Final Technical Report

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Utility of Liquid Nitrogen Fertilizer and Soil Surfactants for Smutgrass Control with Hexazinone

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BACKGROUND

Giant smutgrass (*Sporobolus jacquemontii*) is native to tropical Asia but has become a problematic weed in improved and native perennial grass pastures throughout Florida. Control of giant smutgrass can be achieved with 1.0 lb/A (2 qt/A) hexazinone during July, August, and early September when rainfall is sufficient for uptake from the soil solution (Mislevy et al. 2002; Ferrell et al. 2006); however, previous research funded through the FCEB has found that hexazinone activity is typically diminished when <0.25 and >3 inches of rainfall occur within a week of hexazinone application. Therefore, research is needed to determine ways to increase hexazinone activity when rainfall is either limited or excessive.

The use of liquid nitrogen fertilizers as a carrier for herbicides is not new and provides an option for growers to control weeds and fertilize the crop in one-pass (Soltani et al. 2012). Most of the research in this area has been conducted solely with postemergence herbicides, and not with herbicides that are absorbed through the roots. However, preliminary evidence from our program has shown that the use of 32% urea ammonium nitrate (UAN) with hexazinone at 1 qt/A provides smutgrass control at similar levels to 2 qt/A of hexazinone applied in water. While this provides the basis for using UAN as a carrier for hexazinone, applying 50 lb/A of N during extreme rainfall events may not be environmentally friendly. Therefore, it is necessary to determine if lower rates of UAN could be utilized as carrier solution to increase the efficacy of hexazinone.

In recent years, the use of soil surfactants to increase water infiltration or to provide improved herbicide performance by increasing the adsorption of soil residual herbicides in the upper soil profile have become available in the market. Since hexazinone is highly water soluble, extreme rainfall events often result in hexazinone leaching below the smutgrass rootzone ultimately reducing smutgrass control. Therefore, the use of soil surfactants that reportedly reduce herbicide leaching should be investigated.

APPROACH

Using UAN as a carrier for hexazinone.

Plots were established in smutgrass-infested pastures to validate the appropriate UAN and hexazinone rates near Ona (giant smutgrass and Marianna (small smutgrass), FL to control smutgrass in 2022 and 2023. Hexazinone at 1 or 2 qt/A were mixed in diluted UAN at various rates. Rates of UAN included 0, 10, 20, 30, 40 and 50 lb N/A. The hexazinone:UAN:water mixture was applied at 30 gallons per acre during the early-season (May), mid-season (July), and late-season (September). These same treatments were applied to smutgrass-free bahiagrass in Ona in 2022 and 2023 and Marianna only in 2022 to evaluate crop response.

Smutgrass control was evaluated visually and by recording smutgrass densities at 0, 30, and 60 days after treatment (DAT). Smutgrass densities at 30 and 60 days after treatment (DAT) were converted to percent of pretreatment counts for analysis. Bahiagrass was harvested at 30 and 60 DAT, and dry weights recorded after 3 to 4 days in a hot oven to estimate bahiagrass yield. Data were subjected to analysis of variance and means separated using the appropriate non-parametric test. The influence of nitrogen rate on bahiagrass herbage accumulation was modeled using a linear regression model ($y= ax + b$; y = cumulative bahiagrass biomass, x = nitrogen rate).

Effect of soil surfactants on hexazinone activity.

Five soil surfactants, including Nanopro™, Grounded™, Hydrovant™, Sorbyx™, and Break Thru™ were investigated in smutgrass-infested pastures near Ona (giant smutgrass) and Marianna (small smutgrass) in 2022 and 2023. Experiments were conducted in a randomized complete block design using a 2 x 5 factorial arrangement of treatments and four replications. The surfactants were mixed with either 1 or 2 qt/A hexazinone and applied at 30 gallons per acre. Control plots were treated with hexazinone at 1 or 2 qt/A with no soil surfactant included. Smutgrass control was evaluated visually and by recording smutgrass densities at 0, 30, and 60 DAT. Smutgrass densities were converted to percent of pretreatment counts for analysis. Data were subjected to analysis of variance and means separated using an appropriate non-parametric test.

A controlled greenhouse experiment was also conducted based to evaluate soil surfactants with hexazinone under simulated rainfall. Clumps of giant smutgrass were collected from a nearby pasture and individual culms with intact roots were planted into field soil that was sieved into 1-gallon pots. Plants were allowed to grow for 2 months, clipped to a 3-inch stubble height and allowed to grow an additional month before treatments were applied. The experiment was conducted as a randomized complete block design using a 4 x 6 factorial treatment arrangement with three replicates and two experimental runs. Hexazinone was applied at 2 qt/A with either no surfactant, NanoPro, Sorbyx, or Grounded at their labeled rates of 0.1%, 0.3%, and 1% v/v, respectively, and six simulated rainfall accumulation volumes (0, 0.25, 0.5, 1, 2, and 4 inches). Replicates were blocked based on smutgrass height and clump width. A non-treated control was also included and was not subjected to rainfall simulation and was only sub-irrigated. Each pot was sub-irrigated up to the saturation point and allowed to drain for 48 hrs prior to treatment application. A Tlaloc 3000 rainfall simulator was used to simulate rainfall 2 hrs following treatment application. All pots were allowed to drain for 24 hrs before transfer back to the greenhouse. Plants were sub-irrigated with 60 cc water at 48 hr intervals until the end of the experiment. Smutgrass control was determined qualitatively by visual estimates of control ranging from 0 (no injury) to 100% (complete death) 30 DAT; and quantitatively by clipping above-ground biomass 30 and 60 DAT at 3 inches above the soil surface. Dry biomass was converted to percent of the non-treated control prior to analysis. Data were subjected to regression analysis to determine the influence of surfactants on smutgrass control and biomass across the simulated rainfall accumulation volumes. The rainfall range required for at least 80% visual control as well as 50 and 80% reductions in smutgrass biomass at 30 and 60 DAT were determined using a quadratic equation ($y=ax^2 + bx + c$; y=response variable, x=rainfall volume).

