Implementation of Field Recommendations for the NCDOT Wildflower Program

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Implementation of Field Recommendations for the NCDOT Wildflower Program

FINAL REPORT

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Submitted by
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16. Abstract

The North Carolina Department of Transportation (NCDOT) Roadside Wildflower Program is a highway beautification initiative that spans 1,500 acres of wildflower beds across the state (NCDOT Wildflower Handbook 2025). These wildflower beds are intended to provide aesthetically pleasing displays of native and non-native species for both residents and tourists driving North Carolina highways. However, maintaining these species can be challenging. Without proper management, wildflower beds often revert to weedy, successional growth (Gallitano 1992).

Two experiments were conducted in 2023 and 2024 near Clayton and Four Oaks, NC, to determine additional herbicides to be used POST-emergence on Cosmos bipinnatus. Pendimethalin and S-metolachlor applied at planting. In this trial fluometuron at 1 qt/A served served as a standard comparison treatment, as it is labeled and used by NCDOT, as well as a untreated check plot. In 2023, fluometuron, pyroxasulfone, a premix of flufenacet + metribuzin, a premix of flufenacet + metribuzin, isoxaflutole, flumioxazin, and a premix of flumioxazin + prodiamine caused little to no bloom reduction compared to the standard treatments. In 2024, the same treatments were safe, as well as fluridone, with little to no bloom reduction compared to the standard NCDOT treatment. In conclusion, cosmos was tolerant of several herbicides, which may be candidates for future use in roadside cosmos.

During the summers of 2023 and 2024, four transplanted wildflower species were screened for herbicide tolerance. Wildflower species included black-eyed Susan, purple coneflower, scarlet beebalm, and Shasta daisy. Herbicide treatments consisted of PRE-transplants (PRE-T) and POST-transplants (POST-T) herbicides. For PRE-T treatments, injury varied greatly by year. For black-eye Susan, acceptable PRE-T treatments included sulfentrazone, pyrithiobac, and fluridone. For scarlet beebalm, sulfentrazone resulted in acceptable injury. For purple coneflower, indaziflam, sulfentrazone, pyrithiobac, fluridone, were acceptable. For Shasta daisy, sulfentrazone and fluometuron resulted in acceptable injury. Pendimethalin, S-metolachlor, and their combinations applied POST-T caused little to no stand reduction or visual injury across wildflower species. In conclusion, several herbicides may fit transplant establishment of the wildflower's species included in this study.

Two experiments were conducted in 2023 and 2024 near Clayton and Smithfield, NC, to evaluate the tolerance of seven wildflower species to PRE and POST herbicides. Wildflower species included narrow-leaved sunflower, black-eyed Susan, Maximilian sunflower, sweet William, clasping coneflower, bur-marigold, and Indian blanket. Experiments were initiated in late spring of 2023 and in early winter of 2024 to promote uniform emergence across species. In 2023, narrow-leaved sunflower, Maximilian sunflower, clasping coneflower, black-eyed Susan, and sweet William successfully emerged, and PRE and POST data were collected on these five species. In 2024, bur-marigold, Indian blanket, clasping coneflower, black-eyed Susan, and sweet William emerged, and data were collected accordingly. More injury from PRE and POST herbicides was observed in 2023 compared to 2024 and may be explained by varying environmental conditions. Among all treatments, flufenacet + metribuzin and S-metolachlor applied PRE caused the least injury and bloom reduction across species. For the POST experiment, flufenacet + metribuzin and 2,4-DB were the safest treatments across wildflower species.

17. Key Words	18. Distribution Statement		
Wildflower wildflowers herbicide native non-native weed weeds cosmos bipinnatus black-eyed Susan purple coneflower scarlet beebalm Shasta daisy transplant narrow-leaved sunflower Maximilian sweet william clasping bur-marigold Indian blanket Bidens			
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Table of Contents

Executive Summary

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Chapter I: Literature Review

Introduction

The North Carolina Department of Transportation (NCDOT) Roadside Wildflower Program was created as a way of adding beautification along the highways and interstates of North Carolina (NCDOT Wildflower Handbook 2025). The tourism industry in North Carolina generates $35.6 billion per year and many tourists travel by vehicle. This allows the Roadside Wildflower Program to provide appealing sites for tourists traversing the state (NCDOT Wildflower Handbook 2025). The Roadside Wildflower Program was started in 1985 by former First Lady Dottie Martin, wife of Gov. Jim Martin, after reading about the wildflower beds along Texas roadways (NCDOT Wildflower Handbook 2025). After initiation, twelve experimental acres of wildflowers were planted; currently, there are over 1500 acres of wildflower beds across North Carolina with fourteen highway divisions managing the beds (NCDOT Wildflower Handbook 2025). Statewide, the program cultivates approximately 130 varieties of wildflowers, including annuals, biennials, and perennials (Garnes 2021; NCDOT Wildflower Handbook 2025). In 2023, Former Governor Roy Cooper signed a bill that would prioritize the Wildflower Program to use native plants along the North Carolina roadway (Garnes 2021; Senate Bill 606 2023). The objective of the wildflower beds is to provide residents and tourists with vibrant displays of native and non-native wildflowers while traveling through North Carolina. However, without proper management, these beds can quickly become overrun with weedy, successional growth, diminishing their visual appeal (Gallitano 1992). As the beds are planted with both annuals and perennials, managing weeds becomes increasingly challenging (Weisberger et al. 2019). Given the persistent weed issues faced by NCDOT, various control strategies have been adopted to manage and minimize weed growth in beds, like no-till plantings, increased seeding rates, and chemical weed control (Rick Seagroves and Kevin Clemmer, personal communication). Chemical weed control has been the main weed control method for the NCDOT with the help of 24(c) Special Local Needs labels (Rick Seagroves and Kevin Clemmer, personal communication). This allows the NCDOT to spray registered herbicides preemergence or postemergence on certain wildflower species. However, because wildflowers are not grown as commercial crops, limited research exists on their herbicide tolerance. As a result, NCDOT has few proven herbicide options available for use in wildflower beds (Rick Seagroves and Kevin Clemmer, personal communication).

Current Herbicide Use on Wildflowers

Currently, the NCDOT holds many 24(c) Special Local Needs labels to use on wildflowers including fluometuron, and pyrithiobac (Rick Seagroves and Kevin Clemmer, personal communication; Telus 2024). These products can either be applied pre-emergence or postemergence and many of the currently registered herbicide labels came from previous collaborations between North Carolina State University researchers and NCDOT (Rick Seagroves and Kevin Clemmer, personal communication). Currently, the NCDOT employs a three-step approach to prevent weed emergence in wildflower beds (Rick Seagroves and Kevin Clemmer, personal communication). First, establishing a clean seedbed before planting wildflowers can significantly reduce weed pressure — a practice shown to lower weed competition by up to 50% (Fennimore 2017). Second, implementing cultural weed management strategies, such as narrow row spacing and increased plant populations, has been proven to suppress weed growth and extend the window for effective weed control (Knezevic et al. 2017). Lastly, NCDOT incorporates herbicides to limit weed populations. At the time of planting, a single or combination of pre-emergence (PRE) herbicide is applied to prevent weed emergence (Rick Seagroves and Kevin Clemmer, personal communication). This is followed by postemergence (POST) herbicide(s) as weeds and wildflowers are actively growing; a residual herbicide is usually included POST to limit weeds from emerging later in the season (Rick Seagroves and Kevin Clemmer, personal communication; Lammers et al. 2025). Among the residual herbicide options, fluometuron is commonly used to control the emerging broadleaf weeds as well as provide residual activity (Anonymous 2022; Rick Seagroves and Kevin Clemmer, personal communication). In 2016, the Environmental Protection Agency (EPA) initiated a registration review for fluometuron (Anonymous 2022). During that review, the EPA raised concern over potential dietary cancer risk through potential groundwater contamination (Haigwood), To mitigate this risk, the EPA proposed to prohibit fluometuron applications to Hydrologic Group A (low runoff potential and <10% clay) and B (moderately low runoff potential and 10 to 20% clay) soils. This would prohibit the use of fluometuron in most roadside wildflower beds in NC's coastal plain leaving NCDOT with further limited options for weed control in the cosmos (Kevin Clemmer and Rick Seagroves, personal communication). 2022).

Although long used in turf and ornamental, interest in herbicide-coated fertilizers has been rejuvenated by their use in cotton (Buhler 1987; Dean 2024; Steckel 2021). Herbicides coated on fertilizer are primarily used for residual control of weeds (Dean 2024; Steckel 2021). This technique would allow NCDOT to apply herbicides that would normally injure wildflower species, as the herbicide is coated onto the fertilizer and falls directly to the soil beneath the canopy, minimizing contact and leaf uptake by the wildflowers (Derr 1994; Yelverton 1998). This approach would allow the use of new modes of action (MOAs) and herbicides not currently registered for wildflowers due to the risk of injury.

Wildflower Growth and Establishment

When growing wildflowers, the most important steps in producing quality flowers are planting conditions and limiting weed emergence (Wilson 1992; Angelella et al. 2017). Seeding depth can affect germination and seedling growth; fatal germination occurs when seeds are planted too deep and unable to reach the soil surface (Davis et al., 2007). Research is limited to the establishment of native wildflowers therefore, seeding depth recommendations are based on seed size (Monsen et al. 2004; Ogle et al. 2008); smaller seeds are to be planted shallow whereas larger seeds may be planted deeper. Angelella and O'Rourke (2017) also found that seedbed preparation impacted wildflower bloom percentage with no tillage resulting in more blooms than conventional tillage. With non-tillage planted wildflowers, getting to a shallow, consistent seeding depth can be difficult, which necessitates proper planting equipment is used.

Native wildflowers have a prolonged bloom period in North Carolina, ranging from mid-May, until the first frost in October-November (NC Wildlife Federation 2022). This wide range of bloom periods dictates when these species should be planted; the earlier the bloom period, the earlier it should be planted in the fall and winter, except some annuals that shouldn't be planted until after the last frost date

(NCDOT Wildflower Handbook 2025). Native wildflower species must break dormancy to germinate with dormancy rates varying across species and years (Norcini 2007). Early planting in the fall or winter to allow seeds to go through cold stratification is the easiest way to break dormancy and increase germination (Gillard et al. 2017). Cold stratification occurs naturally when seeds are planted in the fall or winter and exposed to cold temperatures and moisture which help break down the seed coat; once soils warm, seeds will be ready to germinate (Parker 2022).

As previously mentioned, Former Governor Roy Cooper signed a bill into law that prioritizes planting native plants and wildflowers across North Carolina. In response, NCDOT has replaced many non-natives in roadside beds with native wildflower species. However, native wildflowers are harder to establish from seed than non-native species (Byun 2018). This has led the NCDOT to try different planting methods outside of the usual no-till planting (Rick Seagroves and Kevin Clemmer, personal communication). Englert and others (1994) and Leskovar and others (2021) found that native plugs and transplants grow faster and maximize space efficiency better than direct-seeded plantings. This would allow the NCDOT to use transplanted natives in areas where non-natives are usually grown (Rick Seagroves and Kevin Clemmer, personal communication). Since plug transplants are already actively growing when planted, they may provide NCDOT with another effective weed management strategy, as their rapid establishment can suppress the later emergence of problematic weeds (Chiduza et al. 2017; Reiners 2021).

Wildflower Pollinator Impact

Wildflowers play a crucial role in the health and success of local insects and pollinator species (Angelella et al. 2017). There are many different types of pollinators, from honeybees and bumblebees to butterflies and hummingbirds, and even certain types of wasps. There is one thing these pollinators all have in common, the need for diverse floral resources that allow them to collect pollen throughout the growing months (Ritchie et al. 2016; Williams et al. 2015).

When thinking about pollinator insects, European honeybees are what the public associates with pollinating most plants and crops, but a study conducted in 2013 by Garibaldi and others (2013) found that native species pollinate were most important to food crops regardless of European honeybee abundance. Changes in land-use patterns, like urbanization and intensive farming, have negatively affected the role of native pollinator insects by producing vast monocultures and limited resources (Vaughn and Skinner 2008; Goulson et al. 2015). Biesmeijer and others (2006) suggested there is a direct correlation between the decline in native plant species and native pollinators. Pollinator refuge habitats, made up of wildflowers, provide pollinating insect blooms and suitable nesting habitats and may support the rehabilitation of native pollinators (Bates et al. 2011; Farm Service Agency 2013; Foley et al. 2005; Vaughn and Skinner 2008). It's often said that one out of every three bites of food are made possible by the pollination provided by insects, which contribute an estimated $200 to $300 billion to the global economy each year (USDA 2020). The NCDOT wants to help contribute to the sustainability of the pollinators by creating and providing native or non-native pollinator insects with refuge habitats along roads and highways (NCDOT Wildflower Handbook 2025). By providing this habitat, the NCDOT is ensuring the longevity of pollinators in North Carolina while also providing tourists with visually appealing flowers (NCDOT Wildflower Handbook 2025; Rick Seagroves and Kevin Clemmer, personal communication). The primary objectives of this research were to evaluate the tolerance of various wildflowers to PRE and POST herbicides, potentially providing the NCDOT with additional tools to manage weeds in roadside wildflower plantings.

Literature Cited

Angelella, G.M. & O'Rourke, M.E. 2017 Pollinator habitat establishment after organic and no-till seedbed preparation methods *HortScience 52* 1349 1355

Anonymous (2022a). Cotoran 4L Herbicide Label. ADAMA US, Raleigh, NC.

Bates, A.J., Sadler, J.P., Fairbrass, A.J., Falk, S.J., Hale, J.D. & Matthews, T.J. 2011 Changing bee and hoverfly pollinator assembles along an urban-rural gradient *PLoS One 6* e23459. Available online at: https://doi.org/10.1371/journal.pone.0023459. Accessed March 5, 2025

Biesmeijer J.C, et al. 2006 Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*. 313, 351–354.

Byun, C., de Blois, S. & Brisson, J. Management of invasive plants through ecological resistance. *Biol Invasions* 20, 13–27 (2018). Available online at: https://doi.org/10.1007/s10530-017-1529-7. Accessed March 5, 2025

Chiduza, C., Mnkeni, P. N. S., & Department of Agronomy, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa. (2017). Comparative performance of direct seeding and transplanting green maize under farmer management in small scale irrigation: A case study of Zanyokwe, Eastern Cape, South Africa. *International Journal of Irrigation and Water Management*, *4*(3), 001–008.

Davis AS, Renner KA (2007) Influence of seed depth and pathogens on fatal germination of velvetleaf (*Abutilon theophrasti*) and giant foxtail (*Setaria faberi*). Weed Sci 55(1):30–35

Derr JF (1994) Innovative herbicide application methods and their potential for use in the nursery and landscape industries. HortTechnol 4:345-350

D. Ogle, L. St. John, J. Cornwell, M. Stannard, L Holzworth; Pasture and range seedings: planninginstallation-evaluation-management USDA, Washington, DC, USA (2008), p. 36 NRCS Technical Note PM-TN-10p

Englert, J. M., & Meyer, G. C. (1994). 568 PB 009 IMPROVING PROPAGATION AND PRODUCTION TECHNIQUES FOR NATIVE PLANTS. *HortScience HortSci*, *29*(5), 513b-513. Available online at: https://doi.org/10.21273/HORTSCI.29.5.513b. Accessed March 5, 2025

Fennimore, S. A. & University of California, Davis. (2017). *Weed seed Biology, Seedbanks and Management* (pp. 14–3). https://ucanr.edu/sites/Grown_in_Marin/files/276001.pdf

Foley, J., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N. & Snyder, P.K. 2005 Global consequences of land use *Science 309* 570 574, Available online at: https://doi.org/10.1126/science.1111772. Accessed March 5, 2025

[Farm Service Agency] FSA 2013 CP42 pollinator habitat: Establishing and supporting diverse pollinator-friendly habitat. Farm Serv. Agency, U.S. Dept. Agr., Washington, D.C

Gallitano, L., Skroch, W. A., & Bailey, D. A. (1992). Weed Management for Wildflowers. North Carolina Cooperative Extension Service, Department of Horticultural Science.

Garibaldi L. A., Steffan-Dewenter I., Winfree R., Aizen M. A., Bommarco R., Cunningham S. A., Kremen C., Carvalheiro L. G., Harder L. D., Afik O., Bartomeus I., Benjamin F., Boreux V., Cariveau D., Chacoff N. P., Dudenhöffer J. H., Freitas B. M., Ghazoul J., Greenleaf S., Hipólito J., Holzschuh A., Howlett B., Isaacs R., Javorek S. K., Kennedy C. M., Krewenka K. M., Krishnan S., Mandelik Y., Mayfield M. M., Motzke I., Munyuli T., Nault B. A., Otieno M., Petersen J., Pisanty G., Potts S. G., Rader R., Ricketts T. H., Rundlöf M., Seymour C. L., Schüepp C., Szentgyörgyi H., Taki H., Tscharntke T., Vergara C. H., Viana B. F., Wanger T. C., Westphal C., Williams N., Klein A. M., Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science 339*, 1608–1611 (2013). 10.1126/science.1230200

Garnes, L. (2021, April 5). *Who do we thank for all the flowers along North Carolina's roads? - J.M. Teague Traffic Engineering*. J.M. Teague Traffic Engineering. https://www.jmteagueengineering.com/who-do-we-thank-for-all-the-flowers-along-north-carolinas-roads/

Goulson, D., Nicholls, E., Botias, C. & Rotheray, E.L. 2015 Bee declines driven by combined stress from parasites, pesticides, and lack of flowers *Science 347* 6229 1255957

Haigwood W (2022) Pigweed, herbicides, and the EPA. Pigweed, herbicides, and the EPA Available online at: farmprogress.com. Accessed February 26, 2024

Knezevic SZ, Evans SP, Mainz M. Row Spacing Influences the Critical Timing for Weed Removal in Soybean (Glycine max). *Weed Technology*. 2003;17(4):666-673. doi:10.1614/WT02-49

Lammers C, Roozeboom K, Ibendahl G, Lancaster S. Row spacing and layered residual herbicides influence weed control and profitability in herbicide-resistant soybean. *Weed Technology*. Published online 2025:1-24. doi:10.1017/wet.2025.10

Leskovar DI, Othman YA. Direct Seeding and Transplanting Influence Root Dynamics, Morpho-Physiology, Yield, and Head Quality of Globe Artichoke. Plants (Basel). 2021 Apr 29;10(5):899. doi: 10.3390/plants10050899.

Milstein, Gene P. "The uses and potential of wildflower seed in landscaping." *Flower seeds: biology and technology*. Wallingford UK: CABI Publishing, 2005. 39-51.

Monsen, S. B., Stevens, R., and Shaw, N. L. 2004. Restoring western ranges and wildlands. *RMRS-GTR-136-Vol-2, 1*(September):295–698.

Norcini, J. G., & Aldrich, J. H. (2007). Storage Effects on Dormancy and Germination of Native Tickseed Species. *HortTechnology hortte*, *17*(4), 505-512. Available online at: https://doi.org/10.21273/HORTTECH.17.4.505. Accessed March 5, 2025

[NCDOT Wildflower Handbook] North Carolina Department of Transportation. (2025). *WILDFLOWERS on North Carolina roadsides*. Available online at: https://www.ncdot.gov/initiatives-policies/environmental/wildflower/Documents/ncdot-wildflower-booklet.pdf. Accessed March 5, 2025

[NC Wildlife Federation] Federation, N. C. W. (2022b, June 30). *North Carolina Native pollinator Perennial and annual flowers - North Carolina Wildlife Federation*. North Carolina Wildlife Federation. Available online at: https://ncwf.org/habitat/native-pollinator-plants/perennial-annual-flowers/. Accessed March 5, 2025

Parker, Katie (2022). *Seed stratification: What seeds require cold treatment*? Illinois Extension. Available online at: https://extension.illinois.edu/blogs/good-growing/2022-01-27-seed-stratification-what-seeds-require-cold-treatment Accessed March 5, 2025

Reiners, S. (2020). Transplants or Direct Seeding – What's best? *Cornell CALS*. Available online at: https://cals.cornell.edu/school-integrative-plant-science/school-sections/horticulture-section/outreach-and-extension/pandemic-vegetable-gardening/pandemic-vegetable-gardening-2021-archive/transplants-or-direct-seeding-whats-best. Accessed March 5, 2025

Ritchie, A.D., Ruppel, R. & Jha, S. 2016 Generalist behavior describes pollen foraging for perceived oligolectic and polylectic bees *Environ. Entomol. 45* 909 919

Seagroves Rick, Clemmer Kevin. Personal Interview. June 22nd, 2023

Senate Bill 606 (2023-2024 session) - North Carolina General Assembly. (2023). Available online at: https://www.ncleg.gov/BillLookup/2023/S606 Accessed March 5, 2025

Steckel LE (2021) Zidua® impregnated on fertilizer applications in cotton. Zidua Impregnated on Fertilizer Applications in Cotton - UT Crops News.

