%) = Confront (98%) > Plateau (78%) = Patron 170 (77%) > Arsenal (56%) = Oust (46%). Within 5% drift rate applied 0 WBP Garlon 4, Escort, and Confront caused 100%, 98% and 92% injury, respectively and was greater than other herbicides (≤ 54%). Escort applied at 1% drift rate 0 WBP injured soybean 84%, while other herbicides (1% drift rate) caused less injury ranging from 9% to 46%. Similar to 6 WBP and 0 WBP injury data, within 10% drift rate applied 6 WAP, Garlon 4, Escort and Confront caused 100%, 90% and 88% respectively, which was greater than Patron 170 (58%), Arsenal (51%), Oust (50%), and Plateau (49%). An identical trend was observed when applied 6 WAP within 5% drift rate with Confront, Escort, and Garlon 4 causing ≥ 81%, while Arsenal, Oust, Patron 170, and Plateau injured soybean ≤ 50%. Finally, within 1% drift rate applied 6 WAP, soybean injury ranked: Garlon 4 (74%) > Escort (58%) > Confront (44%) = Patron 170 (36%) ≥ Arsenal (28%) = Plateau (20%) = Oust (17%).

Soybean Aboveground Fresh Biomass Reduction. A significant herbicide-by-herbicide rate interaction was observed for soybean aboveground fresh biomass reduction applied 0 WBP. Trends in soybean aboveground fresh biomass reduction were similar to trends observed with soybean visual injury data. Specifically, Confront, Escort, and Garlon applied 0 WBP at ≥ 5% drift rates reduced soybean aboveground biomass ≥ 83%, which was greater than 5% drift rate of Arsenal, Oust, Patron 170, and Plateau (≤ 52%). Within 1% drift rate applied 0 WBP, Escort reduced soybean aboveground biomass 81% and was greater than Arsenal, Confront, Garlon 4, Oust, Patron 170 which were ≤ 38%.

Soybean Aboveground Dry Biomass Reduction. A significant herbicide-by-herbicide rate interaction was detected for soybean aboveground dry biomass reduction when applied 6 WBP and 0 WBP. Within 10% drift rate applied 6 WBP, aboveground dry biomass reduction ranked: Garlon 4 (99%) > Confront (73%) = Escort (64%) ≥ Patron 170 (40%) = Arsenal (40%) = Plateau (34%) = Oust (30%) (Table 49). A similar trend was observed when applied at 5% drift rate 6 WBP with Garlon reducing aboveground biomass 97%, which was greater than Confront (49%), Escort (42%), Oust (15%), Patron 170 (31%), and Plateau (32%). Excluding Garlon 4 (48% aboveground dry biomass reduction), no differences were detected between herbicides applied 6 WBP at 1% drift rate (≤ 21%). Confront, Escort, and Garlon 4 applied 0 WBP at ≥ 5% drift rate reduced soybean aboveground dry biomass ≥ 87%, while Arsenal, Oust, Patron 170, and Plateau applied at 10% and 5% drift rates caused 47% to 79% and 19% to 53% aboveground dry biomass reductions, respectively. Within the 1% drift rate applied 0 WBP, soybean aboveground dry biomass reduction ranked: Escort (80%) > Arsenal (39%) = Confront (37%) = Garlon 4 (32%) = Oust (19%) ≥ Patron 170 (5%) = Plateau (-10%).

Soybean Height Reduction. A significant herbicide-by-herbicide rate interaction was observed for soybean height reduction applied 6 WBP, 0 WBP, and 6 WAP. Garlon 4 (≥ 5% drift rate) applied 6 WBP reduced soybean height ≥ 81%, which was greater than 10% and 5% drift rates of Arsenal (≤ 29%), Confront (≤ 55%), Escort (≤ 45%), Oust (≤ 20%), Patron 170 (≤ 24%), and Plateau (≤ 22%). Excluding Garlon 4 (29% height reduction), no differences were observed between herbicides (1% drift rate) applied 6 WBP and ranged from -1% to 16%. Similar to soybean aboveground biomass data 0 WBP, within 10% drift rate applied 0 WBP, Confront, Escort, and Garlon 4 reduced aboveground dry biomass ≥ 94% and was greater than Patron 170 (61%) and Plateau (64%), which were greater than or equal to Arsenal (46%) and Oust (38%). A similar trend was observed within 5% drift rate applied 0 WBP with Garlon 4 and Escort causing ≥ 95% height reductions, which was greater than Confront (60%), while other herbicides were ≤ 37%. Within the 1% drift rate applied 0 WBP, Escort reduced soybean height 75%, which was greater than other herbicides (≤ 26%). Confront, Escort, and Garlon 4 applied 6 WAP at ≥ 5% drift rate reduced soybean height ≥ 57%, which were greater reductions than Arsenal (≤ 37%), Oust (≤ 33%), Patron 170 (≤ 38%), and Plateau (≤ 16%) applied across drift rates. Within 1%

drift rate applied 6 WAP, Escort and Garlon 4 caused 52% and 37% height reductions, respectively, while other herbicides reduced soybean height (≤ 25%).

Tobacco Injury. ANOVA identified a significant herbicide-by-herbicide rate interaction for tobacco visual injury applied 6 WBP, 0 WBP, and 6 WAP. Within 10% drift rate applied 6 WBP, Garlon 4 and Oust resulted in 63% injury and were greater than other herbicides, which ranged from 46% to 53% (Table 51). Garlon 4 applied 6 WBP at 5% drift rate injured tobacco 61%, which was greater than all other herbicides applied at 5% drift rate including Oust (43%), Escort (35%), Plateau (34%), Confront (32%), Patron 170 (28%), and Arsenal (26%). Within 1% drift rate applied 6 WBP, Escort, Garlon 4 and Oust injured tobacco ≥ 32%, which was greater than other herbicides (≤ 20%). Within 10% drift rate applied 0 WBP, tobacco injury ranked: Garlon 4 (92%) > Escort (78%) = Oust (73%) = Arsenal (67%) > Confront (54%) = Patron 170 (54%) = Plateau (54%). A similar trend was observed within 5% drift rate applied 0 WBP with Garlon 4 injuring tobacco 83% and was greater than Escort (62%) and Oust (58%), while other herbicides were less injurious (≤ 44%). Within 1% drift rate applied 0 WBP, Escort and Garlon 4 resulted in ≥ 56% injury and was greater injury compared to Arsenal (26%), Confront (34%), Patron 170 (26%), and Plateau (26%). Applied 6 WAP at 10% drift rate, tobacco injury ranked: Garlon 4 (100%) = Patron 170 (100%) > Escort (89%) > Arsenal (77%) = Confront (75%) > Oust (64%) > Plateau (49%). Importantly, Garlon applied 6 WAP at 5% and 1% drift rates caused 100% and 89% injury, respectively. This result suggests tobacco is extremely sensitivity to Garlon 4 and precautions should be taken if applied in the wk or months following tobacco transplanting. Excluding Garlon 4, Escort (5% drift rate) caused greater injury (73%) compared to other herbicides applied at 5% drift rate 6 WAP (≤ 58%). Plateau (≤ 10% drift rate) applied 6 WAP resulted in less injury (18% to 49%) compared other herbicides within each drift rate. Applied 6 WAP at 1% drift rate, Escort and Patron 170 injured tobacco 61% and 48%, respectively while no differences were observed between Confront (39%), Arsenal (36%), and Oust (35%).

Tobacco Aboveground Fresh Biomass Reduction. A significant herbicide-by-herbicide rate interaction was observed for tobacco aboveground fresh biomass reduction applied 6 WAP. Within 10% drift rate applied 6 WAP, tobacco aboveground fresh biomass ranked: Garlon 4 (97%) = Patron 170 (94%) = Escort (85%) ≥ Arsenal (79%) = Confront (70%) > Oust (56%) > Plateau (35%). Further, Garlon 4 (≥ 1% drift rate) applied 6 WAP reduced aboveground fresh biomass ≥ 82%, which was greater than 5% and 1% drift rates of Arsenal (≤ 59%), Confront (≤ 45%), Escort (≤ 63%), Oust (≤ 42%), Patron 170 (≤ 41%), and Plateau (≤ 27%). Additionally, it should be noted, Plateau (≤ 10% drift rate) applied 6 WAP reduced aboveground fresh biomass 16% to 35%, which was less than other herbicides applied at 10% and 5% drift rates. Finally, no differences were detected between Arsenal (30% aboveground fresh biomass reduction), Confront (33%), Oust (27%), and Patron 170 (29%) applied 6 WAP at 1% drift rate.

Tobacco Aboveground Dry Biomass Reduction. ANOVA detected a significant herbicide-by-herbicide rate interaction for tobacco aboveground dry biomass reduction applied 0 WBP and 6 WAP. Within 10% drift rate, Escort, Garlon 4, and Arsenal applied 0 WBP reduced tobacco aboveground dry biomass ≥ 76%, which was similar to Oust (73%) but greater than Confront (46%), Patron 170 (55%), and Plateau (54%) (Table 53). Applied 0 WBP at 5% rate, Garlon 4, Escort, and Oust, reduced tobacco aboveground dry biomass ≥ 64%, which was greater than Confront (38%), Plateau (32%) and Patron 170 (28%). Similarly, within the 1% drift rate applied 0 WBP, tobacco aboveground dry biomass reduction ranked: Garlon 4 (70%) = Escort (64%) ≥ Oust (50%) > Confront (34%) = Plateau (25%) = Arsenal (21%) > Plateau (1%). Excluding

Plateau, herbicides applied 6 WAP at 10% drift rate reduced aboveground biomass ≥ 66%. When applied 6 WAP at 5% drift rate, Garlon 4 and Escort caused ≥ 75% aboveground fresh biomass reductions and were greater than Confront (49%), Oust (48%), Patron 170 (48%), and Plateau (38%). A similar trend was observed within 1% drift rate applied 6 WAP, with aboveground dry biomass reduction ranking: Garlon 4 (84%) > Escort (61%) > Patron 170 (40%) = Arsenal (39%) = Confront (35%) = Oust (32%) = Plateau (30%).

Tobacco Height Reduction. ANOVA identified a significant herbicide-by-herbicide rate interaction for tobacco height reduction applied 0 WBP and 6 WAP. Similar to aboveground biomass data, Garlon 4 (≥ 5% drift rate) applied 0 WBP reduced tobacco height ≥ 77%, which was greater than 10% drift rate of Arsenal (56%), Confront (32%), Escort (60%), Oust (47%), Patron 170 (40%), and Plateau (47%) (Table 54). Within the 5% drift rate applied 0 WBP, tobacco height reduction ranked: Garlon 4 (77%) > Oust (44%) = Escort (42%) = Arsenal (28%) = Plateau (28%) ≥ Confront (24%) = Patron 170 (18%). No differences were detected between Arsenal, Confront, Escort, Garlon 4, and Oust applied 0 WBP at 1% drift rate causing tobacco height reductions ranging from 24% to 38% and were greater than Patron 170 (3%). Within 10% drift rate applied 6 WAP, Escort, Garlon 4, and Patron 170 reduced tobacco height ≥ 73% and was greater than or equal to Arsenal (66%) and Oust (55%), which were all greater than Plateau (30%). Applied 6 WAP at 5% drift rate, Garlon 4 reduced tobacco height 93%, which was greater than Escort (64%) and other herbicides (≤ 50%). Additionally, no differences were detected between 5% drift rate of Confront, Oust, Arsenal and Patron 170 caused 41%, 46%, 50% and 52% respectively applied 6 WAP. Similarly, Garlon 4 (1% drift rate) applied 6 WAP caused 84% height reduction, which was greater than Escort (54%), Arsenal (29%), Confront (16%) Oust (24%), Patron 170 (37%), and Plateau (12%).

Tomato Injury. A significant herbicide-by-herbicide rate interaction was detected for tomato visual injury applied 6 WBP, 0 WBP, and 6 WAP. Within 10% drift rate applied 6 WBP, Garlon 4 injured tomato 74%, which was similar to Oust (61%) but greater than Confront (58%), Arsenal (44%), Escort (44%), Patron 170 (43%), and Plateau (41%) (Table 55). Within 5% drift rate applied 6 WBP, tomato injury ranked: Garlon 4 (68%) = Confront (56%) ≥ Oust (43%) = Plateau (37%) = Arsenal (35%) = Escort (34%) = Patron 170 (31%). Applied 6 WBP at 1% drift rate, no differences were detected between Confront (39% injury), Escort (33%), Garlon 4 (36%), Oust (38%), Patron 170 (26%), and Plateau (34%), although all were more injurious than Arsenal (5%). Across herbicides applied 0 WBP at 10% and 5% drift rates, tomato injury ranged from 89% to 100% and 72% to 100%, respectively, highlighting tomato sensitivity to these herbicides. Further, within the 1% drift rate applied 0 WBP, tomato injury ranked: Patron 170 (74%) = Arsenal (71%) = Garlon 4 (65%) ≥ Oust (60%) = Escort (56%) ≥ Plateau (49%) > Confront (19%). Applied 6 WAP at 10% drift rate, tomato injury ranked: Garlon 4 (99%) = Patron 170 (94%) ≥ Confront (86%) > Arsenal (64%) = Escort (54%) ≥ Oust (51%) > Plateau (36%). A similar trend was observed within the 5% drift rate applied 6 WAP with tomato injury ranking: Garlon 4 (93%) > Patron 170 (76%) = Confront (71%) > Arsenal (42%) = Oust (42%) = Escort (36%) ≥ Plateau (28%). Interestingly, Garlon 4 (1% drift rate) applied 6 WAP injured tomato 90%, which was greater than other herbicides applied at 5% (≤ 76%) and 1% (≤ 49%) drift rates.

Tomato Aboveground Fresh Biomass Reduction. ANOVA identified a significant herbicide-by-herbicide rate interaction for tomato aboveground fresh biomass reduction applied 0 WBP. Overall, tomato aboveground fresh biomass data followed similar trends compared to tomato injury data 0 WBP. More specifically, across herbicides applied 0 WBP at 5% and 10%

drift rates, aboveground fresh biomass reductions ranged from 81% to 100% and 87% to 100%, respectively (Table 56). Additionally, no differences were detected between herbicides applied 0 WBP at 10% drift rate. Similarly, within 5% drift rate applied 0 WBP, Garlon 4 reduced tomato aboveground fresh biomass 100%, which was greater than Confront (82%) and Escort (81%), while other herbicides caused similar reduction ranging from 88% to 96%. Within 1% drift rate applied 0 WBP, tomato aboveground fresh biomass reduction ranked: Arsenal (85%) = Oust (81%) = Garlon 4 (71%) ≥ Escort (65%) = Patron 170 (62%) = Plateau (61%) > Confront (38%).

