Implementation of Field Recommendations for the NCDOT Wildflower Program

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16. Abstract

A herbicide screening study was conducted on eight wildflower species being planted or considered by the NC Department of Transportation Roadside Environmental Unit for inclusion in the wildflower program. The following eight species were investigated: narrow-leaf sunflower (*Helianthus angustifolius*), black-eyed susans (*Rudbeckia hirta*), maximilian sunflower (*Helianthus maximiliani*), sweet william (Dianthus barbatus), clasping coneflower (*Dracopis amplexicaulis*), bidens (*Bidens aristosa*), dame's rocket (*Hesperis matronalis*), and indian blanket (*Gaillardia pulchella*). These species will henceforth be referred to by their common names.

NC DOT planted all eight wildflower species on May 10, 2023, at Central Crops Research Station in Clayton, North Carolina and Garrett Seed Farm in Smithfield, North Carolina. All PRE-emergence plots were rated 7, 14, and 28 days after emergence. As they were rated, percent injury was taken. Bloom data as well as stand counts were also taken. To determine safe and unsafe herbicides, bloom data should not exceed ten percent, stand counts should not be statistically different than the untreated and percent injury should not cause significant injury to the wildflowers. POST-emergence injury was visually rated 1, 2, and 4 weeks after treatment. To determine acceptable herbicides, injury and bloom data was evaluated. If injury exceeded thirty percent injury 4 weeks after treatment and had greater than fifteen percent reduction in bloom, the herbicide was deemed unacceptable.

There are several viable herbicide options for weed control in each of these wildflower species. Growing conditions were ideal at the Smithfield location, and as a result all species of wildflowers grew very well and had minimal weed issues. This might be due to the nature of planting later than optimal conditions. Sweet william was the only species that did not bloom, likely due to the late planting timing. As such, I would recommend further screening of many of these treatments before widespread adoption on sweet william to ensure safety. The weedy nature of narrow-leaf sunflower and maximilian sunflower allowed these plants to recover from many treatments which caused initial injury. This may allow several treatment options to be used for roadside use where bloom is the primary goal.

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Report Prepared for N.C. Department of Transportation Roadside Environmental Unit

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Submitted by

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Chapter 1

PRE and POST Screening of Herbicide Tolerance on *Helianthus angustifolius, Helianthus maximiliani, Rudbeckia hirta, Dracopis amplexicaulis,* and *Dianthus barbatus*

Materials and Methods

During the summer of 2023, a herbicide screening study was conducted on eight wildflower species currently being planted or considered by the N.C. Department of Transportation (NC DOT) Roadside Environmental Unit for inclusion in the wildflower program. The following eight species were investigated: narrow-leaf sunflower (*Helianthus angustifolius*), black-eyed susans (*Rudbeckia hirta*), maximilian sunflower (*Helianthus maximiliani*), sweet william (Dianthus barbatus), clasping coneflower (*Dracopis amplexicaulis*), bidens (*Bidens aristosa*), dame's rocket (*Hesperis matronalis*), and indian blanket (*Gaillardia pulchella*). These species will henceforth be referred to by their common names.

NC DOT planted all eight wildflower species on May 10, 2023, at Central Crops Research Station in Clayton, North Carolina and Garrett Seed Farm in Smithfield, North Carolina. At the Clayton site, emergence was considerably variable across all species, likely due to a significant hard-packing rain a week after planting. All wildflowers did not emerge evenly, and data was not taken at this location due to high variability in each plot. At the Smithfield location, five species (black-eyed susan, narrow-leaf sunflower, maximilian sunflower, clasping coneflower, and sweet william) emerged consistently across the trial area. Data was collected and will be presented on these five species.

At planting, a PRE-emergence herbicide trial was established based on products currently registered for use on roadsides and products with potential safety on these species. Herbicides treatments and rates are listed in Table 1. All treatments were applied immediately following planting on May 10, 2023, using a CO2 pressurized backpack sprayer equipped with Teejet flat-fan AIXR 11002 nozzles, calibrated to deliver fifteen gallons per acre at three miles per hour. Treated plots at both locations were eight feet wide by seven feet long. The site was weed free at the time of application. An activating rainfall occurred within the first week of planting. Herbicide treatments were replicated 4 times and randomized in a strip block design, withs species being a fixed variable. Stand counts were taken four weeks after emergence and were taken per two feet of row within each plot.

Additionally, a POST trial was established at the Smithfield location on the five emerged species. Treatments are listed in Table 2 and were applied POST on July 9th, 2023. When required by label recommendations non-ionic surfactant was added at 0.25% v/v. Treatments were applied using a CO2 pressurized backpack sprayer equipped with Teejet flat-fan AIXR 11002 nozzles, calibrated to deliver fifteen gallons per acre at three miles per hour. Treated plots were eight feet wide by seven feet long. At the time of application narrow-leaf sunflower averaged 7 inches in height and had on average 12 leaves, maximilian averaged 18 inches in height and had on average 14 leaves, clasping coneflower averaged 18 inches in height and had

on average 10 leaves, black-eyed susan averaged 14 inches in height and had on average 10 leaves, and sweet william averaged 4 inches in height and had on average 12 leaves.

Visual ratings were recorded on general phytotoxicity at one, two, and four weeks after treatment for all species and treatments. Percent bloom reduction was also visually estimated for all species, with the exception of sweet william at their respective time of bloom.

Results

PRE-emergence

All PRE-emergence plots were rated 7, 14, and 28 days after emergence. As they were rated, percent injury was taken. Bloom data as well as stand counts were also taken. To determine safe and unsafe herbicides, bloom data should not exceed ten percent, stand counts should not be statistically different than the untreated and percent injury should not cause significant injury to the wildflowers.

Black-Eyed Susan

The percent total injury of treatments applied PRE-emergence at the Smithfield site is shown in Table 3. Bloom reduction at this site was rated at peak bloom on July 8, 2022.

Treatments of Prowl, Portfolio edge, and Spartan 4F at 2 and 4 fl. oz. per acre, had little to no effect on bloom. Dual Magnum caused moderate injury at 2 and 4 weeks after emergence with twenty-five percent and eighteen percent injury, and a thirty percent reduction in bloom.

All other treatments appear to cause both severe plant injury and bloom reduction when applied PRE-emergence.

Narrow-leaf Sunflower

The percent of total injury of treatments applied PRE-emergence at the Smithfield site is shown in Table 4. Bloom reduction at this site was rated at peak bloom for narrow-leaf sunflower on October 5, 2023.

The treatments of Prowl, Dual Magnum, Staple, Portfolio edge, Callsito, Axiom DF, Spartan 4F at 2 and 4 fl. oz. per acre all caused less than fifteen percent injury and caused a slight reduction in bloom to narrow-leaf sunflower. Cotoran appeared to have caused moderate injury 2 and 4 weeks after emergence with forty percent and forty percent injury but caused little bloom reduction at ten percent reduction in bloom. This could mean that Cotoran delays and stunts growth early, but the narrow-leaf is able to grow out of the injury.

All other treatments cause significant injury and appear to affect bloom when applied PRE-emergence.

Maximilian Sunflower

The percent total injury of treatments applied PRE-emergence at the Smithfield site is shown in Table 5. Bloom reduction at this site was rated at peak bloom for maximillian sunflowers on August 15th, 2023.

Prowl, Dual Magnum, Callisto, Axiom DF, Spartan 4F at 2 and 4 fl. oz. per acre, and Portfolio edge, all had moderate injury. For bloom reduction these treatments all saw less than a ten percent reduction. Prowl and Dual caused moderate injury early, with a forty percent injury one week after emergence and twenty-five percent injury two weeks after emergence and zero percent injury 4 weeks after emergence, this could be attributed to delayed emergence across these treatments. Prowl and Dual could be used, but they delay and stunt germination early. Balance flexx cause little injury early in the season with ten percent one week after emergence, jumping to forty percent two weeks after, and reducing to twenty percent 4 weeks after. It also had a ten percent reduction in bloom. This means that Balance flex does cause stunting after emergence, but the injury is minimal with the ability to grow out of it with only a ten percent reduction in bloom.

All other treatments cause significant injury and appear to affect bloom when applied PRE-emergence.

Clasping Coneflower

The percent total injury of treatments applied PRE-emergence at the Smithfield site is shown in Table 6. Bloom reduction at this site was rated at peak bloom for clasping coneflower on July 20th, 2023.