RESULTS

Using UAN as a carrier for hexazinone

***Giant smutgrass control (Ona)*.** Data were analyzed by year for visual control and density reduction 30 and 60 DAT due to the significant effect of year x application time and year x hexazinone rate. Overall, no interactions were observed for application time x nitrogen dose, hexazinone rate x nitrogen dose, nor the three-way interaction of application time x hexazinone rate x nitrogen dose for both response variables. The main effect of nitrogen dose was also not significant for either variable.

The main effect of application time was significant for both response variables in 2022 and 2023 (Table 1). In 2022, mid-season hexazinone application resulted in 1.5-times greater control at 30 DAT (64%) than early- and late-season applications. By 60 DAT, mid-season application of hexazinone resulted in 1.5-times greater control than early-season application but was similar to late-season application. However, in 2023 late season applications resulted in the greatest visual control (75%) followed by the mid-season (69%) and early season (38%) with the least control at 30 DAT. This trend was similar at 60 DAT with late- and mid-season hexazinone applications providing 2.0- and 1.5-times greater control, respectively, compared to early season applications. Density reduction was not greater than 10% at 30 DAT in 2022, but density reduction was at least 5-times greater with the mid-season application of hexazinone compared to the early- and late-season applications. The same trends were observed at 60 DAT and density reductions were not greater than 29%. Smutgrass density reductions were at least 6.4-times greater following mid- and late-season than the early-season application timing at 30 DAT in 2023. By 60 DAT, late season applications resulted in the greatest density reduction (75%) followed by mid-season (61%) and early season applications with the least density reduction (15%).

The main effect of the hexazinone rate was significant for visual control and density reduction at 30 and 60 DAT in 2022 and 2023 (Table 2). The high rate of hexazinone (1 lb/A) resulted in greater visual control at 30 and 60 DAT compared to 0.5 lb/A in 2022 and 2023. Hexazinone at 1 lb/A provided 1.5-times to 1.9- times greater control compared to hexazinone

0.5 lb/A. The trend was similar for density reduction in 2022 and 2023, as hexazinone 1 lb/A resulted in 2-times to 7-times greater density reduction than hexazinone 0.5 lb/A.

Application time and hexazinone rate significantly influenced visual estimates of giant smutgrass control and density reduction except for visual estimates of control at 30 DAT in 2022 (Table 3). Early-season application in 2022 with hexazinone 0.5 lb/A resulted in the lowest visual control while early- mid- and late-season application with hexazinone 1 lb/A resulted in the greatest visual control at 60 DAT. In 2023, early application with both hexazinone rates resulted in the lowest smutgrass control while mid- and late-season applications with hexazinone 1 lb/A resulted in greater visual control (> 70%) at 30 DAT. At 60 DAT, the greatest visual control was observed in mid-season application of 1 lb/A hexazinone and late-season applications at both rates. Similar results were observed with density reduction. Density reduction in 2022 was less than 20% at 30 DAT, however, density reduction was at least 6-times greater following the mid-season application of 1 lb/A hexazinone than all other application timings regardless of rate. However, by 60 DAT, density reduction was at least 1.8-times greater when treated mid-season with 1 lb/A than all other application times regardless of hexazinone rate. In 2023, mid and late-season applications of hexazinone 1 lb/A resulted in a greater density reduction (>73 %) while early-season application with both hexazinone rates resulted in the lowest density reduction at 30 DAT. The trend is similar at 60 DAT as mid and late-season hexazinone application at 1 lb/A resulted in the greatest density reduction (>80%).

Table 1. Giant smutgrass visual control and density reduction 30 and 60 DAT at three application times in 2022 and 2023 at Ona, FL[a].

Application time	Visual control				Density reduction			
	30 DAT		60 DAT		30 DAT		60 DAT	
	2022	2023	2022	2023	2022	2023	2022	2023
	----------------% control----------------				----------------% reduction-------------			
Early	43 b	38 c	28 b	41 c	2 b	9 b	13 b	15 c
Mid	64 a	69 b	42 a	61 b	10 a	59 a	29 a	61 b
Late	40 b	75 a	45 a	81 a	1 a	58 a	5 b	75 a
P-value	0.0004	0.0002	0.0003	0.0002	0.0005	0.0002	0.0002	0.0002

[a]Means of a response variable within a single year with different letters are significantly different at $P \leq 0.05$. There was a significant effect of year x application time ($P = 0.0002$) on all four response variables, so data were analyzed per year.

Table 2. Giant smutgrass visual control and density reduction 30 and 60 DAT at two hexazinone rates in 2022 and 2023 at Ona, FL [a].

Rate (lb/A)	Visual control				Density reduction			
	30 DAT		60 DAT		30 DAT		60 DAT	
	2022	2023	2022	2023	2022	2023	2022	2023
	-----------------% control-----------------				-------------% reduction--------------			
0.50	39 b	48 b	27 b	48 b	1 b	27 b	6 b	34 b
1.00	59 a	73 a	50 a	74 a	7 a	58 a	25 a	67 a
P-value	0.0002	0.0002	0.0006	0.0001	0.0002	0.0001	0.0002	0.0002

[a]Means of a response variable within a single year with different letters are significantly different at P ≤ 0.05. There was a significant effect of year x hexazinone rate (P = 0.0018) on the density reduction at 30 DAT and 60 DAT.

Table 3. Giant smutgrass visual control and density reduction 30 and 60 DAT at two hexazinone rates and three application times in 2022 and 2023 at Ona, FL[a].

Time	Hex. Rate (lb/A)	Visual control				Density reduction			
		30 DAT		60 DAT		30 DAT		60 DAT	
		2022	2023	2022	2023	2022	2023	2022	2023
		------------------% control-----------------				---------------% reduction---------------			
Early	0.50	30 a	1 c	14 d	26 d	1 b	1 c	1 c	2 d
	1.00	56 a	17 c	43 ab	57 b	3 b	17 c	25 b	28 c
Mid	0.50	59 a	36 b	28 c	43 c	2 b	36 b	12 bc	38 c
	1.00	75 a	82 a	56 a	79 a	18 a	82 a	46 a	83 a
Late	0.50	34 a	43 b	40 bc	76 a	1 b	43 b	5 c	61 b
	1.00	47 a	73 a	51 ab	87 a	1 b	73 a	5 c	90 a
P-value		0.1734	0.0015	0.0119	0.0151	0.0002	0.0498	0.0003	0.0028

[a]Means of a response variable within a single year with different letters are significantly different at P ≤ 0.05.