Tomato Aboveground Dry Biomass Reduction. ANOVA detected a significant herbicide-by-herbicide rate interaction for tomato dry biomass reduction applied 0 WBP. Tomato aboveground dry biomass data followed similar trends to injury and aboveground fresh biomass data. Specifically, across herbicides applied 0 WBP, aboveground dry biomass reductions were ≥ 78% and ≥ 90% applied at 5% and 10% drift rates, respectively (Table 57). Further, no differences in aboveground dry biomass were detected between herbicides applied at 10% drift rate and ranged from 90% to 100%. Within 5% drift rate applied 0 WBP, Garlon 4 injured tomato 100%, which was greater than Confront (78%), while other herbicides caused similar injury ranging from 85% to 96%. Within 1% drift rate applied 0 WBP, tomato aboveground dry biomass reduction ranked: Arsenal (87%) = Oust (80%) = Garlon 4 (73%) = Escort (72%) = Patron 170 (72%) ≥ Plateau (65%) > Confront (32%).

Tomato Height Reduction. ANOVA identified a significant herbicide-by-herbicide rate interaction for tomato height reduction when applied 0 WBP. Unlike visual injury and fresh- and dry-biomass data, differences in tomato height were detected between herbicides applied at 10% drift rate 0 WBP. Specifically, within 10% drift rate applied 0 WBP, Garlon 4 reduced tomato height 100%, which was greater than Confront and Patron (68%), while other herbicides caused similar reductions ranging from 77% to 91% (Table 58). Within the 5% drift rate, tomato height reduction ranked: Garlon 4 (100%) = Arsenal (78%) ≥ Patron 170 (67%) = Oust (65%) = Escort (48%) = Confront (42%). Finally, excluding Confront (-9% height reduction), no differences were detected between herbicides applied at 1% drift rate 0 WBP and ranged from 29% to 52%.

Research Implications. In general, plant growth responses varied among herbicides and application timings. It should be noted, injury and growth reductions in greenhouse experiment were elevated compared to the field experiment, although overall trends were similar. This result may be due to irrigation and soil characteristics in the greenhouse compared to the field experiment. More specifically, irrigation was administered using overhead mist nozzles during the time from herbicide treatment to crop planting on pots treated 6 WBP, whereas plants treated 6 WAP were irrigated by hand and caution was taken to avoid contact with treated foliage. Additionally, soil used in the greenhouse experiment was sand amended with organic matter; however, organic matter may not have been homogenized throughout the profile to the extent that would be expected in a native soil. Collectively, irrigation procedures may have increased herbicide persistence in soil and on plant foliage, while soil characteristics may have increased herbicide bioavailability.

Cotton was most sensitive to herbicides applied 0 WBP (≤ 2 h prior to planting). Escort and Oust applied at 1% drift rate as well as Arsenal, Garlon 4, and Patron 170 applied at 5% drift rate caused significant cotton injury and biomass reductions (≥ 70%) applied 0 WBP. Garlon 4, Escort, and Oust applied 6 WBP at 5% drift rate caused cotton injury and biomass reductions exceeding 50%. Cotton treated 6 WAP, displayed numerically lower growth reductions compared to when applied 6 and 0 WBP. Data suggest caution should be taken applying Escort, Garlon 4, and Oust prior to planting (March, April) as well as with Escort following planting (June, July) in eastern North Carolina counties such as Halifax, Northampton, Martin, Bertie, Edgecombe, Pitt, Hertford, Sampson, and Gates, among others (NCDA&CS 2020).

Specific to peanuts, herbicides applied 0 WBP resulted in greater visual injury and growth reductions compared to 6 WBP and 6 WAP application timings. Similar to cotton, Escort and Oust applied at 1% drift rate as well as Garlon 4 and Patron 170 applied at 5% drift rate caused significant peanut injury and biomass reductions (≥ 65%). Garlon 4, Escort, and Oust applied 6 WBP at 5% drift rate injured peanut > 50% and plants responded similarly when treated with Garlon 4 and Escort 6 WAP. Data suggest caution should be taken applying Escort, Oust, Garlon 4, and Patron 170 prior to planting (March, April) as well as with Escort following planting (May, June) in northeastern North Carolina counties with high peanut production such as Martin, Pitt, Edgecombe, Northampton, Chowan, Hertford, and Gates (NCDA&CS 2020).

In general, herbicides applied 0 WBP and 6 WAP caused greater pepper injury and growth reductions compared to 6 WBP. Across application timing, Escort (1% drift rate) injured pepper and reduced fresh biomass > 50%, while Garlon 4 (5% drift rate) applied 6 and 0 WBP produced similar pepper responses. In comparison, Confront, Oust, Patron 170, and Plateau were relatively safe to pepper when applied 6 WBP. Across herbicides (5% drift rate) injury and dry biomass reductions exceeded 40% and 50% applied 0 WBP and 6 WAP, respectively. Data suggest Escort and Garlon 4 applications should be made with caution in the months prior to pepper transplanting (February, March) as well as in the time near or following pepper transplanting planting (April, May).

Across herbicides, soybean injury and growth reductions ranked: 0 WBP > 6 WAP > 6 WBP. Garlon 4 (1% drift rate) caused nearly twofold increases in injury and biomass reductions compared to other herbicides applied at 1% drift rate 6 WBP. Excluding Garlon 4, fresh mass and height reductions never exceeded 20% across herbicides applied 6 WBP at 1% drift rate. Escort (≥ 1% drift rate), Confront (≥ 5% drift rate), and Garlon 4 (≥ 5% drift rate), applied 0 WBP injured soybean > 80% and caused biomass reductions of > 75%. Similarly, Confront, Escort, and Garlon 4 applied 6 WAP at 5% drift rate injured soybean > 80%, whereas other herbicides (5% drift rate) were < 40% (excluding Patron 170). Data suggest caution should be taken while performing Garlon 4 applications prior to soybean planting (late-March through May) as well as with Escort and Confront following planting (May through July) in prominent soybean producing counties such as Beaufort, Pasquotank, Sampson, Union, Perquimans, Wayne, Johnson, Tyrrell, Edgecombe, and Camden, among others (NCDA&CS 2020).

In general, tobacco injury and growth reductions were greater when herbicides were applied 0 WBP and 6 WAP compared to 6 WBP. Escort, Garlon 4, and Oust applied 6 WBP at 1% drift rate injured tobacco > 30%, while other herbicides (1% drift rate) caused ≤ 20% injury. Similarly, within 1% drift rate applied 0 WBP, Escort, Garlon 4, and Oust reduced tobacco aboveground dry biomass ≥ 50%, while other herbicides were < 35%. Interestingly, across drift rates, Escort and Garlon 4 caused similar or increased injury and growth reductions applied 6 WAP compared 0 WBP, while Oust trended in the opposite direction. Data suggest Escort, Garlon 4, and Oust should be applied with caution in the weeks and months prior to tobacco transplanting (March, early-April) as well as with Escort following planting (late-April, May) in prominent tobacco producing counties such as Nash, Johnston, Wilson, Sampson, Pitt, Greene, Wayne, Lenoir, Harnett, and Person (NCDA&CS 2019).

In general, tomato displayed greater sensitivity to evaluated herbicides when applied 0 WBP compared to 6 WBP or 6 WAP. More specifically, across herbicides applied 0 WBP 5%

drift rate tomato injury was > 70% and biomass reductions > 80%. Additionally, across herbicides applied at 1% drift rate 0 WBP tomato aboveground biomass was reduced > 60%. Oust (≥ 1% drift rate) applied 6 WBP reduced fresh biomass ≥ 50%, while other herbicides (1% drift rate) caused < 35% reductions. Further, Garlon 4 (≥ 5% drift rate) applied 6 WBP reduced dry biomass > 75%. Interestingly, Arsenal, Escort, and Patron 170 applied 6 WBP reduced tomato aboveground dry biomass < 50%, < 40%, and ≤ 30% applied at 10%, 5%, and 1% drift rate, respectively. Excluding Garlon 4 and Patron 170, across herbicides applied at 1% drift rate 6 WAP tomato aboveground dry biomass was reduced > 20%. Overall, herbicides applied 6 WAP caused less injury and growth reductions compared to 0 WBP but caution is still warranted. Data from 0 WBP suggest, all herbicide applications performed during the usual planting dates for tomato in North Carolina (mid-April through May) should be made with extreme caution in prominent tomato producing counties such as Henderson, Buncombe, Rowan, Brunswick, Haywood, Cherokee, and Jackson (NCDA&CS 2020).

Assess Residual of Roadside Treatments from Dormant-Stem Applications. No differences in leaf-out were detected between spray volume (P = 0.33) or tree species (P = 0.21) treated with Garlon 4 + Patron 170; however, ANOVA revealed the main effect of application timings (P < 0.0001) was significant. It should be noted that decreasing leaf-out percentages equate to greater herbicide efficacy. Overall, leaf-out data were highly variable across application timings, tree species, and even within plots with smaller trees (< 4 ft) being affected more than larger more mature trees (> 5ft) (personal observation). Pooled over spray volumes and tree species, leaf-out from plots treated with Garlon 4 + Patron 170 ranked: December (60%) = January (57%) ≥ February (46%) > March (29%) > April (11%) (Table 60).

Similar to leaf-out data, no differences in tree height reductions were observed between spray volume (P = 0.75); therefore, data were pooled over spray volumes for statistical analysis. ANOVA determined the main effects of tree species (P = 0.013) and application timing (P = 0.003) were significant. Pooled over application timings, Garlon 4 + Patron 170 reduced maple height 84%, which was greater than oak (49%) or sweetgum (48%) (Table 62). Pooled over tree species, Garlon 4 + Patron 170 reduced tree height greater when applied in April (88%) compared to March (64%), February (60%), January (46%), or December (43%) (Table 63). Further, ANOVA identified a significant tree species-by-application timing interaction (P = 0.03) for plots treated with Garlon 4 + Patron 170. Pooled over spray volumes, Garlon 4 + Patron 170 applied December, January, or February caused maple height reductions ranging from 83% to 88%, which were greater than oak (25% to 50%) or sweetgum (22% to 44%) treated December, January, or February (Table 64). No differences in height reductions were detected between tree species treated with Garlon 4 + Patron 170 in March (50% to 76%) or April (77% to 95%). Additionally, numerical trends in height reduction were observed with oak and sweetgum as a function of application timing with December (22% to 25%) causing the lowest, followed by January (27%), February (44% to 50%), March (50% to 66%), and April (77% to 95%).

Specific to oak trees treated with Arsenal, no differences in leaf-out were detected between spray volume (P = 0.91); however, ANOVA determined the main effect of application timing (P < 0.0001) was significant. Pooled over spray volumes, Arsenal reduced leaf-out more when applied in April (60%) compared to December (95%), January (96%), February (98%), and March (88%) (Table 65). Finally, no differences in tree height reductions were detected between spray volume (P = 0.91) or application timings (P = 0.12), although numerical trends as a function of application timing were observed (Table 66).

Regarding residual herbicide activity, mustard plants displayed no visual injury and differences in aboveground biomass were not observed between application timings or herbicide treatments (data not shown). These results suggest, Garlon 4 + Patron 170 and Arsenal carryover from applications performed the prior year are not problematic.

Research Implications. Results suggest Garlon 4 + Patron 170 applied in spring (March and April) suppress maple, oak, and sweetgum growth more than applications conducted in winter (December, January, February). However, it should be noted applications performed in March and April may present increased risk to neighboring sensitive crops compared to applications conducted in winter. Further, Garlon 4 + Patron 170 applied to maple, oak, or sweetgum in April could result in visual brown-out if trees have begun to leaf-out. Overall, no evaluated treatment resulted in complete maple, oak, or sweetgum suppression, suggesting herbicide inputs may be required over multiple years.

OVERALL CONCLUSIONS

- Herbicide Fate and Transport from Applications via Passive Air Samplers.
    - Across seasonal application timings, all evaluated spray heads provided acceptable coverage in the treated spray swath
    - Spray heads used by the NC DOT (i.e., boomless spray heads) have low spray drift potential
        - Drift detected 3 ft from treated area at 3 in height was ≤ 1.57% of applied
        - Drift detected 3 ft from treated area at 5 ft height was ≤ 0.22% of applied
        - Drift detected ≥ 9 ft from treated area at 5 ft height was ≤ 0.01% of applied
    - In general, spray drift potential increased as application volume decreased (Boominator > Air Induction ≥ Nutating)
    - Observed Garlon 3A volatility was minimal regardless of seasonal application timing or spray head
    - Results suggest, wind direction and/or speed may be better indicator of potential spray drift compared to seasonal application timings
    - Future research should characterize drift and volatility of other herbicides routinely used by NC DOT using active air samplers

- Drift and Volatility of Herbicides to Adjacent Crops and Off-Target Species
    - Research implications based on projected roadside vegetation management and planting/harvest calendars for North Carolina (Figures 6 and 7)
        - Corn
            - Oust applied from January through July poses significant risk
            - Arsenal, Escort, and Plateau should be applied with caution from April through July
            - Confront and Patron 170 pose relatively low-risk
            - Garlon 4 applied December through March for dormant-stem applications poses relatively low-risk
        - Cotton

            - Oust applied from January through the production season poses significant risk
            - Arsenal, Escort, and Plateau should be applied from March through the production season pose significant risk
            - Confront should be applied with Caution from April through the production season
            - Garlon 4 and Patron 170 applied December through March for dormant-stem applications poses relatively low-risk
        - Soybean
            - Arsenal, Confront, and Escort applied from May through the production season pose significant risk
            - Oust and Plateau should be applied with caution from May through the production season
            - Garlon 4 and Patron 170 applied December through March for dormant-stem applications poses relatively low-risk
        - Tobacco
            - Oust applied from January through the production season poses significant risk
            - Arsenal, Confront, Escort, Garlon 4, Patron 170, and Plateau applied January through March pose relatively low-risk
            - Arsenal applied from March through mid-July poses significant risk
    - With appropriate spray drift-prevention practices, Arsenal, Confront, Escort, Garlon 4, Patron 170, and Plateau can be applied safely 6 WBP
    - Oust should be applied with caution when roadside applications are performed in proximity to corn, cotton, and tobacco production fields
    - Implications of Dormant-Stem Brush Control
        - These data imply applications for dormant-stem brush control conducted in December or January pose notably less risk to cotton, soybean, and tobacco compared to applications conducted in February or March, while Patron 170 and Garlon 4 are relatively safe on corn when applied December through March

- Assess Residual of Roadside Treatments from Dormant-Stem Applications
    - Sprayer application volume did not affect maple, oak, and sweetgum suppression
    - Across tree species, leaf-out from plots treated with Garlon 4 + Patron 170 ranked: December = January ≥ February > March > April
    - Garlon 4 + Patron 170 applied in March and April suppressed oak and sweetgum height more than when applied in December, January, and February
    - Maple height reductions were similar across application timings
    - Arsenal applied in April reduced oak growth, while Arsenal applied December through March did not provide oak suppression

RECOMMENDATIONS AND IMPLEMENTATION

Data from these projects cover many considerations when developing strategies to be utilized by NC DOT for effective vegetation management while minimizing potential impacts to adjacent cropping systems. Factors such as chemical selection, application timing, meteorological conditions, and application delivery method can all affect off-target movement of pesticides and should all be taken into account when developing a plan for safe and effective vegetation management. Additionally, data from these projects have shown vastly differing herbicide tolerances for evaluated crops, commonly grown throughout North Carolina.