Prowl had a zero percent injury two weeks after, then jumped to twenty-seven percent injury and caused a six percent reduction in bloom to clasping coneflower. Spartan 4F caused

significant injury early with seventy and eighty percent respectively two weeks after emergence. The injury proved to be delayed emergence, by 4 weeks Spartan at 2 oz. caused twelve percent injury and 4 oz. caused 27 percent injury. By the bloom rating, plots had recovered and there was around a ten percent reduction for both.

Portfolio edge acted similarly to Spartan with high injury 2 weeks after emergence with fifty percent, then reducing to 13 percent. There was also no statistical difference between stand counts when compared to the untreated check. Portfolio edge had a seven percent reduction in bloom.

Clasping coneflower was not tolerant to many treatments with only one being acceptable. Clasping coneflower should be studied more to see if there are some delayed pre-emergence products available.

All other treatments cause significant injury and appear to affect bloom when applied PRE-emergence.

Sweet William

The percent total injury of treatments applied PRE-emergence at the Smithfield site is shown in Table 7. Due to planting timing, sweet william did not bloom in 2023.

Dual Magnum, Spartan at 2 fl. oz., and Balance flexx caused moderate injury sweet william 1-2 weeks after emergence. By 4 weeks, stand was filling in an there was overall less injury. This means that there is a delayed emergence with these herbicides, but sweet william seems to recover after 4+ weeks. Spartan was very rate dependent in the trial, 2 fl. oz. was acceptable, but 4 fl. oz. was an unacceptable treatment. Balance flexx caused moderate injury to the sweet william with eighteen percent injury 4 weeks after emergence but there was statistically no difference in stand compared to the check.

All other treatments cause significant injury when applied PRE-emergence.

POST-Emergence

POST-emergence injury was visually rated 1, 2, and 4 weeks after treatment. To determine acceptable herbicides, injury and bloom data was evaluated. If injury exceeded thirty percent injury 4 weeks after treatment and had greater than fifteen percent reduction in bloom, the herbicide was deemed unacceptable.

Black-eyed Susan

The percent total injury of POST-emergence applications is shown in Table 8.

Butyrac caused minimal injury at the 11.43 and 14.86 fl. oz. per acre rates, with both rates showing less than five percent injury 4 weeks after treatment. For the higher rate of butyrac at 18.29 fl. oz., there was an increase in injury at 4 weeks after treatment, rated at twenty-five percent. There was a five percent reduction in bloom with the two lower rates. The higher rate of 18.29 fl. oz. had a forty-two percent reduction in bloom. This herbicide appears safe when applied at rates below 14.86 fl. oz. per acre for black-eyed susan.

Axiom DF showed little injury to the black-eyed susan with nine percent injury 4 weeks after treatment. It also showed a six percent bloom reduction. This herbicide seems safe to be applied POST-emergence to black-eyed susan.

Cotoran at 1 qt. per acre showed minimal injury to the black-eyed susan with seven percent injury 4 weeks after treatment. It also showed a ten percent bloom reduction. At higher rates than 1 qt. per acre, more injury was observed, twenty-one percent at 4 weeks after treatment for 1.5 qt. per acre and a twenty-five percent injury for 2 qt. per acre. Bloom reduction was rate dependent with a twenty percent reduction for 1.5 qt. per acre and a thirty percent reduction for 2 qt. per acre. This herbicide seems safe to be applied POST-emergence to black-eyed susan at the recommended rate of 1 qt. per acre. Higher application rates resulted in unacceptable injury and should not be applied.

All other treatments cause significant injury and appear to affect bloom when applied POST-emergence.

Narrowleaf Sunflower

The percent total injury of POST-emergence applications is shown in Table 9.

Axiom DF caused no injury to the narrow-leaf sunflower. At any rating date and there was no reduction in bloom. This herbicide would be an acceptable POST-emergent treatment for narrow-leaf sunflower.

Butyrac showed minimal injury to the narrow-leaf sunflower at the three different rates. One, two, and four weeks after treatment all showed zero percent injury. For the bloom data, the low rate of 11.43 fl. oz showed a five percent reduction, the middle rate of 14.86 fl. oz.

showed a fifteen percent reduction, and the high rate of 18.29 fl. oz. showed a seventeen percent reduction in bloom. Though the bloom reduction is increasing as the rate of butyrac increases, I would suggest that the low rates of Butyrac is an acceptable treatment to be used on narrow-leaf sunflower.

Callisto showed very minimal injury to narrow-leaf sunflower. After the first week of treatment, there was bleaching and necrosis to the leaves, the necrosis peaked at two weeks after treatment at ten percent for the high rate. By 4 weeks, there was eight percent injury at both rates of 2 and 3 fl. oz per acre. A five percent bloom reduction was seen throughout the plots of Callisto. This herbicide appears safe as a POST-emergence product for Narrow-leaf Sunflower.

Cotoran injury was variable across the different rates. injury to the narrow-leaf sunflower. Injury was moderate to severe withing the first two weeks, mainly necrotic leaf edges and spots with stunting. By four weeks, injury was minimal at 1 qt. per acre and 1.5 qt. per acre with zero percent and forty percent, respectively. The 2 qt. per acre was the most injurious. One and two weeks after treatment 2 qt. per acre caused significant injury. 4 weeks after treatment, twenty-five percent injury was observed. For the bloom reduction, there was no reduction in bloom for any rate of Cotoran. Though there was no bloom reduction, the injury was too great with 2 qt. per acre of Cotoran and it is not suggested to use the higher rate.

All other treatments cause significant injury and appear to reduce bloom when applied POST-emergence.

Maximilan Sunflower

The percent total injury of POST-emergence applications is shown in Table 10

Axiom DF caused no injury to the Maximillian sunflower at any rating date and there was no reduction in bloom. This herbicide would be an acceptable POST-emergent treatment for Maximillian Sunflower.

Cotoran caused minimal injury to maximilian sunflower one-two weeks after treatment, with the 1 qt. per acre and 1.5 qt. per acre rates causing ten percent injury. By 4 weeks after treatment, 1 qt. per acre was caused fifteen percent injury, while 2 qt. per acre was still causing a twenty percent injury. The bloom reduction showed similar data to the narrow-leaf sunflower and there was little bloom reduction. The 1 qt. per acre showed zero percent reduction, the 1.5 qt. per acre was five percent and the 2 qt. per acre caused a five percent reduction. Though this herbicide is very rate dependent, it is a viable option to be used POST-emergence on maximilian sunflower.

Harmony SG caused little to moderate injury depending on the rate that was used. Between the two rates of .125 and .25 oz., .25 was more injurious. At two weeks, .125 and .25 oz. were both at fifteen percent injury, but at 4 weeks after treatment, .125 oz. was at six percent injury and .25 oz. was at twenty-eight percent injury to the Maximillian sunflower. For the bloom data, the lower rate caused three percent injury, but the higher rate caused twenty-three percent injury. For the use of Harmony SG on maximilian sunflower, the use rate is important to not exceed .125 oz. This herbicide is very rate-dependent but is an acceptable herbicide to be used POST-emergence on maximillian sunflower.

All other treatments cause significant injury and appear to reduce bloom when applied POST-emergence.

Clasping Coneflower

The percent of total injury of POST-emergence applications is shown in Table 11.

Axiom DF showed minimal injury to the clasping coneflower. 4 weeks after treatment there was a ten percent injury. There was no reduction in bloom. This herbicide would be an acceptable POST-emergent treatment for clasping coneflower.

Butyrac showed minimal injury to the clasping coneflower at the two lower rates. One, two, and four weeks after treatment, the lower rates caused less than ten percent injury. For the bloom data, the low rate of 11.43 fl. oz showed a zero percent reduction, the middle rate of 14.86 fl. oz. showed a zero percent reduction. For the high rate of 18.29 fl. oz., it had a fifteen percent injury. Though the bloom reduction is increasing as the rate of Butyrac increases, the high rate of 18.29 fl. oz. should not be applied to clasping coneflower. The lower rates of Butyrac are an acceptable treatment to be applied POST-emergence to clasping coneflower.