Small smutgrass control (Marianna). Data were analyzed by year for visual control and density reduction 30 and 60 DAT due to a significant effect of year x application time and year x application time x hexazinone rate on both response variables. Similar to giant smutgrass, no interactions were observed for application time x nitrogen dose, nor the three-way interaction of application time x hexazinone rate x nitrogen dose for both response variables. The main effect of nitrogen dose was also not significant for either variable. However, hexazinone rate x nitrogen dose interaction was observed in 2023.

The main effect of application time was significant for visual control and density reduction at 30 and 60 DAT in 2022 and 2023 (Table 4). Mid-season application in 2022 resulted in 1.3- and 2.2-times greater visual control (46 and 59%, respectively) at 30 DAT and 60 DAT, respectively. Similarly, in 2023, mid-season application provided the greatest control (65%) followed by early (56%) and late season (48%) at 30 DAT. At 60 DAT, mid-season hexazinone application resulted in 1.3-times greater control (67%) compared to early-season applications, but late-season applications were similar to other application timings. Similarly, in 2022, mid-season application resulted in greater density reduction (28%) at 30 DAT compared to early- and late-season applications. A similar trend was observed at 60 DAT with mid-season application resulting in the greatest density reduction (≥ 44%) than early and late season applications. Additionally, in 2023, mid-season applications resulted in density reductions that were 1.8- and 1.4- times greater than the early- and late-season applications at 30 and 60 DAT, respectively.

Hexazinone rate significantly influenced the visual control and density reduction in 2022 and 2023 (Table 5). Hexazinone at 1 lb/A provided 1.3- to 1.5-times greater visual control than hexazinone at 0.5 lb/A at 30 and 60 DAT in 2022 and 2023. Smutgrass density reduction was 2.2 and 2.1-times greater at 30 and 60 DAT, respectively when hexazinone was applied at 1 lb/A compared to 0.5 lb/A in 2022. In 2023, density reduction was 1.8- and 1.3-times greater at 30 and 60 DAT, respectively, when smutgrass was treated with 1 lb/A compared to 0.5 lb/A.

The interaction of application time x hexazinone rate was significant for visual control and density reduction 30 and 60 DAT in 2022 and 2023 except for visual control 60 DAT and density reduction 30 DAT in 2022 (Table 6). In 2022, mid-season applications of hexazinone at 1 lb/A resulted in the greatest visual control at 30 DAT, with control estimated at 1.5-times greater than all other application times regardless of hexazinone rate, but no differences were detected by 60 DAT. In 2023 at 30 DAT, early- and mid-season applications of hexazinone at 1 lb/A resulted in 78 and 68% control, respectively, but control following application of 0.5 lb/A during the mid-season was similar to the high rate applied at the same timing. By 60 DAT there were no differences in application timing when hexazinone was applied at 1 lb/A and the mid-season application of 0.5 lb/A. Density reductions followed the same general trends as observed with visual estimates of control. In 2022, mid-season applications of hexazinone at 1 lb/A resulted in the greatest density reduction (60%) at 60 DAT while in 2023 early- and mid-season applications of hexazinone at 1 lb/A and mid-season applications of hexazinone at 0.5 lb/A resulted in the greater density reduction at both 30 and 60 DAT.

Although there was a significant hexazinone rate x nitrogen dose interaction for density reduction data in 2023, there is no indication that increasing the nitrogen dose will increase small smutgrass control as density was reduced by no more than 61% (data not shown) following any combination of hexazinone with or without nitrogen. Furthermore, this interaction was not significant for visual estimates of control at 30 and 60 DAT nor density reduction at 60 DAT.

Table 4. Small smutgrass visual control and density reduction 30 and 60 DAT at three application times in 2022 and 2023 at Mariana, FL[a].

Application time	Visual control				Density reduction			
	30 DAT		60 DAT		30 DAT		60 DAT	
	2022	2023	2022	2023	2022	2023	2022	2023
	---------------% control----------------				-------------------% reduction-----------			
Early	36 b	56 b	27 b	52 b	18 b	36 b	26 b	53 b
Mid	46 a	65 a	59 a	67 a	28 a	64 a	44 a	70 a
Late	36 b	48 c	27 b	60 ab	8 c	12 c	8 c	49 b
P-value	0.0044	0.0002	0.0002	0.0017	0.0004	0.0001	0.0002	0.0003

[a]Means of a response variable within a single year with different letters are significantly different at $P \leq 0.05$. There was a significant effect of year x application time ($P = 0.0368$), so data were analyzed per year.

Table 5. Small smutgrass visual control and density reduction 30 and 60 DAT at two hexazinone rates in 2022 and 2023 at Mariana, FL[a].

Rate (lb/A)	Visual control				Density reduction			
	30 DAT		60 DAT		30 DAT		60 DAT	
	2022	2023	2022	2023	2022	2023	2022	2023
	-----------------% control ----------------				-----------------% reduction----------			
0.50	33 b	46 b	32 b	52 b	11 b	26 b	17 b	49 b
1.00	45 a	67 a	43 a	67 a	24 a	48 a	35 a	66 a
P-value	0.0002	0.0006	0.0005	0.0006	0.0003	0.0006	0.0002	0.0001

[a]Means of a response variable within a single year with different letters are significantly different at $P \leq 0.05$.

Table 6. Small smutgrass visual control and density reduction 30 and 60 DAT with application time x hexazinone rate in 2022 and 2023 at Mariana, FL[a].