When making herbicide applications for roadside vegetation management, sprayer operators should assume that any crop could be planted in a fallow field. In addition to varying herbicide sensitivities between crops, certain crops utilize farming practices that disturb the soil, particularly in instances of tillage and bedding. Even in no-till settings, farm equipment is capable of moving herbicide and dispersing it through fields. Sprayer operators should take great care to avoid direct sprays to fallow and planted fields.

During the evaluation of currently utilized NC DOT herbicide application equipment, residue samples collected 6 in from the soil surface and 3 ft from the treated swath, or 25 ft from pavement edge, detected less than 2% of herbicide applied on recovery pads. Air samples collected 5 ft from the soil surface and 3 ft from the treated swath, recovered less than 0.22% of the applied herbicide. Samples collected 9 ft from the treated swath, or 31 ft from the pavement edge, detected less than 0.01% of the herbicide applied. While a reduction of drift was observed 31 ft from the pavement edge, this study did not differentiate between particle and vapor drift. Research to further quantify the percentage of particle and vapor drift from spray equipment utilized by the NC DOT may be beneficial in better defining a window after application in which drift is likely to occur. Sprayer operators, regardless of whether off target movement is a result of particle or vapor drift, should take great care when applying all herbicide but especially herbicides known to have a greater vapor pressure as this may increase the window in which off target movement can occur. Additionally, it is recommended that spray operators monitor environmental conditions that could increase particle or vapor drift of herbicides.

When considering meteorological conditions, sprayer operators should refer to the herbicide label to identify environmental conditions that could move the selected product(s) off target (e.g., excessive wind conditions, temperature inversion, etc.). Applications should be avoided within time windows when conditions are forecasted to increase risk of off-target movement.

Lastly, it is recommended that a risk level is assigned to geographic regions based on crops planted, area, and the production value of the crop. While caution should be taken with every roadside application, data from NCDA&CS's 2019 North Carolina Agricultural Statistics identified specific counties where multiple crops are grown on a large scale as illustrated in Figures 8 through 12 (e.g., Pitt, Wayne, Johnston, and Sampson). Thus, applicators should be cognizant of potential increased risks of damage to crops when making roadside applications in those counties or geographic regions.

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APPENDICES

Table 1. Application parameters relating to the three evaluated spray heads.

Spray head	Spray volume (gal A^{-1})	Pressure (psi)	Spray swath (ft)	Ground speed (mph)	Release height (in)
Nutating[a]	49	38	21	7	84
Air induction[b]	37	41	22	7	78
Boominator[c]	26	32	21	7	48

[a]Model NSC-20108-V2; Norstar Industries, Inc. Auburn, WA.
[b]Model RSI-2870-V2; Roadside, Inc., Auburn, AL.
[c]Model 2650FM; Udor USA, Lino Lakes, MN.

Table 2. Season, year, time, date, and climatic conditions at application.[a,b]

Spray head	Season and year	Date and time (EST)	Relative humidity (%)[c]	Air temperature (°F)	Wind direction (degrees)	Wind speed (MPH)
Nutating	Summer; 2020	7/28; 9:50 AM	52	89	W (262)	4
Air induction	Summer; 2020	7/28; 10:30 AM	47	92	WNW (290)	5
Boominator	Summer; 2020	7/28; 11:00 AM	43	94	W (280)	5
Nutating	Fall; 2020	10/20; 10:35 AM	76	70	NNW (340)	4
Air induction	Fall; 2020	10/20; 11:10 AM	64	74	NNW (340)	5
Boominator	Fall; 2020	10/20; 11:50 AM	62	77	SW (230)	5
Nutating	Winter; 2021	2/24; 10:00 AM	29	61	SSE (159)	13
Air induction	Winter; 2021	2/24; 10:35 AM	28	63	SSE (162)	9
Boominator	Winter; 2021	2/24; 11:05 AM	27	65	S (170)	9
Nutating	Spring; 2021	4/21; 8:40 AM	31	51	SW (230)	13
Air induction	Spring; 2021	4/21; 9:10 AM	32	49	W (270)	10
Boominator	Spring; 2021	4/21; 9:40 AM	33	48	SW (230)	9

[a]Abbreviations: N, North; S, South; SSE, South southeast; SW, Southwest; W, West; WNW, West northwest; NNW, North northwest.

[b]Climatic conditions recorded within the research site using a using a mini-weather station (WatchDog 2000 Weather Station; Spectrum Technologies, Inc., Plainfield, IL).

[c]Relative humidity, air temperature, wind direction, and wind speed recorded at 5 ft height.

Table 3. Garlon 3A concentration in spray solution as a percent of applied.[a,b]

Spray head	Seasonal application timing: Summer	Fall	Winter	Spring
	% of applied[c]			
Nutating	90	97	112	104
Air induction	99	103	107	112
Boominator	104	98	113	101

[a]Research conducted on a roadside in Wake County, NC.
[b]Garlon 3A concentration quantified from sample (2 fl oz) of the spray solution collected prior to application for each nozzle and seasonal application timing.
[c]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 4. Garlon 3A residue on spray recovery pads placed in the center of the treated area as a percent of applied.[a,b,c]

Spray head	Seasonal application timing			
	Summer	Fall	Winter	Spring
	% of applied[d]			
Nutating	100	87	98	106
Air induction	99	88	103	106
Boominator	86	97	107	110
$LSD_{0.05}$	NS			

[a]Abbreviations: NS, nonsignificant.
[b]Research conducted on a roadside in Wake County, NC.
[c]Spray recovery pad samples collected within 15 minutes of spray application.
[d]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 5. Garlon 3A residue on spray recovery pads placed 3 ft outside of the treated area as a percent of applied.[a,b,c]

	Seasonal application timing			
Spray head	Summer	Fall	Winter	Spring
	% of applied[d]			
Nutating	SNP	0.75	0.83	0.89
Air induction	SNP	0.81	1.23	0.75
Boominator	SNP	0.83	1.57	1.00
$LSD_{0.05}$	0.31			

[a]Abbreviations: SNP, sample not produced.
[b]Research conducted on a roadside in Wake County, NC.
[c]Spray recovery pad samples were collected within 15 minutes of spray application.
[d]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 6. Main effect of sampling time interval on Garlon 3A residue detected in polyurethane foam samples following application.[a,b,c]

	Sampling time interval	
	0 to 4 HAT	4 to 24 HAT
	% of applied[d]	
Garlon 3A	0.0677	0.0020
$LSD_{0.05}$	0.0023	

[a]Abbreviations: HAT, hr after treatment.

[b]Research conducted on a roadside in Wake County, NC.

[c]Data pooled over four seasonal application timings, three spray heads, and three sampling distances.

[d]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 7. Main effect of sampling distance on Garlon 3A residue detected in polyurethane foam samples following application.[a,b]

	Distance from treated area[c]		
	3 ft	9 ft	30 ft
	% of applied[c]		
Garlon 3A	0.1006	0.0036	0.0003
$LSD_{0.05}$	0.0028		

[a]Research conducted on a roadside in Wake County, NC.
[b]Data pooled over four seasonal application timings, three spray heads, and two sampling time intervals.
[c]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 8. Spray head-by-sampling time interval-by-sampling distance interaction on Garlon 3A residue detected in polyurethane foam samples following application.[a,b,c]

	Sampling time interval					
	0 to 4 hr after treatment			4 to 24 hr after treatment		
	Distance from treated area					
Spray head	3 ft	9 ft	30 ft	3 ft	9 ft	30 ft
	% of applied[d]					
Nutating	0.1950	0.0080	0.0005	0.0045	0.0008	ND
Air induction	0.1831	0.0042	0.0006	0.0042	0.0011	< LOQ
Boominator	0.2104	0.0064	0.0009	0.0063	0.0014	0.0001
$LSD_{0.05}$	0.0070					

[a]Abbreviations: ND, nondetectable (< 1.0 ppb; 0.00006% of applied); < LOQ, below limit of quantification (1.6 ppb; 0.0001% of applied).
[b]Research conducted on a roadside in Wake County, NC.
[c]Data pooled over four seasonal application timings.
[d]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 9. Seasonal application timing-by-sampling time interval-by-sampling distance interaction on Garlon 3A residue detected in polyurethane foam samples following application.[a,b,c]

Seasonal application timing	Sampling time interval: 0 to 4 hr after treatment			4 to 24 hr after treatment		
	Distance from treated area					
	3 ft	9 ft	30 ft	3 ft	9 ft	30 ft
	% of applied[d]					
Winter	0.2185	0.0065	0.0008	0.0055	0.0003	< LOQ
Spring	0.2060	0.0060	0.0007	0.0050	0.0009	< LOQ
Summer	0.1627	0.0072	0.0002	0.0045	0.0021	ND
Fall	0.1973	0.0051	0.0009	0.0051	0.0010	0.0001
$LSD_{0.05}$	0.0084					

[a]Abbreviations: ND, nondetectable (< 1.0 ppb; 0.00006% of applied); < LOQ, below limit of quantification (1.6 ppb; 0.0001% of applied).
[b]Research conducted on a roadside in Wake County, NC.
[c]Data pooled over three spray heads.
[d]Percent of the nominal 1 gal A^{-1} Garlon 3A spray application rate.

Table 10. Application date, final harvest date, precipitation, average air- and soil-temperature within each year.

	Wk before planting				Wk after planting	
Year	18	12	6	0	4	8
	Application date[a]					
2019	17 Jan.	1 March	12 Apr.	13 May	12 June	8 July
2020	23 Jan.	28 Feb.	9 Apr.	11 May	18 June	15 July
	Harvest date[b]					
2019	27, 28 June	27, 28 June	27, 28 June	27, 28 June	22, 23 July	22, 23 Aug
2020	1, 2 July	1, 2 July	1, 2 July	1, 2 July	30, 31 July	27, 28 Aug
	Cumulative precipitation (in H_2O)[c]					
2019	21.5	14.1	7.5	0.0	4.5	6.2
2020	14.7	7.1	4.4	0.0	4.8	5.9
	Average air temperature (F)[d]					
2019	54.3	58.8	67.3	72.3	78.6	78.6
2020	55.2	59.0	60.0	59.9	78.3	78.1
	Average soil temperature (F)[e]					
2019	56.1	61.7	71.2	73.6	84.9	85.1
2020	57.7	62.4	65.5	67.1	85.3	84.9

[a]Application date refers to the date which herbicide application were applied.
[b]Harvest date refers to the date which final injury rating, plant height and aboveground biomass data were collected.
[c]Precipitation was recorded daily on site at Sandhill Research Station in Jackson Springs, NC at 3 ft height and refers to the cumulative precipitation (in H_2O) from application date through planting for herbicide treatments applied 18, 12, 6, and 0 wk before planting or application date through harvest date for herbicide treatments applied 4 and 8 wk after planting.
[d]Hourly average air temperature was recorded on site at Sandhill Research Station in Jackson Springs, NC at 6 ft height and refers to average air temperature (F) from application date through planting for herbicide treatments applied 18, 12, 6, and 0 wk before planting or application date through harvest date for herbicide treatments applied 4 and 8 wk after planting.
[e]Hourly average soil temperature was recorded on site at Sandhill Research Station in Jackson Springs, NC at 0.3 ft depth and refers to average soil temperature (F) from application date through planting for herbicide treatments applied 18, 12, 6, and 0 wk before planting or application date through harvest date for herbicide treatments applied 4 and 8 wk after planting.

Table 11. Effect of simulated drift rates on corn injury treated 18, 12, 6 or 0 wk before planting and rated 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% visual injury[d]															
Arsenal	1	1	1	1	0	1	1	4	3	3	2	9	8	10	14	97
Confront	1	3	3	2	0	4	1	7	1	0	2	12	6	10	8	23
Escort	2	2	1	3	1	3	2	11	2	4	3	8	13	21	33	89
Garlon 4	0	1	1	1	1	1	2	6	3	3	5	13	4	9	24	65
Oust	1	13	39	80	7	23	42	88	15	18	39	90	47	80	74	100
Patron 170	0	0	2	1	0	1	2	4	2	1	3	10	6	8	8	27
Plateau	1	1	1	1	2	2	1	12	2	2	4	14	5	9	13	76
Nontreated[e]	0				0				1				2			
$LSD_{0.05}$	6				6				8				17			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 12. Effect of simulated drift rates on corn visual injury treated 4 or 8 wk after planting and rated 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% visual injury[d]							
Arsenal	18	63	90	100	18	23	38	43
Confront	8	13	26	23	12	18	18	27
Escort	20	67	77	97	21	31	31	45
Garlon 4	10	26	39	76	23	23	33	56
Oust	83	93	99	100	28	33	38	52
Patron 170	8	11	19	31	12	22	17	27
Plateau	9	27	23	82	18	15	16	30
Nontreated[e]	3				3			
$LSD_{0.05}$	17				11			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 13. Effect of simulated drift rates on corn aboveground biomass reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	0	4	5	5	-4	-1	4	0	4	0	2	9	7	10	5	100
Confront	-6	5	4	5	-9	3	6	10	4	4	5	18	-3	7	10	8
Escort	-1	3	6	6	-5	-4	4	0	2	7	6	7	15	15	29	93
Garlon 4	2	4	0	3	4	10	4	2	6	6	7	17	2	5	16	69
Oust	2	15	48	97	9	30	49	99	19	20	43	99	46	82	73	100
Patron 170	3	5	5	5	-1	-2	-1	11	4	8	8	10	5	10	9	18
Plateau	2	0	4	8	2	1	0	13	0	5	9	19	1	7	11	76
$LSD_{0.05}$	15				16				15				24			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.

[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.

[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 14. Effect of simulated drift rates on corn aboveground biomass reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	18	41	88	94	7	5	24	27
Confront	1	10	19	27	10	18	2	14
Escort	13	52	64	92	14	4	9	18
Garlon 4	11	22	30	67	21	25	25	39
Oust	71	84	91	94	10	9	24	24
Patron 170	24	9	24	18	14	10	22	13
Plateau	7	38	22	76	12	8	13	16
$LSD_{0.05}$	23				NS			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 15. Effect of simulated drift rates on corn plant height reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	0	2	0	3	-6	5	3	1	5	1	2	5	9	8	8	94
Confront	0	5	2	3	-2	1	-4	4	3	3	2	8	5	7	10	12
Escort	0	2	3	1	1	2	1	2	6	4	2	4	9	13	15	77
Garlon 4	2	2	2	0	4	2	-1	2	4	5	5	8	6	9	17	56
Oust	5	5	21	74	4	14	28	89	10	10	23	90	38	67	64	100
Patron 170	2	4	4	-1	3	-3	2	3	4	4	3	9	5	11	10	13
Plateau	1	2	0	1	5	-1	1	8	1	5	6	9	4	9	10	57
$LSD_{0.05}$	8				9				8				18			

[a] Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.