Harmony SG caused little to moderate injury depending on the rate that was used. Between the two rates of .125 and .25 oz., .25 was more injurious. At two weeks, .125 and .25 oz. were both at fifteen percent injury, but at 4 weeks after treatment, .125 oz. was at sixteen percent injury and .25 oz. was at thirty-eight percent injury. For the bloom data, the lower rate caused five percent injury, but the higher rate caused twenty-nine percent injury. For the use of Harmony SG on clasping coneflower, the use rate is very important and to not exceed .125 oz. This herbicide is very rate- dependent but is an acceptable herbicide to be used POST-emergence on clasping coneflower.

All other treatments cause significant injury and appear to reduce bloom when applied POST-emergence.

Sweet William

The percent of total injury of POST-emergence applications is shown in table 12. For the sweet william POST-emergent plots, weeds got very thick later in the season and overtook some plots. For the sweet william plots that did not get overtaken, very few of the plots were affected by the treatments and this could be from the plants not growing quickly and missing their blooming window from late planting. And as stated earlier, sweet william is an early spring bloomer. Therefor bloom reductions could not be taken on this species.

Axiom DF caused minimal injury to sweet william. 4 weeks after treatment there was five percent injury. This herbicide would be an acceptable POST-emergent treatment for sweet William.

Staple LX caused moderate injury 2 weeks after treatment, but by 4 weeks little to no injury to sweet william was observed. At all three treatments that were applied, less than five percent injury was observed. This herbicide would be an acceptable POST-emergent treatment for sweet william.

Brake caused no injury to sweet william at both rates of 16 fl. oz. and 24 fl. oz. There was minimal bleaching on the leaves in the first week but faded over time. This herbicide would be an acceptable POST-emergent treatment for sweet william.

Butyrac caused no injury to sweet william at all three rates that were applied. This herbicide would be an acceptable POST-emergent treatment for sweet william.

Callisto caused little injury after treatment. One-two weeks after treatment, there was minimal bleaching on leaves which slowly turned necrotic, however, injury remained below fifteen percent injury at both rates and at all rating timings. This herbicide would be an acceptable POST-emergent product for sweet William.

Outrider caused no injury for the low rate of .25 fl. oz. 4 weeks after application. For the higher rates, greater injury was seen from .5 fl. oz. sixteen percent injury was observed and at .75 fl. oz. eighteen percent injury was observed on the sweet william. The low rate would be an acceptable POST-emergent herbicide option for sweet william.

All other treatments cause significant injury and appear to reduce bloom when applied POST-emergence. Due to being replicated four times throughout each trial it is not recommend that these treatments be applied POST-emergence for sweet william.

Sweet william acted very different than the other species with not much injury occurring late in the season. In conclusion, sweet william should be studied more and sprayed when it is actively growing early in the spring months to see if the plant reacts differently when it is actively growing.

Conclusion

In conclusion, there are several viable herbicide options for weed control in each of these wildflower species. Growing conditions were ideal at the Smithfield location, and as a result all species of wildflowers grew very well and had minimal weed issues. This might be due to the nature of planting later than optimal conditions. Sweet william was the only species that did not bloom, likely due to the late planting timing. As such, I would recommend further screening of many of these treatments before widespread adoption on sweet william to ensure safety. The weedy nature of narrow-leaf sunflower and maximilian sunflower allowed these plants to recover from many treatments which caused initial injury. This may allow several treatment options to be used for roadside use where bloom is the primary goal.

Table 1. Treatments applied PRE-emergence in Smithfield and Clayton, NC.

Trt no.	Herbicide		Application rate	
	Active ingredient	Trade name	product/A	lb. ai/A
1	Pendimethalin	Prowl H2O	1 qt.	0.950
2	S-metolachlor	Dual Magnum	1 pt.	0.950
3	Pyrithiobac	Staple LX	2 fl oz.	0.050
4	Indaziflam	Esplanade	2 fl. oz.	0.026
5	Mesotrione	Callsito	4 fl. oz.	0.125
6	Fluometuron	Cotoran	1 qt.	1.000
7	Pyroxasulfone + Flumioxazin	Piper EZ	3 oz.	0.071
8	Pyroxasulfone + Flumioxazin	Piper EZ	6 oz.	0.142
9	Sulfentrazone	Spartan 4F	2 oz.	0.062
10	Sulfentrazone	Spartan 4F	4 oz.	0.125
11	Pyroxasulfone + Imazethapyr	Portfolio Edge	3 oz.	0.093
12	Metribuzen + Flufenacet	Axiom DF	10 oz.	0.425
13	Fluridone	Brake	10 oz.	0.094
14	Fluridone	Brake	1 pt.	0.150
15	Pendimethalin Fluridone	Prowl H2O Brake	1 qt. 1 pt.	0.950 0.150
16	Pendimethalin S-metolachlor	Prowl H2O Dual Magnum	1 qt. 1 pt.	0.950 0.950
17	Isoxaflutole	Balance Flexx	6 fl. oz.	0.094
18	Fluridone Pyrithiobac	Brake Staple	1 pt. 2 fl. oz.	0.150 0.050
19	Untreated			

Table 2. Treatments applied POST-emergence in Smithfield, NC.

Trt no.	Herbicide		Adjuvant	Application rate	
	Active ingredient	Trade name		product/A	lb. ai/A
1	2,4-DB	Butyrac 175	N/A	11.43 fl. oz.	0.156
2	2,4-DB	Butyrac 175	N/A	14.86 fl. oz.	0.203
3	2,4-DB	Butyrac 175	N/A	18.29 fl. oz.	0.248
4	Mesotrione	Callisto	NIS	2 fl. oz.	0.063
5	Mesotrione	Callisto	NIS	3 fl. oz.	0.093
6	Thifensulfuron	Harmony SG	NIS	.125 oz.	0.068
7	Thifensulfuron	Harmony SG	NIS	.25 oz.	0.125
8	Imazamox	Beyond	NIS	4 fl. oz.	0.031
9	Halosulfuron	Permit	NIS	.125 fl. oz.	0.094
10	Halosulfuron	Permit	NIS	.25 fl. oz.	0.188
11	Halosulfuron	Permit	NIS	.5 fl. oz.	0.375
12	Fluometuron	Cotoran	N/A	1 qt.	1.000
13	Fluometuron	Cotoran	N/A	1.5 qt.	1.500
14	Fluometuron	Cotoran	N/A	2 qt.	2.000
15	Metribuzen + Flufenacet	Axiom DF	N/A	8 oz.	0.340
16	Fluridone	Brake	N/A	1 pt.	0.150
17	Fluridone	Brake	N/A	24 fl. oz.	0.225
18	Pyrithiobac	Staple LX	NIS	2 fl oz.	0.050
19	Pyrithiobac	Staple LX	N/A	2.3 fl oz.	0.058
20	Pyrithiobac	Staple LX	N/A	2.6 fl oz.	0.065
21	Sulfosulfuron	Outrider	NIS	0.25 oz.	0.186
22	Sulfosulfuron	Outrider	NIS	0.5 oz.	0.375
23	Sulfosulfuron	Outrider	NIS	0.275 oz.	0.563
24	Untreated				

Table 3. Black-eyed susan percent total injury two and four weeks after emergence (WAE), Stand count, and bloom reduction. Treatments applied PPRE-emergence at the site in Smithfield.

Trt No.	Treatment	Injury 2 WAE	Injury 4 WAE	Stand Count per 2 ft	Bloom Reduction
1	Prowl H2O	15	23	10	6
2	Dual Magnum	25	18	12	30
3	Staple LX	25	17	17	15
4	Esplanade	99	100	1	100
5	Callsito	99	87	2	81
6	Cotoran	99	96	6	40
7	Piper EZ	99	100	0	100
8	Piper EZ	99	100	0	100
9	Spartan 4F	25	12	17	6
10	Spartan 4F	25	27	11	12
11	Portfolio Edge	25	13	23	7
12	Axiom DF	75	76	4	62
13	Brake	99	100	0	100
14	Brake	99	100	0	100
15	Prowl H2O Brake	99	100	0	90
16	Prowl H2O Dual Magnum	59	74	6	27
17	Balance Flexx	75	86	5	56
18	Brake Staple	99	100	0	95
19	Untreated	0	0	16	0

Table 4. Narrow-leaf sunflower percent total injury two and four weeks after emergence (WAE), stand count, and bloom reduction. Treatments applied PRE-emergence at the site in Smithfield, NC.