Time	Rate (lb/A)	Visual control				Density reduction			
		30 DAT		60 DAT		30 DAT		60 DAT	
		2022	2023	2022	2023	2022	2023	2022	2023
		----------------% control-----------------				-------------% reduction ------------------			
Early	0.50	30 b	34 e	21 a	35 c	11 a	9 b	19 bc	35 d
	1.00	41 b	78 a	31 a	69 a	24 a	63 a	32 b	71 a
Mid	0.50	31 b	63 bc	52 a	67 ab	18 a	60 a	28 b	68 ab
	1.00	60 a	68 ab	66 a	66 ab	37 a	68 a	60 a	71 ab
Late	0.50	37 b	42 de	23 a	53 b	4 a	10 b	4 c	42 cd
	1.00	36 b	54 cd	31 a	67 a	12 a	14 b	12 c	56 bc
P-value		0.0003	0.0001	0.6919	0.0001	0.5797	0.0001	0.0088	0.0008

[a]Means of a response variable within a single year with different letters are significantly different at P ≤ 0.05. There was a significant effect of year x application time x hexazinone rate (P = 0.0477) on all four response variables, so data were analyzed per year.

Smutgrass control discussion. Overall, fluctuations in visual control and density reduction were observed across application times for both species. These variations may be attributed to rainfall within 7 days after treatment (DAT) as previous research by Dias (2019) determined that the optimum rainfall range for smutgrass control was 6-to 77-mm (0.25- to 3 in) within 7 days of hexazinone application. In the mid-season of 2022 and both the mid- and late- seasons of 2023, greater giant smutgrass control was observed, coinciding with optimal rainfall within 7 DAT (31 mm (1.2 in), 18 mm (0.7 in), and 27 mm (1.1 in), respectively). Conversely, the early season of 2022 experienced below-optimal rainfall (4 mm (0.2 in)), while 2023 had above-optimal rainfall (83 mm (3.3 in)). Additionally, the exceptionally high rainfall (128 mm (5.0 in)) following the late- season of treatments in 2022 likely resulted in hexazinone leaching below the root zone of smutgrass plants. Similarly, for small smutgrass, superior visual control and density reduction were observed during the mid-season application of hexazinone in 2022, while in 2023, early- and mid-season applications resulted in greater efficacy. At Mariana, in 2022, early (10 mm (0.4 in)) and late season (0 mm) rainfall was below the optimal range, whereas mid-season received optimal rainfall (33 mm (1.3 in)). However, in 2023, early and mid-season rainfall (22 mm (0.9 in) and 18 mm (0.7), respectively) fell within the optimal range, while late-season rainfall (9 mm (0.4 in)) was below optimal. In summary, mid-season applications consistently demonstrate effective smutgrass control for both species, which supports previous research findings. Mislevy et al. (1999) identified summer and fall applications as optimal for smutgrass control. Later, Howard et al. (2023) reported summer application as the most effective timing for smutgrass control.

Furthermore, for both species, hexazinone at 1 lb/A provided greater visual control and density reduction compared to hexazinone at 0.5 lb/A. This could be due increasing lethal effect of hexazinone on smutgrass while doubling its dose. Interestingly, mid-season application of hexazinone 0.5 lb/A showed a similar response to 1 lb/A for visual control 60 DAT in giant smutgrass and for visual control and density reduction 30 and 60 DAT in small smutgrass in 2023. This could be due to inconsistencies associated with hexazinone at 0.5 lb/A. Mislevy et al. (1999) observed 86 to 91% smutgrass control with hexazinone at 0.5 lb/A. But, Wilder et al. (2011) showed that hexazinone at 0.5 lb/A provided below 60% control of both species of smutgrass. Similarly, Rana et al. (2015) observed no giant smutgrass control with 0.5 lb/A of hexazinone. Dias (2019) also confirmed the high degree of inconsistencies with hexazinone at 0.5 lb/A.

In contrast to giant smutgrass, we observed the significant effect of nitrogen on small smutgrass density reduction at 60 DAT. Co-applied nitrogen at or above 28 kg ha^{-1} resulted in at least 1.37 times greater control compared to hexazinone alone (Table 6). Although this only occurred in one site-year, this might be due to the increased competitive ability of bahiagrass with the increasing nitrogen dose. Applied hexazinone injured the bahiagrass, meanwhile, co-applied nitrogen promoted bahiagrass recovery and growth competing with the dying smutgrass. The previous findings from Shay et al. (2022) also corroborate this result. The author further mentioned the hexazinone application suppressed smutgrass competition with bahiagrass while nitrogen and potassium addition provided essential nutrients for the bahiagrass to increase groundcover. However, we did not observe the nitrogen effect on giant smutgrass density reduction. This result on giant smutgrass is in contrast with the findings from the preliminary research in which hexazinone at 1.12 and 0.5 lb/A were applied with water or urea ammonium nitrate as a carrier (Sellers and Dias, 2020). Hexazinone at 0.5 lb/A with nitrogen at 56 kg ha^{-1} resulted in 1.4-times greater giant smutgrass visual control and 2.2-times greater density reduction compared to hexazinone alone at the same rate and was similar that of hexazinone alone at 1 lb/A. One of the possible reasons for the deviation in the result could be due to the use of a different sprayer. A PTO-driven tractor sprayer was used where there was continuous agitation of the spray solution in the previous research. However, in the current study, agitation was not possible due to the compressed air systems utilized for treatment applications. In addition, the variation in observation location-wise (species-wise) could be due to the difference in the coverage of smutgrass and bahiagrass. At Ona, smutgrass coverage on the bahiagrass pasture was 90% while at Mariana was 60%. When the bahiagrass coverage is higher, overall competitive ability is higher exerting more pressure on smutgrass. Ferrell et. al (2006) also observed a similar result on the competitive ability of bahiagrass with the smutgrass. The author mentioned that bahiagrass was able to compete with smutgrass at low density while unable to do so at higher infestation levels.