TELUS Agronomy - *Label search*. (2024). Available online at: https://www.agrian.com/labelcenter/results.cfm. Accessed March 5, 2025

[USDA] United States Department of Agriculture. (2020, June 23). *The value of birds and bees*. Farmers.gov. Available online at: https://www.farmers.gov/blog/value-birds-and-bees. Accessed March 5, 2025

Vaughan, M. & Skinner, M. 2008 Using farm bill programs for pollinator conservation. U.S. Dept. Agr. Natl. Resource Conserv. Serv. National Plant Data Center. Available online at: <http://www.xerces.org/wp-content/uploads/2008/11/using_farm_bill_programs_xerces_society.pdf. Accessed March 5, 2025

Weisberger D, Nichols V, Liebman M (2019) Does diversify crop rotations suppress weeds? A meta-analysis. PLoS ONE 14(7): e0219847. https://doi.org/10.1371/journal.pone.0219847

Williams, N.M., Ward, K.L., Pope, N., Isaacs, R., Wilson, J. & May, E.A. 2015 Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States *Ecol. Appl. 25* 2119 2131

Wilson, J.W. 1992 Landscaping with wildflowers: An environmental approach to gardening. Houghton Mifflin Harcourt Publishing Co., Boston, MA

Yelverton F (1998) Utilizing preemergence herbicides with and without fertilizer carriers. USGA Green Section Record 36:13–16

York, Alan. "Herbicide screening on Cosmos and Zinnia species PRE and POST treatments" 2013 NC State University. Presentation to NCDOT

Chapter II - Evaluating POST Herbicide Options for *Cosmos bipinnatus.*

Abstract

Two experiments were conducted in 2023 and 2024 near Clayton and Four Oaks, NC, to determine additional herbicides to be used POST-emergence on *Cosmos bipinnatus*. Pendimethalin at 1 qt/A and *S*-metolachlor at 1 pt/A applied at planting. The following herbicides were applied (rates in parenthesis) postemergence: fluometuron (1 qt/A), fluometuron (2 qt/a), 2,4-DB (11.43 fl oz/A), 2,4-DB (13.71 fl oz/A), 2,4-DB (16 fl oz/A), a premix of flufenacet + metribuzin (8 oz/A), a premix of flufenacet + metribuzin (10 oz/A), tolpyralate (1 fl oz/A), topramezone (0.5 fl oz/A), flumetsulam (0.125 oz/A), flumetsulam (0.8 oz/A), fluroxypyr (4.8 fl oz/A), tembotrione (3 fl oz/A), acifluorfen (8 fl oz/A), imazapyr (2 fl oz/A), imazapyr (10 fl oz/A), pyroxasulfone (1.75 fl oz/A), sulfentrazone (4 fl oz/A), isoxaflutole (3 fl oz/A), simazine (1 qt/A), halauxifen (1 fl oz/A), tiafenacil (1 fl oz/A), fluridone (1 pt/A), flumioxazin (150 lb/A), a premix of flumioxazin + prodiamine (100 lb/A). In this trial fluometuron at 1qt/A served as a standard comparison treatment, as it is labeled and used by NCDOT, as well as an untreated check plot. At treatment, the average height of cosmos was 4 to 6 inches. In 2023, fluometuron (2 qt/A), pyroxasulfone (1.75 fl oz/A), a premix of flufenacet + metribuzin (8 oz/A), a premix of flufenacet + metribuzin (10 oz/A), isoxaflutole (3 fl oz/A), flumioxazin (150 lb/A), and a premix of flumioxazin + prodiamine (100 lb/A) caused little to no bloom reduction compared to the standard treatments. In 2024, the same treatments were safe, as well as fluridone (1 pt/A), with little to no bloom reduction compared to the standard NCDOT treatment. In conclusion, the cosmos was tolerant to several herbicides, which may be candidates for future use in roadside cosmos.

Introduction

Cosmos (*Cosmos bipinnatus*) is regularly planted by the North Carolina Department of Transportation (NCDOT) Roadside Wildflower Program (Kevin Clemmer and Rick Seagroves, personal communication). Cosmos is an herbaceous annual species native to Mexico (Vargas-Amado et al. 2013). This wildflower is popular because of its hardy nature and ability to grow in hot-dry conditions (NCSU

Extension 2020), making it well adapted to grow in coarse-textured soils typical of North Carolina's coastal plain. Cosmos has simple leaves that are thinly cut and narrow and range in height from 2-6 feet. It has distinct pink, purple, and white flowers 2-3 inches in diameter (Olajuyigbe et al. 2014; Gilman et al. 1999). Cosmos is also desirable for its fast growth rate; plants are capable of flowering in 2-3 months (Gilman et al. 1999). This allows the NCDOT to quickly establish this pollinator species, attracting butterflies and bees while also increasing the aesthetics of NC roadsides.

Historically, herbicides registered for use in Cosmos are limited to imazepic, pyrithiobac, and fluometuron for postemergence broadleaf weed control (Telus, 2024). Out of the three products that are labeled, fluometuron was found to be the only safe postemergence option for the cosmos (York, 2013). In 2013, the NCDOT received a 24-C Special Local Needs label for fluometuron. This label allows the postemergence use of fluometuron in Cosmos. Fluometuron, a PSII-inhibiting herbicide (Group 5), is primarily used preemergence in cotton (*Gossypium hiristrum*) for control of broadleaf and select grass weeds (Anonymous, 2016; Cahoon and York 2024; Whitaker et al. 2011). Fluometuron, a urea herbicide, binds to the D1 protein in the PSII pathway (Anonymous, 2012). Group 5 herbicides work by blocking the electron transport within the PSII system, which stops the fixation of CO_2 and photosynthesis (Duke, 1990). The NCDOT relies on fluometuron because of its broad-spectrum activity against broadleaf weeds and the limited availability of other herbicide options in Cosmos.

In 2016, the Environmental Protection Agency (EPA) initiated a registration review for fluometuron (Anonymous, 2022). During that review, the EPA raised concerns over potential dietary cancer risks through potential groundwater contamination. To mitigate this risk, EPA proposed to prohibit fluometuron applications to Hydrologic Group A (low runoff potential and <10% clay) and B (moderately low runoff potential and 10 to 20% clay) soils. This would prohibit the use of fluometuron in most roadside wildflower beds in NC's coastal plain leaving NCDOT with further limited options for weed control in the cosmos (Kevin Clemmer and Rick Seagroves, personal communication). The NCDOT currently uses many cultural control methods like narrow row spacing, increased plant population, and delayed planting timing (Mohler, 1996). However, the NCDOT has not adopted mechanical weed control options like hand weeding and tillage because of the feasibility and expense (Machleb et al. 2020). Though these methods are the most effective, they are also the most expensive. Hand weeding is a labor-intensive method, and labor shortages and other factors have led to an increase in the cost of this weed control method (Duke, 2012; Westwood et al., 2018). This trend of increasing labor costs will likely make hand-weeding an expensive option for NCDOT.

Due to limited weed management options and the possible loss of fluometuron, the objective of this research was to evaluate the Cosmos tolerance to various herbicides applied postemergence.

Materials and Methods

Experiments were established in 2023 and 2024 at the Central Crops Research Station near Clayton, NC (35.67°N, -78.51°W) and a private farm near Four Oaks, NC (35.43°N, -78.36°W). In 2023, the cosmos was planted in Clayton on July 25 and in Four Oaks on August 3. During 2024, the cosmos was planted in Clayton and Four Oaks on July 29 and August 25, respectively. Postemergence herbicide treatments and rates are listed in Table 1. When required, crop oil concentrate, methylated seed oil, nonionic surfactant, or ammonium sulfate were added at label-recommended rates. Two treatments were granular formulations designed to be spread in turf and ornamental settings. As the current standard, fluometuron at 1 qt/A was included as a comparison treatment. Detailed materials and methods can be found in Appendix 2.

Results and Discussion

The main effects of treatment and year were significant for cosmos injury. This two-way interaction of the main effects was significant; therefore, data for cosmos injury will be presented by year and pooled over locations. Cosmos injury consisted of a composite rating of visual chlorosis, necrosis, and growth reduction.

At 7 DAT in 2023, imazapyr at both rates and tiafenacil was the most injurious, resulting in rapid cosmos death (100%) (Appendix 2, Table 2). Meanwhile, other treatments caused minor cosmos injury

(<20%) 7 DAT including 2,4-DB at 16 fl oz/A (10%), the low rate of flumetsulam (13%), and isoxaflutole (20%). Notably, 2, 4-DB at 11.43 and 13.71 fl oz/A**,** both rates of flufenacet + metribuzin (0%), pyroxasulfone (0%), simazine (1%), flumioxazin (0%), and flumioxazin + prodiamine (0%) were no more injurious than the current NCDOT standard of fluometuron at 1 qt/A.

Injury 7 DAT differed in 2024 compared to 2023. In 2024, halauxifen and fluroxypyr injured the cosmos 25% and 18% more in 2024 than in 2023 (Appendix 2, Table 3). Topramezone and the low rate of flumetsulam were less injurious in 2024 than in 2023. Similar to 2023, imazapyr and tiafenacil injured cosmos 100% and the low rate of 2, 4-DB (6%), both rates of flufenacet + metribuzin (1 and 2%), the low rate flumetsulam (7%), pyroxasulfone (0%), isoxaflutole (7%), simazine (0%), flumioxazin (1%), and flumioxazin + prodiamine (2% caused minimal injury (<10%). Unlike 2023, flumetsulam at 0.8 oz/A and isoxaflutole caused no more injury than the NCDOT standard in 2024. 2,4-DB at 13.71 and 16 fl oz/A, tolpyralate, and topramezone caused ≤ 20% injury 7 DAT, respectively but were more injurious than fluometuron at 1 qt/A.

By 21 DAT in 2023, all treatments, except of flufenacet + metribuzin (0% and 5%), pyroxasulfone (0%), flumioxazin (1%), and flumioxazin + prodiamine (2%) resulted in cosmos injury statistically different than the current standard. Imazapyr and tiafenacil continued to injure the cosmos 100%. Additionally, halauxifen at 21 DAT also causes complete cosmos death (100%). Similar to 7 DAT, 2,4-DB at 11.43 (10%) and 13.71 (17%) fl oz/A, the low rate of flumetsulam (20%), isoxaflutole (12%), and fluridone (19%) caused less than 20% cosmos injury at 21 DAT.

By 21 DAT in 2024, treatments that were statistically similar to the NCDOT standard included both rates of flufenacet + metribuzin, pyroxasulfone, flumioxazin, and flumioxazin + prodiamine. At 21 DAT, isoxaflutole (2%) was less injurious in 2024 than in 2023 (12%). Over two growing seasons, cosmos response to imazapyr, tiafenacil, and halauxifen all resulted in complete cosmos death by 21 DAT. All rates of 2,4-DB (12 to 14%), topramezone (19%), the low rate of flumetsulam (13%), simazine (15%), and fluridone (17%) resulted in injury.

Across both years, initial injury 7DAT from acifluorfen (47%) and sulfentrazone (41 to 48%) decreased over time; by 21 DAT, these herbicides injured cosmos ≤ 30%. Acifluorfen and sulfentrazone are both PPO-inhibiting herbicides; previous research on injury resulting from PPO-inhibiting herbicides suggests injury is greatest shortly after application and decreases as time passes and plants can recover from the initial necrosis (Priess et al. 2020; Mize et al. 2002; Wallace 2004).

Cosmos Bloom

The main effects of treatment and year were significant for cosmos bloom reduction. Therefore, data for cosmos bloom reduction is presented by year and pooled over locations. Cosmos bloom reduction was a general visual reduction in the number of blooms compared to the standard NCDOT treatment.

For cosmos bloom reductions in 2023, imazapyr, halauxifen, and tiafenacil, which showed the most injury, resulted in the greatest bloom reduction (100%) (Appendix 2, Table 4). Sulfentrazone injury to the cosmos 7 DAT was significant at 41%, this injury was mainly necrosis, and the cosmos was able to recover to a 14% reduction in bloom, which is similar to what Wallace (2004) found that sulfentrazone injury was transient. For the treatments that were statistically similar to the standard treatment 21 DAT, both rates of flufenacet + metribuzin (0% and 1%), pyroxasulfone (0%), flumioxazin (0%), and flumioxazin + prodiamine (0%), proved to be statistically similar to the standard treatment for percent bloom reduction.

In 2024, the greatest bloom reductions were caused by tiafenacil, both rates of imazapyr, and halauxifen all caused 100% bloom reduction (Appendix 2, Table 4). Overall, 2023 bloom reductions were less in 2024, with the largest decrease in bloom reduction coming from tembotrione (44%) and acifluorfen (21%) both at a 24% reduced reduction in bloom. The treatments of both rates of flufenacet + metribuzin (0% and 2%), pyroxasulfone (0%), isoxaflutole (3%), fluridone (5%), flumioxazin (0%), and flumioxazin + prodiamine (0%) were statistically similar to standard NCDOT treatment. Across both years, the safest treatments were both rates of flufenacet + metribuzin, pyroxasulfone, and flumioxazin, with the four treatments resulting in less than 2% reduction in cosmos bloom.

Cosmos Height

The objectives of this research were to find comparable treatments to the current standard treatment and the average height was not a consistent indication of the bloom reduction in the plots and therefore not discussed in this report. Height data collected are shown in Appendix 2, Table 4 and a full description can be found in Appendix 3.

Literature Cited

A. Beziat, M. Dardaine, E. Mouche, Measurements of the thermal conductivity of clay-sand and clay-graphite mixtures used as engineered barriers for high-level radioactive waste disposal, Applied Clay Science, Volume 6, Issue 4, 1992, Pages 245-263

Anonymous (2023). Brake herbicide. Carmel, IN: SePRO Corp. 52 p

Anonymous (2022). Cotoran 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2020). Balance flexx herbicide. St. Louis, MO: Bayer CropScience LP. 21 p

Anonymous (2019a). Axiom DF herbicide Label. Bayer CropScience LP. 29 p

Anonymous (2019b). Perfection Fuerte herbicide label. OHP Inc.

Anonymous (2016). Cotoran 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2012). Direx 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2011). BroadStar Herbicide Label. Valent U.S.A. Corp. Walnut Creek, CA.

Cahoon CW, York AC (2024) Weed management in cotton. Pages 76-116 in 2024 cotton information. Raleigh, NC: North Carolina Cooperative Extension

Cahoon CW, York AC, Jordan DL, Seagroves RW, Everman WJ, Jennings KM (2015) Cotton response and Palmer amaranth control with pyroxasulfone applied preemergence and postemergence. J Cotton Sci 19:212-223

Dean, Brock and Charlie Cahoon. *Residual Weed Control in Cotton (Gossypium Hirsutum) Utilizing Herbicide-Coated Fertilizer*. 2024, pp. 68–101.

Duke, SO (2012) Why have no new herbicide modes of action appeared in recent years? Pest Manag Sci 68:505–512

Duke S. O. 1990. Overview of herbicide mechanisms of action. Environmental Health Perspectives, 87, pp 263-271.

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. In: Camper, N.D.,

Ed., Southern Weed Science Society, Research Methods in Weed Science, 3rd Edition, WSSA, Champaign, 29-46

Georgia Farm Bureau. *Agricultural News from GFB - Georgia Farm Bureau*, Mar. 2022, www.gfb.org/news/ag-news.

Gilman, Edward F, and Teresa Howe. 1999, pp. 1–3, *Cosmos Bipinnatus*.

Jannis Machleb, Gerassimos G. Peteinatos, Benjamin L. Kollenda, Dionisio Andújar, Roland Gerhards, Sensor-based mechanical weed control: Present state and prospects, Computers and Electronics in Agriculture, Volume 176, 2020

Jerry A. Ivany and Jason Reddin. 2002. Effect of post-emergence herbicide injury and planting date on yield of narrow-row soybean (*Glycine max*). *Canadian Journal of Plant Science*. 82(1): 249-252.

Mize, T.W., Mitchell, H.R. & Crumby, T.I. 2002 AIM herbicide/harvest aid for rapid control in cotton—research and commercial results 5 Proc. Beltwide Cotton Conf Memphis, TN

Mohler, C.L. (1996), Ecological Bases for the Cultural Control of Annual Weeds. Journal of Production Agriculture, 9: 468-474.

[NCSU Extension] North Carolina State University Extension, North Carolina Extension 2020, *(Cosmos) Gardener Plant Toolbox*, Available online at: plants.ces.ncsu.edu/plants/cosmos/. Accessed 14 Jan. 2025.

Olajuyigbe, O., & Ashafa, A. Chemical Composition and Antibacterial Activity of Essential Oil of Cosmos bipinnatus Cav. Leaves from South Africa. *Iranian Journal of Pharmaceutical Research: IJPR*, *13*(4), 1417.

Priess GL, Norsworthy JK, Roberts TL, Gbur EE. Impact of postemergence herbicides on soybean injury and canopy formation. *Weed Technology*. 2020;34(5):727-734. doi:10.1017/wet.2020.55

Rabaey TL, Harvey RG. Efficacy of Corn (Zea mays) Herbicides Applied at Reduced Rates Impregnated in Dry Fertilizer. *Weed Technology*. 1994;8(4):830-835

TELUS Agronomy – *Label search.* (2024). Available online at: https://www.agrian.com/labelcentter/results.cfm. Accessed January 5, 2025

Vargas-Amado, Georgina et al. Geographic distribution and richness of the genus *Cosmos* (Asteraceae: Coreopsideae). *Rev. Mex. Biodiv.* [on-line]. 2013, vol.84,

Wallace, R. W. (2004). Pre and Early Postemergence Herbicide Phytotoxicity and Yield Effects in Transplanted Peppers. *HortScience HortSci*, *39*(4), 746C-746. Available online at: https://doi.org/10.21273/HORTSCI.39.4.746C. Accessed January 5, 2025

Westwood JH, Charudattan R, Duke SO, et al. Weed Management in 2050: Perspectives on the Future of Weed Science. *Weed Science*. 2018

Whitaker, J.R., A.C. York, D.L. Jordan, A.S. Culpepper, and L.M. Sosnoskie. 2011. Residual herbicides for Palmer amaranth control. J Cotton Sci, 15(1), pp.89-99.

Table 1. Herbicide treatments applied postemergence to *Cosmos bipinnatus*

Herbicide[a, b]	Trade Names	Formulation Concentration	Application Rate	Manufacturer
		lb ai/gal or %	oz/A	
fluometuron	Cotoran® 4L	4	32	Adama US
fluometuron	Cotoran® 4L	4	48	Adama US
2,4-DB	Butyrac® 175	1.75	11.43	Albaugh Inc.
2,4-DB	Butyrac® 175	1.75	13.71	Albaugh Inc.
2,4-DB	Butyrac® 175	1.75	16	Albaugh Inc.
flufen + metri	Axiom DF®	54.4+13.6%	8	Bayer CropScience
flufen + metri	Axiom DF®	54.4+13.6%	10	Bayer CropScience
tolpyralate	Sheildex®	3.33	1	Summit Agro USA
topramezone	Armezon®	2.8	0.5	BASF Corporation
flumetsulam	Python®	80% WG	0.125	Amvac
flumetsulam	Python®	80% WG	0.8	Amvac
fluroxypyr	Flagstaff®	2.8	4.8	Adama US
tembotrione	Laudis®	3.5	3	Bayer CropScience
acifluorfen	Ultra Blazer®	2	8	United Phosphorus, Inc
imazapyr	Arsenal®	2	2	BASF Corporation
imazapyr	Arsenal®	2	10	BASF Corporation
pyroxasulfone	Zidua® SC	4.17	1.75	BASF Corporation
sulfentrazone	Spartan® 4F	4	4	FMC Corporation
isoxaflutole	Alite 27®	2	3	BASF Corporation
simazine	Simazine 4L	4	32	Drexel
halauxifen	Elevore®	0.572	1	Corteva Agriscience
tiafenacil	Reviton®	2.83	1	Helm Ag
fluridone	Brake	1.2	16	SePRO Corporation
flumioxazin	Broadstar®	0.25%	150 pound	Valent USA
flumi + prodi	Perfection Fuerte®	.125, .75%	100 pound	OHP Inc

[a]Specimen labels for each product and mailing addresses and website of each manufacturer can be found at www.cdms.net.

[b]Abbreviations: Flufen + metri, flufenacet + metribuzin; flumi + prodi, flumioxazin + prodiamine.

Chapter III: Investigating Herbicides for Potential Use in the North Carolina Wildflower Program

Abstract

Two experiments were conducted in 2023 and 2024 near Clayton and Smithfield, NC, to evaluate the tolerance of seven wildflower species to PRE and POST herbicides. Wildflower species included narrowleaf sunflower, black-eyed Susan, Maximilian sunflower, sweet William, clasping coneflower, bur-marigold, and Indian blanket. Experiments were initiated in late spring of 2023 and in early winter of 2024 to promote uniform emergence across species. In 2023, narrowleaf sunflower, Maximilian sunflower, clasping coneflower, black-eyed Susan, and sweet William successfully emerged, and PRE and POST data were collected on these five species. In 2024, bur-marigold, Indian blanket, clasping coneflower, black-eyed Susan, and sweet William emerged, and data were collected accordingly. The PRE trial included 18 different herbicide treatments and combinations, while the POST experiment evaluated 23 different herbicides and application rates. More injury from PRE and POST herbicides was observed in 2023 compared to 2024 and may be explained by varying environmental conditions. Among all treatments, flufenacet + metribuzin and S-metolachlor applied PRE caused the least injury and bloom reduction across all species. For the POST experiment, flufenacet + metribuzin and 2,4-DB were the safest treatments across wildflower species.

Introduction

The North Carolina Department of Transportation (NCDOT) Roadside Wildflower Program is a highway beautification initiative that spans 1,500 acres of wildflower beds across the state (NCDOT Wildflower Handbook 2025). These wildflower beds are intended to provide aesthetically pleasing displays of native and non-native species for both residents and tourists driving North Carolina highways. However, maintaining these species can be challenging. Without proper management, wildflower beds often revert to weedy, successional growth (Gallitano 1992). As these beds transition to long-term wildflower plantings, weed management becomes increasingly difficult (Weisberger et al. 2019). Weeds present a significant problem for the NCDOT, prompting them to adopt various weed management strategies. The primary method of weed management is chemical. Currently, the NCDOT holds 24(c) Special Local Needs labels for several herbicides, allowing application to some wildflower species (Rick Seagroves and Kevin Clemmer, personal communication). Another weed management tactic employed by the NCDOT involves no-till planting which is shown to reduce weed emergence and competition (Barnes et al. 1983; Anderson 2015). Previous research also demonstrated that wildflowers tend to produce more blooms in no-till compared to conventional tillage (Angelella et al. 2019). Given the success of these weed management strategies, the NCDOT is seeking more herbicide options across a wider range of wildflower species capable of being planted no-till (Rick Seagroves & Kevin Clemmer, personal communication).