Trt No.	Treatment	Injury 2 WAE	Injury 4 WAE	Stand Count per 2 ft	Bloom Reduction
1	Prowl H2O	0	4	27	0
2	Dual Magnum	0	5	36	0
3	Staple LX	0	1	28	5
4	Esplanade	90	82	4	45
5	Callsito	0	0	33	15
6	Cotoran	40	40	27	10
7	Piper EZ	99	95	6	37
8	Piper EZ	99	95	3	43
9	Spartan 4F	0	1	30	2.5
10	Spartan 4F	10	12	25	7
11	Portfolio Edge	0	1	38	5
12	Axiom DF	40	17	30	0
13	Brake	80	85	8	50
14	Brake	80	95	7	50
15	Prowl H2O Brake	99	88	4	81
16	Prowl H2O Dual Magnum	0	25	25	0
17	Balance Flexx	15	12	33	6
18	Brake Staple	90	90	3	71
19	Untreated	0	0	33	0

Table 5. Maximillian sunflower percent total injury two and four weeks after emergence (WAE), stand count, and bloom reduction. Treatments applied PRE-emergence at the site near Smithfield, NC.

Trt No.	Treatment	Injury 2 WAE	Injury 4 WAE	Stand Count per 2 ft	Bloom Reduction
1	Prowl H2O	25	2	12	0
2	Dual Magnum	25	15	10	0
3	Staple LX	50	5	12	0
4	Esplanade	99	78	2	64
5	Callsito	10	30	7	1
6	Cotoran	50	66	7	15
7	Piper EZ	99	88	1	87
8	Piper EZ	99	95	1	95
9	Spartan 4F	0	2	16	0
10	Spartan 4F	5	12	12	5
11	Portfolio Edge	15	8	16	0
12	Axiom DF	10	10	7	5
13	Brake	80	66	3	85
14	Brake	80	87	1	95
15	Prowl H2O Brake	99	93	2	68
16	Prowl H2O Dual Magnum	25	20	11	10
17	Balance Flexx	40	20	11	0
18	Brake Staple	99	87	1	75
19	Untreated	0	0	12	0

Table 6. Clasping coneflower percent total injury two and four weeks after emergence (WAE), Stand count, and bloom reduction. Treatments applied PRE-emergence at the site in Smithfield, NC.

Trt No.	Treatment	Injury 2 WAE	Injury 4 WAE	Stand Count per 2 ft	Bloom reduction
1	Prowl H2O	0	27	10	6
2	Dual Magnum	40	23	12	30
3	Staple LX	50	27	17	15
4	Esplanade	99	100	2	100
5	Callsito	60	87	3	81
6	Cotoran	99	100	6	40
7	Piper EZ	99	100	0	100
8	Piper EZ	99	100	0	100
9	Spartan 4F	70	12	17	6
10	Spartan 4F	80	27	11	12
11	Portfolio Edge	50	13	23	7
12	Axiom DF	40	76	4	63
13	Brake	99	100	1	100
14	Brake	99	100	1	100
15	Prowl H2O Brake	99	100	0	100
16	Prowl H2O Dual Magnum	0	75	5	27
17	Balance Flexx	70	86	5	56
18	Brake Staple	99	100	0	100
19	Untreated	0	0	15	0

Table 7. Sweet william percent total injury two and four weeks after emergence (WAE), stand count, and bloom reduction. Treatments applied PRE-emergence at the site in Smithfield, NC.

Trt No.	Treatment	Injury 2 WAE	Injury 4 WAE	Stand Count per 2 ft	Bloom Reduction
1	Prowl H2O	75	74	1	N/A
2	Dual Magnum	35	8	17	N/A
3	Staple LX	99	100	3	N/A
4	Esplanade	99	100	0	N/A
5	Callsito	50	37	6	N/A
6	Cotoran	99	100	0	N/A
7	Piper EZ	99	100	0	N/A
8	Piper EZ	99	100	0	N/A
9	Spartan 4F	20	11	10	N/A
10	Spartan 4F	50	31	11	N/A
11	Portfolio Edge	50	23	10	N/A
12	Axiom DF	25	26	7	N/A
13	Brake	99	100	0	N/A
14	Brake	99	100	0	N/A
15	Prowl H2O Brake	99	100	0	N/A
16	Prowl H2O Dual Magnum	99	100	1	N/A
17	Balance Flexx	50	18	14	N/A
18	Brake Staple	99	100	0	N/A
19	Untreated	0	0	21	N/A

*Sweet William had no bloom data

Table 8. Black-eyed susan percent total injury two and four weeks after treatment (WAT) and bloom reduction. Treatments applied POST-emergence at site in Smithfield, NC.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Bloom Reduction
1	Butyrac 175	0	2	6
2	Butyrac 175	0	4	6
3	Butyrac 175	0	25	42
4	Callisto	10	20	52
5	Callisto	15	41	18
6	Harmony SG	50	45	46
7	Harmony SG	50	52	95
8	Beyond	35	38	23
9	Permit	75	100	100
10	Permit	90	100	100
11	Permit	90	100	100
12	Cotoran	25	7	10
13	Cotoran	25	21	22
14	Cotoran	25	25	28
15	Axiom DF	0	9	6
16	Brake	65	52	70
17	Brake	75	63	93
18	Staple LX	65	48	66
19	Staple LX	65	48	80
20	Staple LX	65	68	93
21	Outrider	75	100	100
22	Outrider	75	100	100
23	Outrider	75	100	100
24	Untreated	0	0	0

Table 9. Narrow-leaf sunflower percent total injury two and four weeks after treatment (WAT) and bloom reduction. Treatments applied POST-emergence at site in Smithfield, NC.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Bloom Reduction
1	Butyrac 175	0	5	5
2	Butyrac 175	0	5	15
3	Butyrac 175	0	13	17
4	Callisto	0	8	5
5	Callisto	10	8	5
6	Harmony SG	20	28	30
7	Harmony SG	40	36	45
8	Beyond	60	55	50
9	Permit	60	52	90
10	Permit	75	80	75
11	Permit	75	90	68
12	Cotoran	0	5	0
13	Cotoran	40	12	0
14	Cotoran	40	25	0
15	Axiom DF	0	0	0
16	Brake	50	26	20
17	Brake	90	75	36
18	Staple LX	99	100	100
19	Staple LX	99	100	100
20	Staple LX	99	100	100
21	Outrider	99	100	100
22	Outrider	99	100	100
23	Outrider	99	100	100
24	Untreated	0	0	0

Table 10. Maximillian sunflower percent total injury two and four weeks after treatment (WAT) and bloom reduction. Treatments applied POST-emergence at site in Smithfield, NC.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Bloom Reduction
1	Butyrac 175	0	28	11
2	Butyrac 175	0	28	11
3	Butyrac 175	10	35	13
4	Callisto	15	22	26
5	Callisto	35	48	42
6	Harmony SG	15	6	3
7	Harmony SG	15	28	23
8	Beyond	65	63	53
9	Permit	20	33	28
10	Permit	35	48	50
11	Permit	35	48	68
12	Cotoran	10	12	0
13	Cotoran	10	15	5
14	Cotoran	20	20	5
15	Axiom DF	0	0	0
16	Brake	20	22	22
17	Brake	35	26	30
18	Staple LX	50	50	60
19	Staple LX	65	66	63
20	Staple LX	75	70	78
21	Outrider	99	100	100
22	Outrider	99	100	100
23	Outrider	99	100	100
24	Untreated	0	0	0

Table 11. Clasping coneflower percent total injury two and four weeks after treatment (WAT) and bloom reduction. Treatments applied POST-emergence at site in Smithfield, NC.

Trt No.	Treatment	2 WAT	4 WAT	Bloom Reduction
1	Butyrac 175	0	0	0
2	Butyrac 175	0	7	0
3	Butyrac 175	0	15	15
4	Callisto	50	68	66
5	Callisto	35	70	81
6	Harmony SG	15	16	5
7	Harmony SG	15	38	29
8	Beyond	25	45	28
9	Permit	15	27	31
10	Permit	50	42	60
11	Permit	50	43	70
12	Cotoran	50	35	53
13	Cotoran	75	51	76
14	Cotoran	90	90	81
15	Axiom DF	0	10	0
16	Brake	75	45	72
17	Brake	90	81	100
18	Staple LX	50	76	66
19	Staple LX	65	80	76
20	Staple LX	65	85	93
21	Outrider	50	53	76
22	Outrider	50	75	88
23	Outrider	75	90	92
24	Untreated	0	0	0

Table 12. Sweet william percent total injury two and four weeks after treatment (WAT) and bloom reduction. Treatments applied POST-emergence at site in Smithfield, NC.