[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.

[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 16. Effect of simulated drift rates on corn plant height reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	1	28	78	81	2	1	4	4
Confront	-2	6	3	3	-1	1	1	2
Escort	2	41	59	79	2	1	3	2
Garlon 4	2	6	7	42	5	3	1	13
Oust	65	69	78	87	3	0	2	2
Patron 170	2	5	2	12	1	0	1	3
Plateau	0	12	5	55	1	3	1	6
$LSD_{0.05}$	22				NS			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 17. Effect of simulated drift rates on cotton injury treated 18, 12, 6 or 0 wk before planting and rated 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% visual injury[d]															
Arsenal	2	3	4	17	2	7	7	33	7	10	23	71	26	56	81	100
Confront	3	3	2	8	5	6	12	8	12	10	15	25	15	23	31	86
Escort	3	6	11	13	12	5	13	16	8	10	12	46	28	59	80	100
Garlon 4	3	4	6	12	5	10	14	18	22	13	13	47	24	53	69	100
Oust	3	8	26	81	11	20	30	86	9	26	43	88	50	86	91	99
Patron 170	1	3	5	8	6	3	8	7	25	14	11	19	16	27	40	93
Plateau	3	2	3	34	2	3	3	33	13	11	13	58	19	23	49	99
Nontreated[e]	2				2				2				6			
$LSD_{0.05}$	8				11				16				17			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 18. Effect of simulated drift rates on cotton visual injury treated 4 or 8 wk after planting and rated 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% visual injury[d]							
Arsenal	28	69	75	100	23	43	44	71
Confront	14	18	33	68	17	27	33	77
Escort	30	70	85	99	31	48	61	82
Garlon 4	22	42	58	100	42	63	72	96
Oust	29	43	58	95	23	38	43	68
Patron 170	61	77	80	99	41	53	83	81
Plateau	8	16	32	82	28	25	36	59
Nontreated[e]	6				7			
$LSD_{0.05}$	17				NS			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 19. Effect of simulated drift rates on cotton aboveground biomass reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	-2	3	3	15	-1	0	4	24	5	3	19	74	10	47	89	100
Confront	1	0	1	8	0	2	6	5	4	3	29	24	2	13	17	71
Escort	4	6	7	13	3	4	2	1	4	5	11	38	9	55	77	100
Garlon 4	1	7	7	10	6	6	6	10	9	10	15	48	15	30	48	89
Oust	4	10	37	88	6	20	34	94	4	6	58	97	33	84	85	100
Patron 170	8	13	21	17	-4	-5	-2	-4	13	4	6	8	16	10	23	86
Plateau	6	4	5	31	0	1	3	35	2	18	15	59	32	5	30	99
$LSD_{0.05}$	18				19				26				27			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.

[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.

[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 20. Effect of simulated drift rates on cotton aboveground biomass reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	24	57	72	99	9	11	26	48
Confront	-10	-1	14	55	17	6	17	43
Escort	30	70	81	99	22	30	32	49
Garlon 4	9	37	51	100	37	49	42	78
Oust	27	39	53	94	17	20	25	45
Patron 170	42	60	61	100	22	42	42	72
Plateau	10	6	22	76	23	14	35	46
$LSD_{0.05}$	NS				NS			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 21. Effect of simulated drift rates on cotton plant height reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	2	5	5	16	2	6	2	20	9	-1	17	48	8	25	49	100
Confront	7	0	4	7	1	1	9	9	6	3	20	12	-1	9	9	61
Escort	2	5	11	7	6	5	6	8	5	8	3	27	6	34	48	100
Garlon 4	7	6	6	9	7	9	6	8	10	4	10	28	5	16	40	100
Oust	5	11	27	68	6	12	25	79	14	12	35	86	26	50	63	95
Patron 170	8	6	13	14	2	4	2	2	15	5	12	5	7	6	22	86
Plateau	4	5	12	20	1	-1	1	18	3	6	10	42	8	5	13	89
$LSD_{0.05}$	11				11				15				NS			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 22. Effect of simulated drift rates on cotton plant height reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	3	38	59	89	10	15	17	33
Confront	-1	-2	5	41	7	4	7	25
Escort	8	50	60	90	16	22	28	30
Garlon 4	8	28	31	92	16	29	31	42
Oust	10	26	37	86	9	13	15	25
Patron 170	26	40	40	88	9	30	32	41
Plateau	2	4	13	59	16	9	16	24
$LSD_{0.05}$	18				10			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 23. Effect of simulated drift rates on soybean injury treated 18, 12, 6 or 0 wk before planting and rated 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% visual injury[d]															
Arsenal	1	0	0	0	0	0	1	4	0	1	5	29	8	10	19	85
Confront	0	0	0	0	0	0	0	1	1	2	3	10	8	13	25	76
Escort	0	0	0	0	0	1	1	3	2	3	2	5	9	12	13	60
Garlon 4	0	0	0	0	1	1	1	2	4	3	7	38	10	39	58	100
Oust	0	0	0	1	0	1	1	0	2	1	2	1	8	13	11	21
Patron 170	0	0	0	0	0	0	1	1	2	0	4	8	9	13	17	48
Plateau	0	0	1	1	0	0	1	4	1	3	3	13	8	12	12	39
Nontreated[e]	0				0				1				3			
$LSD_{0.05}$	NS				NS				8				10			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 24. Effect of simulated drift rates on soybean visual injury treated 4 or 8 wk after planting and rated 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% visual injury[d]							
Arsenal	14	26	28	92	6	16	32	67
Confront	23	48	61	98	19	43	59	96
Escort	9	39	56	93	12	43	57	68
Garlon 4	42	89	99	100	55	83	95	100
Oust	10	18	24	39	4	7	8	43
Patron 170	15	18	33	92	25	24	43	77
Plateau	8	15	17	29	6	10	17	38
Nontreated[e]	3				3			
$LSD_{0.05}$	11				13			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 25. Effect of simulated drift rates on soybean aboveground biomass reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	1	2	2	11	2	-4	4	9	4	5	5	22	14	16	30	86
Confront	1	-6	5	-1	-3	0	4	0	-4	2	2	12	-1	6	32	70
Escort	2	2	3	4	4	0	0	13	0	5	4	6	-1	6	32	70
Garlon 4	3	-3	0	0	3	-3	3	9	-2	0	10	45	8	26	34	100
Oust	-1	4	0	-1	3	-3	8	8	1	-1	1	1	2	0	14	20
Patron 170	0	-3	-4	-1	4	0	4	2	3	-3	6	11	12	21	17	48
Plateau	2	-3	-7	0	3	3	2	14	2	10	14	17	20	18	12	28
$LSD_{0.05}$	NS				NS				13				19			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.

[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.

[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 26. Effect of simulated drift rates on soybean aboveground biomass reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	4	16	35	93	9	15	16	43
Confront	8	21	44	98	10	28	41	86
Escort	8	21	44	98	10	28	41	86
Garlon 4	42	92	99	100	48	77	89	95
Oust	7	6	14	38	1	10	13	23
Patron 170	18	24	34	94	2	9	23	60
Plateau	3	15	13	44	3	8	13	21
$LSD_{0.05}$	13				13			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 27. Effect of simulated drift rates on soybean plant height reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	2	3	3	13	0	0	-2	8	3	5	8	15	11	7	17	74
Confront	1	5	2	2	-1	0	-2	8	2	3	4	4	4	4	14	61
Escort	-2	2	2	4	0	-2	0	9	1	4	5	7	6	12	11	38
Garlon 4	4	1	1	2	-4	-5	3	6	3	1	9	33	4	22	27	100
Oust	5	4	3	2	-2	-3	2	-1	5	4	1	7	0	6	14	19
Patron	2	-3	2	2	-1	0	4	-1	4	0	5	11	6	10	13	32
Plateau	2	-2	-2	1	0	1	-1	6	1	7	7	13	9	15	11	25
$LSD_{0.05}$	NS				NS				8				13			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 28. Effect of simulated drift rates on soybean plant height reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	5	7	12	78	0	10	12	43
Confront	3	20	27	97	15	30	41	65
Escort	0	17	29	80	7	18	24	47
Garlon 4	21	75	92	94	33	48	67	65
Oust	3	4	6	22	2	4	9	19
Patron 170	6	13	17	81	8	14	27	39
Plateau	1	8	4	12	0	10	7	19
$LSD_{0.05}$	11				10			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.

[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.

[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 29. Effect of simulated drift rates on tobacco injury treated 18, 12, 6 or 0 wk before planting and rated 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% visual injury[d]															
Arsenal	1	3	2	6	3	3	9	13	11	17	16	38	20	29	48	86
Confront	3	3	4	5	1	8	8	9	13	11	17	38	27	23	32	65
Escort	2	5	4	6	7	8	11	28	11	17	15	33	28	30	43	86
Garlon 4	0	0	5	6	4	5	12	20	9	17	18	51	22	34	67	99
Oust	3	6	18	54	8	23	25	65	27	27	28	68	27	42	48	84
Patron 170	3	3	3	2	3	7	8	11	10	11	17	26	24	23	23	48
Plateau	1	2	4	8	8	9	9	26	13	6	13	41	20	21	36	79
Nontreated[e]	1				2				3				6			
$LSD_{0.05}$	6				8				NS				17			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 30. Effect of simulated drift rates on tobacco visual injury treated 4 or 8 wk after planting and rated 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% visual injury[d]							
Arsenal	24	53	70	100	27	40	68	96
Confront	21	23	33	73	31	42	44	80
Escort	36	76	80	98	41	71	83	98
Garlon 4	45	65	74	100	60	81	84	100
Oust	38	47	66	83	36	42	50	83
Patron 170	27	56	64	97	38	49	58	91
Plateau	29	25	28	63	26	38	40	74
Nontreated[e]	6				5			
$LSD_{0.05}$	15				12			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[e]Nontreated visual injury not included in statistical analysis.

Table 31. Effect of simulated drift rates on tobacco aboveground biomass reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	5	8	2	7	5	1	11	12	6	8	16	62	10	26	54	89
Confront	4	6	11	12	-11	3	6	9	7	11	26	48	30	8	30	55
Escort	10	11	11	9	14	6	2	19	20	23	26	41	20	38	48	86
Garlon 4	6	3	5	6	2	1	7	8	1	26	27	60	15	21	71	98
Oust	0	20	15	71	1	15	30	83	17	39	43	86	15	43	61	80
Patron 170	5	11	8	7	10	0	4	2	7	3	32	42	33	34	27	54
Plateau	0	3	4	16	1	-2	5	29	7	4	16	51	13	28	39	89
$LSD_{0.05}$	20				19				NS				26			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.

[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.

[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 32. Effect of simulated drift rates on tobacco aboveground biomass reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	18	50	70	100	4	10	13	60
Confront	24	27	22	61	-7	15	16	11
Escort	48	71	77	98	3	23	36	76
Garlon 4	48	64	78	100	12	22	41	88
Oust	43	50	67	79	8	17	5	31
Patron 170	24	39	55	93	3	9	14	37
Plateau	36	22	27	64	16	23	22	21
$LSD_{0.05}$	22				21			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 33. Effect of simulated drift rates on tobacco plant height reduction treated 18, 12, 6 or 0 wk before planting and harvested 6 wk after planting.[a,b]

	Herbicide application timing															
	18 wk before planting				12 wk before planting				6 wk before planting				0 wk before planting			
	% of 1X application rate															
Herbicide[c]	1	5	10	100	1	5	10	100	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]															
Arsenal	6	5	1	10	4	4	14	7	8	9	6	43	12	21	37	79
Confront	5	8	13	13	-1	12	3	7	5	10	16	45	21	11	20	44
Escort	5	8	9	11	14	7	10	27	12	17	19	35	23	32	42	78
Garlon 4	7	8	4	10	2	5	12	17	3	17	23	44	18	28	57	94
Oust	10	13	20	57	2	27	24	68	13	31	26	69	16	40	46	67
Patron 170	2	10	5	2	8	7	8	9	1	4	20	25	26	26	17	36
Plateau	0	6	6	18	4	2	11	26	9	3	6	37	16	24	32	69
$LSD_{0.05}$	13				12				NS				21			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 18 wk before: 17 Jan.; 12 wk before: 1 March; 6 wk before: 12 Apr.; 0 wk before planting: 13 May 2019; 18 wk before: 23 Jan.; 12 wk before: 28 Feb.; 6 wk before: 9 Apr.; 0 wk before planting: 11 May 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 34. Effect of simulated drift rates on tobacco plant height reduction treated 4 or 8 wk after planting and harvested 6 wk after treatment.[a,b]

	Herbicide application timing							
	4 wk after planting				8 wk after planting			
	% of 1X application rate							
Herbicide[c]	1	5	10	100	1	5	10	100
	% reduction relative to nontreated[d]							
Arsenal	7	53	62	92	1	3	23	44
Confront	10	10	16	52	3	13	4	18
Escort	33	63	70	94	1	13	38	56
Garlon 4	32	43	62	98	8	20	32	82
Oust	26	41	48	62	7	14	12	22
Patron 170	14	27	29	90	2	7	4	32
Plateau	23	16	14	57	3	7	9	18
$LSD_{0.05}$	17				11			

[a]Data pooled over two experimental runs conducted at Sandhills Research Station in Jackson Springs, NC in 2019 and 2020 and planting occurred on May 13, 2019, and May 11, 2020.
[b]Applications: 4 wk after planting: 12 June; 8 wk after planting: 8 July 2019; 4 wk after planting: 18 June; 8 wk after planting: 15 July 2020.
[c]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[d]% reduction = {[(*nontreated – treated)/nontreated*]× 100}.

Table 35. Effect of simulated drift rates on cotton visual injury treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% visual injury[c]								
Arsenal	43	49	56	43	74	92	38	49	58
Confront	20	28	46	31	49	58	31	46	58
Escort	26	51	74	71	92	98	48	60	66
Garlon 4	29	78	81	40	79	93	51	65	75
Oust	43	56	73	78	93	96	35	43	51
Patron 170	21	38	46	36	74	87	46	58	64
Plateau	9	16	28	21	45	82	41	48	54
Nontreated[d]	4			9			7		
$LSD_{0.05}$	21			14			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[d]Nontreated visual injury not included in statistical analysis.