Bahiagrass biomass. Data were analyzed by site-year due to the significant effect of site-year x application time (P = 0.0001), site-year x hexazinone rate (P= 0.0367), and site-year x application time x hexazinone rate (P = 0.0307) on bahiagrass cumulative biomass. The main effect of application time was significant for bahiagrass cumulative biomass in all site-years (Table 7). At Ona, late application of hexazinone resulted in the greatest cumulative biomass (118%), and it was at least 1.4-times greater than when hexazinone was applied at the mid-and early-application timings (≤ 85%) in 2022. Conversely, cumulative bahiagrass biomass was at least 1.1-times greater following the early application timing compared to mid- and late-season application timings in 2023. At the Marianna location in 2022, cumulative bahiagrass biomass was >100% of the non-treated control with only the early-season application resulting in 1.2-times greater bahiagrass biomass than the late-season application of hexazinone. The fluctuation in cumulative biomass could be associated with the rainfall within 7 DAT. At Ona, in 2022, 128 mm (5 in) of rainfall were recorded within 7 DAT of the late-season application of treatments (Table 2-1). This could have resulted in significant leaching and less injury to bahiagrass. In 2023, 83 mm (3.3 in) of rainfall were recorded within 7 DAT following the early-season application of hexazinone. Similarly, at Mariana, rainfall that fell within 7 DAT following the early- and mid-season applications was 10 mm (0.4 in) and 33 mm (1.3 in), respectively, but no rainfall was recorded within 7 DAT following the late-season application. In addition, during the late season, the first harvest (30 DAT) was followed by a long dry period resulting in very low regrowth.

Similarly, hexazinone rate was significant for cumulative bahiagrass biomass at Ona in 2023 and at Mariana (Table 8). Hexazinone 0.5 lb/A resulted in 1.1- times greater biomass than when hexazinone was applied at 1 lb/A. Similarly at Mariana, the application of hexazinone at 0.5 lb/A resulted in 1.3-fold greater biomass than hexazinone at 1 lb/A. However, in 2023 at Ona, there was a significant interaction of application time by hexazinone rate on bahiagrass cumulative biomass (Table 9). Mid- and late-season applications of hexazinone at 1 lb/A resulted in biomass which was 1.3-fold lower than early application, which is likely attributed to the differences in rainfall within 7 DAT as discussed previously.

Nitrogen dose significantly influenced the cumulative bahiagrass biomass in all site years. Cumulative biomass increased linearly with increasing nitrogen dose. Moreover, it revealed that with every 1 kg ha^{-1} increase in nitrogen dose, there was a 9.03, 13.45, and 13.28% increase in cumulative biomass in 2022 (Figure 1) and 2023 (Figure 2-2) at Ona and in 2022 at Mariana, respectively. Furthermore, at Ona in 2022 nitrogen applications at or above 42 kg ha^{-1} were fully able to recover the bahiagrass biomass beyond the non-treated control while in 2023 nitrogen application at 56 kg ha^{-1} resulted in bahiagrass biomass above the non-treated control. Additionally, at Mariana, the co-applied nitrogen at or above 28 kg ha^{-1} exceeded bahiagrass biomass of the non-treated control.

In all site years, the low rate of hexazinone (0.5 lb/A) typically resulted in greater biomass compared to the hexazinone applied at 1 lb/A. The results corroborate the findings of Sellers et al. (2008) who reported that 0.5 lb/A resulted in insignificant bahiagrass injury while 1 lb/A resulted in a 9–38% reduction in cumulative dry biomass of bahiagrass. Similarly, in both locations, increasing nitrogen dose linearly increased cumulative biomass. This could be due to co-applied nitrogen enhancing the recovery and growth rate of bahiagrass. Hexazinone is injurious to bahiagrass, however, the co-applied nitrogen likely enhanced the recovery and growth rate of injured bahiagrass. The observations are comparable to the results of Silveira et. al (2015) who reported a 50–60% cumulative bahiagrass dry matter increase following treatment with 60–120 kg ha^{-1} nitrogen compared to the control. The authors further indicated that increasing nitrogen dose did not only have a linear connection with cumulative dry matter yield but also with crude protein. Furthermore, Obour et. al (2009), Newman et al. (2009), and Sigua et. al (2012) observed a linear association between increasing nitrogen with dry matter yield and crude protein in bahiagrass, limpograss (*Hemarthria altissima* Stapf & Hubb), and maidencane (*Panicum hemitomon* Schult), respectively.

Table 7. Cumulative bahiagrass biomass (% of untreated) with application time in 2022 and 2023 at Ona, and in 2022 at Mariana, FL[a].

Time	Ona[b]		Mariana
	2022	2023	2022
	---%	--------------------------------------	
Early	85 b	93 a	127 a
Mid	79 b	78 b	118 ab
Late	119 a	81 b	107 b
P-value	0.0001	0.0041	0.0204

[a]Means of a response variable within a single year with different letters are significantly different at P ≤ 0.05. There was a significant effect of site-year x application time (P = 0.0001) for cumulative biomass, so data were analyzed per year.
[b]Control plot biomass was 2357, 2658, and 1969 lb/A for early, mid, and late seasons, respectively for Ona 2022. Similarly, the control plot biomass was 2475, 1720, and 519 lb/A for early, mid, and late seasons, respectively for Ona 2023. The control plot biomass was 1838, 2226, and 797 lb/A for early, mid, and late seasons, respectively.

Table 8. Cumulative bahiagrass biomass (% of untreated) with hexazinone rate in 2022 and 2023 at Ona, and in 2022 at Mariana, FL[a].

Rate (lb/A)	Ona		Mariana
	2022	2023	2022
	---%	--	
0.50	99 a	90 a	132 a
1.00	89 a	79 b	103 b
P-value	0.1177	0.0037	0.0001

[a]Means of a response variable within a single year with different letters are significantly different at P ≤ 0.05. There was a significant effect of site-year x application time (P = 0.0367) for cumulative bahiagrass biomass, so data were analyzed per year.

Table 9. Cumulative bahiagrass biomass (% of untreated) with application time by hexazinone rate in 2022 and 2023 at Ona, and in 2022 at Mariana, FL[a].

Time	Rate (lb/A)	Ona		Mariana
		2022	2023	2022
		---------------------------	%	---------------------------
Early	0.50	98 a	92 a	127 a
	1.00	71 a	94 a	107 a
Mid	0.50	83 a	86 ab	139 a
	1.00	74 a	70 b	115 a
Late	0.50	116 a	91 a	128 a
	1.00	122 a	72 b	87 a
P-value		0.1051	0.0387	0.2535

[a]Means of a response variable within a single year with different letters are significantly different at $P \leq 0.05$. There was a significant effect of site-year x application time x hexazinone rate ($P = 0.0307$) for cumulative bahiagrass biomass, so data were analyzed per year.