Trt No.	Treatment	2 WAT	4 WAT	Bloom Reduction
1	Butyrac 175	0	0	N/A
2	Butyrac 175	0	0	N/A
3	Butyrac 175	0	0	N/A
4	Callisto	10	0	N/A
5	Callisto	15	5	N/A
6	Harmony SG	15	18	N/A
7	Harmony SG	25	39	N/A
8	Beyond	25	18	N/A
9	Permit	25	0	N/A
10	Permit	25	0	N/A
11	Permit	25	43	N/A
12	Cotoran	36	18	N/A
13	Cotoran	50	38	N/A
14	Cotoran	50	50	N/A
15	Axiom DF	0	5	N/A
16	Brake	35	0	N/A
17	Brake	62	0	N/A
18	Staple LX	20	2	N/A
19	Staple LX	23	2	N/A
20	Staple LX	28	5	N/A
21	Outrider	35	0	N/A
22	Outrider	35	16	N/A
23	Outrider	50	18	N/A
24	Untreated	0	0	N/A

Chapter 2

Evaluating PRE and POST Transplant Applied Herbicides of Transplanted Wildflowers Species: *Monarda, Leucanthemum, Echinacea, and Rudbeckia species*

Materials and Methods

During the summer of 2023, a screening of residual herbicides was conducted on four wildflower species currently being considered for transplanting planting by the N.C. Department of Transportation (NC DOT) Roadside Environmental Unit for inclusion in the wildflower program. Available cultivars within the following four species were investigated *Monarda, Leucanthemum, Echincloa, and Rudbeckia*. Herbicides were selected based on products currently registered for use in roadside wildflower plantings and products with potential safety on these species. Herbicides and rates are listed in Table 1. An untreated check was included for comparison. Treatments were replicated 3 times in a randomized complete block design.

The four species were transplanted at Central Crops Research Station in Clayton, North Carolina on June 10, 2023. Species were planted on 44 inch row spacings with 24 inch spacing within row. Plots consisted of 2 rows for a total of 88 inches wide and were 20 feet long. Planting was done without beds into conventionally tilled soil. Treatments in Table 1 were applied to the plots either before transplanting (PRE-T), or immediately following transplanting (POST-T. All applications were made using a CO2 pressurized backpack sprayer equipped with Teejet flat-fan AIXR 11002 nozzles, calibrated to deliver fifteen gallons per acre at three miles per hour.

The trial was rated for visual percent injury one, two, four, and eight weeks after treatment. Plot stand counts of the entire plot were taken at eight weeks after transplanting.

Results

Monarda

The percent of total injury of treatments applied PRE-T and POST-T at the site is shown in Table 2.

Cotoran showed overall little injury to Monarda following a PRE-T application. Four weeks after treatment eight percent injury was observed, presented mainly as necrosis. However, these symptoms were minimal and by eight weeks after treatment Cotoran showed zero percent injury. Stands averaged 11 plants per plot were not different from the untreated check. Cotoran seems to be an acceptable PRE-T treatment for transplanted Monarda.

Callsito was moderately injurious to Monarda following a PRE-T application, four weeks after treatment, a forty-eight percent injury was the most injurious of all treatments to Monarda. By eight weeks, injury had reduced to forty percent and was mostly necrotic leaves. For the stand count, the average treatment of 4 living plants, compared to the average of 11 plants in the untreated check. Callsito is not an acceptable PRE-T treatment for transplanted Monarda.

Piper EZ caused minimal injury to Monarda following a PRE-T application. Four weeks after treatment, three percent injury was observed. By eight weeks, the injury had reduced to zero percent. For the stand count, the average treatment of 12 living plants, compared to the average of 11 plants in the untreated check. Piper EZ is an acceptable PRE-T treatment for transplanted Monarda.

Spartan 4F caused minimal injury to Monarda following a PRE-T application. Four weeks after treatment, three percent injury was observed, and remained consistent through eight weeks. For the stand count, The average treatment of 10 living plants was not statistically different than the untreated check. Spartan 4F is an acceptable PRE-T treatment for transplanted Monarda.

Esplanade was moderately injurious to Monarda following a PRE-T application. Four weeks after treatment, forty percent injury was observed. By eight weeks, forty percent was observed, and was mostly necrotic leaves and visual stunting. For the stand count, the average treatment of 5 living plants was not statistically different when compared to the untreated check. Esplanade is not an acceptable PRE-T treatment for transplanted Monarda.

Staple LX caused minimal injury to Monarda following a PRE-T treatment, four weeks after treatment, six percent injury was observed. Injury increased to ten percent 8 weeks after treatment. For the stand count, the average treatment of 8 living plants was not statistically

different than the untreated check. Staple LX is an acceptable PRE-T treatment for transplanted Monarda.

Brake caused minor injury to Monarda following a PRE-T application. There was bleaching one-two weeks after transplanting, but the injury was insignificant. Four weeks after treatment, three percent injury was observed. Plants recovered and no injury was observed. For the stand count, the average treatment of 8 living plants was not statistically different than the untreated check. Brake is an acceptable PRE-T treatment for transplanted Monarda.

Prowl H2O caused little to no injury to Monarda following a POST-T application. Four weeks after treatment, both application rates of 1 qt. per acre and 2 qt. per acre resulted in less than five percent injury. At eight weeks, the observed injury decreased to zero percent for both rates. For the stand count, both rates of Prowl had the average stand of 12 plants and were not statistically different than the untreated check. Prowl H2O is an acceptable POST-T treatment for transplanted Monarda.

Dual Magnum caused minimal injury to Monarda following a POST-T application. Four weeks after treatment, three percent injury was observed and persisted through the eight week rating period. For the stand count, the average treatment of 12 living plants was not statistically different than the untreated check. Dual Magnum is an acceptable POST-T treatment for transplanted Monarda.

Prowl + Dual Magnum caused more initial injury to the Monarda following POST-T application than Prowl or Dual Magnum alone. Symptoms one to two weeks after transplanting was necrotic spots on the leaves, however this injury proved to be insignificant for the Monarda. By four weeks injury was ten percent and by eight weeks it was three percent. The treatment average of 11 plants per plot was not statistically different than the untreated check. Prowl + Dual Magnum is an acceptable POST-T treatment for transplanted Monarda.

Rudbeckia

The percent of total injury of treatments applied PRE-T and POST-T at the Clayton site is shown in Table 3.

Cotoran caused minor injury to Rudbeckia following a PRE-T application. Four weeks after treatment, three percent injury with minimal necrotic symptoms was observed. By eight weeks after treatment, Cotoran caused eight percent injury. For the stand counts, the treatment average of 10 plants was not statistically different than the untreated check. Cotoran seems to be an acceptable PRE-T treatment for transplanted Rudbeckia.

Callsito caused minor injury to Rudbeckia following a PRE-T application. Four weeks after treatment, three percent injury with minimal bleaching symptoms was observed. By eight weeks after treatment, eight percent injury remained. For the stand counts, the treatment average of 8 plants was statistically different than the untreated of 11 living plants. Callisto's stand count was statistically different, However, it is important to note that one plot had 5 living plants, while the other plots had 10, this could be an environmental factor that is making the difference. More data is needed before conclusions can be drawn on the safety of Callsito on Rudbeckia.

Piper EZ caused minimal injury to Rudbeckia following a PRE-T application. Four weeks after treatment, two percent injury was observed. By eight weeks, the injury had increased to three percent. For the stand count, the treatment average of 9 living plants which is not statistically different compared to the untreated check. Piper EZ is an acceptable PRE-T treatment for transplanted Rudbeckia.

Spartan 4F caused minimal injury to Rudbeckia following a PRE-T application. Four weeks after treatment, it showed a five percent injury. Plants recovered and there was no kinjury at eight weeks after treatment. For the stand count, the treatment average of 10 living plants was not statistically different than the untreated check. Spartan 4F is an acceptable PRE-T treatment for transplanted Rudbeckia.

Esplanade was moderately injurious to Rudbeckia following a PRE-T application. Four weeks after treatment, fifteen percent injury was observed. By eight weeks, the injury had increased to twenty percent, presented as mostly necrotic leaves and visual stunting. For the stand count, the treatment average of 9 living plants was not statistically different than the untreated check. Though the stand counts are not statistically different, Esplanade is not an acceptable PRE-T treatment for transplanted Monarda due to visible injury to the plant.