Six of the seven species evaluated for herbicide tolerance are members of the *Asteraceae* family including narrowleaf sunflower (*Helianthus angustifolius)*, black-eyed Susan (*Rudbeckia hirta)*, Maximilian sunflower (*Helianthus maximiliani)*, bur-marigold (*Bidens aristosa)*, clasping coneflower (*Dracopsis amplexicaulis)*, and Indian blanket (*Galardia pulchella)*. Narrowleaf sunflower is a shrubby, herbaceous perennial that can grow up to eight feet tall (UT Austin 2022a). It is native to the eastern and central United States and thrives in a wide range of environments—from dry uplands to swampy lowlands (NCSU Extension 2025a). This adaptability makes it an ideal candidate for the Roadside Wildflower Program. The Narrowleaf sunflowers also serve as a valuable pollinator plant, attracting bees, butterflies, and other insects (Brackie 2021). It features dark green, narrow leaves covered in coarse hairs, and its 1-2 inch flowers have a brown-purple center surrounded by bright yellow petals (UT Austin 2022a). Black-eyed Susan is native to North Carolina (Brackie 2019a). Depending on conditions, it may grow as an annual, biennial, or short-lived perennial (Missouri Botanical Gardens 2019). This species is widely used in the Roadside Wildflower Program due to its drought tolerance and extended summer bloom period (Rick Seagroves, personal communication; UT Austin 2023a). Plants grow to 1.5 to 3 feet in height, with each stem bearing a single daisy-like, yellow-orange flower (Brackie 2019a). NCDOT typically seeds black-eyed Susan in the fall or winter, with some early spring plantings as well (Rick Seagroves & Kevin Clemmer, personal communication)

Maximilian sunflower is a shrubby perennial native to much of the United States; the species is particularly adapted to the organic soils of the Midwest (Wennerberg 2004). Its growth habit resembles that of narrowleaf sunflower, reaching heights of 3-10 feet. The light green leaves are densely covered in white hairs (UT Austin 2014). This species features a dense, rhizomatous root system that facilitates spreading (Wennerberg 2004). Flowers form along branching stems from the leaf axils, each 2-3 inch in diameter with 20–40 yellow petals surrounding a green disk (UT Austin 2014). Maximilian sunflower blooms from late August to early October, providing a tall, vibrant floral display (NCSU Extension 2025b).

Bur-marigold is a native annual found throughout the central and eastern United States and into Canada (UT Austin 2021). It grows well in diverse environments and is widespread across North Carolina (NCSU Extension 2024a). Plants reach 5 feet in height and produce conspicuous golden-yellow flowers with 10–20 petals arranged radially (UT Austin 2021). Rapid growth and an extended bloom period, from August through October, make bur-marigold well-suited for roadside wildflower beds (Rick Seagroves & Kevin Clemmer, personal conversation; NCSU Extension 2024a).

Clasping coneflower, the only North American species in the *Dracopis* genus, is native to the southern U.S. (UT Austin 2023). It grows 1.5 to 4 feet tall and shares growth similarities with black-eyed Susan and Mexican hat (Brackie 2019b). Leaves alternate and wrap around the stem, a key distinguishing feature (Brackie 2019b). The yellow petals transition to reddish-purple at the base and droop downward, while the central cone rises 1-3 inches above the flower head (UT Austin 2023). The plant performs well in a variety of soil types and blooms from June to July.

Indian blanket is native to nearly all U.S. states except Wyoming, Montana, Idaho, and Washington (UT Austin 2022b). It thrives in high, dry, sandy upland soils, making it highly drought-tolerant (Maher 2020). Plants reach 1.5 to 3 feet in height, producing distinctive flowers with red petals tipped in yellow and a reddish-brown central cone (UT Austin 2022b). Blooming from May through August, this species is especially suited to the coarse-textured soils of North Carolina's coastal plain (Maher 2020; Rick Seagroves & Kevin Clemmer, personal conversation).

Sweet William, a member of the *Caryophyllaceae* family, is a low-growing biennial or short-lived perennial native to the mountains of Europe (NCSU Extension 2024b). Although Sweet William is not native to NC, the NCDOT plants this wildflower for its striking floral colors (Rick Seagroves & Kevin Clemmer, personal conversation). Flowers range in color from pink and purple to white and bright red, often with variegated patterns (NCSU Extension, 2024b). Sweet William is one of the earliest blooming species, flowering from late March through early May—an advantage for spring color (Rick Seagroves & Kevin Clemmer, personal conversation). Due to its modest height (1 – 1.5 feet), effective weed control is crucial to prevent taller weeds from obscuring their blooms (Rick Seagroves & Kevin Clemmer, personal conversation; Go Botany 2025).

Currently, herbicide options in these wildflower species are limited. Therefore, the objectives of this study were to evaluate the tolerance of narrowleaf sunflower, black-eyed Susan, Maximilian sunflower, clasping coneflower, bur-marigold, Indian blanket, and sweet William to preemergence (PRE) and postemergence (POST) herbicides.

Materials and Methods

Separate PRE and POST experiments were conducted in 2023 at the Central Crops Research Station near Clayton, NC (35.67°N, 78.51°W) and a private farm near Smithfield, NC (35.52°N, 78.41°W), and in fall 2023 into spring of 2024 at the same private farm near Smithfield and another near Four Oaks, NC (35.40°N, 78.45°W). At the Smithfield site in 2023, five species—black-eyed Susan, narrowleaf sunflower, Maximilian sunflower, clasping coneflower, and sweet William—emerged consistently. To improve germination for the second year of the study, wildflowers were planted in the fall on November 29, 2023. Across both private farm locations in fall 2023/2024, bur-marigold, Indian blanket, clasping coneflower, black-eyed Susan, and sweet William successfully emerged.

PRE herbicide treatments were applied immediately after planting. PRE herbicide treatments and rates are listed in Table 1. POST herbicide treatments were applied on July 9, 2023, and May 7, 2024, and are detailed in Table 2, including necessary adjuvants—such as crop oil concentrate, methylated seed oil, nonionic surfactant, or ammonium sulfate—at label-recommended rates. Detailed material and methods can be found in Appendix 5.

Results and Discussion

Because of high variability and inconsistent emergence at Clayton, no data was collected from this location in 2023. Black-eyed Susan, narrowleaf sunflower, Maximilian sunflower, clasping coneflower, and sweet William emerged at Smithfield in 2023. Bur-marigold, Indian blanket, clasping coneflower, black-eyed Susan, and sweet William successfully emerged at both locations in fall 2023/2024. In summary data for narrowleaf sunflower and Maximilian sunflower was collected at only one (Smithfield 2023) site*year whereas data for bur-marigold and Indian blanket was collected at 2 (Smithfield and Four Oaks in fall 2023/2024) site*years and data for black-eyed Susan, clasping coneflower, and sweet William was collected at three (Smithfield 2023 and Smithfield and Four Oaks fall 2023/2024) site*years. For species with multiple sites*years, the main effects of PRE herbicide treatment and year, and their interaction, were significant. Therefore, data for all wildflower species will be presented by year.

Preemergence Herbicide Study

Data for narrowleaf sunflowers were only collected in 2023 at Smithfield. At 7 DAE, pendimethalin + fluridone (92%), pyrithiobac + fluridone (84%), both rates of fluridone (80% and 81%), indaziflam (93%), and both rates of pyroxasulfone + flumioxazin (97%) caused the greatest injury to narrowleaf sunflower (Appendix 5, Table 3). Conversely, pendimethalin (12%), S-metolachlor (7%), mesotrione (5%), the low rate of sulfentrazone (4%), and sulfentrazone + imazethapyr (7%) resulted in the least injury 7 DAE. Similar to 7 DAE, both rates of fluridone (86% and 94%), pyrithiobac + fluridone

(90%), pendimethalin + fluridone (88%), indaziflam (82%), and both rates of pyroxasulfone + flumioxazin (84% and 94%) continued to be the most injurious 28 DAE. At the same time, narrowleaf sunflower injury from pendimethalin, S-metolachlor, pyrithiobac, mesotrione, flufenacet + metribuzin, isoxaflutole, the low rate of sulfentrazone, and sulfentrazone + imazethapyr all resulted in injury ≤ 12%.

For bloom reduction, both rates of fluridone (51%, 52%), pyrithiobac + fluridone (71%), pendimethalin + fluridone (81%), indaziflam (45%), and both rates of pyroxasulfone + flumioxazin (50%, 37%) reduced bloom the greatest. Bloom reduction across the remaining PRE treatments ranged from 0 to 7%. The narrowleaf sunflower density was 32 plants per 2 foot of row in the nontreated check. PRE treatments that reduced plot density compared to the nontreated check included both rates of fluridone (8 and 7 plants), pendimethalin + fluridone (3 plants), pyrithiobac + fluridone (4 plants), indaziflam (5 plants), and both rates of pyroxasulfone + flumioxazin (6 and 1 plants). Narrowleaf sunflower density in all other PRE treatments resulted in a similar density as the non-treated check.

Maximilian Sunflower

Maximilian sunflower germinated in 2023 at Smithfield. At 7 DAE, pendimethalin (20%), pendimethalin + S-metolachlor (19%), pyrithiobac (19%), flufenacet + metribuzin (18%), isoxaflutole (16%), both rates of sulfentrazone (7%, 12%), and sulfentrazone + imazethapyr (7%) resulted in the lowest injury (Appendix 5, Table 4). By 28 DAE, the treatments of pendimethalin (1%), S-metolachlor (0%), pendimethalin + S-metolachlor (2%), pyrithiobac (0%), mesotrione (1%), flufenacet + metribuzin (2%), isoxaflutole (0%), fluometuron (6%), both rates of sulfentrazone (0%, 4%), and sulfentrazone + imazethapyr (0%) continued to cause the lowest injury. Furthermore, at bloom reduction, the same treatments of pendimethalin, S-metolachlor, pyrithiobac, mesotrione, flufenacet + metribuzin, isoxaflutole, fluometuron, both rates of sulfentrazone, and sulfentrazone + imazethapyr all preceded to have ≤ a 6% reduction in bloom, respectively. All other treatments caused ≤ 48% reduction in bloom to Maximilian sunflowers. When plot densities were taken, pendimethalin (12 plants), S-metolachlor (10 plants), pendimethalin + S-metolachlor (11 plants), pyrithiobac (13 plants), isoxaflutole (12 plants), both rates of sulfentrazone (16 and 12 plants), and sulfentrazone + imazethapyr (16 plants) resulted in density that was comparable to the nontreated check, all other treatments reduced Maximilian stand different to the nontreated check.

Clasping Coneflower

Clasping coneflower emerged in both years—Smithfield location in 2023 and both locations in fall 2023/2024. In 2023, at 7 DAE, all treatments resulted in significant injury to the coneflower with all treatments causing > 41% (Appendix 5, Table 5). By 28 DAE, *S*-metolachlor (19%) was the least injurious treatment, all other treatments caused ≥ 27%. For bloom reduction, pendimethalin (12%), *S*-metolachlor (6%), pendimethalin + *S*-metolachlor (5%), pyrithiobac (11%), flufenacet + metribuzin (2%) and sulfentrazone + imazethapyr (16%) resulted in the lowest bloom reductions across treatments. Furthermore, early season injury from the lowest bloom reductions proves that early season injury was transient as certain treatments had little effect on bloom reductions. Clasping coneflower plot density was 17 plants per 2 foot of row in the nontreated check. PRE treatments of S-metolachlor (9 plants), pyrithiobac (11 plants), both rates of sulfentrazone (12 10 plants), and sulfentrazone + imazethapyr (9 plants)

Injury across the years was not consistent for clasping coneflower. At 7 DAE, pyrithiobac (21%) was the most injurious treatment followed by fluridone (14%), whereas all other treatments caused ≤ 12% injury (Appendix 5, Table 6). By 28 DAE, the high rate of fluridone (12%) resulted in the greatest injury to clasping coneflower with all other treatments experiencing 10% injury or less. For clasping coneflower density, all PRE treatments were comparable to the nontreated check (5.6 plants) except for the high rate of fluridone at 3.3 plants per 2 foot of row. For bloom reduction, mesotrione (10%), isoxaflutole (10%), fluometuron (11%), and sulfentrazone + imazethapyr (14%) reduced bloom the greatest. Bloom reduction across the remaining PRE treatments ranged from 0 to 6%.

Black-eyed Susan

Black-eyed Susan emerged in both years—Smithfield location in 2023 and both locations in fall 2023/2024. In 2023, at 7 DAE, injury was significant across all treatments, sulfentrazone + imazethapyr (20%) was the least injurious treatment, and all other PRE treatments resulted in 28% or greater injury

(Appendix 5, Table 7). By 28 DAE, the injury had decreased for some treatments, the low rate of sulfentrazone (12%) and sulfentrazone + imazethapyr (14%) were the least injurious treatments, and all other treatments caused > 17% injury to black-eyed Susan. However, black-eyed Susan density was not correlated with visual injury, pendimethalin (10 plants), S-metolachlor (12 plants), pyrithiobac (17 plants), mesotrione (8 plants), both rates of sulfentrazone (17 and 12 plants), and sulfentrazone + imazethapyr (23 plants) were comparable to the nontreated check of 15 plants per 2 foot of row. Bloom reduction followed similarly to density results: pendimethalin (17%), *S*-metolachlor (16%), pyrithiobac (16%), the low rate of sulfentrazone (6%), and sulfentrazone + imazethapyr (10%) all resulted in the least reductions in bloom across all treatments.

In 2024, the injury was not consistent with 2023. At 7 DAE, the low rate of pyroxasulfone + flumioxazin (34%) in all other treatments resulted in $\leq$ 12% injury (Appendix 5, Table 8). By 28 DAE, all treatments injuries were between 0% to 5%. For bloom reduction, the PRE treatment of the low rate of pyroxasulfone + flumioxazin (31%) reduced bloom the greatest, followed by fluometuron (22%). Pendimethalin, *S*-metolachlor, both rates of fluridone, pyrithiobac, pendimethalin + fluridone, mesotrione, and isoxaflutole resulted in the least reduction in bloom, all causing $\leq$ 6% reductions. Densities for PRE treatments of the high rate of fluridone (4.3 plants), pyrithiobac (3.2 plants), indaziflam (3.8 plants), both rates of flumioxazin (2.8 and 3.3 plants), isoxaflutole (4.1 plants), fluometuron (3.6 plants), and both rates of sulfentrazone (4.3 and 5.1 plants) revealed reductions in plot densities when compared to the nontreated check (9.4 plants). All other treatments were comparable to the non-treated check.

Sweet William

Sweet William emerged in both years, the Smithfield location in 2023 and both locations in fall 2023/2024. However, sweet William did not bloom in either year. In 2023, at 7 DAE, flufenacet + metribuzin (19%), isoxaflutole (18%), and the low rate of sulfentrazone (13%) resulted in the lowest injury across treatments (Appendix 5, Table 9). By 28 DAE, injury increased across all treatments, flufenacet + metribuzin resulted in the least injury of all treatments, and all other PRE treatments resulted in $\geq$ 31% injury to sweet William. When plot densities were taken, only S-metolachlor (18) was statistically similar to the nontreated check (21), all other treatments resulted in reductions not similar to the nontreated check.

The injury was not consistent between 2023 and 2024. At 7 DAE, the PRE treatment of sulfentrazone + imazethapyr (15%) resulted in the lowest injury levels, all other treatments resulted in injury ≤ 25% (Appendix 5, Table 10). By 28 DAE, injury recovery was observed across all treatments, with all PRE treatments causing 9% injury or less to sweet William. Plot density for sweet William resulted in all treatments being comparable to the nontreated check (7.4 plants) except for the low rate of pyroxasulfone + flumioxazin (3.7 plants).

Bur-marigold

Bur-marigold emerged in 2024 at both locations. At 7 DAE, injury was minimal across all treatments, the low rate of pyroxasulfone + flumioxazin (27%) caused the greatest injury to bur-marigold followed by indaziflam (24%), all other treatments resulted in 18% or less (Appendix 5, Table 11). By 28 DAE, injury decreased, and all treatments caused less than 15% injury to bur-marigold. Bloom reductions were comparable to visual injury ratings, one treatment, pyrithiobac + fluridone (15%), caused the greatest reduction in bloom across treatments, with all other treatments causing a 12% reduction or less. At density timing, two treatments, indaziflam (3 plants) and the low rate of sulfentrazone (3 plants) resulted in fewer plants when compared to the nontreated check (6 plants), all other treatments were comparable to the non-treated check.

Indian Blanket

Indian blanket emerged in 2024 at both locations. At 7 DAE, S-metolachlor (7%), pendimethalin + S-metolachlor (12%), low rate of fluridone (6%), flufenacet + metribuzin (12%), the high rate of sulfentrazone (8%), and sulfentrazone + imazethapyr (7%) resulted in the lowest injury to Indian blanket (Appendix 5, Table 12). Similar to bur-marigold, most treatments had recovered by 28 DAE. Mesotrione (14%) was the most injurious across PRE treatments followed by a low rate of sulfentrazone (12%); all other treatments injured Indian blanket by 7% or less. When bloom reductions were rated, the injury was minimal except for mesotrione (15%) and a low rate of sulfentrazone (12%) which caused the greatest bloom reductions. Densities ratings resulted in reductions for the high rate of fluridone (2.7 plants), pendimethalin (3 plants), the low rate of pyroxasulfone + flumioxazin (1.6 plants), isoxaflutole (3.2 plants), fluometuron (1.7 plants), and both rates of sulfentrazone (2.8 and 2.7 plants) compared to the nontreated check (5.7 plants).

Postemergence Herbicide Study

Narrowleaf Sunflower

At 7 DAT, all rates of 2,4-DB (1%), the low rate of mesotrione (12%), and flufenacet + metribuzin (5%) had the lowest injury; all other treatments injured the narrowleaf sunflower by 16% or greater (Appendix 5, Table 13). Furthermore, many treatments injured narrowleaf sunflower >40% including imazamox (43%), halosulfuron (56 to 72%), fluridone (50 to 56%), fluometuron at the two highest rates (43 to 58%), pyrithiobac (42 to 50%), and sulfosulfuron (47 to 68%). At 14 DAT, injury trends were consistent with those observed at 7 DAT, with all rates of 2,4-DB (≤ 2%), the low rate of mesotrione (15%), flufenacet + metribuzin (0%), and the low rate of fluometuron (7%) still resulting in the least injury. Imazamox, halosulfuron, fluridone, pyrithiobac, and sulfosulfuron remained the most injurious, injuring narrowleaf sunflowers ≥ 62%. At 28 DAT, all rates of 2,4-DB (≤ 13%), both rates of mesotrione (9%), flufenacet + metribuzin (0%), and the low and middle rates of fluometuron (5% and 12%) had the least amount of injury. Furthermore, at the same time, imazamox (55%), halosulfuron (52 to 91%), the high rate of fluridone (72%), pyrithiobac (99%), and sulfosulfuron (99%) remain most injurious to narrowleaf sunflower. In general, bloom reduction data closely mirrored visual estimates of injury. For narrowleaf sunflower bloom reduction, all rates of 2,4-DB (≤ 17%), both rates of mesotrione (6% and 5%), flufenacet + metribuzin (0%), and all rates of fluometuron (0%) had the lowest reduction in bloom. All other treatments caused ≥ 20% bloom reduction including imazamox (50%), halosulfuron (68 to 93%), pyrithiobac (97 to 100%), and sulfosulfuron (100%).

Maximilian Sunflower

At 7 DAT, all three rates of 2,4-DB (≤ 10%), both rates of thifensulfuron (4% and 7%), the low rate of halosulfuron (14%), flufenacet + metribuzin (4%), the low rate of fluridone (11%), and the low rate of fluometuron (5%) resulted in the lowest injury; whereas sulfosulfuron was the most injurious treatment throughout all rating timings (Appendix 5, Table 14). Similar to 7 DAT, all rates of 2,4-DB (≤16%), the low rate of thifensulfuron (7%), flufenacet + metribuzin (0%), and the low rate of fluometuron (2%) remained the least injurious. Additionally, imazamox, halosulfuron, pyrithiobac, and sulfosulfuron were the most injurious POST treatments for Maximilian sunflower. At 28 DAT, injury increased, the low rate of thifensulfuron (5%), flufenacet + metribuzin (0%), and the low rate of fluometuron (12%) resulting in the least amount of injury across treatments. Furthermore, the POST treatments of imazamox (63%), pyrithiobac (57% to 66%), and sulfosulfuron (87% to 97%) resulted in the greatest injury. Bloom reduction data revealed some herbicide treatment recovery with the low and middle rates of 2,4-DB (9% and 5%), the low rate of thifensulfuron (2%), flufenacet + metribuzin (0%), and all three rates of fluometuron (≤ 9%) resulted in the lowest bloom reductions. All other treatments resulted in a >24% reduction in bloom, including imazamox (53%), pyrithiobac (53% to 72%), and sulfosulfuron (74% to 100%).

Clasping Coneflower

In 2023, at 7 DAT, all rates of 2,4-DB (<1%), both rates of thifensulfuron (7% and 12%), imazamox (8%), flufenacet + metribuzin (5%), and the low rate of pyrithiobac (7%) resulted in the least injury (Appendix 5, Table 15). The injury was relatively low 7 DAT, with only the high rate of fluridone the middle and high rate of fluometuron, and the high rate of pyrithiobac resulting in > 30% injury. By 14 DAT, only the 2,4-DB rates (≤ 5%), the low rate of thifensulfuron (7%), and flufenacet + metribuzin (0%) remained the least injurious treatments. Furthermore, many treatments injured clasping coneflower > 40%, mesotrione (42% to 46%), the high rate of halosulfuron (50%), fluridone (56%-76%), fluometuron (42% to 88%), pyrithiobac (33% to 50%), and sulfosulfuron (40% to 63%). At 28 DAT, only the low and middle rates of 2,4-DB (7%, 0%) and flufenacet + metribuzin (10%) had the lowest injury, all other treatments caused > 20% to the coneflower including mesotrione, fluridone, fluometuron, pyrithiobac, and sulfosulfuron remaining the most injurious at > 45%. Unlike many other wildflowers, coneflowers were not able to grow out of early season injury, therefore the herbicide treatments of all rates of 2,4-DB ($\leq$ 15%) and flufenacet + metribuzin (0%) resulted in the least reductions in bloom.