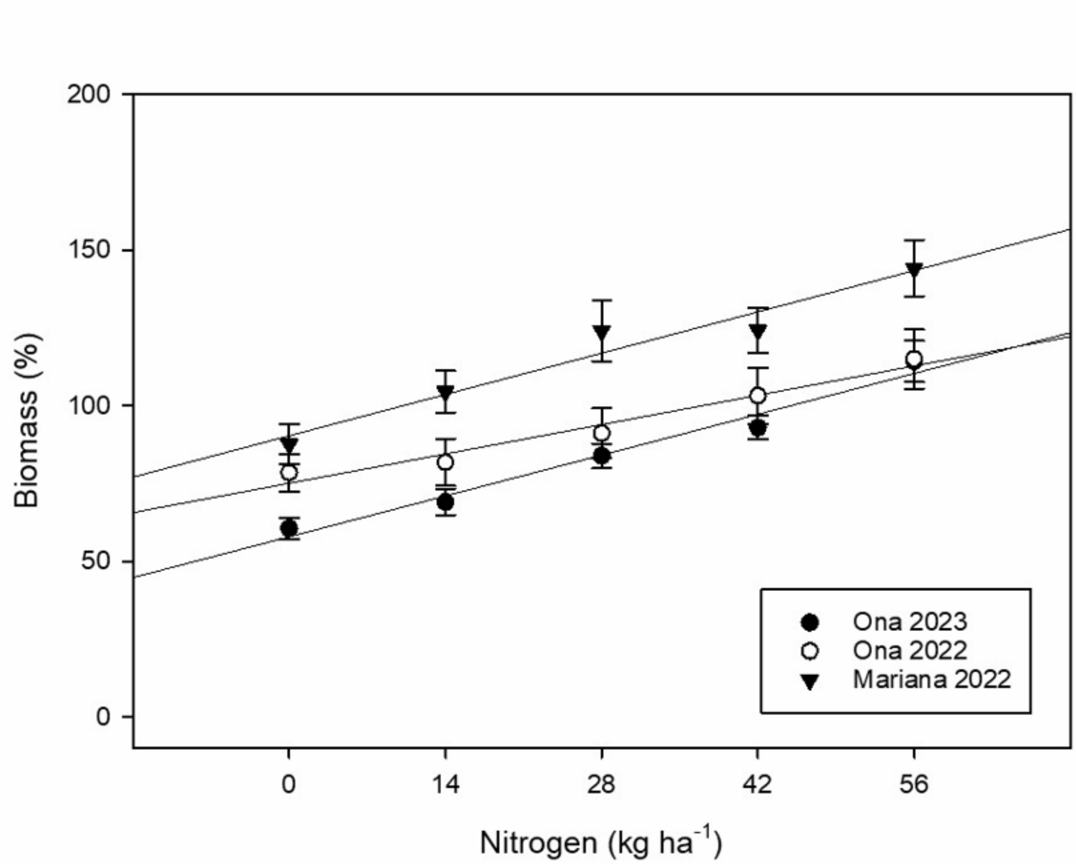

Figure 1. Cumulative biomass in response to increasing nitrogen dose for each site- year. Nitrogen levels were maintained at 0, 14, 28, 42, and 56 kg ha 1. Data were averaged across application time and hexazinone rate. Control plot biomass for three site years was 2328, 1571, and 1620 lb/A for Ona 2022, Ona 2023, and Mariana 2022, respectively. Predicted lines are plotted with the mean and standard error. The predicted model for Ona 2022: y = 9.43x + 75 (R^2=0.10); for Ona 2023 is y = 13.14x + 57.87 (R^2=0.41); for Mariana 2022 is y = 13.28x + 90.36 (R^2=0.19), where y= bahiagrass biomass, a = slope, and b is intercept.

Effect of soil surfactants on hexazinone activity.

Field experiments. The addition of surfactants at Ona did not have any impact on giant smutgrass visual control at 30 (P=0.2817) and 60 DAT (P=0.2240) and density reduction at 30 DAT (P=0.3910; Table 10). There was a significant interaction of year by hexazinone rate (P-value= 0.0373) for density reduction at 60 DAT; therefore, data were analyzed by year. In 2022, adding Grounded to hexazinone resulted in a greater (71%) density reduction than adding Breakthru and no surfactant addition (<44%) at 60 DAT (Table 10), and only Grounded was found to provide greater control than hexazinone alone. Similarly, the addition of Grounded to hexazinone was also the only surfactant to provide greater control than hexazinone alone in 2023. However, control with Nanopro was similar to that with Grounded. Similar to giant smutgrass, surfactant addition had no impact on visual control 30 and 60 DAT and density reduction 30 DAT on small smutgrass in Marianna. In addition, for small smutgrass, contrary to giant smutgrass, we did not observe the influence of surfactant on small smutgrass density reduction (Table 11).

Table 10. Giant smutgrass visual control and density reduction at 30 and 60 DAT when using different surfactants with hexazinone in a field experiment at Ona, FL[a].

Surfactants	Visual control		Density reduction		
	30 DAT	60 DAT	30 DAT	60 DAT	
				2022	2023
	----------------control (%) -------		-------------------reduction (%) --------------		
Grounded	65 a	63 a	45 a	71 a	80 a
Nanopro	63 a	60 a	35 a	64 ab	71 ab
Sorbyx	66 a	62 a	38 a	57 abc	68 b
Breakthru	59 a	53 a	33 a	42 c	65 b
None	59 a	56 a	34 a	44 bc	67 b
P-value	0.2817	0.2240	0.5934	0.0011	0.0040

[a]Means within a year followed by the same letters are not significantly different according to TukeyHSD test at P ≤ 0.05.

Table 11. Small smutgrass visual control and density reduction at 30 and 60 DAT when using different surfactants with hexazinone in a field experiment at Mariana, FL[a].

Surfactants	Visual control		Density reduction	
	30 DAT	60 DAT	30 DAT	60 DAT
	-----------------control (%)----------		---------------reduction (%)--------------	
Grounded	50 a	54 a	55 a	59 a
Nanopro	57 a	62 a	61 a	65 a
Sorbyx	49 a	59 a	53 a	57 a
Breakthru	49 a	62 a	49 a	54 a
None	50 a	55 a	47 a	51 a
P-value	0.4131	0.4571	0.3079	0.0554

[a]Means followed by the same letters are not significantly different according to TukeyHSD test at P ≤0.05.