Table 36. Effect of simulated drift rates on cotton aboveground fresh biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	56	55	54	29	75	90	12	10	23
Confront	6	19	37	14	46	49	-6	13	23
Escort	33	56	82	78	92	98	20	30	19
Garlon 4	23	80	83	43	82	95	17	31	27
Oust	49	63	86	81	96	98	12	18	14
Patron 170	30	52	55	49	73	86	23	13	38
Plateau	15	17	37	11	45	84	21	27	15
$LSD_{0.05}$		NS			23			NS	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 37. Effect of simulated drift rates on cotton aboveground dry biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	58	55	59	37	80	93	7	0	26
Confront	0	18	38	19	50	58	-14	14	21
Escort	33	61	85	80	94	99	17	24	24
Garlon 4	29	79	83	53	84	96	13	32	35
Oust	51	67	87	84	96	98	7	9	9
Patron 170	26	45	57	56	77	89	20	15	28
Plateau	13	17	35	10	50	87	18	29	12
$LSD_{0.05}$	NS			24			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 38. Effect of simulated drift rates on cotton plant height reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	29	43	30	26	59	78	3	18	24
Confront	1	7	17	13	28	28	12	10	18
Escort	15	28	65	57	78	91	15	25	27
Garlon 4	9	70	71	24	70	83	13	27	20
Oust	28	40	59	67	80	90	15	15	9
Patron 170	9	25	35	31	53	72	19	18	24
Plateau	5	12	19	10	38	65	15	16	24
$LSD_{0.05}$	26			NS			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 39. Effect of simulated drift rates on peanut visual injury treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% visual injury[c]								
Arsenal	23	57	57	20	55	71	15	27	50
Confront	25	64	83	44	74	91	36	47	59
Escort	51	71	84	70	84	94	26	50	68
Garlon 4	58	77	93	44	91	99	55	64	82
Oust	33	57	70	65	86	93	9	23	33
Patron 170	28	34	56	64	84	93	29	45	54
Plateau	1	5	4	0	3	16	1	3	4
Nontreated[d]		2			7			6	
$LSD_{0.05}$		16			13			9	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).

[d]Nontreated visual injury not included in statistical analysis.

Table 40. Effect of simulated drift rates on peanut aboveground fresh biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	23	48	51	11	66	69	13	27	51
Confront	-8	46	77	21	59	80	17	6	23
Escort	51	54	87	71	81	91	18	49	68
Garlon 4	55	85	92	35	94	99	31	57	72
Oust	37	56	75	73	90	95	1	24	29
Patron 170	2	26	48	71	91	98	39	37	46
Plateau	-10	3	11	0	4	23	-4	9	12
$LSD_{0.05}$		NS			23			NS	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 41. Effect of simulated drift rates on peanut aboveground dry biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	21	44	47	14	65	70	13	26	51
Confront	-15	48	81	25	61	82	10	0	25
Escort	49	56	88	72	85	92	21	43	64
Garlon 4	51	87	92	39	95	99	33	67	78
Oust	39	54	75	72	89	94	1	19	31
Patron 170	2	24	45	70	90	98	43	36	49
Plateau	-5	-4	3	2	-1	25	-5	10	7
$LSD_{0.05}$	31			23			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 42. Effect of simulated drift rates on peanut plant height reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	5	41	51	4	30	46	6	10	28
Confront	12	41	63	17	43	64	9	9	23
Escort	31	47	74	49	74	82	20	23	42
Garlon 4	33	55	69	12	81	96	34	50	62
Oust	18	32	41	44	72	74	5	6	18
Patron 170	1	14	22	38	61	82	16	19	26
Plateau	-2	10	4	-1	7	12	4	14	15
$LSD_{0.05}$	NS			26			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 43. Effect of simulated drift rates on pepper visual injury treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% visual injury[c]								
Arsenal	25	37	55	32	52	86	48	71	82
Confront	23	26	41	38	59	81	49	58	75
Escort	59	66	69	51	74	90	71	80	89
Garlon 4	36	58	87	74	88	100	56	100	100
Oust	35	43	51	39	56	74	51	64	77
Patron 170	16	26	48	17	31	54	46	71	82
Plateau	33	40	47	41	69	81	36	53	69
Nontreated[d]		3			6			7	
$LSD_{0.05}$		12			9			11	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[d]Nontreated visual injury not included in statistical analysis.

Table 44. Effect of simulated drift rates on pepper aboveground fresh biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	20	36	46	40	63	88	42	78	82
Confront	11	12	36	33	44	86	52	67	73
Escort	51	59	78	54	85	92	69	80	87
Garlon 4	25	54	83	80	82	98	71	98	98
Oust	33	38	50	35	61	77	43	69	78
Patron 170	0	13	42	18	33	66	58	76	85
Plateau	24	33	45	58	67	78	46	55	65
$LSD_{0.05}$		NS			17			NS	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 45. Effect of simulated drift rates on pepper aboveground dry biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	14	27	40	40	68	88	41	70	73
Confront	7	6	34	38	45	87	40	51	68
Escort	49	53	66	47	78	89	62	76	76
Garlon 4	21	53	82	79	77	98	59	86	87
Oust	21	30	38	40	59	75	31	58	71
Patron 170	-11	8	39	28	43	65	45	67	74
Plateau	21	31	41	57	63	71	32	51	53
$LSD_{0.05}$		NS			15			NS	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 46. Effect of simulated drift rates on pepper plant height reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	7	12	32	7	39	57	28	48	68
Confront	4	3	10	17	34	57	16	24	51
Escort	21	24	47	21	42	66	59	64	82
Garlon 4	8	30	57	35	38	94	28	89	91
Oust	15	24	21	23	29	52	26	50	62
Patron 170	-5	4	15	9	17	27	18	40	62
Plateau	1	23	20	27	47	58	37	35	47
$LSD_{0.05}$	NS			15			16		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 47. Effect of simulated drift rates on soybean visual injury treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% visual injury[c]								
Arsenal	19	26	44	36	45	56	28	39	51
Confront	31	63	77	46	92	98	44	81	88
Escort	29	41	62	84	98	100	58	84	90
Garlon 4	54	96	98	36	100	100	74	99	100
Oust	24	28	38	28	41	46	17	36	50
Patron 170	28	38	43	15	54	77	36	50	58
Plateau	11	31	41	9	26	78	20	24	49
Nontreated[d]	1			4			12		
$LSD_{0.05}$	12			16			12		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[d]Nontreated visual injury not included in statistical analysis.

Table 48. Effect of simulated drift rates on soybean aboveground fresh biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	6	15	39	38	52	44	19	33	38
Confront	15	44	70	23	83	98	16	77	86
Escort	17	40	63	81	98	99	57	81	88
Garlon 4	43	96	98	22	100	100	70	93	96
Oust	14	14	36	16	37	41	17	39	53
Patron 170	17	32	37	12	39	67	27	27	55
Plateau	-1	28	35	-3	19	80	9	8	34
$LSD_{0.05}$	NS			30			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 49. Effect of simulated drift rates on soybean aboveground dry biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	-2	18	40	39	53	51	21	35	41
Confront	17	49	73	37	87	97	31	78	87
Escort	21	42	64	80	98	98	55	81	87
Garlon 4	48	97	99	32	100	100	73	89	90
Oust	19	15	30	19	43	47	22	46	58
Patron 170	16	31	40	5	38	71	28	37	59
Plateau	0	32	34	-10	19	79	16	18	42
$LSD_{0.05}$		24			28			NS	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 50. Effect of simulated drift rates on soybean plant height reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	1	5	29	24	33	46	15	27	37
Confront	16	37	55	26	60	94	24	61	68
Escort	11	24	45	75	95	98	37	57	63
Garlon 4	29	81	89	19	100	100	52	76	78
Oust	13	19	20	15	37	38	10	23	33
Patron 170	16	24	24	11	32	61	25	21	38
Plateau	-1	8	22	-4	8	64	16	12	15
$LSD_{0.05}$	21			24			17		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 51. Effect of simulated drift rates on tobacco visual injury treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% visual injury[c]								
Arsenal	13	26	49	26	44	67	36	58	77
Confront	14	32	49	34	39	54	39	56	75
Escort	32	35	53	56	62	78	61	73	89
Garlon 4	36	61	63	59	83	92	89	100	100
Oust	33	43	63	44	58	73	35	48	64
Patron 170	16	28	46	26	27	54	48	58	100
Plateau	20	34	49	26	27	54	18	32	49
Nontreated[d]		7			4			14	
$LSD_{0.05}$		9			12			9	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[d]Nontreated visual injury not included in statistical analysis.

Table 52. Effect of simulated drift rates on tobacco aboveground fresh biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	5	25	44	32	49	76	30	59	79
Confront	0	20	37	33	36	41	33	45	70
Escort	29	36	48	62	68	77	54	63	85
Garlon 4	35	57	63	61	80	87	82	95	97
Oust	38	53	65	48	63	70	27	42	56
Patron 170	12	21	45	9	33	50	29	41	94
Plateau	22	35	47	26	37	57	16	27	35
$LSD_{0.05}$	NS			NS			14		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 53. Effect of simulated drift rates on tobacco aboveground dry biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	3	19	45	21	45	76	39	59	81
Confront	4	18	36	34	38	46	35	49	72
Escort	28	35	49	64	70	77	61	75	84
Garlon 4	37	54	67	70	84	90	84	88	94
Oust	34	47	63	50	64	73	32	48	66
Patron 170	16	25	41	1	28	55	40	48	88
Plateau	23	33	38	25	32	54	30	38	42
$LSD_{0.05}$		NS			19			13	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 54. Effect of simulated drift rates on tobacco plant height reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	9	29	35	24	28	56	29	50	66
Confront	11	16	33	26	24	32	16	41	73
Escort	25	27	34	38	42	60	54	64	84
Garlon 4	28	41	57	33	77	84	84	93	96
Oust	25	33	47	35	44	47	24	46	55
Patron 170	16	22	42	3	18	40	37	52	91
Plateau	21	30	38	20	28	47	12	19	30
$LSD_{0.05}$	NS			16			14		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 55. Effect of simulated drift rates on tomato visual injury treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% visual injury[c]								
Arsenal	5	35	44	71	88	94	17	42	64
Confront	39	56	58	19	72	89	34	71	86
Escort	33	34	44	56	80	94	24	36	54
Garlon 4	36	68	74	65	100	100	90	93	99
Oust	38	43	61	60	86	94	33	42	51
Patron 170	26	31	43	74	90	93	49	76	94
Plateau	34	37	41	49	94	96	18	28	36
Nontreated[d]		2			4			6	
$LSD_{0.05}$		14			9			11	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.
[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.
[c]Visual injury rated on a scale of 0 (no injury) to 100% (complete plant death).
[d]Nontreated visual injury not included in statistical analysis.

Table 56. Effect of simulated drift rates on tomato aboveground fresh biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	17	26	21	85	96	98	6	41	58
Confront	28	43	49	38	82	88	23	38	64
Escort	27	31	49	65	81	91	20	30	34
Garlon 4	30	71	86	71	100	100	57	60	90
Oust	50	61	78	81	88	95	25	21	55
Patron 170	20	40	41	62	88	87	27	50	65
Plateau	34	34	52	61	95	98	15	29	34
$LSD_{0.05}$		NS			16			NS	

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 57. Effect of simulated drift rates on tomato aboveground dry biomass reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	11	26	30	87	96	98	7	39	58
Confront	31	51	53	32	78	90	17	49	67
Escort	30	28	47	72	85	90	14	33	38
Garlon 4	31	76	88	73	100	100	58	67	81
Oust	52	61	80	80	88	94	2	19	55
Patron 170	16	39	42	72	92	90	33	58	72
Plateau	38	39	50	65	95	97	19	26	37
$LSD_{0.05}$	NS			17			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 58. Effect of simulated drift rates on tomato plant height reduction treated 6 or 0 wk before planting or 6 wk after planting.[a]

	Herbicide application timing								
	6 wk before planting			0 wk before planting			6 wk after planting		
	% of 1X application rate								
Herbicide[b]	1	5	10	1	5	10	1	5	10
	% reduction relative to nontreated[c]								
Arsenal	7	15	12	52	78	85	9	24	34
Confront	16	35	47	-9	42	68	10	41	56
Escort	10	17	22	34	48	77	12	24	29
Garlon 4	26	44	63	38	100	100	63	64	78
Oust	23	29	52	44	65	80	7	22	41
Patron 170	12	16	30	40	67	68	32	44	67
Plateau	20	13	33	29	83	91	9	15	34
$LSD_{0.05}$	NS			26			NS		

[a]Data pooled over two experimental runs conducted at Method Road Greenhouses in Raleigh, NC in 2019 and 2020.

[b]All herbicide applications include a nonionic surfactant at 0.25% v/v.

[c]% reduction = {[(*nontreated – treated)/nontreated*] × 100}.

Table 59. Main effect of tree species on percent leaf-out treated with Garlon 4 + Patron 170.[a,b,c,d,e]

Tree Species	% leaf-out[f]
Maple *(Acer* spp.)	35
Oak (*Quercus* spp.)	45
Sweetgum (*Liquidambar* spp.)	42
LSD	NS

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes and five application timings.
[c]Applications: 12 Dec. 2019, 16 Jan. 2020, 13 Feb. 2020, 20 Mar. 2020, and 16 Apr. 2020.
[d]Garlon 4 (2 gal A^{-1}) + Patron 170 (6.9 pt A^{-1}) tank-mixed.
[e]All applications included a crop oil concentrate at 2.5% v/v.
[f]Leaf-out visually estimated 6 May 2021 on a 0 (no canopy cover) to 100% (complete canopy cover).

Table 60. Main effect of application timing on maple (*Acer* spp.), oak (*Quercus* spp.), and sweetgum (*Liquidambar* spp.) percent leaf-out treated with Garlon 4 + Patron 170.[a,b,c,d]

Application timing	% leaf-out[e]
12 Dec. 2019	60
16 Jan. 2020	57
13 Feb. 2020	46
20 Mar. 2020	29
16 Apr. 2020	11
LSD	11

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes and three tree species.
[c]Garlon 4 (2 gal A^{-1}) + Patron 170 (6.9 pt A^{-1}) tank-mixed.
[d]All applications included a crop oil concentrate at 2.5% v/v.
[e]Leaf-out visually estimated 6 May 2021 on a 0 (no canopy cover) to 100% (complete canopy cover).

Table 61. Effect of Garlon 4 + Patron 170 on maple (*Acer* spp.), oak (*Quercus* spp.), and sweetgum (*Liquidambar* spp.) leaf-out as affected by application timing.[a,b,c,d,e]

Tree Species	Dec.	Jan.	Feb.	Mar.	Apr.
	Application timing				
	% leaf-out[f]				
Maple (*Acer* spp.)	48	56	31	27	13
Oak (*Quercus* spp.)	67	58	49	38	12
Sweetgum (*Liquidambar* spp.)	66	57	57	22	8
LSD	NS				

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes.
[c]Applications: 12 Dec. 2019, 16 Jan. 2020, 13 Feb. 2020, 20 Mar. 2020, and 16 Apr. 2020.
[d]Garlon 4 (2 gal A^{-1}) + Patron 170 (6.9 pt A^{-1}) tank-mixed.
[e]All applications included a crop oil concentrate at 2.5% v/v.
[f]Leaf-out visually estimated 6 May 2021 on a 0 (no canopy cover) to 100% (complete canopy cover).