Over 2023 and 2024, the injury was not consistent. At 7 DAT, all rates of 2,4-DB ($\leq$ 5%), the low rate of thifensulfuron (8%), imazamox (2%), the low rate of pyrithiobac (7%), and flufenacet + metribuzin (9%) resulted in the least injurious POST treatments. (Appendix 5, Table 16). By 14 DAT, no treatment injury reached > 30%, whereas in 2023, there were several treatments above 50% injury. 2,4-DB ($\leq$ 3%) and flufenacet + metribuzin (1%) were the least injurious herbicide treatments. At 28 DAT, injury levels were similar to 7 DAT with 2,4-DB ($\leq$ 15%) and flufenacet + metribuzin (4%) resulting in the lowest injury across treatments. Both rates of fluridone (9% and 12%) and the low rate of fluometuron (12%) injury levels had also decreased. Furthermore, at the same time, the high rate of mesotrione (60%), pyrithiobac (48% to 62%), and sulfosulfuron (47% to 62%) remained the most injurious POST treatments across the years. Bloom reduction mirrored visual ratings with 2,4-DB (3%-11%), flufenacet + metribuzin (1%), both rates of fluridone (7% and 5%), and the low rate of fluometuron (5%) had the least amount of bloom reduction across treatments. Whereas, in 2023, the low rate of fluometuron reduced bloom by 52% and both rates of fluridone reduced bloom by 76% and 100%, respectively. Pyrithiobac and sulfosulfuron reduced bloom the greatest across treatments and years > 71%.

Black-eyed Susan

In 2023, at 7 DAT, all rates of 2,4-DB ($\leq$ 4%), flufenacet + metribuzin (2%), and the low rate of fluometuron (12%) resulted in the least injury (Appendix 5, Table 17). By 14 DAT, injury increased across treatments, with only all rates of 2,4-DB (5%-9%) and flufenacet + metribuzin (10%) remaining as the lowest injury to black-eyed Susan. Furthermore, the treatments of the high rate of thifensulfuron (53%), halosulfuron (76% to 90%), fluridone (51% to 56%), pyrithiobac (60% to 70%), and sulfosulfuron (78% to 86%) caused the greatest injury to black-eyed Susan. At 28 DAT, similar to 7 DAT, the low and middle rates of 2,4-DB and flufenacet + metribuzin both resulted in $\leq$ 10% injury and were the least injurious treatments. Halosulfuron and sulfosulfuron both resulted in > 97% injury to black-eyed Susan. Similarly, at bloom reduction ratings, the low and middle rates of 2,4-DB (5%), flufenacet + metribuzin

(10%), and the low rate of fluometuron (10%) resulted in minimal bloom reductions. Whereas halosulfuron and sulfosulfuron resulted in a 100% reduction in bloom.

In 2024, injury levels were not consistent in 2023. At 7 DAT, treatments including all rates of 2,4-DB (4%-7%), flufenacet + metribuzin (5%), the low and middle rates of fluometuron (7%), and the low and middle rate of pyrithiobac (8%) resulted in the least injury over treatments (Appendix 5, Table 18). At 14 DAT, similar treatments of 2,4-DB (1%-6%), flufenacet + metribuzin (5%), and fluometuron (1% and 0%) resulted in the lowest injury across black-eyed Susan. Additionally, all POST treatments resulted in ≤ 30% injury to black-eyed Susan, with the greatest injury resulting from halosulfuron. By 28 DAT, the same treatments of 2,4-DB (7% to 9%), flufenacet + metribuzin (5%), the low and middle rates of fluometuron (3% and 8%)—plus both rates of fluridone (11% and 12%)—remained the least injurious. Halosulfuron (37%-56%) and sulfosulfuron (42% to 58%) were the most injurious POST treatments. All rates of 2,4-DB (2%-8%), the low rate of mesotrione (16%), low rate of thifensulfuron (11%), imazamox (11%), flufenacet + metribuzin (5%), both rates of fluridone (12% and 7%), the low and middle rate of fluometuron (13% and 16%), and all rates of pyrithiobac (13%-16%) resulted in the least amount of bloom reduction to black-eyed Susan. At the same time, halosulfuron (52% to 98%) and sulfosulfuron (81% to 98%) remained the reducing bloom the greatest.

Sweet William

In 2023, at 7 DAT, the three rates of 2,4-DB (≤ 2%) and the low rate of thifensulfuron (11%) resulted in the lowest injury, however, all treatments did not exceed > 40%, with the greatest injury resulting from the low rate of fluridone (38%) (Appendix 5, Table 19). At 14 DAT, injury peaked, with all rates of 2,4-DB (< 2%), the low rate of mesotrione (8%), and flufenacet + metribuzin (0%) resulting in the least injury across treatments. Furthermore, fluridone (36% and 50%), fluometuron (32% to 50%), sulfosulfuron (48% to 58%) caused the greatest injury across POST treatments. By 28 DAT, injury declined significantly, with all treatments causing 13% or less.

In 2024, injury was considerably reduced across all treatments at both 7 and 14 DAT. At 7 DAT, all treatments caused ≤ 10% injury across all treatments (Appendix 5, Table 20). At 14 DAT, injury remained low, with the POST treatment of the high rate of fluridone resulting in 14% all other treatments caused 11% or less injury to sweet William. By 28 DAT, injury increased for some treatments, with the high rate of halosulfuron (13%), both rates of fluridone (13%, 23%), all rates of fluometuron (11%-30%), and the middle and high rates of sulfosulfuron (18%) resulting in the greatest injury.

Bur-marigold

At 7 DAT, all rates of 2,4-DB (8%-12%), flufenacet + metribuzin (5%), both rates of fluridone (12% and 6%), and the low and middle rates of fluometuron (6% and 10%) caused the least amount of injury (Appendix 5, Table 21). The same treatments at 14 DAT—2,4-DB (9%- 11%), flufenacet + metribuzin (1%), both fluridone rates (7%), and the low and middle rates of fluometuron (2%, 8%)—remained the least injurious. Additionally, imazamox (33%), the high rate of halosulfuron (36%), and sulfosulfuron (26% to 46%) caused the greatest injury. At 28 DAT, injury increased for 2,4-DB with all three rates causing > 15% injury, however, flufenacet + metribuzin (3%), both rates of fluridone (5% and 6%,) and the low rate of fluometuron (6%) still resulted in the least injurious treatments. Furthermore, the high rate of thifensulfuron (41%), imazamox (35%), pyrithiobac (33% to 37%), and sulfosulfuron (37% to 56%) remained as the most injurious POST treatments to bur-marigold. By the time bloom reductions were taken, all treatments caused ≤ 13% reduction, except for the high rate of sulfosulfuron (31%) which reduced the bloom the greatest to bur-marigold.

Indian Blanket

At 7 DAT, minimal injury was observed, with all treatments resulting in ≤ 11%, respectively. At 14 DAT, injury began increasing, sulfosulfuron (18%-22%), mesotrione 17%-19%), pyrithiobac (10-17%) caused the greatest injury across treatments to Indian blanket. By 28 DAT, all three rates of 2,4-DB (7%-15%), the low rate of halosulfuron (9%), flufenacet + metribuzin (0%), fluridone (3% and 5%) and the low rate of fluometuron (7%) resulted in the least amount of injury to Indian blanket. Similar to 14 DAT, mesotrione (23% to 24%), thifensulfuron (26% to 35%), pyrithiobac (28% to 32%), and sulfosulfuron (37% to 38%) caused the greatest injury across treatments. At the bloom reduction rating, all rates of 2,4-DB (10%-12%), flufenacet + metribuzin (0%), the low and middle rate of halosulfuron

(9%) and both rates of fluridone (7% and 4%) had the lowest reductions in bloom, whereas imazamox, pyrithiobac, and sulfosulfuron had 36% or greater reductions in bloom.

Literature Cited

Angelella, G. M., Stange, L., Scoggins, H. L., & O'Rourke, M. E. (2019). Pollinator Refuge Establishment and Conservation Value: Impacts of Seedbed Preparations, Seed Mixtures, and Herbicides. *HortScience horts*, *54*(3), 445-451. Retrieved Feb 11, 2025, from https://doi.org/10.21273/HORTSCI13600-18

Barnes, J.P., Putnam, A.R. Rye residues contribute to weed suppression in non-tillage cropping systems. *J Chem Ecol* 9, 1045–1057 (1983). https://doi.org/10.1007/BF00982210

Brakie, M. 2021. Plant Guide for swamp sunflower (Helianthus angustifolius). USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches, TX.

Brakie, M. 2019a. Plant Guide for black-eyed Susan (Rudbeckia hirta). USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches, TX.

Brakie, M. 2019b. Plant Guide for clasping coneflower (Dracopis amplexicaulis). USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches, TX 75964.

Frans RE, Talbert R, Marx D, Crowely H (1986) Experimental design and techniques for measuring and analyzing plant responses to weed control practices. Pages 29-46 in N. D. Camper (eds.) Research Methods in Weed Science. South. Weed Sci. Soc. Champaign, IL

Gallitano, L., Skroch, W. A., & Bailey, D. A. (1992). Weed Management for Wildflowers. North Carolina Cooperative Extension Service, Department of Horticultural Science.

[Go Botany] Native Plant Trust 2025. *Go Botany*. *Dianthus barbatus.* Available online at: https://gobotany.nativeplanttrust.org/species/dianthus/barbatus/. Accessed April 16, 2025

Khalil Y, Flower K, Siddique KHM, Ward P. Rainfall affects leaching of pre-emergent herbicide from wheat residue into the soil. PLoS One. 2019 Feb 1;14(2): e0210219. doi: 10.1371/journal.pone.0210219. PMID: 30707698; PMCID: PMC6358059.

Maher S., and J. Reilley. 2020. Plant guide for Indian blanket (Gaillardia pulchella). USDA-Natural Resources Conservation Service, E. “Kika” de la Garza Plant Materials Center, Kingsville, TX.

[Missouri Botanical Garden] *Missouri Botanical Garden. 2019. Rudbeckia hirta. Accessed online: 2/6/2025 at http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=277225*

NCDOT Wildflower Handbook. Wildflowers on the Roadsides. (2025). Available online at: https://www.ncdot.gov/initiatives-policies/environmental/wildflower/Documents/ncdot-wildflower-booklet.pdf. Accessed April 16, 2025

[NCSU Extension] North Carolina State University Extension – North Carolina Extension. 2025a Gardener Plant Toolbox. *Helianthus angustifolius*. Available online at: https://plants.ces.ncsu.edu/plants/helianthus-angustifolius/ Accessed April 16, 2025

[NCSU Extension] North Carolina State University Extension – North Carolina Extension. 2025b Gardener Plant Toolbox. *Helianthus maximiliani*. Available online at: https://plants.ces.ncsu.edu/plants/helianthus-maximiliani/ Accessed April 16, 2025

[NCSU Extension] North Carolina State University Extension – North Carolina Extension 2024a Gardener Plant Toolbox. *Bidens aristosa*. Available online at: https://plants.ces.ncsu.edu/plants/bidens-aristosa/. Accessed April 16, 2025

[NCSU Extension] North Carolina State University Extension – North Carolina Extension 2024b *Gardener Plant Toolbox*. *Dianthus barbatus.* Available online at: https://plants.ces.ncsu.edu/plants/dianthus-barbatus/ Accessed April 16, 2025

Shaner DL, ed (2014) Herbicide Handbook. 10th edn. Lawrence, KS: Weed Science Society of America.

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2023a *Rudbeckia hirta.* Available online at: https://www.wildflower.org/plants/result.php?id_plant=RUHI2. Accessed April 16, 2025

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2023b *Dracopsis amplexicaulis*, Available online at: https://www.wildflower.org/plants/result.php?id_plant=DRAM. Accessed April 16, 2025

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2022. *Helianthus angustifolius*. Available online at: https://www.wildflower.org/plants/result.php?id_plant=HEAN2. Accessed April 16, 2025.

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2022b. *Galardia pulchella*, Available online at: https://www.wildflower.org/plants/result.php?id_plant=GAPU. Accessed April 16, 2025.

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2021. *Bidens airstosa*, Available online at: https://www.wildflower.org/plants/result.php?id_plant=BIAR Accessed April 16, 2025.

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2014. *Helianthus maximiliani*, Available online at: https://www.wildflower.org/plants/result.php?id_plant=HEMA2. Accessed April 16, 2025

Weisberger D, Nichols V, Liebman M (2019) Does diversify crop rotations suppress weeds? A meta-analysis. PLoS ONE 14(7): e0219847. https://doi.org/10.1371/journal.pone.0219847

Wennerberg, S. 2004. Plant Guide for Maximilian sunflower (Helianthus maximiliani). USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches, TX.

Table 1. Preemergence herbicide treatments.

Herbicide[a,b]	Trade Names	Formulation Concentration	Application Rate	Manufacturer
Active ingredient	Trade name	lb/gal or %	oz or fl oz/A	
pendimethalin	Prowl H2O	3.8	32	BASF Corp.
S-metolachlor	Dual II Magnum	7.62	16	Syngenta
pendi + S-metol	Prowl + Dual	3.8 + 7.62	32 + 16	BASF + Syngenta
fluridone	Brake	1.2	16	SePRO Corp.
fluridone	Brake	1.2	10	SePRO Corp.
pyrithiobac	Staple LX	3.2	2	DuPont
pyrith + fluri	Staple LX + Brake	3.2 + 1.2	2 + 16	DuPont + SePRO
pendi + fluri	Prowl + Brake	3.8 + 1.2	32 + 16	BASF + SePRO
mesotrione	Tenacity	4	4	Syngenta
flufen + metri	Axiom DF®	54.4 + 13.6%	10	Bayer CropSci
indaziflam	EsplAnade	1.67	2	Bayer CropSci
pyrox + flumi	Piper EZ	1.7 + 1.34	3	Valent U.S.A.
pyrox + flumi	Piper EZ	1.7 + 1.34	6	Valent U.S.A.
isoxaflutole	Alite 27	2	6	BASF Corp.
fluometuron	Cotoran® 4L	4	32	Adama US
sulfentrazone	Spartan® 4F	4	2	FMC Corp.
sulfentrazone	Spartan® 4F	4	4	FMC Corp.
sulfen + imazet	Portfolio Edge	3.33 + 0.67	3	FMC Corp.

[a]Specimen labels for each product and mailing addresses and website of each manufacturer can be found at www.cdms.net.
[b]Abbreviations: pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr.

Table 2. Postemergence herbicide treatments.

Herbicide[a,b]	Trade Names	Formulation Concentration	Application Rate	Manufacturer
		lb/gal or %	oz or fl oz/A	
2,4-DB	Butyrac® 175	1.75	11.43	Albaugh Inc.
2,4-DB	Butyrac® 175	1.75	14.86	Albaugh Inc.
2,4-DB	Butyrac® 175	1.75	18.29	Albaugh Inc.
mesotrione	Tenacity	4	2	Syngenta
mesotrione	Tenacity	4	3	Syngenta
thifensulfuron	Harmony SG	50%	0.125	FMC
thifensulfuron	Harmony SG	50%	0.25	FMC
imazamox	Raptor	1	4	BASF
halosulfuron	Permit	75%	0.125	Gowan Company
halosulfuron	Permit	75%	0.25	Gowan Company
halosulfuron	Permit	75%	0.5	Gowan Company
flufen + metri	Axiom DF	54.4+13.6%	8	Bayer CropScience
fluridone	Brake	1.2	16	SePRO Corporation
fluridone	Brake	1.2	24	SePRO Corporation
fluometuron	Cotoran® 4L	4	32	Adama US
fluometuron	Cotoran® 4L	4	48	Adama US
fluometuron	Cotoran® 4L	4	64	Adama US
pyrithiobac	Staple LX	3.2	2	DuPont
pyrithiobac	Staple LX	3.2	2.3	DuPont
pyrithiobac	Staple LX	3.2	2.6	DuPont
sulfosulfuron	Outrider	75%	0.25	Monsanto
sulfosulfuron	Outrider	75%	0.5	Monsanto
sulfosulfuron	Outrider	75%	0.75	Monsanto

[a]Specimen labels for each product and mailing addresses and website of each manufacturer can be found at www.cdms.net.

[b]Abbreviations: flufen + metri, flufenacet + metribuzin

Chapter IV: Evaluating Pre-Emergent Herbicides on Pollinator Transplants

Abstract

During the summers of 2023 and 2024, four transplanted wildflower species were screened for herbicide tolerance. Wildflower species included black-eyed Susan, purple coneflower, scarlet beebalm, and Shasta daisy. Herbicide treatments consisted of PRE-transplant (PRE-T) and POST-transplant (POST-T) herbicides. PRE-T treatments included pyrithiobac pyrithiobac (2.6 fl oz/A), mesotrione (4 fl oz/A), fluometuron (1 qt/A), sulfentrazone (6 fl oz/A), indaziflam (4 fl oz/A), a premix of pyroxasulfone and flumioxazin (6 fl oz/A), and fluridone (1 pt/A). POST-T treatments were pendimethalin (1 qt/A), pendimethalin (2 qt/A), S-metolachlor (1 pt/A), and pendimethalin + S-metolachlor (2 qt and 1 pt/A). A nontreated check for each wildflower species was included for comparison. For PRE-T treatments, injury varied greatly by year. Acceptable treatments are defended as $\leq$ 15% injury 56 DAT and comparable stand to the non-treated check. For black-eye Susan, acceptable PRE-T treatments were sulfentrazone, pyrithiobac, and fluridone. For scarlet beebalm, sulfentrazone resulted in acceptable injury. Purple coneflower, indaziflam, sulfentrazone, pyrithiobac, and fluridone, were acceptable treatments. For Shasta daisy, sulfentrazone and fluometuron resulted in acceptable treatments. Pendimethalin, *S*-metolachlor, and their combinations were applied POST-T caused little to no stand reduction or visual injury across wildflower species. In conclusion, several herbicides may fit the transplant establishment of the wildflower species included in this study.

Introduction

The N.C. Department of Transportation (NCDOT) struggles to establish uniform stands for wildflowers in roadside beds (Kevin Clemmer and Rick Seagroves, personal communication). Options for weed management in wildflowers are limited (Henry et al. 2023; Wiese et al. 2011) and, if left uncontrolled, weeds can further inhibit stand establishment (Wiese et al. 2011; Angelella et al. 2017). Currently, the NCDOT uses a Remlinger (Remlinger Manufacturing, Kalida, OH) no-till drill, equipped with a small seed/native grass box, to seed wildflowers across the state. When using the small seed/native grass box, the no-till drill drops seed into shallow furrows which are then lightly packed with press wheels; this process is also known as direct seeding (Kevin Clemmer and Rick Seagroves, personal communication). Given the challenges of direct seeding, like uneven seeding depth and variable seed dormancy, NCDOT is interested in exploring the transplant establishment of wildflowers. Stand establishment is often more successful and uniform with transplanting compared to direct seeding. Furthermore, transplants can grow faster and reach canopy closure sooner than plants established from seeds which helps late-season weed management (Englert et al. 1994; Leskovar et al. 2021). More specifically, the NCDOT is interested in integrating native wildflowers into their roadside bed program. These species typically grow slower and have uneven emergence when directly seeded (Elstrom 1975; Leskovar et al. 2021). Transplanting may facilitate NCDOT's goal of incorporating more native species. Additionally, transplants are often more tolerant of residual and postemergence herbicides than plants established from seed, potentially expanding the weed management toolbox for native wildflowers (Norsworthy et al. 2007; Reiners 2021).

Black-eyed Susan *(Rudbeckia hirta)* is a member of the *Asteraceae* family native to North Carolina (Brakie 2019). It has a wide range of growth habits, acting as an annual, biennial, or short-lived perennial depending on growing conditions and location (Missouri Botanical Garden 2019). This plant is a popular wildflower due to its drought tolerance and prolonged blooming during the summer months (UT Austin 2023b). Black-eyed Susan grows to a height of 2-3 feet with each stem producing a single yellow-orange daisy-like bloom (Brakie 2019). The wildflower is planted by the NCDOT in the fall or winter months with some plantings established in early spring (Kevin Clemmer and Rick Seagroves, personal communication).

Scarlet beebalm *(Monarda didyma*) is an herbaceous perennial wildflower in the *Lamiacea* family, native to the eastern United States and Canada, and is an excellent attractant for bees, butterflies, and hummingbirds (UT Austin 2023a). Scarlet beebalm grows 1.5 to 6.5 feet tall and flowers June through September with clusters of scarlet red flowers; individual flowers are tube-shaped with clusters making up the entire flower (USDA NRCS 2019b). Beebalm species are not commonly planted on the roadsides of North Carolina due to seed cost. However scarlet beebalm's ability to attract and provide habitat for pollinators has renewed its interest in roadside beds (Kevin Clemmer and Rick Seagroves, personal communication; USDA NRCS 2019b). Transplanting beebalm would be an effective way to ensure the uniform stand of this excellent pollinator plant which is difficult to establish from seed (Kevin Clemmer and Rick Seagroves, personal communication).

The Shasta daisy *(Leucanthemum superbum)* is an herbaceous perennial wildflower and a member of the *Asteraceae* family. The *Leucanthemum* genus of flowers is native to Europe, but this cross-bred flower was bred near Mt. Shasta, California by Luther Burbank to create a highly attractive flower with large, white, and long-lasting blooms (Burbank 2019). The flowers consist of one per stem and are a distinct bright white with a yellow circular center (USDA Plant Database 2019). Shasta daisy can grow to a height of 1 to 3 feet. Traditionally, the NCDOT drills this flower into roadside beds in early fall through early winter, targeting a bloom period of May to July (Kevin Clemmer and Rick Seagroves, personal communication; Gilman 1999).

Purple coneflower *(Echinacea purpurea)* is an herbaceous perennial species in the *Asteraceae* family and is native to the central and eastern US and Canada (USDA NRCS 2019a; Cech 1995). The species attracts bees, butterflies, and hummingbirds to its recognizable long-lasting pink flowers making it important for pollinator habitat. Purple coneflower stems produce a single flower, pinkish to purple with drooping petals and spiny reddish-brown centers (UT Austin 2023). It has an extended blooming period from May until September depending on location and environment (USDA NRCS 2019a) and can grow to a height of 1 to 3 feet (Cech 1995). NCDOT plants purple coneflowers from late summer to early fall but struggles to achieve uniform emergence of the wildflower from seed. Although NCDOT would like to plant more purple coneflowers due to its ability to attract pollinators, establishing stands from seed has prohibited an increase in its production (Kevin Clemmer and Rick Seagroves, personal communication).