Staple LX caused minor injury to Rudbeckia following a PRE-T application. Four weeks after treatment, five percent injury was observed. By eight weeks, the injury had decreased to three percent. For the stand count, the treatment average of 10 living plants was not statistically different than the untreated check. Staple LX is an acceptable PRE-T treatment for transplanted Rudbeckia.

Brake caused little to no injury to Rudbeckia following a PRE-T application. There was bleaching one-two weeks after transplanting, however the injury was insignificant. Four weeks after treatment, one percent injury was observed. For the stand count, the treatment average of 10 living plants was not statistically different than the untreated check of 11 living plants. Brake is an acceptable PRE-T treatment for transplanted Rudbeckia.

Prowl H2O caused little to no injury to Rudbeckia following a POST-T application. Four weeks after treatment, both rates of 1 qt. per acre and 2 qt. per acre showed a zero percent injury. At eight weeks, the injury had increased to three percent for both rates. For the stand

count, the treatment average of 11 living plants was not statistically different than the untreated check. Prowl H2O is an acceptable POST-T treatment for transplanted Rudbeckia.

Dual Magnum caused minor injury to Rudbeckia following a POST-T application. Four weeks after treatment there was zero percent injury. At eight weeks, the injury had increased to six percent. For the stand count, the treatment average of 10 living plants was not statistically different than the untreated check. Dual Magnum is an acceptable POST-T treatment for transplanted Rudbeckia.

Prowl + Dual Magnum caused minimal injury the Rudbeckia following POST-T application. After four weeks, the injury was two percent and by eight weeks it was zero percent. The treatment average of 10 plants per plot was not statistically different than the untreated check. Prowl + Dual Magnum is an acceptable POST-T treatment for transplanted Rudbeckia.

Leucanthemum

The percent of total injury of treatments applied PRE-T and POST-T at the site is shown in Table 4.

Cotoran showed minor injury to Leucanthemum following a PRE-T application. Four weeks after treatment, a three percent injury with minimal necrotic symptoms was observed. By eight weeks after treatment Cotoran showed a similar three percent injury. For the stand counts, the treatment average of 9 plants was not statistically different than the untreated check. Cotoran seems to be an acceptable PRE-T treatment for transplanted Leucanthemum.

Callsito showed moderate injury to Leucanthemum following a PRE-T application. Four weeks after treatment, thirty percent injury with bleaching symptoms was observed. By eight weeks after treatment injury increased to thirty-three percent injury, and the bleached leaves had turned necrotic. For the stand counts, the treatment average of 6 plants was statistically different than the untreated check. Callsito is not an acceptable PRE-T treatment for Leucanthemum

Piper EZ caused minimal injury to Leucanthemum following a PRE-T application. Four weeks after treatment, no injury was observed. By eight weeks, the injury had increased to six percent. For the stand count, the treatment average of 9 living plants was not statistically different compared to the untreated check. Piper EZ is an acceptable PRE-T treatment for transplanted Leucanthemum.

Spartan 4F caused minor injury to Leucanthemum following a PRE-T application. Four weeks after treatment, six percent injury was observed and remained constant through eight

weeks after treatment. Overall, Spartan 4F caused minimal stunting to the Leucanthemum. For the stand count, the treatment average of 9 living plants was not statistically different than the untreated check. Spartan 4F is an acceptable PRE-T treatment for transplanted Leucanthemum.

Esplanade was moderately injurious to Leucanthemum following a PRE-T applcation. Four weeks after treatment, thirty percent injury was observed. By eight weeks, the injury decreased to twenty percent and mostly presented necrotic leaves and visual stunting. For the stand count, the treatment average of 8 living plants which was not statistically different than the untreated check. With the stand count not being statistically different, it should be noted that Esplanade is not an acceptable PRE-T treatment for transplanted Leucanthemum because of the injury to the plant.

Staple LX caused minimal injury to Leucanthemum following a PRE-T application. Four weeks after treatment, six percent injury was observed. By eight weeks, the injury decreased to three percent. For the stand count, the treatment average of 8 living plants was not statistically different than the untreated check. Staple LX is an acceptable PRE-T treatment for transplanted Leucanthemum.

Brake caused minor injury to Leucanthemum following a PRE-T application. There was minor bleaching one to two weeks after transplanting, but injury was insignificant. Four weeks after treatment, no injury was observed. By eight weeks, injury slightly increased to two percent. For the stand count, the treatment average of 10 living plants which was not statistically different than the untreated check. Brake is an acceptable PRE-T treatment for transplanted Leucanthemum.

Prowl H2O caused little to no injury to Leucanthemum following a POST-T application. Four weeks after treatment, the rate of 1 qt. per acre resulted in observed injury of three percent injury and the rate of 2 qt. per acre resulted in ten percent injury. Eight weeks after, both rates of Prowl resulted in less than five percent injury. For the stand count, both treatment rates had a stand of 11 living plants, which was not statistically different than the untreated check. Prowl H2O is an acceptable POST-T treatment for transplanted Leucanthemum.

Dual Magnum caused little injury to Leucanthemum following a POST-T application. Four weeks after treatment, there was a ten percent injury, mainly observed as necrotic burn on the leaves. At eight weeks, the injury had decreased to one percent. For the stand count, the treatment average of 8 living plants which was not statistically different than the untreated check. Dual Magnum is an acceptable POST-T treatment for transplanted Leucanthemum.

Prowl + Dual Magnum caused minimal injury to the Leucanthemum following POST-T application. After four weeks, there was no observed injury, and by eight weeks, injury was minimal, at two percent. The treatment average stand count of 9 plants per plot was not statistically different than the untreated check. Prowl + Dual Magnum is an acceptable POST-T treatment for transplanted Leucanthemum.

Echinacea

The percent of total injury of treatments applied PRE-T and POST-T at the site is shown in Table 5.

Cotoran showed moderate injury to Echinacea following a PRE-T application. Four weeks after treatment, sixteen percent injury with necrotic symptoms was observed. By eight weeks after treatment Cotoran caused an increase to twenty-six percent injury presented mainly as necrotic leaves and stunted growth. The treatment average stand count of 11 plants which was not statistically different than the untreated check. Despite acceptable stand counts, Cotoran seems to not be an acceptable PRE-T treatment for transplanted Echinacea due to plant injury.

Callsito showed moderate injury to Echinacea following a PRE-T application. Four weeks after treatment, a forty-two percent injury with bleaching and necrotic symptoms was observed. By eight weeks after treatment the injury had decreased to twenty-five percent with the bleached leaves turning necrotic. The treatment average stand count of 7 plants was statistically different than the untreated check. Callsito is not an acceptable PRE-T treatment for Echinacea.

Piper EZ caused minimal injury to Echinacea following a PRE-T application. Four weeks after treatment, sixteen percent injury was observed. By eight weeks, the injury had decreased to ten percent. For the stand count, the treatment average of 8 living plants was not statistically different compared to the untreated check. Piper EZ is an acceptable PRE-T treatment for transplanted Echinacea.

Spartan 4F caused moderate injury to Echinacea following a PRE-T application. Four weeks after treatment, thirty-two percent injury was observed. By eight weeks, the injury had decreased to ten percent. Injury overall, presented as moderate necrosis at 4 weeks after treatment, but by 8 weeks the Echinacea had grown out of the necrosis and only minimal stunting. For the stand count, the treatment average of 9 living plants was not statistically different than the untreated check. Spartan 4F is an acceptable PRE-T treatment for transplanted Echinacea.

Esplanade was moderately injurious to Echinacea following a PRE-T treatment. Four weeks after application, thirty percent injury was observed. By eight weeks, the injury had decreased to fifteen percent, mostly presented as necrotic leaves and stunting. For the stand count, the treatment average of 7 living plants which was statistically different than the untreated check. With the stand count being statistically different, Esplanade is not an acceptable PRE-T treatment for transplanted Echinacea.

Staple LX caused little to no injury to Leucanthemum following a PRE-T application. Four weeks after treatment, a six percent injury was observed. By eight weeks, the injury had decreased to three percent. For the stand count, the treatment average of 9 living plants was not statistically different than the untreated check. Staple LX is an acceptable PRE-T treatment for transplanted Echinacea.