Table 62. Main effect of tree species on percent height reduction treated with Garlon 4 + Patron 170.[a,b,c,d,e]

Tree Species	% height reduction[f]
Maple *(Acer* spp.)	84
Oak (*Quercus* spp.)	49
Sweetgum (*Liquidambar* spp.)	48
LSD	22

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes and five application timings.
[c]Applications: 12 Dec. 2019, 16 Jan. 2020, 13 Feb. 2020, 20 Mar. 2020, and 16 Apr. 2020.
[d]Garlon 4 (2 gal A^{-1}) + Patron 170 (6.9 pt A^{-1}) tank-mixed.
[e]All applications included a crop oil concentrate at 2.5% v/v.
[f]% height reduction = {[(*nontreated – treated)/nontreated*]× 100}. Treated and nontreated tree height measured (in) at each respective application timing and 6 May 2021.

Table 63. Main effect of application timing on maple (*Acer* spp.), oak (*Quercus* spp.), and sweetgum (*Liquidambar* spp.) percent height reduction treated with Garlon 4 + Patron 170.[a,b,c,d]

Application timing	% height reduction[e]
12 Dec. 2019	43
16 Jan. 2020	46
13 Feb. 2020	60
20 Mar. 2020	64
16 Apr. 2020	88
LSD	17

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes and three tree species.
[c]Garlon 4 (2 gal A^{-1}) + Patron 170 (6.9 pt A^{-1}) tank-mixed.
[d]All applications included a crop oil concentrate at 2.5% v/v.
[e]% height reduction = {[(*nontreated – treated)/nontreated*]× 100}. Treated and nontreated tree height measured (in) at each respective application timing and 6 May 2021.

Table 64. Effect of Garlon 4 + Patron 170 on maple (*Acer* spp.), oak (*Quercus* spp.), and sweetgum (*Liquidambar* spp.) percent height reduction as affected by application timing.[a,b,c,d]

	Application timing				
Tree Species	Dec.	Jan.	Feb.	Mar.	Apr.
	% height reduction[e]				
Maple (*Acer* spp.)	83	84	88	76	95
Oak (*Quercus* spp.)	25	27	50	66	77
Sweetgum (*Liquidambar* spp.)	22	27	44	50	95
LSD	30				

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes.
[c]Garlon 4 (2 gal A^{-1}) + Patron 170 (6.9 pt A^{-1}) tank-mixed.
[d]All applications included a crop oil concentrate at 2.5% v/v.
[e]% height reduction = {[(*nontreated – treated)/nontreated*]× 100}. Treated and nontreated tree height measured (in) at each respective application timing and 6 May 2021.

Table 65. Main effect of application timing on Oak (*Quercus* spp.) percent leaf-out treated with Arsenal.[a,b,c,d,e]

Application timing	% leaf-out[f]
Dec. 12, 2019	95
Jan. 16, 2020	96
Feb. 13, 2020	98
Mar. 20, 2020	88
Apr. 20, 2020	60
LSD	10

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes.
[c]Applications: 12 Dec. 2019, 16 Jan. 2020, 13 Feb. 2020, 20 Mar. 2020, and 16 Apr. 2020.
[d]Arsenal applied alone at 12 fl oz A^{-1}.
[e]All applications included a crop oil concentrate at 2.5% v/v.
[f]Leaf-out visually estimated 6 May 2021 on a 0 (no canopy cover) to 100% (complete canopy cover).

Table 66. Main effect of application timing on Oak (*Quercus* spp.) percent height reduction treated with Arsenal.[a,b,c,d]

Application timing	% height reduction[e]
12 Dec. 2019	0
16 Jan. 2020	1
13 Feb. 2020	-3
20 Mar. 2020	13
16 Apr. 2020	36
LSD	NS

[a]Research conducted on a roadside in Franklin County, NC.
[b]Data pooled over two spray volumes.
[c]Arsenal applied alone at 12 fl oz A^{-1}.
[d]All applications included a crop oil concentrate at 2.5% v/v.
[e]% height reduction = {[(*nontreated – treated)/nontreated*]× 100}. Treated and nontreated tree height measured (in) at each respective application timing and 6 May 2021.

Figure 1. Research area along Interstate 540 in Wake County, North Carolina.

Figure 2. Nutating spray head and spray pattern.

Figure 3. Air induction spray head and spray pattern.

Figure 4. Boominator spray head and spray pattern.

Figure 5A. Passive air samplers were placed at 3, 9, or 30 ft from the treated area.

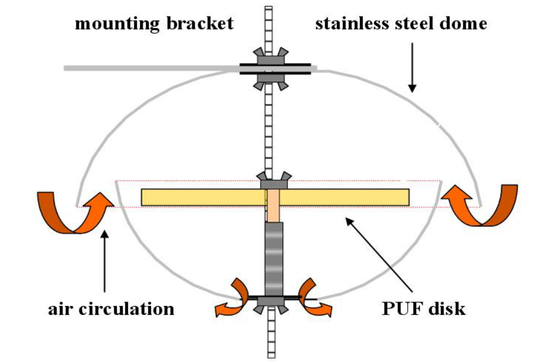


Figure 5B. Cross-section of a passive air sampler (image from Holoubek et al., 2011).

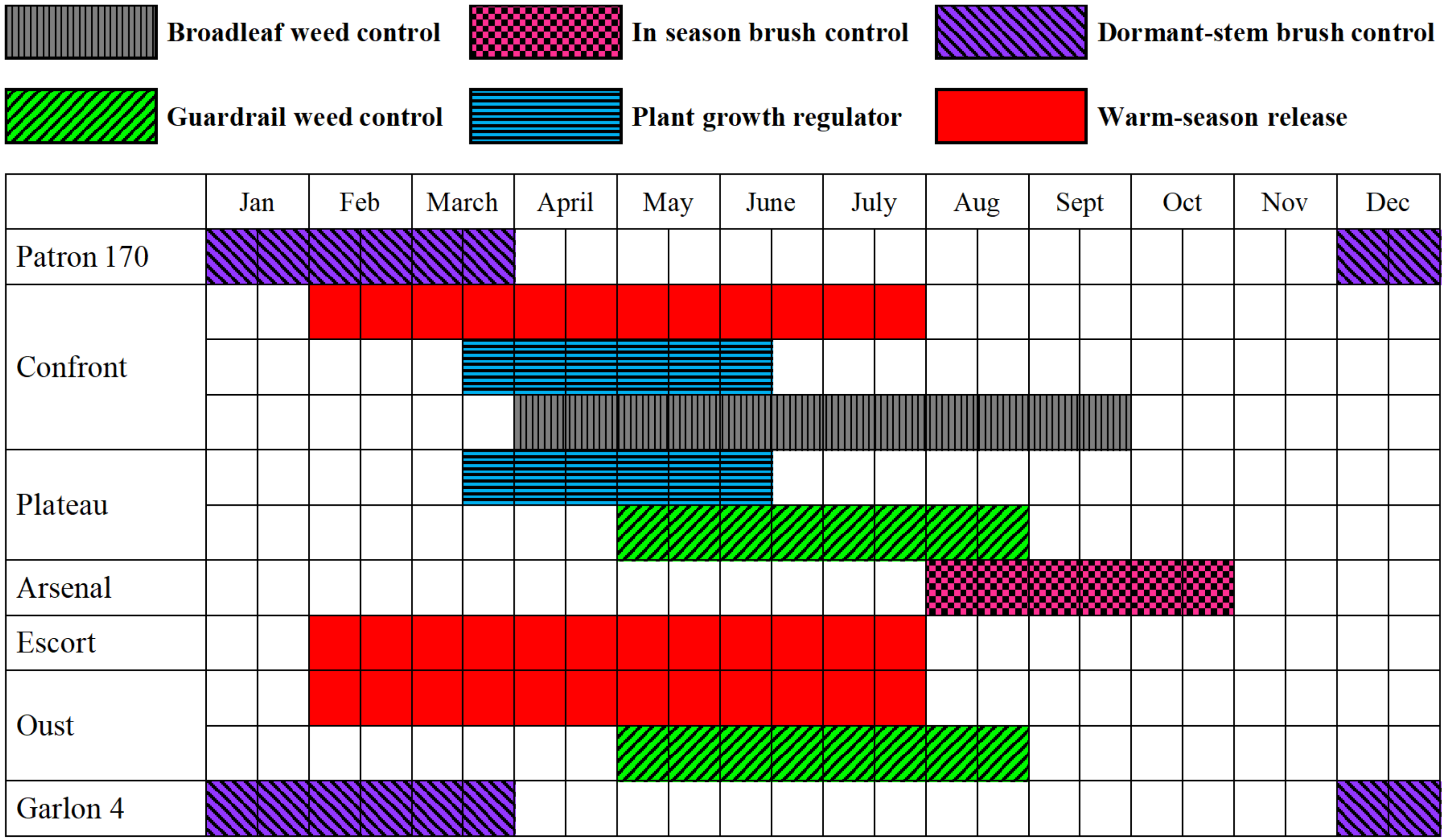
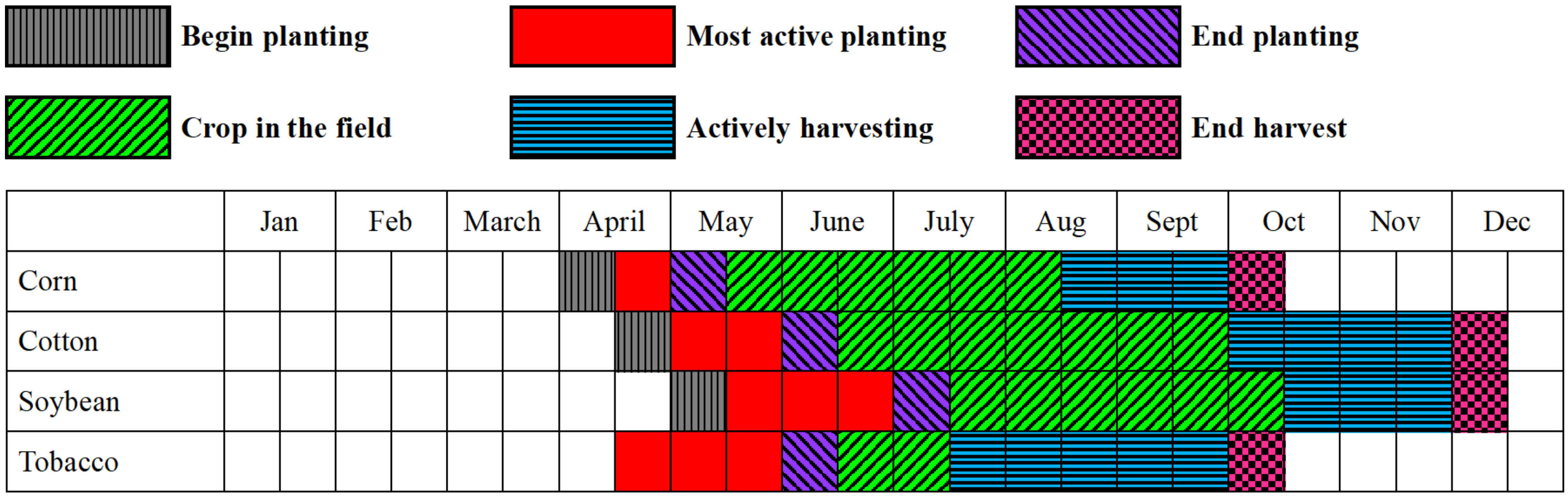


Figure 6. North Carolina Department of Transportation Vegetation Management Objective Calendar.



Crops	Usual Planting Dates			Usual Harvest Dates		
	Begin	Most active	End	Begin	Most active	End
Corn	Apr 1	Apr 10 – Apr 25	May 20	Aug 20	Sept 10 – Oct 10	Oct 10
Cotton	Apr 20	May 1 – May 20	June 10	Sept 30	Oct 10 – Nov 15	Dec 15
Soybean	May 1	May 20 – June 30	July 20	Oct 10	Nov 10 – Dec 5	Dec 20
Tobacco	Apr 15	Apr 20 – May 25	June 5	July 1	July 20 – Sept 15	Oct 10

Figure 7. Usual planting and harvest dates for corn, cotton, soybean, and tobacco in North Carolina. Data sourced from North Carolina Department of Agriculture and Consumer Services (2020) North Carolina Agricultural Statistics.

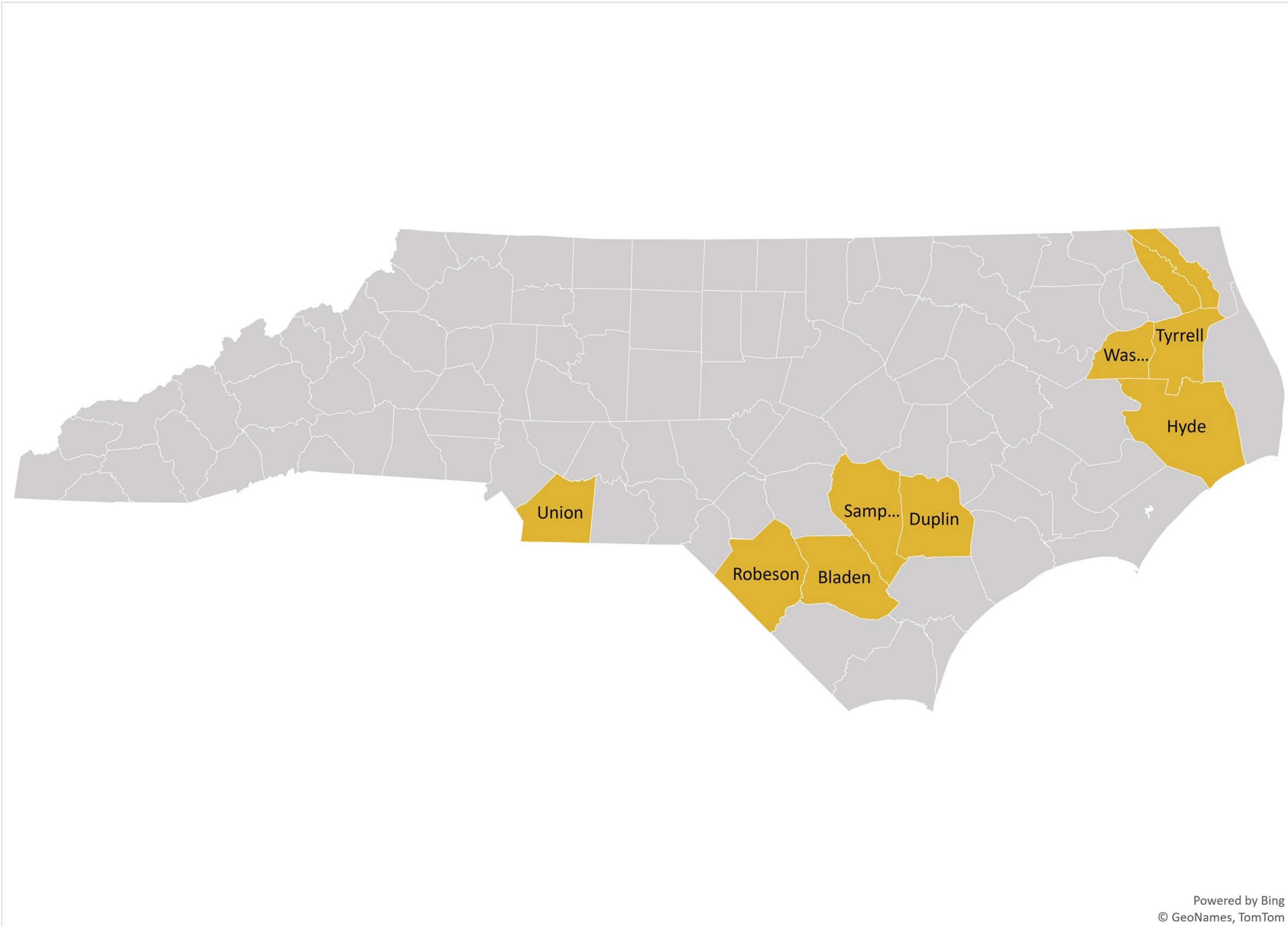


Figure 8. Largest corn producing counties in North Carolina (NCDA&CS 2019).