Despite higher initial investments to transplant these species compared to seeding, NCDOT is interested in this method of planting to get a more consistent establishment (Kacheyo et al. 2023). Furthermore, the aforementioned species are perennials; once established in roadside beds, NCDOT may be able to maintain them long-term without replanting. The objective of this research was to evaluate the tolerance of transplanted black-eyed Susan, scarlet beebalm, Shasta daisy, and purple coneflower to preemergence transplant (PRE-T) and postemergence-transplant (POST-T) herbicides.

Materials and Methods

Experiments were conducted in 2023 and 2024 at the Central Crops Research Station near Clayton, North Carolina (35.67ºN, -78.51ºW). Ornamental cultivars of wildflower species were used for the experiment, with plant plugs sourced from Walter's Gardens (The Walter's Gardens, Zeeland, MI). Wildflower cultivars included "Goldstrum" black-eyed Susan, "Berry Taffy" scarlet beebalm, "Whoops-a-Daisy" Shasta daisy, and "PowWow Wild Berry" purple coneflower.

Herbicide treatments were broken into two groups: PRE-T and POST-T. All PRE-T herbicide treatments were applied immediately before transplanting. POST-T herbicide treatments were applied immediately after transplanting over, wildflower plants. PRE-T herbicide treatments, including rates and sources, are listed in Table 1. POST-T treatments consisted of two rates of pendimethalin (1 qt and 2 qt/A), *S*-metolachlor (1 pt/A), and the combination of pendimethalin plus *S*-metolachlor (2 qt + 1 pt/A). Detailed materials and methods can be found in Appendix 8.

Results and Discussion

The main effects of herbicide treatment and year, and their interaction, were significant for all four wildflower species. Therefore, data for all four wildflower species will be presented by year. Differences in injury between 2023 and 2024 are likely explained by rainfall. In 2023, 3 inches of rainfall was received 0 to 14 days after transplant whereas only 1.1 inches of rain was received during the same timeframe in 2024. Excessive rainfall early in the season in 2023 may have moved residual herbicides in closer proximity to transplant roots compared to 2024, resulting in greater herbicide uptake and more visual injury (Jhala 2017).

Wildflower growth during the first 7 days after transplanting was minimal across species in both years. Plants typically experience slow root and shoot growth, also known as “transplant shock”, from stress when transplanted (Pecknold 2024). At 7 DAT, it was difficult to distinguish between herbicide injury and transplant shock. Therefore, injury 7 DAT will not be discussed.

Black-eyed Susan

For black-eyed Susan, injury was minimal 14 DAT in 2023. At this time, indaziflam (15%) applied PRE-T was most injurious, followed by mesotrione (12%) applied PRE-T (Appendix 7, Table 2). All other treatments caused ≤ 7% injury 14 DAT in 2023. At 28 DAT in 2023, indaziflam PRE-T continued to be the most injurious treatment, causing 40% injury, while all other treatments caused no more than 5% injury. Like earlier in the season, injury from indaziflam (20%) applied PRE-T outpaced other herbicide treatments (0 to 7%). Data for black-eyed Susan stood densities reflect visual estimates of injury. At 56 DAT in 2023, black-eyed Susan stand in the nontreated check averaging 10.6 plants per plot. Like visual injury ratings, the only herbicide treatments to reduce black-eyed Susan stand compared to the nontreated check included indaziflam (8.6 plants per plot) and mesotrione (8.3 plants per plot). Black-eyed Susan stands following the application of all other treatments ranging from 9 to 11 plants per plot.

Black-eyed Susan’s injury in 2024 was less than in 2023. In 2024, pyrithiobac (10%) was the most injurious treatment whereas all other treatments caused ≤ 3% injury (Appendix 7, Table 3). On 28 DAT in 2024, no treatment injured black-eyed Susan more than 3%. Furthermore, early season injury from pyrithiobac was transient as the herbicide caused no injury 28 DAT. By 56 DAT, the most injurious treatment was fluometuron (20%); all other treatments injured black-eyed Susan by 9% or less. For black-eyed Susan stand in 2024, fluometuron (10.5 plants per plot) was the only treatment to reduce stand compared to the nontreated check (12.5 plants per plot). Black-eyed Susan injury was not consistent over the years. In 2023, indaziflam and mesotrione caused the greatest early season injury and resulted in decreased black-eyed Susan stand late in the season. These same treatments in 2024 caused no more than 9% injury and did not reduce black-eyed Susan's stand. Furthermore, in 2024, pyrithiobac caused the most injury 14 DAT while fluometuron was most injurious 56 DAT and the only treatment to reduce plant stand whereas these same treatments in 2023 caused little to no injury (0 to 10%) nor stand reduction compared to the nontreated check.

Scarlet beebalm

At 14 DAT in 2023, the most injurious treatments were mesotrione (48%) and indaziflam (40%) applied PRE-T (Appendix 7, Table 4). All other treatments caused ≤ 10% injury 14 DAT in 2023. Mesotrione (57%) and indaziflam (33%) applied PRE-T caused the greatest injury levels across treatments 28 DAT, while all other treatments caused ≤ 8% injury. Trends in scarlet beebalm injury at 56 DAT were similar to injury earlier in the season. Mesotrione (38%) and indaziflam (33%) applied PRE-T again were the most injurious treatments. For scarlet beebalm stands in 2023, three treatments reduced stands compared to the nontreated check (10.6 plants per plot) indaziflam (5.6 plants per plot), pyrithiobac (6 plants per plot), and mesotrione (4 plants per plot) and is consistent with visual estimates of injury.

Scarlet beebalm injury from indaziflam and mesotrione 14 DAT was less in 2024 compared to 2023. In 2023, indaziflam and mesotrione applied PRE-T severely injured scarlet beebalm while the herbicides in 2024 caused ≤ 3% injury 14 DAT in 2024 (Appendix 7, Table 5). At this time, fluometuron-applied PRE-T was the most injurious treatment but only caused 14% injury. By 28 DAT, pyroxasulfone + flumioxazin, indaziflam, and fluridone applied PRE-T were the only treatments to injury scarlet beebalm >20%. By 56 DAT, the four POST-T treatments and the sulfentrazone applied PRE-T resulted in ≤ 6% injury. All other treatments injured scarlet beebalm 10% or greater with fluometuron and pyroxasulfone + flumioxazin injuring the wildflower species >30%. Plot densities in 2024 did not reflect visual estimates of injury. Pyrithiobac (7.5 plants per plot) applied PRE-T was the only treatment that reduced scarlet beebalm stand compared to the nontreated check. Scarlet bee balm stands in all other treatments ranged from 10.25 and 13 plants per plot and were no different than the non-treated check.

Shasta Daisy

In 2023, mesotrione applied PRE-T injured Shasta daisy 45% and was more injurious than all other treatments (≤18%) (Appendix 7, Table 6). By 28 DAT, indaziflam and mesotrione applied PRE-T injured Shasta daisy 25 and 30%, respectively. Conversely, all other treatments caused ≤ 7% injury at 28 DAT. Similar to earlier in the season, indaziflam (30%) and mesotrione (33%) applied PRE-T and continued to be the most injurious 56 DAT. Regarding Shasta daisy stand 56 DAT, mesotrione (6 plants per plot) applied PRE-T was the only treatment that resulted in less stand than the nontreated check (9.3 plants per plot); stand in all other treatments ranged from 8 to 10.6.

In general, Shasta Daisy's injury in 2024 was less than in 2023. In 2024, mesotrione (12%) applied PRE-T was the only treatment to injury Shasta Daisy's > 5% 14 DAT (Appendix 7, Table 7). Shasta Daisy Injury 28 DAT was similar to injury 14 DAT. Again, mesotrione (14%) applied PRE-T was the most injurious treatment whereas all other treatments injured Shasta daisy ≤ 5%. Shasta Daisy injury did increase at 56 DAT. At this time, pyroxasulfone + flumioxazin applied PRE-T injured Shasta daisy 22% with fluometuron (16%), sulfentrazone (15%), pyrithiobac (16%), fluridone (17%), and mesotrione (20%) causing similar injury. At the same time, POST-T treatments and indaziflam PRE-T injured Shasta daisy ≤ 10%. Interestingly, indaziflam was the least injurious PRE-T treatment in 2024 whereas the herbicide was one of the most injurious in 2023. This is likely due to differing degradation of indaziflam with varying environmental conditions (Gonzalez and Shuka 2020). In line with visual estimates of injury, pyroxasulfone + flumioxazin (8.75 plants per plot) applied PRE-T was the only treatment to reduce Shasta daisy stand compared to the nontreated check (12.5 plants per plot); Shasta daisy stand across all other treatments ranged 9 to 12.25 plants per plot.

Purple Coneflower

In 2023, purple coneflower seemed to be most sensitive to herbicide treatments with all treatments resulting in ≥ 10% injury 14 DAT (Appendix 7, Table 8). Furthermore, fluometuron (20%), sulfentrazone (33%), and mesotrione (35%) applied PRE-T were the most injurious at this time. By 28 DAT, sulfentrazone, indaziflam, and mesotrione injured purple coneflower 30 to 41% and were more injurious than the lowest rate of pendimethalin applied POST-T and pyrithiobac and fluridone applied PRE-T. At 56 DAT, only fluometuron (27%) and mesotrione (21%) injured purple coneflower >20%. Purple coneflower injury from pyroxasulfone + flumioxazin, sulfentrazone, pyrithiobac, and fluridone applied PRE-T and all POST-T treatments caused ≤ 10% 56 DAT. It is important to note that purple coneflower injury resulting from sulfentrazone (10%) and indaziflam (15%) at 56 DAT was reduced compared to earlier in the season. Indaziflam (7.6 plants per plot) and mesotrione (7.3 plants per plot) reduced stand 24 to 27% compared to the nontreated check (10 plants per plot) when compared to the nontreated (10 plants per plot)

Like the other wildflower species, purple coneflower injury was less in 2024 compared to 2023. At 14 DAT, all treatments injured purple coneflower ≤ 10% injury. At 28 DAT, sulfentrazone applied PRE-T injured purple coneflower 14%; all other treatments, except pyrithiobac (0%), injured purple coneflower similarly to sulfentrazone at 14 DAT, with injury ranging from 2 to 8%. By 56 DAT, pyroxasulfone + flumioxazin (25%) and mesotrione (20%) applied PRE-T were most injurious whereas all other treatments injured the wildflower species ≤ 10%. Regarding the purple coneflower stand, compared to the nontreated check (14.25 plants per plot), only pyroxasulfone + flumioxazin (9 plants per plot) and sulfentrazone (10.25 plants per plot) reduced plant density. Purple coneflower density resulting from all other treatments ranged from 10.75 to 12.25 plants per plot.

Literature Cited

Angelella, G.M. & O'Rourke, M.E. 2017 Pollinator habitat establishment after organic and no-till seedbed preparation methods *HortScience 52* 1349 1355

Anonymous (2024). Prowl H2O Herbicide Label. BASF Corporation, Research Triangle Park, NC.

Anonymous (2023). Dual II Magnum Herbicide Label. Syngenta Crop Protection, Greensboro, NC.

Ault, J.R., 2007. Coneflower: Echinacea species. In N. O. Anderson, ed. Flower breeding and genetics: issues, challenges and opportunities for the 21st century. Springer Netherlands, pp. 801–824.

Brakie, M. 2019. Plant Guide for black-eyed Susan (Rudbeckia hirta). USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches, TX.

Cech, R.A. 1995. Echinacea Native American tonic roots. A Horizon Herbs Publication, Williams, Oregon.

Elmstrom, G. W. (1973). Watermelon Root Development Affected by Direct Seeding and Transplanting1. *HortScience*, *8*(2), 134-136. Retrieved Apr 10, 2025, from https://doi.org/10.21273/HORTSCI.8.2.134b

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. In: Camper, N.D.,

Gilman, E., Environmental Horticulture Department, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, & Christine Taylor Waddill, Dean. (1999). *FactsheetFPS127*. https://hort.ifas.ufl.edu/database/documents/pdf/shrub_fact_sheets/chrsupa.pdf

González-Delgado, A. M., & Shukla, M. K. (2020). Mobility, Degradation, and Uptake of Indaziflam under Greenhouse Conditions. HortScience horts, 55(8), 1216-1221. Retrieved Apr 15, 2025, from https://doi.org/10.21273/HORTSCI14966-20

Henry, G., Tucker, K., & McCurdy, J. (2023). Response of Common Wildflower Species to Postemergence Herbicides. HortScience, 58(6), 660-665. Retrieved Apr 10, 2025, from https://doi.org/10.21273/HORTSCI17099-23

Jhala, A. (2017). Effect of Excessive Rainfall on Efficacy of Residual Herbicides applied in Corn and Soybean. *Nebraska Extension Publication*. https://cropwatch.unl.edu/2017/effect-excessive-rainfall-efficacy-residual-herbicides-applied-corn-and-soybean/

Kacheyo, O. C., de Vries, M. E., van Dijk, L. C. M., Schneider, H. M., & Struik, P. C. (2024). Agronomic consequences of growing field-transplanted hybrid potato seedlings. *Crop Science*, 64, 1093–1111.

Leskovar DI, Othman YA. Direct Seeding and Transplanting Influence Root Dynamics, Morpho-Physiology, Yield, and Head Quality of Globe Artichoke. Plants (Basel). 2021 Apr 29;10(5):899. doi: 10.3390/plants10050899. PMID: 33946796; PMCID: PMC8145455.

Luther Burbank Home & Gardens. (2019, October 4). *Shasta Daisy - Luther Burbank Home & Gardens*. *Accessed online: 2/6/2025* Available online at: https://lutherburbank.org/about-us/shasta-daisy/. Accessed February 10, 2025

Missouri Botanical Garden. 2019. Rudbeckia hirta. Accessed online: 2/6/2025 at http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=277225.

Natural Resources Conservation Service, Georgetown & USDA. (2019). *SCARLET BEEBALM*. Available online at: https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_modi.pdf. Accessed February 10, 2025

Norsworthy, Jason K, John P. Smith, Tolerance of direct-seeded leafy greens to herbicides applied before or after crop emergence, Crop Protection, Volume 26, Issue 8, 2007, Pages 1158-1165,

Pecknold, Paul, “Transplant Shock of Trees and Shrubs.” (2024). In *Purdue Extension*. Available online at: https://www.extension.purdue.edu/extmedia/bp/bp-31.html5. Accessed March 5, 2025

Reiners, S. (2020). Transplants or Direct Seeding – What’s best? *Cornell CALS*. Available online at: https://cals.cornell.edu/school-integrative-plant-science/school-sections/horticulture-section/outreach-and-extension/pandemic-vegetable-gardening/pandemic-vegetable-gardening-2021-archive/transplants-or-direct-seeding-whats-best Accessed February 10, 2025

[USDA] *The importance of pollinators*. (2024, December 17). USDA Home. *The Importance of Pollinators*. USDA. Available online at: https://www.usda.gov/about-usda/general-information/initiatives-and-highlighted-programs/peoples-garden/importance-pollinators#:~:text=PollinatorsbyNumbers,beeshelpincreasecropyields Accessed February 10, 2025

USDA NRCS. 2019a. The PLANTS Database. 2019. Plant profile of Echinacea purpurea. (http://plants.usda.gov, 3, February 2025). National Plant Data Team, Greensboro, NC 27401-4901 USA.

USDA NRCS. 2019b. The PLANTS Database. 2019. Plant profile of Rudbeckia hirta-subordinate taxa. Available online at: http://plants.usda.gov. Accessed February 20, 2025). National Plant Data Team, Greensboro, NC 27401-4901 USA.

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2023a. *Monarda didyma*, Available online at: https://www.wildflower.org/plants/result.php?id_plant=MODI Accessed February 10, 2025

[UT Austin] University of Texas at Austin – Lady Bird Johnson Wildflower Center. 2023b. *Rudbeckia hirta*, Available online at: *https://www.wildflower.org/plants/result.php?id_plant=ruhi2*. Accessed February 10, 2025

White, Annie, "From Nursery to Nature: Evaluating Native Herbaceous Flowering Plants Versus Native Cultivars for Pollinator Habitat Restoration" (2016). Graduate College Dissertations and Theses. 626.

Wiese, J. L., Keren, E. N., & Menalled, F. D. (2011). Tolerance of native wildflower species to postemergence herbicides. *Native Plants Journal*, *12*(1), 31-33

Table 1. Herbicide treatments applied PRE-T and POST-T

Herbicides[a,b]	Trade Names	Application Method	Formulation Concentration	Application Rate	Manufacturer
Active ingredient	Trade name		lb/gal	fl oz/A	
fluometuron	Cotoran® 4L	PRE-T	4	32	Adama US
pyrox + flumi	Piper EZ®	PRE-T	1.7 + 1.34	6	Valent USA
sulfentrazone	Spartan® 4F	PRE-T	4	6	FMC Corp.
indaziflam	EsplAnade®	PRE-T	1.67	4	BAYER
pyrithiobac	Staple® LX	PRE-T	3.2	2.6	DuPont
fluridone	Brake®	PRE-T	1.2	16	SePRO Corp.
mesotrione	Tenacity®	PRE-T	4	4	Syngenta
pendimethalin	Prowl® H2O	POST-T	3.8	32	BASF Corp.
pendimethalin	Prowl® H2O	POST-T	3.8	64	BASF Corp
S-metolachlor	Dual II Magnum®	POST-T	7.62	16	Syngenta
pendi + S-metol	Prowl + Dual	POST-T	3.8 + 7.62	64 + 16	BASF + Syngenta

[a]Specimen labels for each product and mailing addresses and website of each manufacturer can be found at www.cdms.net.

[b]Abbreviations: Pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Findings and Conclusions

Results of the cosmos postemergence study provide evidence of additional postemergence options for potential use by NCDOT to manage weeds in the cosmos. Many of the herbicides found to be safe provide residual annual weed control. Pyroxasulfone, which caused no injury to the cosmos, provides excellent Palmer amaranth control (>90) (Cahoon et al. 2015). Other herbicides with potential fit in cosmos weed management include flufenacet + metribuzin, fluridone, isoxaflutole, flumioxazin, and flumioxazin + prodiamine also provide residual control of various weeds (Anonymous 2023; Anonymous 2020; Anonymous 2019a; Anonymous 2019b; Anonymous 2011). Isoxaflutole and fluridone are the only two treatments that were statistically similar to the standard treatment on the cosmos to have postemergence control on weeds (Anonymous 2023; Anonymous 2020). Furthermore, granular formulations of flumioxazin and flumioxazin + prodiamine were statistically similar to the untreated check as well as the standard treatment. Coated herbicides have been found to provide excellent residual weed control in ornamentals and agronomic crops (Dean et al. 2024; Raybaey and Harvey 1994). Utilizing granular herbicide formulations, or even residual herbicides coated on granular fertilizers, may provide NCDOT with an alternative approach to integrating new modes of action into their cosmos weed management. Integration of alternative weed management options will also alleviate pressure on the few herbicides the NCDOT currently uses to manage weeds in the cosmos.

Across both the PRE-emergence and POST-emergence experiments on multiple wildflower species, wildflower injury varied considerably by year. In general, greater injury was observed during the 2023 growing season compared to 2024. For the PRE-emergence experiment, the shift in planting date to November influenced the extent of herbicide injury observed among species in 2024. With this adjusted planting window, herbicide applications were exposed to substantial rainfall and a broad germination period across wildflower species, promoting herbicide degradation (Shaner 2014). Within the first month after planting in 2024, the research site received nearly 6 inches of rainfall. This contributed to leaching or reduced herbicide persistence in the soil (Kahlil et al. 2019). This weather pattern in 2024 provides

NCDOT with valuable insights into the flexibility of planting windows and herbicide application timing. The data from the POST-emergence experiment reinforced that several herbicide treatments can be considered safe for use on selected wildflower species. Across the two years of research, at least three herbicide treatments per species were identified as causing reduced injury and resulting in minimal bloom reductions. Notably, the herbicide 2,4-DB was consistently safe across all wildflower species at one or more tested rates. Likewise, the herbicide combination of flufenacet + metribuzin showed consistently low injury ratings across species, indicating it is a strong candidate for broader use.

These findings provide the NCDOT Roadside Wildflower Program with a wider selection of herbicide options that are compatible with their key wildflower species. This knowledge allows for the development of more robust and flexible weed management plans while supporting the long-term health and aesthetic value of wildflower plantings along North Carolina roadsides.

Results of the transplanted plant study suggest some residual herbicides can be applied safely PRE-T and POST-T to transplanted black-eyed Susan, scarlet beebalm, Shasta daisy, and purple coneflower. In general, injury across wildflower species was greater in 2023 than in 2024. This was likely due to greater rainfall in the first 14 DAT which may have leached residual herbicides in the root zone of the transplant plugs. Pendimethalin, *S*-metolachlor, and pendimethalin + *S*-metolachlor applied POST-T were safe for all four wildflower species. Both herbicides would be useful in the management of small-seeded broadleaf weeds and grasses in roadside wildflower beds (Anonymous 2024; Anonymous 2023). Conversely, the most injurious (>20% in either year) treatments were usually applied PRE-T and included indaziflam and fluometuron to black-eyed Susan, indaziflam, fluometuron, mesotrione, and pyroxasulfone + flumioxazin to scarlet beebalm, indaziflam, mesotrione, and pyroxasulfone + flumioxazin to Shasta daisy, and fluometuron, mesotrione, and pyroxasulfone + flumioxazin to purple coneflower. Focusing on PRE-T treatments that caused < 20% injury 56 DAT across species and years, sulfentrazone, pyrithiobac, and fluridone warrant further research for use in transplant production of these wildflower species. As the NCDOT explores new ways to plant wildflower beds, it is important to have multiple weed management options, including herbicides, to facilitate their establishment. Furthermore, this research identified several PRE-T and POST-T herbicides that may fit the production of transplanted black-eyed Susan, scarlet beebalm, Shasta daisy, and purple coneflower; having multiple herbicide modes of action available for use would reduce the risk of selecting weeds-resistant to any one mode of action.