Greenhouse experiment. The addition of surfactants to hexazinone resulted in increased control compared to hexazinone alone at 30 DAT (Figure 3-1). This is exemplified by the differences in the range of rainfall that resulted in at least 80% control. For example, the rainfall range for at least 80% control following the addition of Grounded, Nanopro, and Sorbyx were determined to be 5- to 33-mm (0.2- to 1.3-in), 4- to 19-mm (0.2- to 0.7-in), and 4-43-mm (0.2- to 1.7-in), respectively, while the rainfall range to obtain at least 80% control with hexazinone alone was determined to be 9- to 24-mm (0.4- to 0.9-in). Additionally, adding surfactants to hexazinone resulted in peak visual estimates of control of >93% with 13-16 mm (0.5–0.6 in) rainfall while hexazinone only resulted in 86% control with 0.6 in rainfall.

Smutgrass biomass was also impacted by the addition of surfactants to hexazinone. Adding surfactants to hexazinone resulted in lower biomass compared to hexazinone alone at 30 DAT (Figure 3-2) and 60 DAT (Figure3-3). This is confirmed by the rainfall range for less than 50% biomass at 30 DAT and less than 20% regrowth biomass at 60 DAT. Hexazinone along with the Grounded, Nanopro, and Sorbyx resulted in less than 50% biomass at 5- to 100-mm (0.2- to 3.9-in), 0- to 45-mm (0- to 1.8-in), and 0- to 80-mm (0- to 3.1-in), respectively, while for hexazinone alone it was estimated to be 16- to 33-mm (0.6- to 1.3-in). Moreover, the least biomass by the hexazinone alone was 1.1–1.3-fold greater than applying hexazinone with surfactants. Similarly, for regrowth biomass at 60 DAT, surfactant addition widened the rainfall range compared to hexazinone alone. For example, the rainfall range for less than 20% regrowth following the application of hexazinone with Grounded, Nanopro, and Sorbyx was estimated to be 4- to 80-mm (0.2- to 3.1-in), 4- to 75-mm (0.2- to 3.0-in), and 4- to 95-mm (0.2- to 3.7-in), respectively, while for hexazinone alone it was estimated to be 7-to 60-mm (0.3- to 2.4-in). Furthermore, adding surfactants to hexazinone resulted in at least 4.9-fold greater biomass reduction compared to that treated with hexazinone alone.

Overall, the results indicate that hexazinone efficacy requires rainfall for giant smutgrass control as demonstrated by previous research on giant smutgrass (Dias, 2019). Adding surfactants extended the rainfall range, increased the maximum control, and reduced biomass compared to hexazinone alone. The observations could be attributed to surfactants enabling hexazinone molecules to bind with soil particles and gradually release them, resulting in prolonged hexazinone availability in the soil solution and increased efficacy. Interestingly, Nanopro and Sorbyx showed less than 50% biomass at 30 DAT even with zero rainfall; this might be due to applied treatment directly intercepting on the soil surface without any interception from the foliage part of giant smutgrass and further facilitation of hexazinone absorption by the applied surfactants. The current study considers the ≤20% regrowth biomass as the ideal smutgrass control indicator. Hexazinone alone had a rainfall range of 7–to 60-mm (0.3- to 2.4-in), whereas surfactants extended the range from 4-to 95-mm (0.2- to 3.7-in). The results corroborate the findings of Kočárek et al. (2018) who reported significantly improved herbicide sorption of pendimethalin with the surfactant Grounded, which increased its retention in topsoil demonstrating that Grounded can bind herbicide molecules in the soil. Similarly, Nanopro which uses nanoparticle technology has been reported to aid in the bioavailability of active ingredients to plants while reducing waste products (Dasgupta et al. 2015). de Oliveria et al. (2015) found that the pre-emergence application of nanoparticles containing atrazine and simazine was more efficient on controlling of wild radish (*Raphanus raphanistrum* L.). Furthermore, Sorbyx has been reported to show consistent control of redroot pigweed (*Amaranthus retroflexus*) and common lambsquarter (*Chenopodium giganteum*) when applied with the herbicide sonalan (Ethalfluralin) in silt loam soils (NDSU, 2015).