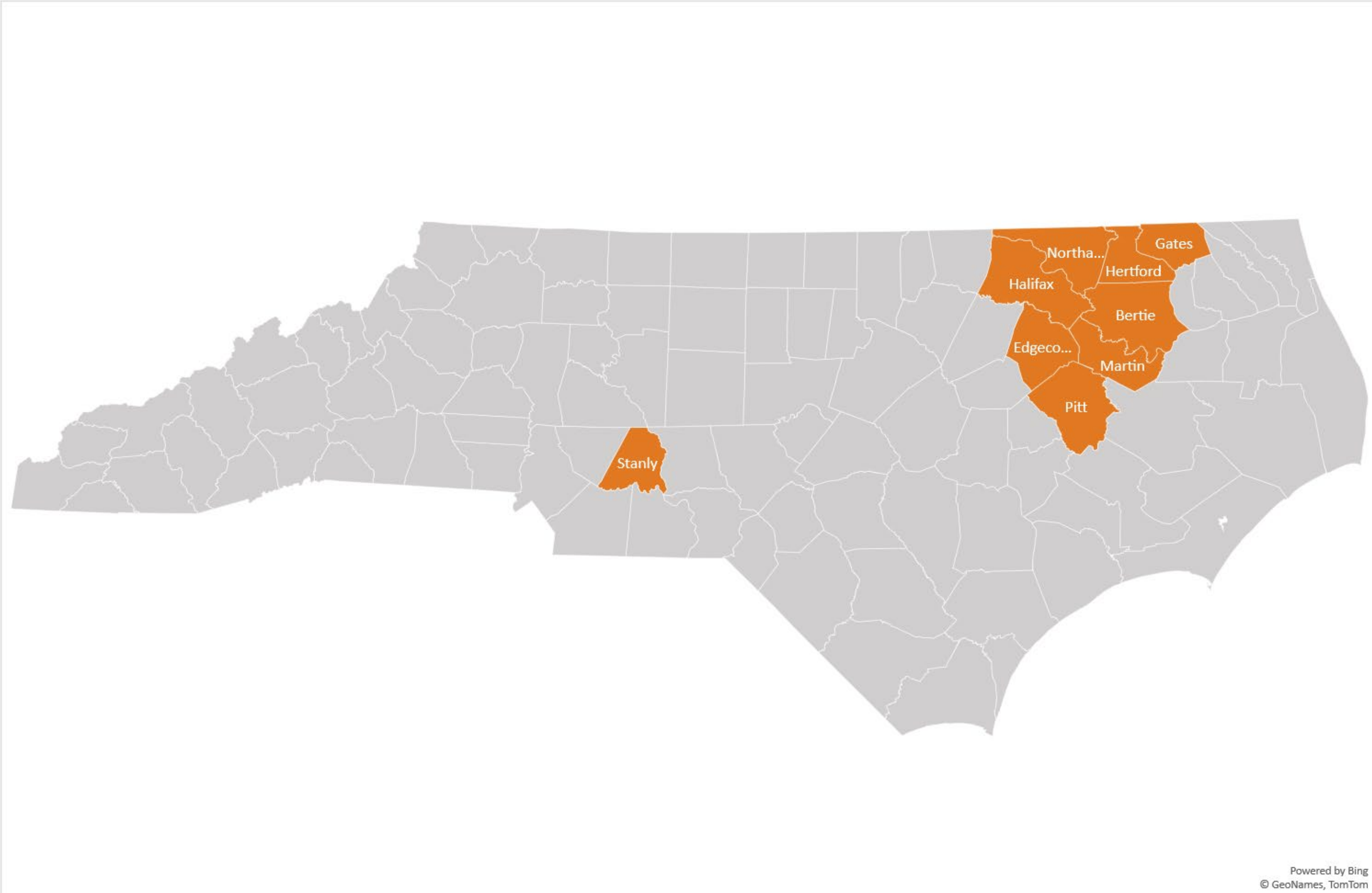


Figure 9. Largest cotton producing counties in North Carolina (NCDA&CS 2019).

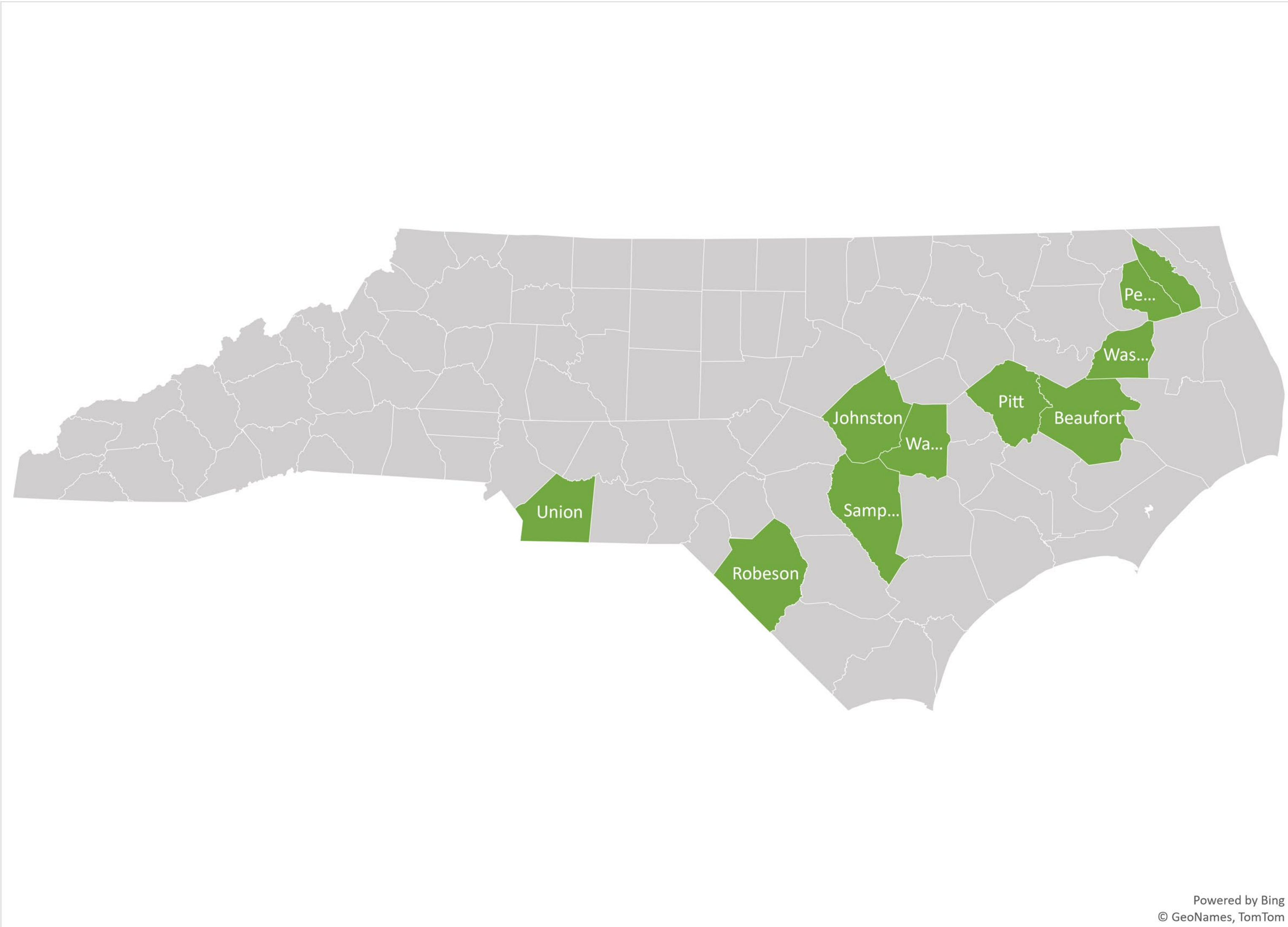


Figure 10. Largest soybean producing counties in North Carolina (NCDA&CS 2019).

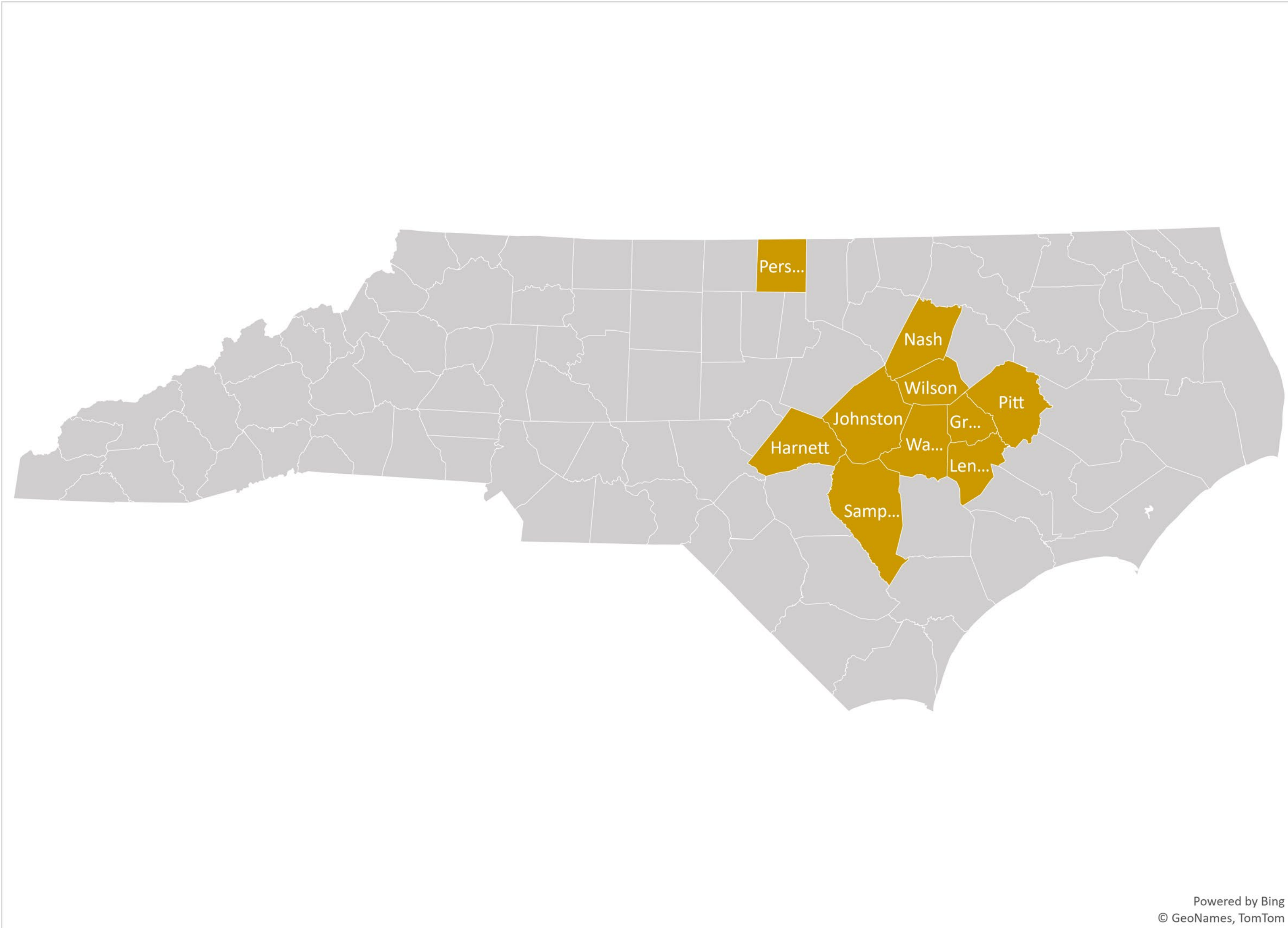


Figure 11. Largest tobacco producing counties in North Carolina (NCDA&CS 2019).