Literature Cited

Anonymous (2024). Prowl H2O Herbicide Label. BASF Corporation, Research Triangle Park, NC.

Anonymous (2023). Brake herbicide. Carmel, IN: SePRO Corp. 52 p

Anonymous (2023). Dual II Magnum Herbicide Label. Syngenta Crop Protection, Greensboro, NC.

Anonymous (2020). Balance flexx herbicide. St. Louis, MO: Bayer CropScience LP. 21 p

Anonymous (2019a). Axiom DF herbicide Label. Bayer CropScience LP. 29 p

Anonymous (2019b). Perfection Fuerte herbicide label. OHP Inc.

Anonymous (2012). Direx 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2011). BroadStar Herbicide Label. Valent U.S.A. Corp. Walnut Creek, CA.

Cahoon CW, York AC, Jordan DL, Seagroves RW, Everman WJ, Jennings KM (2015) Cotton response and Palmer amaranth control with pyroxasulfone applied preemergence and postemergence. J Cotton Sci 19:212-223

Dean, Brock and Charlie Cahoon. *Residual Weed Control in Cotton (Gossypium Hirsutum) Utilizing Herbicide-Coated Fertilizer*. 2024, pp. 68–101.

Khalil Y, Flower K, Siddique KHM, Ward P. Rainfall affects leaching of pre-emergent herbicide from wheat residue into the soil. PLoS One. 2019 Feb 1;14(2): e0210219. doi: 10.1371/journal.pone.0210219. PMID: 30707698; PMCID: PMC6358059.

Rabaey TL, Harvey RG. Efficacy of Corn (Zea mays) Herbicides Applied at Reduced Rates Impregnated in Dry Fertilizer. *Weed Technology*. 1994;8(4):830-835

Shaner DL, ed (2014) Herbicide Handbook. 10th edn. Lawrence, KS: Weed Science Society of America.

Appendix 1. - Chapter II - Evaluating POST Herbicide Options for Cosmos bipinnatus.

Materials and Methods

Experiments were established in 2023 and 2024 at the Central Crops Research Station near Clayton, NC (35.67°N, -78.51°W) and a private farm near Four Oaks, NC (35.43°N, -78.36°W). At Clayton, the soil consisted of Dothan loamy sand (Loamy, kaolinitic, thermic Arenic Kandiudults) with 0.3 to 0.4% humic matter and a pH of 5.5 to 6.0. At the Four Oaks location, the soil consisted of an Altavista fine sandy loam (Loamy, thermic Aquic Hapludult) with a 1.75% humic matter and a pH of 6.0 and a Leaf silt loam (Silty, thermic Typic Albaquult) with a 1.5% humic matter and a pH of 6.0 in 2023 and 2024, respectively. Across both years and locations, the cosmos was planted with a Remlinger (Remlinger Manufacturing, Kalida, OH) no-till drill. Row spacings were 6 inches and the seed was planted to a 0.4 inch depth with a seeding rate of 6 pounds per acre (*Cosmos bipinnatus*, Garrett Seed Farm). In 2023, the cosmos were planted in Clayton on July 25 and in Four Oaks on August 3. During 2024, cosmos was planted in Clayton and Four Oaks on July 29 and August 25, respectively.

In each year and at each location, pendimethalin (Prowl H2O Herbicide, BASF Corporation, Research Triangle Park, NC) at 1 qt/A and *S*-metolachlor (Dual II Magnum Herbicide, Syngenta Crop Protection, LLC Greensboro, NC) at 1 pt/A was applied immediately following planting. Postemergence herbicide treatments and rates are listed in Table 1. When required, crop oil concentrate, methylated seed oil, nonionic surfactant, or ammonium sulfate were added at label-recommended rates. Two treatments were granular formulations designed to be spread in turf and ornamental settings. As the current standard, fluometuron (Cotoran® 4L Herbicide Adama, Raleigh, NC) at 1 qt/A was included as a comparison treatment. In this trial fluometuron at 1 qt/A acts as a standard comparison treatment for cosmos, as this is the current labeled standard practice used by NCDOT. There were untreated checks included in each replication. The experimental design was a randomized complete block design with four replications; plots were 10 feet wide by 30 feet long. At the time of POST application, cosmos averaged 4-6 inches tall at all locations. In 2023, postemergence (POST) herbicide treatments were applied on August 10th at

Clayton and September 18th at Four Oaks. In 2024, POST treatments at Clayton were applied on August 22nd and at Four Oaks on September 3rd. Most treatments were applied using a CO2 pressurized backpack sprayer calculated to deliver 15 gal/A using AIXR 11002 flat-fan nozzles (TeeJet Air Induction XR Flat Spray Tips, TeeJet Technologies, Wheaton, IL). Granular herbicides were spread with a Scotts battery-powered hand spreader (Scotts Miracle-Gro Company, Marysville, OH) to ensure uniform coverage.

Visual estimates of crop tolerance were rated on a 0 to 100 scale with 0% representing no injury and 100% representing complete plot death (Frans et al. 1986). Ratings were recorded at seven, fourteen, and twenty-one days after treatment (DAT). Percent bloom reduction was also visually estimated once individual treatments reached peak bloom. Plant heights were taken in cm on ten random plants per plot and the average was taken. Statistical analysis was conducted in R (R Core Team, 2019) utilizing the base package plus agricolae and means separated using Fisher's Protected LSD at p=0.05.

Literature Cited

Anonymous (2023). Brake herbicide. Carmel, IN: SePRO Corp. 52 p

Anonymous (2022). Cotoran 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2020). Balance flexx herbicide. St. Louis, MO: Bayer CropScience LP. 21 p

Anonymous (2019a). Axiom DF herbicide Label. Bayer CropScience LP. 29 p

Anonymous (2019b). Perfection Fuerte herbicide label. OHP Inc.

Anonymous (2016). Cotoran 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2012). Direx 4L Herbicide Label. ADAMA US, Raleigh, NC.

Anonymous (2011). BroadStar Herbicide Label. Valent U.S.A. Corp. Walnut Creek, CA.

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. In: Camper, N.D., Ed., Southern Weed Science Society, Research Methods in Weed Science, 3rd Edition, WSSA, Champaign, 29-46

Appendix 2. - Chapter II Supporting Data Tables

Table 2. Cosmos bipinnatus injury as affected by postemergence herbicide applications, 2023[a]

Herbicides[b]	Rates	Cosmos Injury 2023					
		7 DAT		14 DAT		21 DAT	
		%					
fluometuron	32	0	m	0	h	1	i
fluometuron	48	0	m	2	h	2	i
2,4-DB	11.43	2	lm	15	g	10	gh
2,4-DB	13.71	5	klm	16	g	17	ef
2,4-DB	16	10	kl	20	fg	22	e
flufen + metri	8	0	m	4	h	0	i
flufen + metri	10	0	m	0	h	5	hi
tolpyralate	1	26	hi	33	e	30	d
topramezone	0.5	35	fgh	50	d	34	d
flumetsulam	0.125	13	jk	22	c	20	e
flumetsulam	0.8	39	efg	64	c	60	c
fluroxypyr	4.8	50	d	90	ab	71	b
tembotrione	3	36	fg	79	b	68	b
acifluorfen	8	47	de	66	c	30	d
imazapyr	2	100	a	100	a	100	a
imazapyr	10	100	a	100	a	100	a
pyroxasulfone	1.75	0	m	0	h	0	i
sulfentrazone	4	41	def	38	e	22	e
isoxaflutole	3	20	ij	22	fg	12	fg
simazine	32	1	lm	28	ef	23	e
halauxifen	1	60	c	100	a	100	a
tiafenacil	1	100	a	100	a	100	a
fluridone	16	30	gh	36	e	19	e
flumioxazin	150 pound	0	m	0	h	1	i
flumi + prodi	100 pound	0	m	0	h	2	i

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin; flumi + prodi, flumioxazin + prodiamine

Table 3. Cosmos bipinnatus injury as affected by postemergence herbicide applications, 2024[a]

Herbicides[b]	Rates	Cosmos Injury 2024					
		7 DAT		14 DAT		21 DAT	
		%					
fluometuron	32	0	l	0	n	0	i
fluometuron	48	0	l	0	n	1	i
2,4-DB	11.43	6	jkl	5	lmn	12	ghi
2,4-DB	13.71	10	h-k	12	hij	14	fg
2,4-DB	16	12	hij	10	i-l	13	ghi
flufen + metri	8	1	l	0	n	2	i
flufen + metri	10	2	kl	2	mn	4	ij
tolpyralate	1	20	efg	16	ghi	28	dc
topramezone	0.5	17	fgh	11	h-k	19	fg
flumetsulam	0.125	7	i-l	6	klm	13	ghi
flumetsulam	0.8	24	ef	33	f	51	c
fluroxypyr	4.8	68	c	63	c	75	c
tembotrione	3	26	e	38	e	34	d
acifluorfen	8	47	d	20	g	19	fg
imazapyr	2	100	a	100	a	100	a
imazapyr	10	100	a	100	a	100	a
pyroxasulfone	1.75	0	l	0	n	0	i
sulfentrazone	4	48	d	15	ghi	23	ef
isoxaflutole	3	7	i-l	9	jkl	2	i
simazine	32	0	l	0	n	15	fg
halauxifen	1	85	b	93	b	100	a
tiafenacil	1	100	a	100	a	100	a
fluridone	16	25	e	19	g	17	fg
flumioxazin	150 pound	1	l	0	n	3	i
flumi + prodi	100 pound	3	kl	0	n	5	hij

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin; flumi + prodi, flumioxazin + prodiamine

Table 4. *Cosmos bipinnatus* bloom reduction and average heights affected by postemergence herbicide applications, 2023-2024[a]

Herbicides[b]	Rates	Cosmos Injury							
		Bloom Reduction				Cosmos Height			
		2023		2024		2023		2024	
		%				in			
fluometuron	32	1	i	0	i	28.0	bc	21.7	abc
fluometuron	48	2	i	1	i	28.7	abc	22.0	abc
2,4-DB	11.43	20	g	12	fgh	25.6	cde	20.5	a-e
2,4-DB	13.71	18	g	19	ef	23.6	de	18.1	d-i
2,4-DB	16	35	ef	15	efg	19.3	f-i	19.3	b-g
flufen + metri	8	0	i	0	i	30.7	ab	19.7	a-f
flufen + metri	10	1	i	2	i	27.2	cd	18.1	c-h
tolpyralate	1	33	f	21	ef	18.9	ghi	13.0	klm
topramezone	0.5	38	ef	24	e	15.7	ij	13.8	jkl
flumetsulam	0.125	14	ghi	14	efg	22.8	ef	14.2	jkl
flumetsulam	0.8	57	cd	58	c	13.8	jk	8.7	n
fluroxypyr	4.8	85	b	87	ab	11.4	k	10.2	mn
tembotrione	3	68	c	44	d	11.8	k	10.6	lmn
acifluorfen	8	45	de	21	ef	18.9	ghi	14.2	jk
imazapyr	2	100	a	100	a	0.0	l	0.0	o
imazapyr	10	100	a	100	a	0.0	l	0.0	o
pyroxasulfone	1.75	0	i	0	i	31.1	ab	22.8	a
sulfentrazone	4	14	ghi	19	ef	22.8	e	16.5	f-j
isoxaflutole	3	6	hij	3	hi	22.4	ef	17.3	e-j
simazine	32	20	g	20	ef	22.0	e-h	15.0	ijk
halauxifen	1	45	de	100	a	0.0	l	0.0	o
tiafenacil	1	100	a	100	a	0.0	l	0.0	o
fluridone	16	17	gh	5	ghi	22.8	ef	15.0	h-k
flumioxazin	150 pound	0	i	0	i	31.5	a	20.1	a-f
flumi + prodi	100 pound	0	i	0	i	31.1	ab	20.9	a-d

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: in, inches; flufen + metri, flufenacet + metribuzin; flumi + prodi, flumioxazin + prodiamine

Appendix 3. - Chapter II - Cosmos Height

The main effects were significant for average height. No significant interactions were detected between locations, therefore average height will be presented by years. In 2023, the low rate of flufenacet + metribuzin (30 inches), pyroxasulfone (31 inches), flumioxazin (31.5 inches), and flumioxazin + prodiamine (31 inches) produced heights that were on average greater than the standard NCDOT treatment. As heights increased, bloom reductions decreased, except for isoxaflutole (22.5 inches). Isoxaflutole was statistically shorter than the standard NCDOT treatment but recovered to have a similar bloom to the standard treatment.

In 2024, average heights were shorter than in 2023, this could be due to increased temperature and only 0.07 inches of rain from August 9th to August 29th. This low amount of rainfall and high temperatures stunted early growth and limited the total height of the cosmos. The average heights follow a similar pattern to 2023 when compared to 2024. The plots that were statistically similar to the standard treatment were pyroxasulfone (23 inches), the low rate of 2,4-DB (20.5 inches), the low rate of flumetsulam (19.5 inches), flumioxazin (20 inches), and flumioxazin + prodiamine (21 inches). Similarly to 2023, some treatments were statistically shorter than the standard treatment but had similar bloom reductions. Isoxaflutole (17 inches), the high rate of flumetsulam + metribuzin (18 inches), and fluridone (15 inches) all resulted in 3 to 8 inch reductions in height compared to the standard treatment. The three treatments all resulted in less than a 5% reduction in cosmos bloom when compared to the standard treatment. This data is consistent with data that Ivany et al. (2002) found that even with stunting up to 30 and 60 days after treatment, plants can still recover to have maximum yield statistically similar to the check plots.

It should be noted that the objectives of this research were to find comparable treatments to the current standard treatment and average height was not a consistent indication of the bloom reduction in the plots.

Appendix 4. - Chapter III Detailed Materials and Methods

Separate PRE and POST experiments were conducted in 2023 at the Central Crops Research Station near Clayton, NC (35.67°N, 78.51°W) and a private farm near Smithfield, NC (35.52°N, 78.41°W), and in fall 2023/2024 at the same private farm near Smithfield and another near Four Oaks, NC (35.40°N, 78.45°W). The soil at Clayton was a Wedowee sandy loam (sandy, 2% to 8% slopes, kaolinitic, thermic Typic Kanhapludults) containing 0.5% humic matter and a pH of 6.0. The soil at Smithfield and Four Oaks consisted of a Norfolk sandy loam (fine-loamy, kaolinitic, 0% to 2% slopes, thermic Typic Kandiudults) with 0.5% to 0.75% humic matter and a pH of 5.5 to 6.0, respectively.

All wildflowers were planted using a Remlinger no-till drill (Remlinger Manufacturing, Kalida, OH), with 6 inch row spacing and seeds were planted at a depth of 0.4 to 1.2 inches. During 2023, wildflowers were planted in the spring on May 10 at both locations. In 2023, emergence was poor across species at Clayton, likely due to a hard-packing, 1.6 inch rainfall one week after planting. At the Smithfield site in 2023, five species—black-eyed Susan, narrowleaf sunflower, Maximilian sunflower, clasping coneflower, and sweet William—emerged consistently. To improve germination for the second year of the study, wildflowers were planted in the fall on November 29, 2023. Across both private farm locations in fall 2023/2024, bur-marigold, Indian blanket, clasping coneflower, black-eyed Susan, and sweet William successfully emerged.

Experiments were conducted in a split-strip design. The main plots consisted of the seven wildflower species planted in strips organized in a randomized complete block design replicated four times. Within each wildflower strip, subplots consisted of PRE or POST herbicide treatments; subplots were 2 m wide by 1.8 m long. A nontreated check for each wildflower species was included for comparison. PRE herbicide treatments were applied immediately after planting. PRE herbicide treatments and rates are listed in Table 1. POST herbicide treatments were applied on July 9, 2023, and May 7, 2024. In 2023, average wildflower height and stage at POST were as follows: narrowleaf sunflower, 7 inches and 12 leaves; Maximilian sunflower, 18 inches and 14 leaves; clasping coneflower, 18 inches and 10 leaves; black-eyed Susan, 14 inches and 10 leaves; and sweet William, 4 inches and 12 leaves. In 2024, the respective averages were: bur-marigold, 10 inches and 4 leaves; Indian blanket, 10 inches and 8 leaves; clasping coneflower, 25 inches and 7 leaves; black-eyed Susan, 7 inches and 7 leaves; and sweet William, 8 inches and 14 leaves. POST herbicide treatments and rates, detailed in Table 2, included necessary adjuvants—such as crop oil concentrate, methylated seed oil, nonionic surfactant, or ammonium sulfate—at label-recommended rates. All herbicides were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/A using AIXR 11002 flat-fan nozzles (TeeJet Air Induction XR Flat Spray Tips, TeeJet Technologies, Wheaton, IL).

Visual estimates of wildflower injury were recorded on a 0–100% scale, where 0% represented no injury and 100% indicated complete plot death (Frans et al. 1986). For the PRE and POST herbicide experiments, wildflower injury was collected 7, 14, and 28 days after emergence (DAE) and 7, 14, and 28 days after treatment (DAT), respectively. For the PRE experiment, average wildflower density was measured by counting plants in 2 feet of row 28 DAE. For the POST experiment, in addition to wildflower injury, visual estimates of bloom reduction were visually estimated once nontreated plots of each species reached peak bloom. Visual estimates of bloom reduction were rated on a 0–100% scale, where 0% represented no bloom reduction and 100% indicated complete bloom reduction.

Literature Cited

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. In: Camper, N.D., Ed., Southern Weed Science Society, Research Methods in Weed Science, 3rd Edition, WSSA, Champaign, 29-46

Appendix 5. - Chapter III Supporting Data Tables

Table 3. Narrowleaf sunflower injury as affected by pre-emergence herbicides at Smithfield, NC during 2023[a]

		Injury									
		7 DAE		14 DAE		28 DAE		Bloom Reduction		Density	
Herbicides[b]	Rate	%								plants 2 feet of row	
nontreated		---		---		---		---		32	abc
pendimethalin	32	12	d	5	de	4	de	2	d	27	bc
S-metolachlor	16	7	d	0	e	5	de	0	d	36	ab
pendi + S-metol	32 + 16	35	b	26	bc	25	c	0	d	25	c
fluridone	16	80	a	89	a	86	a	40	c	8	d
fluridone	10	81	a	89	a	94	a	66	b	7	d
pyrithiobac	2	15	cd	2	de	1	de	5	d	28	bc
pyrith + fluri	2 + 16	84	a	96	a	90	a	93	a	3	d
pendi + fluri	32 + 16	92	a	95	a	88	a	93	a	4	d
mesotrione	4	5	d	4	de	0	e	5	d	33	abc
flufen + metri	10	11	d	20	bcd	17	cd	0	d	30	abc
indaziflam	2	93	a	89	a	82	a	90	a	5	d
pyrox + flumi	3	97	a	95	a	84	a	68	b	6	d
pyrox + flumi	6	97	a	98	a	94	a	50	c	1	d
isoxaflutole	6	17	bcd	14	cde	12	cde	6	d	34	abc
fluometuron	32	34	b	34	b	50	b	7	d	27	bc
sulfentrazone	2	4	d	5	de	1	de	2	d	30	abc
sulfentrazone	4	32	bc	26	bc	13	cd	5	d	25	c
sulfen + imazet	3	7	d	7	cde	1	de	5	d	38	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 4. Maximilian sunflower injury as affected by pre-emergence herbicides at Smithfield, NC during 2023[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Bloom Reduction		Density	
		——————%——————								Plants 2 feet of row	
nontreated		---		---		---		---		12	abc
pendimethalin	32	20	efg	13	d	2	f	1	e	12	abc
S-metolachlor	16	28	ef	17	cd	11	f	0	e	10	cde
pendi + S-metol	32 + 16	19	efg	17	cd	20	ef	2	e	11	cd
fluridone	16	61	d	78	a	66	bd	48	d	3	fgh
fluridone	10	77	bcd	92	a	87	a	66	c	2	h
pyrithiobac	2	20	efg	28	cd	5	f	0	e	13	abc
pyrith + fluri	2 + 16	66	cd	93	a	93	a	79	abc	1	h
pendi + fluri	32 + 16	66	cd	93	a	96	a	75	bc	2	h
mesotrione	4	27	ef	35	c	35	de	1	a	7	def
flufen + metri	10	18	efg	23	cd	10	f	2	e	7	ef
indaziflam	2	85	abc	94	a	78	ab	66	c	3	fgh
pyrox + flumi	3	98	a	99	a	88	a	76	abc	1	h
pyrox + flumi	6	93	ab	99	a	96	a	87	a	1	h
isoxaflutole	6	16	efg	35	c	20	ef	0	e	12	abc
fluometuron	32	36	e	56	b	66	bc	6	e	7	ef
sulfentrazone	2	7	g	8	d	2	f	0	e	16	a
sulfentrazone	4	12	fg	9	d	12	f	4	e	12	abc
sulfen + imazet	3	7	g	16	cd	8	f	0	e	16	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 5. Clasping coneflower injury as affected by preemergence herbicides at Smithfield, NC during 2023[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Bloom Reduction		Density Plants 2 feet of row	
		——————			%			——————			
nontreated		---		---		---		---		17	a
pendimethalin	32	49	ef	36	d	27	ef	12	c	7	b-f
S-metolachlor	16	63	b-e	56	d	19	f	6	c	9	a-d
pendi + S-metol	32 + 16	71	bcd	73	c	72	bc	5	c	3	def
fluridone	16	99	a	99	a	99	a	96	a	1	f
fluridone	10	95	a	96	ab	99	a	96	a	0	f
pyrithiobac	2	42	f	28	d	27	ef	11	c	11	abc
pyrith + fluri	2 + 16	99	a	99	a	99	a	99	a	0	f
pendi + fluri	32 + 16	98	a	99	a	99	a	99	a	0	f
mesotrione	4	79	abc	71	d	87	ab	41	b	8	b-e
flufen + metri	10	52	def	47	d	27	ef	2	c	6	b-f
indaziflam	2	99	a	96	ab	99	a	75	a	1	ef
pyrox + flumi	3	99	a	99	a	99	a	99	a	1	ef
pyrox + flumi	6	99	a	99	a	99	a	97	a	1	ef
isoxaflutole	6	85	ab	78	bc	78	bc	77	a	4	c-f
fluometuron	32	79	abc	80	abc	99	a	92	a	4	c-f
sulfentrazone	2	52	def	36	d	46	de	17	b	12	ab
sulfentrazone	4	62	c-f	68	c	64	cd	28	b	10	abc
sulfen + imazet	3	50	f	38	d	50	d	16	bc	9	a-d