Brake caused little to no injury to Echinacea following a PRE-T application. There was minimal bleaching one to two weeks after transplanting, but the injury was insignificant. Four weeks after treatment, five percent injury was observed. By eight weeks, the injury had slightly increased to six percent. For the stand count, the treatment average of 10 living plants was not statistically different than the untreated check. Brake is an acceptable PRE-T treatment for transplanted Echinacea.

Prowl H2O caused minimal injury to Echinacea following a POST-T treatment. Four weeks after treatment, the rate of 1 qt. per acre caused eight percent injury and the rate of 2 qt. per acre caused thirteen percent injury. Eight weeks after, both rates of Prowl caused five percent injury. For the stand count, the average stand of both treatment rates was 9 living plants which was not statistically different than the untreated check. Prowl H2O is an acceptable POST-T treatment for transplanted Echinacea.

Dual Magnum caused moderate injury to Echinacea following a POST-T application. Four weeks after treatment, fourteen percent injury was observed, presented mainly as necrotic burn on the leaves. At eight weeks, the injury had decreased to five percent. For the stand count, the treatment average of 10 living plants was not statistically different than the untreated check. Dual Magnum is an acceptable POST-T treatment for transplanted Echinacea.

Prowl + Dual Magnum caused slight injury to the Echinacea following POST-T application. After four weeks, the injury was fifteen percent and by eight weeks it was ten percent. Prowl + Dual Magnum caused more injury to the Echinacea than either treatment alone, however the increase was insignificant. Prowl + Dual Magnum had a stand of 10 plants per plot which was not statistically different than the untreated check. Prowl + Dual Magnum is an acceptable POST-T treatment for transplanted Echinacea.

Conclusion

In conclusion, there are several viable herbicide options for weed control in each of these transplanted wildflower species. These wildflowers were transplanted late in the season, which limited the bloom of these species. The transplants grew very slowly, which could have masked some of the injury potential of these herbicides. As such, I would recommend further screening of these treatments before widespread adoption of these treatments in these species in order to ensure safety. By transplanting these flowers, the stand was established quickly and

there were several herbicides that were able to keep the plots clean. Transplanting would be a good option to establish wildflowers.

Table 1. Treatments in Clayton, NC.

Tmt no.	Herbicide		Application Timing	Application rate	
	Active ingredient	Trade name		product/A	lb. ai/A
1	Pendimethalin	Prowl H2O	POST-T	1 qt.	0.95
2	S-metolachlor	Dual Magnum	POST-T	1 pt.	0.95
3	Pendimethalin S-metolachlor	Prowl H2O Dual Magnum	POST-T	2 qt. 1 pt.	1.90 0.95
4	Pendimethalin	Prowl H2O	POST-T	2 qt.	1.90
5	Indaziflam	Esplanade	PRE-T	4 fl. oz.	0.05
6	Fluometuron	Cotoran	PRE-T	1 qt.	1.00
7	Pyroxasulfone + Flumioxazin	Piper EZ	PRE-T	6 oz.	0.14
8	Sulfentrazone	Spartan 4F	PRE-T	6 oz.	0.19
9	Fluridone	Brake	PRE-T	1 pt.	0.15
10	Mesotrione	Callisto	PRE-T	4 fl. oz.	0.17
11	Pyrithiobac	Staple	PRE-T	2.6 fl. oz.	0.07
12	Untreated	Untreated			

Table 2. Monarda percent total injury two, four, and eight weeks after treatment (WAT) and stand count.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Injury 8 WAT	Stand Count
1	Prowl H2O 1qt/A	0	6	5	12
2	Dual Magnum	0	0	3	12
3	Prowl H2O Dual Magnum	20	10	3	12
4	Esplanade	25	40	40	6
5	Prowl H2O 2qt/A	0	0	0	12
6	Cotoran	0	8	0	11
7	Piper EZ	10	3	0	12
8	Spartan 4F	10	3	3	10
9	Brake	0	3	0	11
10	Callsito	55	48	38	4
11	Staple	10	6	10	6
12	Untreated	0	0	0	11

Table 3. Rudbeckia percent total injury two, four, and eight weeks after treatment (WAT) and stand count.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Injury 8 WAT	Stand Count
1	Prowl H2O 1qt/A	0	0	3	11
2	Dual Magnum	0	0	6	10
3	Prowl H2O Dual Magnum	10	2	0	10
4	Esplanade	10	15	20	8
5	Prowl H2O 2qt/A	0	0	3	10
6	Cotoran	10	3	6	10
7	Piper EZ	20	2	3	9
8	Spartan 4F	10	5	0	10
9	Brake	0	2	0	10
10	Callsito	10	3	6	8
11	Staple	10	5	3	10
12	Untreated	0	0	0	11

Table 4. Leucanthemum percent total injury two, four, and eight weeks after treatment (WAT) and stand count.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Injury 8 WAT	Stand Count
1	Prowl H2O 1qt/A	10	3	4	9
2	Dual Magnum	0	10	2	8
3	Prowl H2O Dual Magnum	10	0	2	9
4	Esplanade	0	30	25	8
5	Prowl H2O 2qt/A	0	10	2	9
6	Cotoran	0	3	3	9
7	Piper EZ	0	0	6	9
8	Spartan 4F	0	6	6	9
9	Brake	10	0	2	10
10	Callsito	35	33	30	6
11	Staple	10	6	3	8
12	Untreated	0	0	0	9

Table 5. Echinacea percent total injury two, four, and eight weeks after treatment (WAT) and stand count.

Trt No.	Treatment	Injury 2 WAT	Injury 4 WAT	Injury 8 WAT	Stand Count
1	Prowl H2O 1qt/A	10	8	6	9
2	Dual Magnum	40	14	6	10
3	Prowl H2O Dual Magnum	30	15	10	10
4	Esplanade	25	30	15	7
5	Prowl H2O 2qt/A	10	14	3	9
6	Cotoran	20	16	26	11
7	Piper EZ	10	12	10	9
8	Spartan 4F	50	31	10	8
9	Brake	0	5	6	10
10	Callsito	0	41	25	7
11	Staple	10	6	3	9
12	Untreated	0	0	0	10

Chapter 3

Determining a Post Herbicide Option for Cosmos bipinnatus

Material and Methods

During the summer of 2023, a screening of herbicides was conducted on *Cosmos* bipinnatus, which is commonly planted by the N.C. Department of Transportation (NC DOT) Roadside Environmental Unit for inclusion in the wildflower program. Herbicides were selected based on products currently registered for use in roadside wildflower plantings and products with potential safety for this species determined by looking at previous work done by Dr. Alan York. Herbicides 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. As the current standard, Cotoran at 1 qt/A acts as a comparison treatment. Treatments were replicated 4 times in a randomized complete block design.

NC DOT planted Cosmos at Central Crops Research Station in Clayton, North Carolina on July 25, 2023, and a location provided by Garrett Seed Farm in Smithfield, North Carolina on August 3, 2023. All treatments in Table 1 were applied to the Cosmos POST-emergence on August 10 at Clayton, and September 18 in Smithfield. Treatments were applied using a CO2 pressurized backpack sprayer equipped with Teejet flat-fan AIXR 11002 nozzles, calibrated to deliver fifteen gallons per acre at three miles per hour. At the time of application, the Cosmos averaged 4-6” tall at both locations.

Two treatments were granular herbicides. These granular herbicides were spread evenly throughout the plots with a battery powered hand spreader to ensure uniform coverage. These plots were rated for general phototoxicity just the same as the foliar applied treatments.

Treated plots in all locations and application timings were ten feet wide by thirty feet long. Visual injury ratings were recorded on general phytotoxicity at one, two, and three weeks after treatment. Percent bloom reduction was also visually estimated at their respective time of bloom. Average plant heights were taken 4 weeks after treatment.

Results

Injury to the Cosmos is presented Table 2; with percent injury two and three weeks after treatment. Heights and bloom data is also presented in Table 2.

Arsenal, Elevore, Reviton, and Huskie caused complete plant death within two weeks after treatment. These herbicides should not be applied POST on Cosmos.

Laudis and Flagstaff caused severe injury when applied POST to Cosmos. Two weeks after treatment, there was a fifty to seventy-five percent injury to the Cosmos. Three weeks after, there was between seventy-five and eighty-five percent injury to the Cosmos. For bloom reduction, Laudis caused an seventy percent reduction and Flagstaff caused an eighty percent reduction. These herbicides should not be applied POST to Cosmos.