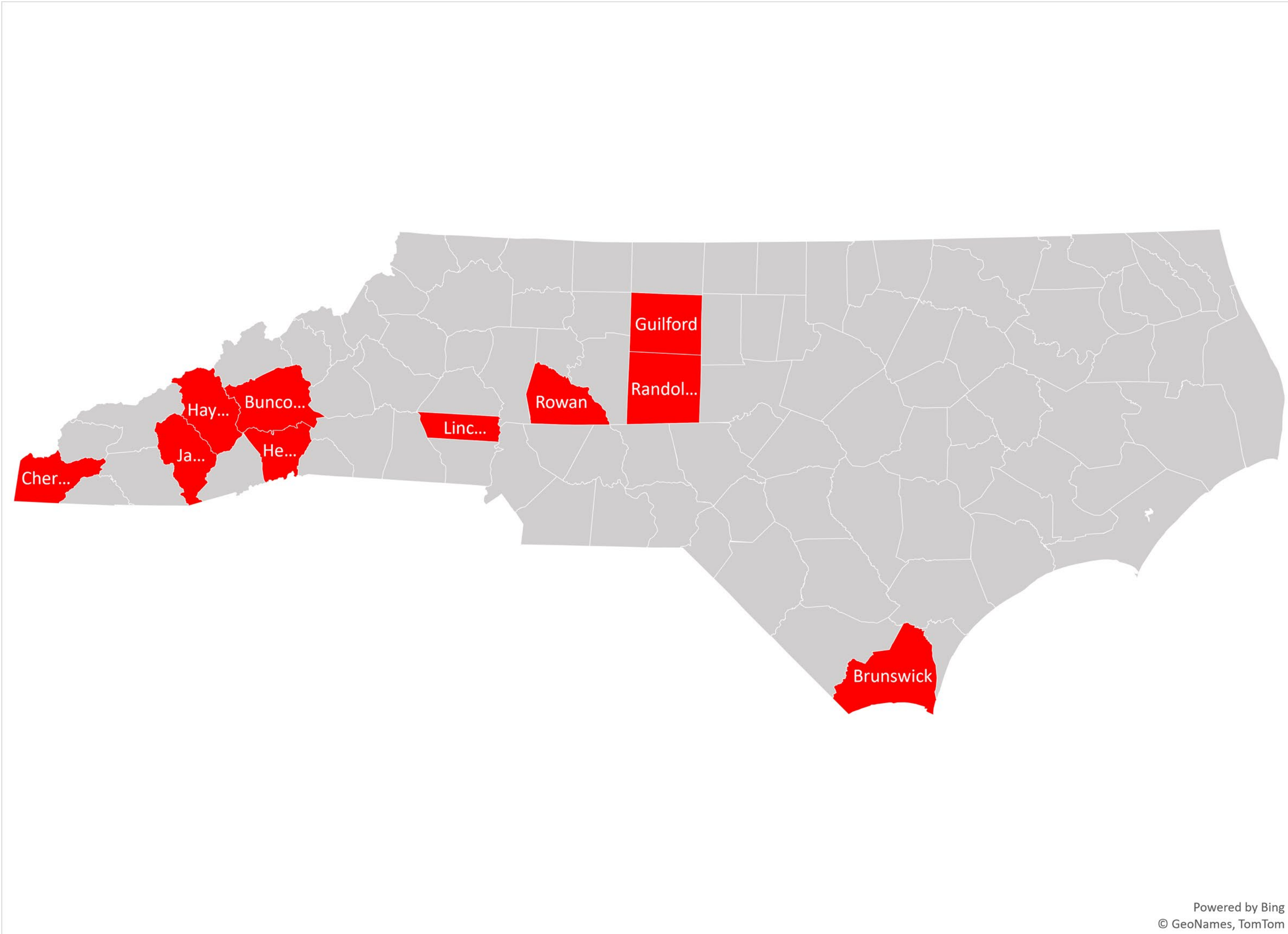


Figure 12. Largest tomato producing counties in North Carolina (NCDA&CS 2019).

Visual injury (%)

1% simulated herbicide drift rate

0 – 14% | 15 – 29% | >30%

Herbicide	Corn					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	1	0	3	8	18	18
Confront	1	0	1	6	8	12
Escort	2	1	2	13	20	21
Garlon 4	0	1	3	4	10	23
Oust	1	7	15	47	83	28
Patron 170	0	0	2	6	8	12
Plateau	1	2	2	5	9	18

Herbicide	Cotton					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	2	2	7	26	28	23
Confront	3	5	12	15	14	17
Escort	3	12	8	28	30	31
Garlon 4	3	5	22	24	22	42
Oust	3	11	9	50	29	23
Patron 170	1	6	25	16	61	41
Plateau	3	2	13	19	8	28

Herbicide	Soybean					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	1	0	0	8	14	6
Confront	0	0	1	8	23	19
Escort	0	0	2	9	9	12
Garlon 4	0	1	4	10	42	55
Oust	0	0	2	8	10	4
Patron 170	0	0	2	9	15	25
Plateau	0	0	1	8	8	6

Herbicide	Tobacco					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	1	3	11	20	24	27
Confront	3	1	13	27	21	31
Escort	2	7	11	28	36	41
Garlon 4	0	4	9	22	45	60
Oust	3	8	27	27	38	36
Patron 170	3	3	10	24	27	38
Plateau	1	8	13	20	29	26

Figure 13. Effect of 1% simulated drift on visual injury of field grown corn, cotton, soybean, and tobacco.

Visual injury (%)

5% simulated herbicide drift rate

Green	0 – 14%
Yellow	15 – 29%
Red	>30%

	Corn					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	1	1	3	10	63	23
Confront	3	4	0	10	13	18
Escort	2	3	4	21	67	31
Garlon 4	1	1	3	9	26	23
Oust	13	23	18	80	93	33
Patron 170	0	1	1	8	11	22
Plateau	1	2	2	9	27	15

	Cotton					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	3	7	10	56	69	43
Confront	3	6	10	23	18	27
Escort	6	5	10	59	70	48
Garlon 4	4	10	13	53	42	63
Oust	8	20	26	86	43	38
Patron 170	3	3	14	27	77	53
Plateau	2	3	11	23	16	25

	Soybean					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	0	0	1	10	26	16
Confront	0	0	2	13	48	43
Escort	0	1	3	12	39	43
Garlon 4	0	1	3	39	89	83
Oust	0	1	1	13	18	7
Patron 170	0	0	0	13	18	24
Plateau	0	0	3	12	15	10

	Tobacco					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	3	3	17	29	53	40
Confront	3	8	11	23	23	42
Escort	5	8	17	30	76	71
Garlon 4	0	5	17	34	65	81
Oust	6	23	27	42	47	42
Patron 170	3	7	11	23	56	49
Plateau	2	9	6	21	25	38

Figure 14. Effect of 5% simulated drift on visual injury of field grown corn, cotton, soybean, and tobacco.

Visual injury (%)

10% simulated herbicide drift rate

0 – 14% (green) | 15 – 29% (yellow) | >30% (red)

Herbicide	Corn: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	1	1	2	14	90	38
Confront	3	1	2	8	26	18
Escort	1	2	3	33	77	31
Garlon 4	1	2	5	24	39	33
Oust	39	42	39	74	99	38
Patron 170	2	2	3	8	19	17
Plateau	1	1	4	13	23	16

Herbicide	Cotton: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	4	7	23	81	75	44
Confront	2	12	15	31	33	33
Escort	11	13	12	80	85	61
Garlon 4	6	14	13	69	58	72
Oust	26	30	43	91	58	43
Patron 170	5	8	11	40	80	83
Plateau	3	3	13	49	32	36

Herbicide	Soybean: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	0	1	5	19	28	32
Confront	0	0	3	25	61	59
Escort	0	1	2	13	56	57
Garlon 4	0	1	7	58	99	95
Oust	0	1	2	11	24	8
Patron 170	0	1	4	17	33	43
Plateau	1	1	3	12	17	17

Herbicide	Tobacco: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	2	9	16	48	70	68
Confront	4	8	17	32	33	44
Escort	4	11	15	43	80	83
Garlon 4	5	12	18	67	74	84
Oust	18	25	28	48	66	50
Patron 170	3	8	17	23	64	58
Plateau	4	9	13	36	28	40

Figure 15. Effect of 10% simulated drift on visual injury of field grown corn, cotton, soybean, and tobacco.

Visual injury (%)

100% simulated herbicide drift rate

0 – 14% | 15 – 29% | >30%

Corn

Herbicide	Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	1	4	9	97	100	43
Confront	2	7	12	23	23	27
Escort	3	11	8	89	97	45
Garlon 4	1	6	13	65	76	56
Oust	80	88	90	100	100	52
Patron 170	1	4	10	27	31	27
Plateau	1	12	14	76	82	30

Cotton

Herbicide	Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	17	33	71	100	100	71
Confront	8	8	25	86	68	77
Escort	13	16	46	100	99	82
Garlon 4	12	18	47	100	100	96
Oust	81	86	88	99	95	68
Patron 170	8	7	19	93	99	81
Plateau	34	33	58	99	82	59

Soybean

Herbicide	Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	0	4	29	85	92	67
Confront	0	1	10	76	98	96
Escort	0	3	5	60	93	68
Garlon 4	0	2	38	100	100	100
Oust	1	0	1	21	39	43
Patron 170	0	1	8	48	92	77
Plateau	1	4	13	39	29	38

Tobacco

Herbicide	Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	6	13	38	86	100	96
Confront	5	9	38	65	73	80
Escort	6	28	33	86	98	98
Garlon 4	6	20	51	99	100	100
Oust	54	65	68	84	83	83
Patron 170	2	11	26	48	97	91
Plateau	8	26	41	79	63	74

Figure 16. Effect of 100% simulated drift on visual injury of field grown corn, cotton, soybean, and tobacco.

Aboveground biomass reduction (%)

1% simulated herbicide drift rate

0 – 14% (green) 15 – 29% (yellow) >30% (red)

	Corn					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	0	-4	4	7	18	7
Confront	-6	-9	4	-3	1	10
Escort	-1	-5	2	15	13	14
Garlon 4	2	4	6	2	11	21
Oust	2	9	19	46	71	10
Patron 170	3	-1	4	5	24	14
Plateau	2	2	0	1	7	12

	Cotton					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	-2	-1	5	10	24	9
Confront	1	0	4	2	-10	17
Escort	4	3	4	9	30	22
Garlon 4	1	6	9	15	9	37
Oust	4	6	4	33	27	17
Patron 170	8	-4	13	16	42	22
Plateau	6	0	2	32	10	23

	Soybean					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	1	2	4	14	4	9
Confront	1	-3	-4	-1	8	10
Escort	2	4	0	-1	8	10
Garlon 4	3	3	-2	8	42	48
Oust	-1	3	1	2	7	1
Patron 170	0	4	3	12	18	2
Plateau	2	3	2	20	3	3

	Tobacco					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	5	5	6	10	18	4
Confront	4	-11	7	30	24	-7
Escort	10	14	20	20	48	3
Garlon 4	6	2	1	15	48	12
Oust	0	1	17	15	43	8
Patron 170	5	10	7	33	24	3
Plateau	0	1	7	13	36	16

Figure 17. Effect of 1% simulated drift on aboveground biomass reduction of field grown corn, cotton, soybean, and tobacco.

Aboveground biomass reduction (%)

5% simulated herbicide drift rate

0 – 14% | 15 – 29% | >30%

Herbicide	Corn					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	4	-1	0	10	41	5
Confront	5	3	4	7	10	18
Escort	3	-4	7	15	52	4
Garlon 4	4	10	6	5	22	25
Oust	15	30	20	82	84	9
Patron 170	5	-2	8	10	9	10
Plateau	0	1	5	7	38	8

Herbicide	Cotton					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	3	0	3	47	57	11
Confront	0	2	3	13	-1	6
Escort	6	4	5	55	70	30
Garlon 4	7	6	10	30	37	49
Oust	10	20	6	84	39	20
Patron 170	13	-5	4	10	60	42
Plateau	4	1	18	5	6	14

Herbicide	Soybean					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	2	-4	5	16	16	15
Confront	-6	0	2	6	21	28
Escort	2	0	5	6	21	28
Garlon 4	-3	-3	0	26	92	77
Oust	4	-3	-1	0	6	10
Patron 170	-3	0	-3	21	24	9
Plateau	-3	3	10	18	15	8

Herbicide	Tobacco					
	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	8	1	8	26	50	10
Confront	6	3	11	8	27	15
Escort	11	6	23	38	71	23
Garlon 4	3	1	26	21	64	22
Oust	20	15	39	43	50	17
Patron 170	11	0	3	34	39	9
Plateau	3	-2	4	28	22	23

Figure 18. Effect of 5% simulated drift on aboveground biomass reduction of field grown corn, cotton, soybean, and tobacco.

Aboveground biomass reduction (%)

10% simulated herbicide drift rate

0 – 14% | 15 – 29% | >30%

	Corn					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	5	4	2	5	88	24
Confront	4	6	5	10	19	2
Escort	6	4	6	29	64	9
Garlon 4	0	4	7	16	30	25
Oust	48	49	43	73	91	24
Patron 170	5	-1	8	9	24	22
Plateau	4	0	9	11	22	13

	Cotton					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	3	4	19	89	72	26
Confront	1	6	29	17	14	17
Escort	7	2	11	77	81	32
Garlon 4	7	6	15	48	51	42
Oust	37	34	58	85	53	25
Patron 170	21	-2	6	23	61	42
Plateau	5	3	15	30	22	35

	Soybean					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	2	4	5	30	35	16
Confront	5	4	2	32	44	41
Escort	3	0	4	32	44	41
Garlon 4	0	3	10	34	99	89
Oust	0	8	1	14	14	13
Patron 170	-4	4	6	17	34	23
Plateau	-7	2	14	12	13	13

	Tobacco					
Herbicide	Wk before planting				Wk after planting	
	18	12	6	0	4	8
Arsenal	2	11	16	54	70	13
Confront	11	6	26	30	22	16
Escort	11	2	26	48	77	36
Garlon 4	5	7	27	71	78	41
Oust	15	30	43	61	67	5
Patron 170	8	4	32	27	55	14
Plateau	4	5	16	39	27	22

Figure 19. Effect of 10% simulated drift on aboveground biomass reduction of field grown corn, cotton, soybean, and tobacco.

Aboveground biomass reduction (%)

100% simulated herbicide drift rate

0 – 14% | 15 – 29% | >30%

Herbicide	Corn: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	5	0	9	100	94	27
Confront	5	10	18	8	27	14
Escort	6	0	7	93	92	18
Garlon 4	3	2	17	69	67	39
Oust	97	99	99	100	94	24
Patron 170	5	11	10	18	18	13
Plateau	8	13	19	76	76	16

Herbicide	Cotton: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	15	24	74	100	99	48
Confront	8	5	24	71	55	43
Escort	13	1	38	100	99	49
Garlon 4	10	10	48	89	100	78
Oust	88	94	97	100	94	45
Patron 170	17	-4	8	86	100	72
Plateau	31	35	59	99	76	46

Herbicide	Soybean: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	11	9	22	86	93	43
Confront	-1	0	12	70	98	86
Escort	4	13	6	70	98	86
Garlon 4	0	9	45	100	100	95
Oust	-1	8	1	20	38	23
Patron 170	-1	2	11	48	94	60
Plateau	0	14	17	28	44	21

Herbicide	Tobacco: Wk before planting 18	12	6	0	Wk after planting 4	8
Arsenal	7	12	62	89	100	60
Confront	12	9	48	55	61	11
Escort	9	19	41	86	98	76
Garlon 4	6	8	60	98	100	88
Oust	71	83	86	80	79	31
Patron 170	7	2	42	54	93	37
Plateau	16	29	51	89	64	21

Figure 20. Effect of 100% simulated drift on aboveground biomass reduction of field grown corn, cotton, soybean, and tobacco.