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 6. Clasping coneflower injury as affected by preemergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Bloom Reduction		Density	
		——————————%——————————								Plants 2 feet of row	
nontreated		---		---		---		---		5.6	abc
pendimethalin	32	0	a	0	b	0	d	1	cd	4.6	abc
S-metolachlor	16	0	a	1	b	0	d	3	bcd	5.8	abc
pendi + S-metol	32 + 16	0	a	0	b	0	d	0	cd	6.8	abc
fluridone	16	0	a	0	b	1	cd	1	cd	3.5	bc
fluridone	10	14	ab	25	a	12	a	6	a-d	3.3	c
pyrithiobac	2	6	ab	9	b	2	cd	4	bcd	6.8	abc
pyrith + fluri	2 + 16	21	a	12	ab	10	ab	6	a-d	7.4	a
pendi + fluri	32 + 16	6	ab	4	b	2	cd	1	cd	4.5	abc
mesotrione	4	9	ab	0	b	0	d	10	abc	6.2	abc
flufen + metri	10	0	a	0	b	2	cd	4	bcd	6.5	abc
indaziflam	2	11	ab	6	b	7	abc	5	a-d	6.4	abc
pyrox + flumi	3	12	ab	6	b	0	d	7	a-d	5.1	abc
pyrox + flumi	6	6	ab	0	b	0	d	1	cd	6.4	abc
isoxaflutole	6	3	ab	4	b	2	cd	10	abc	5	abc
fluometuron	32	0	a	0	b	1	cd	11	ab	6.8	ab
sulfentrazone	2	3	ab	0	b	0	d	1	cd	5.8	abc
sulfentrazone	4	3	ab	0	b	5	bcd	6	a-d	4.4	abc
sulfen + imazet	3	0	a	0	b	5	bcd	14	a	4.8	abc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 7. Black-eyed Susan injury as affected by preemergence herbicides at Smithfield, NC during 2023[a]

		Injury									
		7 DAE		14 DAE		28 DAE		Bloom Reduction		Density	
Herbicides[b]	Rate	%								Plants 2 feet of row	
nontreated		---		---		---		---		15	b
pendimethalin	32	28	bc	23	c	23	c	17	ef	10	bcd
S-metolachlor	16	45	bc	32	c	19	c	16	ef	12	bc
pendi + S-metol	32 + 16	53	b	64	bc	74	b	37	cde	5	cde
fluridone	16	98	a	99	a	99	a	99	a	1	e
fluridone	10	91	a	93	ab	99	a	99	a	1	e
pyrithiobac	2	30	bc	27	c	17	c	16	ef	17	ab
pyrith + fluri	2 + 16	98	a	99	a	99	a	99	a	0	e
pendi + fluri	32 + 16	99	a	99	a	99	a	99	a	0	e
mesotrione	4	99	a	90	ab	87	ab	74	b	8	b-e
flufen + metri	10	92	a	75	c	76	b	46	cd	4	de
indaziflam	2	92	a	93	ab	99	a	99	a	1	e
pyrox + flumi	3	98	a	99	a	99	a	99	a	1	e
pyrox + flumi	6	98	a	99	a	99	a	99	a	0	e
isoxaflutole	6	99	a	82	bc	86	ab	56	bc	5	cde
fluometuron	32	93	a	94	ab	96	a	58	bc	6	cde
sulfentrazone	2	31	bc	22	c	12	cd	6	f	17	ab
sulfentrazone	4	51	bc	31	c	17	c	23	def	12	bc
sulfen + imazet	3	20	c	16	c	14	cd	10	f	23	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 8. Black-eyed Susan injury as affected by pre-emergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Bloom Reduction		Density Plants 2 feet of row	
		——% ——									
nontreated		---		---		---		---		9.4	a
pendimethalin	32	2	b	0	b	0	a	4	gh	6.4	abc
S-metolachlor	16	6	b	0	b	0	a	6	e-h	7	ab
pendi + S-metol	32 + 16	4	b	0	b	2	a	10	e-g	6.1	abc
fluridone	16	3	b	0	b	0	a	6	e-h	5.5	abc
fluridone	10	12	b	10	b	0	a	0	h	4.3	bc
pyrithiobac	2	0	b	0	b	3	a	3	h	7	ab
pyrith + fluri	2 + 16	10	b	3	b	3	a	17	bc	3.2	bc
pendi + fluri	32 + 16	6	b	0	b	2	a	3	h	6.8	abc
mesotrione	4	6	b	0	b	0	a	0	h	5.5	abc
flufen + metri	10	12	b	3	b	3	a	15	cd	5.8	abc
indaziflam	2	3	b	2	b	0	a	12	cde	3.8	bc
pyrox + flumi	3	34	a	28	a	4	a	31	a	2.8	c
pyrox + flumi	6	0	b	0	b	0	a	11	c-f	3.3	bc
isoxaflutole	6	2	b	0	b	5	a	1	h	4.1	bc
fluometuron	32	6	b	0	b	1	a	22	b	3.6	bc
sulfentrazone	2	6	b	0	b	5	a	16	cd	4.3	bc
sulfentrazone	4	9	b	0	b	1	a	12	cde	5.1	bc
sulfen + imazet	3	0	b	0	b	0	a	15	cd	7	ab

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 9. Sweet William injury as affected by preemergence herbicides at Smithfield, NC during 2023[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Density Plants 2 feet of row	
		———————		%		———————			
nontreated		---		---		---		21	a
pendimethalin	32	95	ab	87	a	74	ab	1	h
S-metolachlor	16	22	de	42	bc	31	d	18	ab
pendi + S-metol	32 + 16	87	abc	99	a	99	a	1	gh
fluridone	16	94	ab	99	a	99	a	1	h
fluridone	10	98	a	99	ab	99	a	0	h
pyrithiobac	2	72	c	87	a	99	a	3	fgh
pyrith + fluri	2 + 16	99	a	99	a	99	a	0	h
pendi + fluri	32 + 16	99	a	99	a	99	a	0	h
mesotrione	4	78	bc	60	b	66	abc	6	efg
flufen + metri	10	19	ef	50	bc	26	d	7	def
indaziflam	2	94	ab	99	a	99	a	1	h
pyrox + flumi	3	96	a	99	a	99	a	0	h
pyrox + flumi	6	99	a	99	a	99	a	0	h
isoxaflutole	6	18	ef	46	bc	37	cd	14	bc
fluometuron	32	92	ab	99	a	99	a	1	h
sulfentrazone	2	13	ef	35	c	46	bcd	10	cde
sulfentrazone	4	29	de	50	bc	50	bcd	12	cd
sulfen + imazet	3	39	d	47	bc	54	bcd	11	cde

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 10. Sweet William injury as affected by pre-emergence herbicides at both locations during 2024[a]

		Injury						Plot Density	
		7 DAE		14 DAE		28 DAE		Density	
Herbicides[b]	Rate	——————%——————						Plants 2 feet of row	
nontreated		---		---		---		7.4	bc
pendimethalin	32	25	gh	14	efg	3	a	7.4	bc
S-metolachlor	16	45	b-e	33	bcd	6	a	6.5	bcd
pendi + S-metol	32 + 16	46	bcd	37	bc	0	a	4.7	cd
fluridone	16	40	c-f	37	bc	7	a	6.8	bcd
fluridone	10	58	ab	33	bcd	2	a	7.5	bc
pyrithiobac	2	71	a	39	bc	7	a	4.8	cd
pyrith + fluri	2 + 16	53	bc	35	bc	6	a	4.8	cd
pendi + fluri	32 + 16	34	d-g	31	bcd	7	a	6.6	bcd
mesotrione	4	35	d-g	28	cde	9	a	8.7	b
flufen + metri	10	29	fgh	18	d-g	0	a	8.7	b
indaziflam	2	32	efg	25	c-f	6	a	7	bc
pyrox + flumi	3	55	b	56	a	5	a	3.7	d
pyrox + flumi	6	46	bcd	45	ab	0	a	6.6	bcd
isoxaflutole	6	39	c-g	30	bcd	3	a	5.6	bcd
fluometuron	32	26	fgh	25	cde	7	a	5.2	bcd
sulfentrazone	2	25	gh	7	g	0	a	10	a
sulfentrazone	4	46	bcd	26	cde	4	a	6.3	bcd
sulfen + imazet	3	15	h	10	fg	2	a	8.1	bc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 11. Bur-marigold injury as affected by preemergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Bloom Reduction		Density	
		———			%			———		Plants 2 feet of row	
nontreated		---		---		---		---		6	ab
pendimethalin	32	12	bcd	6	bc	5	a	6	a	7	ab
S-metolachlor	16	2	d	12	bc	8	a	12	a	4	bc
pendi + S-metol	32 + 16	2	d	2	c	6	a	1	a	6	ab
fluridone	16	10	bcd	9	bc	13	a	9	a	6	ab
fluridone	10	17	abc	20	ab	10	a	6	a	4	bc
pyrithiobac	2	7	cd	16	abc	14	a	5	a	6	bc
pyrith + fluri	2 + 16	18	abc	4	bc	6	a	15	b	5	bc
pendi + fluri	32 + 16	18	abc	11	bc	13	a	6	a	6	ab
mesotrione	4	13	bcd	18	abc	6	a	7	a	6	ab
flufen + metri	10	14	bcd	14	abc	14	a	6	a	5	bc
indaziflam	2	24	ab	19	abc	12	a	9	a	3	c
pyrox + flumi	3	27	a	30	a	15	a	2	a	5	bc
pyrox + flumi	6	11	bcd	10	bc	0	a	2	a	8	a
isoxaflutole	6	8	cd	12	bc	2	a	7	a	4	bc
fluometuron	32	10	bcd	9	bc	4	a	11	a	6	ab
sulfentrazone	2	12	bcd	15	abc	11	a	12	a	3	c
sulfentrazone	4	6	cd	13	bc	9	a	9	a	5	bc
sulfen + imazet	3	12	bcd	12	bc	14	a	5	a	5	bc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 12. Indian blanket injury as affected by preemergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAE		Injury 14 DAE		Injury 28 DAE		Bloom Reduction		Density	
		———————————————%———————————————								Plants 2 feet of row	
nontreated		---		---		---		---		5.7	a
pendimethalin	32	13	de	16	e-i	1	c	5	bc	4.3	abc
S-metolachlor	16	7	de	8	hij	0	c	0	c	3.8	a-e
pendi + S-metol	32 + 16	12	de	12	f-j	0	c	2	c	3.3	a-e
fluridone	16	6	e	8	hij	3	bc	4	c	4	a-e
fluridone	10	26	cde	24	c-g	0	bc	5	bc	2.7	cde
pyrithiobac	2	16	cde	10	g-j	0	c	2	c	4.1	a-d
pyrith + fluri	2 + 16	16	cde	1	ij	7	abc	1	c	5.2	ab
pendi + fluri	32 + 16	12	de	26	b-e	5	bc	5	bc	3	b-e
mesotrione	4	28	cd	37	abc	14	a	6	bc	3.5	a-e
flufen + metri	10	12	de	25	b-g	4	bc	5	bc	4.7	abc
indaziflam	2	71	a	33	bcd	3	c	4	c	4.2	abc
pyrox + flumi	3	56	ab	47	a	7	abc	15	a	1.6	e
pyrox + flumi	6	55	ab	37	b-e	4	bc	2	c	4	a-e
isoxaflutole	6	16	cde	25	b-g	2	c	1	c	3.2	b-e
fluometuron	32	36	bc	39	ab	6	abc	12	ab	1.7	de
sulfentrazone	2	17	cde	21	d-h	12	ab	5	bc	2.8	b-e
sulfentrazone	4	8	de	3	ij	3	c	6	bc	2.7	cde
sulfen + imazet	3	7	de	8	hij	3	c	6	bc	4.2	abc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrith + fluri, pyrithiobac + fluridone; pendi + fluri, pendimethalin + fluridone; flufen + metri, flufenacet + metribuzin; pyrox + flumi, pyroxasulfone + flumioxazin; sulfen + imazet, sulfentrazone + imazethapyr

Table 13. Narrowleaf injury as affected by postemergence herbicides at Smithfield, NC during 2023[a]

Herbicides[b]	Rate	Injury 7 DAT		Injury 14 DAT		Injury 28 DAT		Bloom Reduction	
		%							
nontreated		---		---		---		---	
2,4-DB	11.43	1	i	2	fg	5	h	17	fgh
2,4-DB	14.86	1	i	0	g	1	h	5	gh
2,4-DB	18.29	1	i	1	g	13	gh	11	fgh
mesotrione	2	12	ghi	15	efg	9	gh	6	gh
mesotrione	3	20	fgh	31	de	9	gh	5	gh
thifensulfuron	0.125	25	efg	31	de	28	fg	30	def
thifensulfuron	0.25	35	def	50	cd	36	ef	45	cd
imazamox	4	43	bcd	62	bc	55	cd	50	cd
halosulfuron	0.125	56	abc	62	bc	52	de	68	b
halosulfuron	0.25	72	a	70	b	93	a	93	a
halosulfuron	0.5	72	a	70	b	81	ab	75	b
flufen + metri	8	5	hi	0	g	0	h	0	h
fluridone	16	50	bcd	62	bc	26	fg	20	efg
fluridone	24	56	abc	69	b	72	bc	36	cde
fluometuron	32	16	ghi	7	fg	5	h	0	h
fluometuron	48	43	bcd	21	ef	12	gh	0	h
fluometuron	64	58	abc	31	de	25	fg	0	h
pyrithiobac	2	42	cde	62	bc	99	a	100	a
pyrithiobac	2.3	50	bcd	72	ab	99	a	97	a
pyrithiobac	2.6	46	bcd	76	ab	99	a	100	a
sulfosulfuron	0.25	47	bcd	76	ab	99	a	100	a
sulfosulfuron	0.5	60	ab	90	a	99	a	100	a
sulfosulfuron	0.75	68	a	92	a	99	a	100	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 14. Maximilian injury as affected by postemergence herbicides at Smithfield, NC during 2023[a]

Herbicides[b]	Rate	Injury 7 DAT		Injury 14 DAT		Injury 28 DAT		Bloom Reduction	
		%							
nontreated		---		---		---		---	
2,4-DB	11.43	10	f-i	12	g-j	29	fg	9	ghi
2,4-DB	14.86	5	hi	9	g-j	27	fgh	5	hi
2,4-DB	18.29	4	i	16	f-i	35	ef	24	fgh
mesotrione	2	21	cd	20	fgh	25	fgh	26	fg
mesotrione	3	31	b	36	cde	56	bcd	42	ef
thifensulfuron	0.125	4	i	7	hij	5	ij	2	i
thifensulfuron	0.25	7	ghi	17	fgh	35	ef	29	f
imazamox	4	19	de	40	bcd	63	bc	53	de
halosulfuron	0.125	14	efg	17	fgh	27	fgh	37	ef
halosulfuron	0.25	26	bc	52	b	48	cde	48	e
halosulfuron	0.5	30	b	40	bc	46	de	50	e
flufen + metri	8	4	i	0	j	0	j	0	i
fluridone	16	11	fgh	27	def	25	fgh	38	ef
fluridone	24	32	b	42	bc	27	fgh	27	fg
fluometuron	32	5	hi	2	ij	12	hij	0	i
fluometuron	48	21	cd	22	efg	28	fgh	9	ghi
fluometuron	64	15	def	20	fgh	17	ghi	2	i
pyrithiobac	2	20	cde	46	bc	66	b	56	dce
pyrithiobac	2.3	15	def	42	bc	57	bcd	53	de
pyrithiobac	2.6	15	def	52	b	66	b	72	bcd
sulfosulfuron	0.25	31	b	68	a	87	a	85	ab
sulfosulfuron	0.5	40	a	72	a	87	a	74	bc
sulfosulfuron	0.75	43	a	82	a	97	a	100	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 15. Clasping coneflower injury as affected by postemergence herbicides at Smithfield, NC during 2023[a]

		Injury						Bloom Reduction	
		7 DAT		14 DAT		28 DAT			
Herbicides[b]	Rate	%							
nontreated		---		---		---		---	
2,4-DB	11.43	1	fg	4	ij	7	lm	0	i
2,4-DB	14.86	0	g	0	j	0	m	0	i
2,4-DB	18.29	1	fg	5	ij	15	j-m	15	ghi
mesotrione	2	15	def	46	de	73	bcd	66	de
mesotrione	3	23	cd	42	de	72	bcd	88	abc
thifensulfuron	0.125	7	efg	7	hij	20	i-l	10	hi
thifensulfuron	0.25	12	d-g	21	fgh	31	hij	31	fgh
imazamox	4	8	efg	22	fg	45	fgh	33	fg
halosulfuron	0.125	17	def	17	ghi	27	h-k	25	gh
halosulfuron	0.25	23	cd	32	ef	42	fgh	60	de
halosulfuron	0.5	22	cd	50	cd	43	fgh	70	cde
flufen + metri	8	5	fg	0	j	10	klm	0	i
fluridone	16	25	bcd	56	cd	45	fgh	76	bcd
fluridone	24	40	a	76	ab	56	d-g	100	a
fluometuron	32	18	de	42	de	51	efg	52	ef
fluometuron	48	34	abc	48	d	55	d-g	76	bcd
fluometuron	64	40	a	88	a	91	ab	81	a-d
pyrithiobac	2	7	efg	33	ef	68	cde	66	de
pyrithiobac	2.3	17	def	46	de	90	ab	76	bcd
pyrithiobac	2.6	37	ab	50	cd	87	abc	93	ab
sulfosulfuron	0.25	17	def	40	de	57	def	76	bcd
sulfosulfuron	0.5	25	bcd	53	cd	87	abc	88	abc
sulfosulfuron	0.75	22	cd	63	bc	93	a	92	ab

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 16. Clasping Coneflower injury as affected by postemergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAT		Injury 14 DAT		Injury 28 DAT		Bloom Reduction	
		%							
nontreated		---		---		---		---	
2,4-DB	11.43	5	hij	3	ef	6	g	11	ghi
2,4-DB	14.86	4	ij	3	ef	15	d-g	11	ghi
2,4-DB	18.29	3	j	2	ef	5	g	3	i
mesotrione	2	29	a	24	ab	29	cde	26	def
mesotrione	3	28	ab	26	ab	60	a	36	cd
thifensulfuron	0.125	8	f-j	13	cd	27	cde	20	e-h
thifensulfuron	0.25	11	f-j	27	ab	32	cd	45	c
imazamox	4	2	j	10	de	29	cde	42	c
halosulfuron	0.125	11	f-j	13	cd	13	efg	18	e-h
halosulfuron	0.25	13	d-h	13	cd	18	c-g	14	f-i
halosulfuron	0.5	14	d-g	19	bcd	27	cde	45	c
flufen + metri	8	9	f-j	1	f	4	g	1	i
fluridone	16	27	ab	21	abc	9	fg	4	i
fluridone	24	25	abc	20	abc	12	efg	7	hi
fluometuron	32	17	c-f	13	vd	15	d-g	5	hi
fluometuron	48	21	a-d	21	abc	25	c-f	22	d-g
fluometuron	64	27	ab	26	ab	33	bcd	42	c
pyrithiobac	2	10	f-j	19	bcd	48	ab	71	b
pyrithiobac	2.3	7	g-j	22	abc	60	a	81	b
pyrithiobac	2.6	13	d-h	26	ab	62	a	84	b
sulfosulfuron	0.25	9	f-j	23	ab	47	ab	80	b
sulfosulfuron	0.5	15	d-g	29	a	62	a	100	a
sulfosulfuron	0.75	20	b-e	27	ab	61	a	86	ab

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 17. Black-eyed Susan injury as affected by postemergence herbicides at Smithfield, NC during 2023[a]

		Injury							
		7 DAT		14 DAT		28 DAT		Bloom Reduction	
Herbicides[b]	Rate	%							
nontreated		---		---		---		---	
2,4-DB	11.43	0	i	6	n	2	hi	5	h
2,4-DB	14.86	4	hi	5	n	4	hi	5	h
2,4-DB	18.29	4	hi	9	mn	25	efg	30	fg
mesotrione	2	32	cde	27	jkl	20	fgh	25	fgh
mesotrione	3	35	bcd	35	ij	41	de	56	de
thifensulfuron	0.125	20	efg	42	g-j	46	cd	71	cd
thifensulfuron	0.25	32	cde	62	c-f	53	bcd	93	ab
imazamox	4	16	fgh	41	hij	38	def	75	bcd
halosulfuron	0.125	50	a	76	a-d	100	a	100	a
halosulfuron	0.25	50	a	86	ab	97	a	100	a
halosulfuron	0.5	49	a	90	a	100	a	100	a
flufen + metri	8	2	i	10	lmn	9	ghi	10	gh
fluridone	16	42	abc	51	f-i	52	bcd	81	abc
fluridone	24	50	a	56	e-h	63	bc	93	ab
fluometuron	32	12	ghi	16	k-m	7	ghi	10	gh
fluometuron	48	19	fg	25	j-m	21	fgh	36	ef
fluometuron	64	20	efg	31	jkl	26	efg	28	fg
pyrithiobac	2	35	bcd	70	b-e	49	cd	75	bcd
pyrithiobac	2.3	27	def	60	d-g	49	cd	81	abc
pyrithiobac	2.6	43	abc	63	c-f	68	b	94	ab
sulfosulfuron	0.25	40	a-d	80	abc	100	a	100	a
sulfosulfuron	0.5	40	a-d	78	abc	100	a	100	a
sulfosulfuron	0.75	46	ab	86	ab	100	a	100	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 18. Black-eyed Susan injury as affected by postemergence herbicides at both locations during 2024[a]