Python caused moderate to severe injury when applied POST to Cosmos. Two weeks after treatment, the lower rate of .125 oz. per acre caused fifteen percent injury and the higher rate at .8 oz. caused fifty percent injury. Three weeks after treatment, the .125 fl. oz. rate caused ten percent injury and the higher rate caused sixty percent injury. Plants did recover slightly and had a twelve percent reduction in bloom for the low rate, the high rate had a fifty percent reduction to bloom. This herbicide is not safe for use POST for Cosmos.

Ultra Blazer caused moderate injury when applied POST to Cosmos. Two weeks after treatment, there was a sixty-five percent injury. Three weeks after treatment, there was a fifty percent injury. Plants did recover slightly but still had a forty-five percent reduction in bloom. This herbicide is not safe for use POST for Cosmos.

ShieldEx caused moderate injury when applied POST to Cosmos. Two weeks after treatment, there was a fifty percent injury. Three weeks after treatment, there was fifty-five percent injury. Plants recovered slightly but still had a forty percent reduction in bloom. This herbicide is not safe for use POST for Cosmos.

Armezon caused moderate injury when applied POST to Cosmos. Two weeks after treatment, there was a forty-five percent injury. Three weeks after treatment, there was a twenty-five percent injury. Plants did not recover and had a thirty-five percent reduction in bloom. This herbicide is not safe for use POST for Cosmos.

Simazine caused moderate injury when applied POST to Cosmos. Two weeks after treatment, there was thirty percent injury. Three weeks after treatment, there was a twenty percent injury. Plants did not recover and had a twenty percent reduction in bloom. This herbicide is not safe for use POST for Cosmos.

Brake caused moderate injury when applied POST to Cosmos. Two weeks after treatment, there was a twenty percent injury and was mainly bleaching and little necrosis. Injury remained at three weeks after treatment. Plants recovered slightly and had a fifteen percent reduction in bloom. This herbicide is not safe for use POST for Cosmos.

Spartan caused minimal injury when applied POST to Cosmos. Two weeks after treatment, there was a forty percent injury. Three weeks after treatment, there was a fifteen percent injury. Plants did not recover and had a 15 percent reduction in bloom. This herbicide is not safe for use POST for Cosmos.

Butyrac caused moderate injury when applied POST to Cosmos. Two weeks after treatment, for all three rates there was a stair step of injury with the lowest rate 11.43 fl. oz. having the lowest injury at five percent, second rate of 14.86 having ten percent, and the third rate of 18.29 having twenty percent. Three weeks after, it had a similar stair step of lowest and middle rate causing ten percent and the higher rate having twenty-five percent. There was a bloom reduction for all three rates, the lowest rate and middle rate had a twenty percent reduction, and the highest rate had a thirty-five percent reduction. This herbicide is not safe for use POST for Cosmos.

Balance Flexx caused minimal injury when applied POST to Cosmos. Two weeks after treatment, there was a fifteen percent injury, presented as minimal bleaching and necrosis. Three weeks after treatment, there was ten percent injury. Plants did recover and had a 5 percent reduction in bloom. This herbicide is safe for use POST for Cosmos.

Axiom DF caused little injury when applied POST to Cosmos. Two weeks after treatment, there was a ten percent injury observed at both rates. Three weeks after treatment, there was less than a five percent injury observed at both rates. Plants recovered and there was no reduction in bloom. This herbicide is safe for use POST for Cosmos.

Cotoran caused little injury at both rates when applied POST to Cosmos. Two weeks after treatment, there was no injury observed. Three weeks after treatment, there was five percent injury observed at 2 qt. per acre. There was no reduction in bloom observed at either rate. This herbicide is safe for use POST for Cosmos.

Zidua SC caused no observed injury when applied POST to Cosmos and no observed reduction in bloom. This herbicide is safe for use POST for Cosmos.

Fuerte and Broadstar were coated herbicides that were spread in plots. These treatments caused no injury to the Cosmos or caused any bloom reduction. There was an activating rainfall that occurred within the first week after treatment. These herbicides appear safe when spread over the top of Cosmos.

Conclusion

In conclusion, there are several viable herbicide options for weed control in *Cosmos bipinnatus.* This wildflower is planted late in the season which limits weed growth and there are more weed control options. By looking at the treatments that did not injure the Cosmos, the majority provide residual weed control only, and will not control emerged weeds. These herbicides could be used in addition to current at planting herbicide recommendations to prevent weeds from emerging during the growing season.

Table 1. Treatments applied POST in Clayton and Four Oaks, NC.

Tmt no.	Herbicide		Adjuvant	Application rate	
	Active ingredient	Trade name		product/A	lb. ai/A
1	2,4-DB	Butyrac 175	N/A	11.43 fl. oz.	0.156
2	2,4-DB	Butyrac 175	N/A	14.86 fl. oz.	0.203
3	2,4-DB	Butyrac 175	N/A	18.29 fl. oz.	0.248
4	Toppyralate	ShieldEx	NIS	1 fl. oz.	0.026
5	Topremazone	Armezon	COC + AMS	.5 fl. oz.	0.012
6	Flumetsulam	Python	NIS	.125 fl. oz.	0.100
7	Flumetsulam	Python	NIS	.8 fl. oz.	0.640
8	Fluroxypyr	Flagstaff	N/A	4.8 fl. oz.	0.120
9	Tembotrione	Laudis	MSO	3 fl. oz.	0.065
10	Aciflurofen	Ultra Blazer	NIS	8 fl. oz.	0.220
11	Pyroxasulfone	Zidua SC	N/A	1.75 fl. oz	0.050
12	Fluometuron	Cotoran	COC	1 qt.	1.000
13	Fluometuron	Cotoran	COC	2 qt.	2.000
14	Metribuzen + Flufenacet	Axiom DF	N/A	8 oz.	0.340
15	Metribuzen + Flufenacet	Axiom DF	N/A	10 oz.	0.400
16	Fluridone	Brake	N/A	1 pt.	0.150
17	Isoxaflutole	Balance Flexx	N/A	3 fl. oz.	0.046
18	Simazine	Simazine	NIS	1 qt.	1.000
19	Halauxifen	Elevore	COC	1 fl. oz.	0.004
20	Tiafenacil	Reviton	NIS	1 fl. oz.	0.022
21	Flumioxazin	Broadstar	N/A	150 lb	0.375
22	Flumioxazin + Prodiamine	Fuerte	N/A	100 lb	0.875
23	Sulfentrazone	Spartan 4F	N/A	4 fl. oz.	0.125
24	Imazapyr	Arsenal	NIS	2 fl. oz.	0.031
25	Imazapyr	Arensal	NIS	10 fl. oz.	0.156
26	Pyrasulfotole Bromoxynil	Huskie	N/A	11 fl. oz.	0.177

Table 2. Cosmos percent total injury two and three weeks after treatment (WAT), average plant height, and percent bloom reduction.

Trt No.	Treatment	Injury 2 WAT	Injury 3 WAT	Plant Height	Bloom Reduction
1	Butyrac 175 11.43 fl. oz.	5	10	69	20
2	Butyrac 175 14.86 fl. oz	10	10	62	20
3	Butyrac 175 18.29 fl. oz.	20	25	50	35
4	ShieldEx	50	55	31	4
5	Armezon	45	25	37	35
6	Python .125 oz.	15	10	49	12
7	Python .8 oz.	50	60	30	50
8	Flagstaff	75	85	43	80
9	Laudis	50	75	26	80
10	Ultra Blazer	65	50	40	45
11	Zidua SC	0	0	86	0
12	Cotoran 1 qt. Comparison Trt.	0	0	79	0
13	Cotoran 2 qt.	0	5	82	0
14	Axiom DF	10	5	78	0
15	Axiom DF	10	5	69	0
16	Brake	20	20	57	15
17	Balance Flexx	15	10	55	5
18	Simazine	30	20	63	20
19	Elevore	100	100	0	100
20	Reviton	100	100	0	100
21	Broadstar	0	0	79	0
22	Fuerte	0	0	82	0
23	Spartan 4F	45	15	64	15
24	Arsenal 2 fl. oz.	100	100	0	100
25	Arensal 10 fl. oz.	100	100	0	100
26	Huskie	100	100	0	100