		Injury							
		7 DAT		14 DAT		28 DAT		Bloom Reduction	
Herbicides[b]	Rate	—%—							
nontreated		---		---		---		---	
2,4-DB	11.43	5	fg	3	lm	7	hi	2	i
2,4-DB	14.86	7	efg	6	j-m	9	hi	8	ghi
2,4-DB	18.29	4	g	1	m	7	hi	6	hi
mesotrione	2	24	a	15	e-h	15	f-i	16	e-i
mesotrione	3	23	ab	17	d-h	17	e-h	24	def
thifensulfuron	0.125	11	c-g	12	g-j	16	e-i	11	f-i
thifensulfuron	0.25	14	cde	19	c-g	28	de	31	d
imazamox	4	9	d-g	8	i-l	14	f-i	11	f-i
halosulfuron	0.125	12	c-f	21	b-e	37	cd	82	b
halosulfuron	0.25	14	cde	26	ab	49	ab	52	c
halosulfuron	0.5	16	bcd	29	a	56	a	87	ab
flufen + metri	8	5	fg	5	klm	5	gi	5	hi
fluridone	16	19	abc	16	e-h	12	ghi	12	f-i
fluridone	24	22	ab	20	b-f	11	ghi	7	hi
fluometuron	32	7	efg	1	lm	3	i	10	f-i
fluometuron	48	7	efg	0	m	8	hi	16	e-i
fluometuron	64	18	abc	11	h-k	24	efg	18	d-h
pyrithiobac	2	8	d-g	15	f-i	15	f-i	13	e-i
pyrithiobac	2.3	8	d-g	15	f-i	24	efg	23	d-g
pyrithiobac	2.6	12	c-f	24	a-d	22	efg	27	de
sulfosulfuron	0.25	11	c-g	22	a-e	47	abc	81	b
sulfosulfuron	0.5	17	a-d	25	abc	58	a	87	ab
sulfosulfuron	0.75	12	c-f	20	b-f	42	bc	98	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 19. Sweet William injury as affected by post-emergence herbicides at Smithfield, NC during 2023[a]

		Injury					
		7 DAT		14 DAT		28 DAT	
				%			
Herbicides[b]	Rate						
nontreated		---		---		---	
2,4-DB	11.43	0	f	0	i	0	a
2,4-DB	14.86	0	f	0	i	0	a
2,4-DB	18.29	2	ef	2	hi	0	a
mesotrione	2	17	cd	8	ghi	0	a
mesotrione	3	18	bcd	16	fgh	5	a
thifensulfuron	0.125	11	def	25	c-f	5	a
thifensulfuron	0.25	19	bcd	22	efg	5	a
imazamox	4	22	bcd	23	def	0	a
halosulfuron	0.125	20	bcd	25	c-f	12	a
halosulfuron	0.25	17	cd	34	cde	12	a
halosulfuron	0.5	25	bcd	30	c-f	10	a
flufen + metri	8	14	de	0	i	5	a
fluridone	16	38	a	36	bcd	0	a
fluridone	24	27	abc	50	ab	0	a
fluometuron	32	27	abc	32	cde	5	a
fluometuron	48	30	abc	38	bcd	0	a
fluometuron	64	31	ab	50	ab	12	a
pyrithiobac	2	23	bcd	26	c-f	0	a
pyrithiobac	2.3	20	bcd	23	def	2	a
pyrithiobac	2.6	18	bcd	23	def	5	a
sulfosulfuron	0.25	21	bcd	48	ab	0	a
sulfosulfuron	0.5	20	bcd	58	a	5	a
sulfosulfuron	0.75	21	bcd	58	a	5	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 20. Sweet William injury as affected by postemergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAT		Injury 14 DAT		Injury 28 DAT	
		%					
nontreated		---		---		---	
2,4-DB	11.43	2	def	0	f	0	f
2,4-DB	14.86	2	def	0	f	1	f
2,4-DB	18.29	2	def	0	f	0	f
mesotrione	2	9	ab	8	bcd	1	f
mesotrione	3	8	abc	11	ab	2	f
thifensulfuron	0.125	1	def	0	f	5	def
thifensulfuron	0.25	1	def	2	ef	3	ef
imazamox	4	4	b-f	2	ef	7	def
halosulfuron	0.125	4	b-f	2	ef	4	ef
halosulfuron	0.25	3	def	3	def	8	def
halosulfuron	0.5	6	a-d	5	cde	13	cd
flufen + metri	8	1	def	0	f	1	f
fluridone	16	6	a-d	8	abc	13	cd
fluridone	24	10	a	14	a	23	ab
fluometuron	32	2	def	5	c-f	11	cde
fluometuron	48	7	a-d	6	b-e	23	ab
fluometuron	64	9	ab	11	ab	30	a
pyrithiobac	2	0	f	0	f	0	f
pyrithiobac	2.3	2	def	5	cde	4	ef
pyrithiobac	2.6	2	def	1	ef	8	def
sulfosulfuron	0.25	4	b-f	3	def	7	def
sulfosulfuron	0.5	2	def	9	abc	18	bc
sulfosulfuron	0.75	1	ef	1	ef	18	bc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).
[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 21. Bur-marigold injury as affected by postemergence herbicides at both locations during 2024[a]

		Injury							
		7 DAT		14 DAT		28 DAT		Bloom Reduction	
Herbicides[b]	Rate	%							
nontreated		---		---		---		---	
2,4-DB	11.43	8	jk	10	hij	21	efg	7	bc
2,4-DB	14.86	8	jk	9	hij	15	ghi	5	bc
2,4-DB	18.29	12	h-k	11	g-j	25	d-g	5	bc
mesotrione	2	15	f-j	19	e-h	16	ghi	12	b
mesotrione	3	15	f-j	16	f-i	11	ghi	11	bc
thifensulfuron	0.125	21	d-g	16	fgh	20	fgh	3	bc
thifensulfuron	0.25	30	bcd	37	ab	41	bc	13	b
imazamox	4	27	b-e	33	bcd	35	c-f	7	bc
halosulfuron	0.125	24	c-f	23	d-g	15	ghi	3	bc
halosulfuron	0.25	18	f-i	19	e-h	13	ghi	2	bc
halosulfuron	0.5	40	a	36	abc	33	c-f	11	bc
flufen + metri	8	5	k	1	j	3	i	0	c
fluridone	16	12	h-k	7	ij	6	hi	4	bc
fluridone	24	6	jk	7	ij	5	hi	0	c
fluometuron	32	6	jk	2.5	i	6	hi	3	bc
fluometuron	48	10	ijk	8	hij	12	ghi	1	bc
fluometuron	64	23	c-f	25	c-f	33	c-f	9	bc
pyrithiobac	2	19	e-h	26	b-f	36	b-e	7	bc
pyrithiobac	2.3	22	d-g	29	b-e	33	c-f	5	bc
pyrithiobac	2.6	16	f-j	31	b-e	37	bcd	7	bc
sulfosulfuron	0.25	18	f-i	26	b-f	37	bcd	11	bc
sulfosulfuron	0.5	32	abc	38	ab	50	ab	11	bc
sulfosulfuron	0.75	34	ab	46	a	56	a	31	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Table 22. Indian blanket injury as affected by postemergence herbicides at both locations during 2024[a]

Herbicides[b]	Rate	Injury 7 DAT		Injury 14 DAT		Injury 28 DAT		Bloom Reduction	
		%							
nontreated		---		---		---		---	
2,4-DB	11.43	5	c-g	6	ef	10	ghi	12	gh
2,4-DB	14.86	2	efg	6	ef	7	ghi	9	gh
2,4-DB	18.29	4	d-g	2	f	15	e-i	10	gh
mesotrione	2	9	abc	17	ab	23	b-f	28	c-f
mesotrione	3	10	ab	19	a	24	b-f	30	b-e
thifensulfuron	0.125	3	d-g	8	def	35	ab	18	efg
thifensulfuron	0.25	4	d-g	12	bcd	26	b-e	34	a-d
imazamox	4	5	c-g	9	cde	31	abc	45	a
halosulfuron	0.125	3	d-g	4	ef	9	ghi	9	gh
halosulfuron	0.25	1	fg	6	ef	14	f-i	9	gh
halosulfuron	0.5	5	c-g	16	abc	17	d-g	24	def
flufen + metri	8	0	g	5	ef	4	i	0	h
fluridone	16	6	b-e	7	def	3	i	7	gh
fluridone	24	6	b-e	5	ef	5	hi	4	h
fluometuron	32	1	fg	2	f	7	ghi	12	gh
fluometuron	48	3	d-g	6	ef	17	d-g	16	h
fluometuron	64	3	d-g	9	cde	24	b-f	37	abc
pyrithiobac	2	3	d-g	10	cde	32	abc	36	abc
pyrithiobac	2.3	11	a	16	abc	31	abc	41	a
pyrithiobac	2.6	6	b-e	17	ab	28	abc	40	ab
sulfosulfuron	0.25	3	d-g	18	ab	37	a	45	a
sulfosulfuron	0.5	6	b-e	22	a	38	a	43	a
sulfosulfuron	0.75	8	a-d	17	ab	38	a	45	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; flufen + metri, flufenacet + metribuzin

Appendix 6. - Chapter IV Detailed Materials and Methods

Experiments were conducted in 2023 and 2024 at the Central Crops Research Station near Clayton, North Carolina (35.67ºN, -78.51ºW). The soil in 2023 consisted of a Wedowee sandy loam (Sandy, 2% to 8% slopes, kaolinitic, thermic Typic Kanhapludults) with 0.5% humic matter and a pH of 6.0. The soil in 2024 was Dothan loamy sand (Loamy, 2% to 6% slopes, kaolinitic, thermic Arenic Kandiudults) with 0.3 to 0.4% humic matter and a pH of 5.5 to 6.0.

Ornamental cultivars of wildflower species were used for the experiment, with plant plugs sourced from Walter's Gardens (The Walter's Gardens, Zeeland, MI). Wildflower cultivars included "Goldstrum" black-eyed Susan, "Berry Taffy" scarlet beebalm, "Whoops-a-Daisy" Shasta daisy, and "PowWow Wild Berry" purple coneflower. Ornamental cultivars are often hardier than their wild-type relatives, and more adept at handling heat and drought stress (Ault, 2007, White, 2016). Ability to survive hot, dry conditions is critical to survival in NCDOT roadside beds, especially in coarse-textured soils typical of the NC coastal plains. Ornamental cultivars also have prolonged bloom periods, increasing interaction with pollinators.

All species were transplanted with a two-row wildflower transplanter with rows spaced 1 m apart (Garrett Seed Farm, Smithfield, NC). Each plot was 10 feet wide by 3o feet in length with two treated rows and one border row. The experimental design was a split-strip design with three replications in 2023 and four replications in 2024. Strips consisted of a single wildflower species with herbicide treatments randomized within strips. Transplanting depth was 1-2 inches. Black-eyed Susan, scarlet beebalm, Shasta daisy, and purple coneflower plants averaged 5.5, 2.5, and 6 inches in height at transplanting, respectively. In 2023, wildflowers were transplanted on June 19th and in 2024, they were transplanted on May 29th. Herbicide treatments were broken into two groups: PRE-T and POST-T. All PRE-T herbicide treatments were applied immediately before transplanting. POST-T herbicide treatments were applied immediately after transplanting over, over-the-top wildflower plants. PRE-T herbicide treatments included currently registered products and a few possible candidates for registration (Kevin Clemmer and

Rick Seagroves, personal communication). PRE-T herbicide treatments, including rates and sources, are listed in Table 1. POST-T treatments consisted of two rates of pendimethalin (1 and 2 qt/A), *S*-metolachlor (1 pt), and the combination of pendimethalin plus *S*-metolachlor (2 qt and 1 pt/A). Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/A using AIXR 11002 flat-fan nozzles (TeeJet Air Induction XR Flat Spray Tips, TeeJet Technologies, Wheaton, IL).

Visual estimates of wildflower injury were rated on a 0 to 100 scale with 0% representing no injury and 100% representing complete plant death (Frans et al. 1986). Data for wildflower injury were collected 7, 14, 28, and 56 days after treatment (DAT). Visual estimates of injury were a composite rating of visual chlorosis, necrosis, and growth reduction. Wildflower stand density was also collected at 56 DAT by counting all living plants in each plot. Statistical analysis was conducted in R (R Core Team 2019) utilizing the base package plus agricolae and means separated using Fisher's Protected LSD at p=0.05. Because these wildflower species are likely to be established in monocultures, the researchers were interested in herbicide tolerance within each species. Therefore, data for each wildflower species were analyzed separately.

Literature Cited

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. In: Camper, N.D., Ed., Southern Weed Science Society, Research Methods in Weed Science, 3rd Edition, WSSA, Champaign, 29-46

Appendix 7. - Chapter IV Supporting Data Tables

Table 2. Black-eyed Susan injury as affected by the PRE-T and POST-T herbicides in 2023[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot density 56 DAT	
			——————%——————						Plants plot	
Untreated			---		---		---		10.6	ab
pendimethalin	POST-T	32	0	c	0	b	3	b	11	a
pendimethalin	POST-T	6	0	c	0	b	3	b	10.3	abc
S-metolachlor	POST-T	6	0	c	0	b	7	b	10	abc
pendi + *S*-metol	POST-T	4	3	bc	3	b	0	b	10	abc
fluometuron	PRE-T	2.6	7	abc	3	b	7	b	10	abc
pyrox + flumi	PRE-T	16	7	abc	2	b	3	b	9	abc
sulfentrazone	PRE-T	4	3	bc	5	b	0	b	10	abc
indaziflam	PRE-T	32	15	a	15	a	20	a	8.6	bc
pyrithiobac	PRE-T	64	3	bc	5	b	2	b	9.6	abc
fluridone	PRE-T	16	5	abc	2	b	3	b	10.3	abc
mesotrione	PRE-T	64 + 16	12	ab	3	b	7	b	8.3	c

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 3. Black-eyed Susan injury as affected by the PRE-T and POST-T herbicide applications, 2024[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			——%——						Plants plot	
nontreated			---		---		---		10.6	ab
fluometuron	PRE-T	32	7	abc	3	b	7	b	10	abc
pyrox + flumi	PRE-T	6	7	abc	2	b	3	b	9	abc
sulfentrazone	PRE-T	6	3	bc	5	b	0	b	10	abc
indaziflam	PRE-T	4	15	a	15	a	20	a	8.6	bc
pyrithiobac	PRE-T	2.6	3	bc	5	b	2	b	9.6	abc
fluridone	PRE-T	16	5	abc	2	b	3	b	10.3	abc
mesotrione	PRE-T	4	12	ab	3	b	7	b	8.3	c
pendimethalin 1x	POST-T	32	0	c	0	b	3	b	11	a
pendimethalin 2x	POST-T	64	0	c	0	b	3	b	10.3	abc
S-metolachlor	POST-T	16	0	c	0	b	7	b	10	abc
pendi + *S*-metol	POST-T	64 + 16	3	bc	3	b	0	b	10	abc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD ($P<0.05$).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 4. Scarlet beebalm injury as affected by the PRE-T and POST-T herbicide applications, 2023[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			—%—						Plants plot	
nontreated			---		---		---		10.6	a
fluometuron	PRE-T	32	8	b	3	c	0	b	11.3	a
pyrox + flumi	PRE-T	6	3	b	0	c	0	b	12.3	a
sulfentrazone	PRE-T	6	3	b	0	c	10	b	10	a
indaziflam	PRE-T	4	40	a	33	b	33	a	5.6	b
pyrithiobac	PRE-T	2.6	7	b	7	c	10	b	6	b
fluridone	PRE-T	16	3	b	0	c	0	b	11.3	a
mesotrione	PRE-T	4	48	a	57	a	38	a	4	b
pendimethalin 1x	POST-T	32	7	b	6	c	7	b	11	a
pendimethalin 2x	POST-T	64	0	b	0	c	0	b	12.3	a
S-metolachlor	POST-T	16	0	b	2	c	3	b	12	a
pendi + *S*-metol	POST-T	64 + 16	10	b	8	c	3	b	11.6	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).

[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 5. Scarlet beebalm injury as affected by the PRE-T and POST-T herbicide applications, 2024[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			———%———						Plants plot	
nontreated			---		---		---		12.5	ab
fluometuron	PRE-T	32	14	a	19	a	35	a	10.25	b
pyrox + flumi	PRE-T	6	10	ab	28	a	32	ab	10.5	b
sulfentrazone	PRE-T	6	2	ab	5	b	0	e	12.5	ab
indaziflam	PRE-T	4	3	ab	27	a	17	cd	10.5	b
pyrithiobac	PRE-T	2.6	2	ab	0	b	22	abc	7.5	c
fluridone	PRE-T	16	0	b	21	a	19	bcd	10.25	b
mesotrione	PRE-T	4	0	b	10	ab	12	cde	11.25	ab
pendimethalin 1x	POST-T	32	9	ab	8	ab	0	e	12.25	ab
pendimethalin 2x	POST-T	64	2	ab	4	b	5	de	12	ab
S-metolachlor	POST-T	16	2	ab	5	b	6	de	13	a
pendi + *S*-metol	POST-T	64 + 16	2	ab	10	ab	10	bc	12	ab

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 6. Shasta Daisy injury as affected by the PRE-T and POST-T herbicide applications, 2023[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			%						Plants plot	
nontreated			---		---		---		9.3	ab
fluometuron	PRE-T	32	7	bcd	3	b	3	c	9.3	ab
pyrox + flumi	PRE-T	6	3	cd	7	b	0	c	9.3	ab
sulfentrazone	PRE-T	6	7	bcd	7	b	7	c	9	ab
indaziflam	PRE-T	4	18	bc	25	a	30	a	8	ab
pyrithiobac	PRE-T	2.6	13	bcd	3	b	7	c	8	ab
fluridone	PRE-T	16	3	cd	2	b	0	c	10.6	a
mesotrione	PRE-T	4	45	a	30	a	33	a	6	b
pendimethalin 1x	POST-T	32	6	bcd	4	b	3	c	8.6	ab
pendimethalin 2x	POST-T	64	0	d	2	b	10	bc	9	ab
S-metolachlor	POST-T	16	3	cd	2	b	10	bc	8	ab
pendi + *S*-metol	POST-T	64 + 16	7	bcd	2	b	0	c	8.6	ab

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 7. Shasta Daisy injury as affected by the PRE-T and POST-T herbicide applications, 2024[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			———%———						Plants plot	
nontreated			---		---		---		12.5	a
fluometuron	PRE-T	32	5	ab	2	b	16	abc	10	ab
pyrox + flumi	PRE-T	6	2	b	5	b	22	a	8.75	b
sulfentrazone	PRE-T	6	0	b	0	b	15	abc	11	ab
indaziflam	PRE-T	4	0	b	0	b	5	cd	12	ab
pyrithiobac	PRE-T	2.6	2	b	2	b	16	abc	9	ab
fluridone	PRE-T	16	0	b	2	b	17	abc	11.25	ab
mesotrione	PRE-T	4	12	a	14	a	20	ab	9	ab
pendimethalin 1x	POST-T	32	2	b	5	b	4	cd	11	ab
pendimethalin 2x	POST-T	64	0	b	0	b	10	cd	11	ab
S-metolachlor	POST-T	16	5	ab	0	b	5	cd	12	ab
pendi + *S*-metol	POST-T	64 + 16	0	b	0	b	7	bcd	12.25	a

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 8. Purple Coneflower injury as affected by the PRE-T and POST-T herbicide applications, 2023[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			——%——						Plants plot	
nontreated			---		---		---		10	ab
fluometuron	PRE-T	32	20	ab	17	bcd	27	a	10.6	a
pyrox + flumi	PRE-T	6	11	bc	12	cd	10	abc	8.3	bc
sulfentrazone	PRE-T	6	33	a	31	ab	10	abc	8.6	abc
indaziflam	PRE-T	4	13	abc	30	abc	15	abc	7.6	c
pyrithiobac	PRE-T	2.6	15	abc	7	d	3	c	9	abc
fluridone	PRE-T	16	10	c	5	d	7	bc	10.3	ab
mesotrione	PRE-T	4	31	a	41	a	21	ab	7.3	c
pendimethalin 1x	POST-T	32	10	c	8	d	7	bc	9	abc
pendimethalin 2x	POST-T	64	10	c	13	bcd	3	c	9	abc
S-metolachlor	POST-T	16	10	c	14	bcd	7	bc	10	ab
pendi + *S*-metol	POST-T	64 + 16	15	abc	15	bcd	10	abc	10.3	ab

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin

Table 9. Purple coneflower injury as affected by the PRE-T and POST-T herbicide applications, 2024[a]

Herbicides[b]	Application Method	Rate	Injury 14 DAT		Injury 28 DAT		Injury 56 DAT		Plot Density 56 DAT	
			———%———						Plants plot	
nontreated			---		---		---		14.25	a
fluometuron	PRE-T	32	4	ab	5	ab	5	bc	12	abc
pyrox + flumi	PRE-T	6	2	ab	7	ab	25	a	9	c
sulfentrazone	PRE-T	6	4	ab	14	a	10	bc	10.75	bc
indaziflam	PRE-T	4	0	b	7	ab	2	b	12.25	ab
pyrithiobac	PRE-T	2.6	0	b	0	b	0	b	12.25	ab
fluridone	PRE-T	16	1	b	7	ab	5	bc	12	abc
mesotrione	PRE-T	4	1	b	2	ab	20	a	11.75	abc
pendimethalin 1x	POST-T	32	10	a	5	ab	2	b	12.25	ab
pendimethalin 2x	POST-T	64	0	b	8	ab	5	bc	11.5	abc
S-metolachlor	POST-T	16	0	b	7	ab	10	bc	11.75	abc
pendi + *S*-metol	POST-T	64 + 16	5	ab	10	ab	5	bc	11.75	abc

[a]Means within a column followed by the same letter are not statistically different according to Fishers protected LSD (P<0.05).
[b]Abbreviations: DAT, days after treatment; pendi + *S*-metol, pendimethalin + *S*-metolachlor; pyrox + flumi, pyroxasulfone + flumioxazin