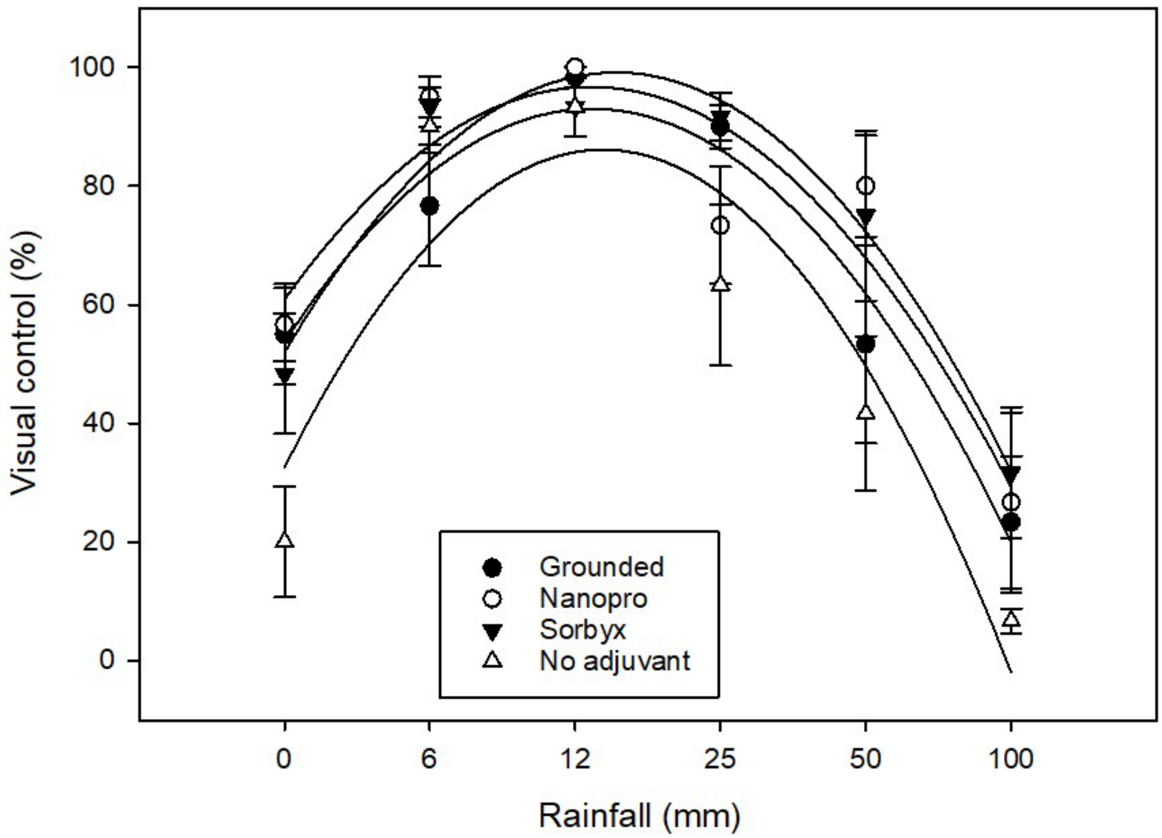

Figure 3-1. Visual estimates of giant smutgrass control 30 days after treatment (DAT) in response to increasing rainfall accumulation volumes (0, 6, 12, 25, 50, and 100mm) for each surfactant including hexazinone alone (no surfactant). The predicted model for Grounded: $y = 37.14x^2 - 8.78x + 53.75$, ($R^2$=0.54); for Nanopro: $y = 33.99x^2 - 8.07x + 60.89$, ($R^2$=0.52); for Sorbyx: $y = 41.4x^2 - 9.08x + 51.96$, ($R^2$=0.57); and for No surfactant: $y = 48.9x^2 - 11.16x + 32.56$, ($R^2$= 0.61); where y= visual control (%), and x = rainfall accumulation volume (mm).

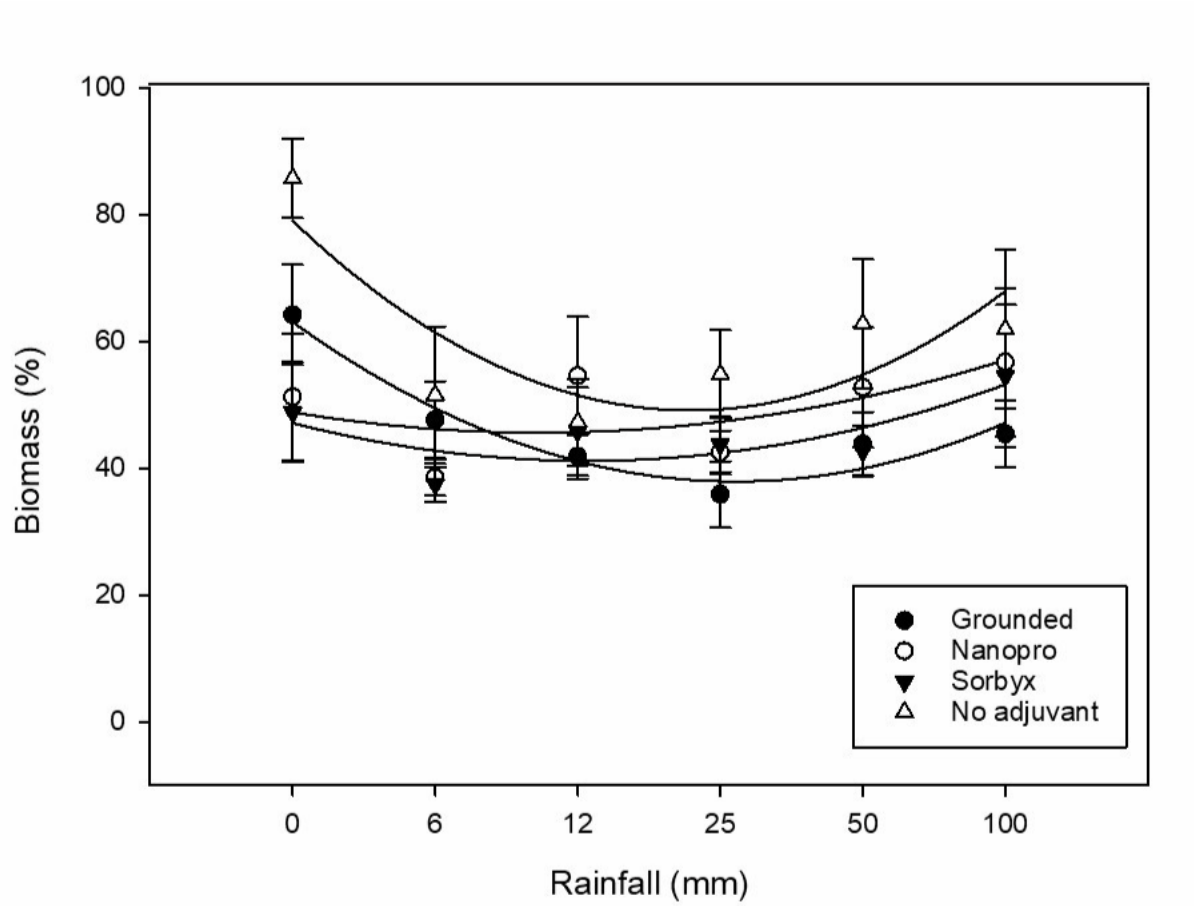

Figure 3-2. Dry biomass (% of untreated) of giant smutgrass 30 days after treatment (DAT) in response to increasing rainfall accumulation volumes (0, 6, 12, 25, 50, and 100mm) for each surfactant including hexazinone alone (No surfactant). Predicted lines are plotted with the mean and standard error. The predicted model for Grounded: $y = -16.17x^2 + 2.6x + 63.05$, ($R^2$=0.3); for Nanopro: $y = 7.18x^2 + 1.38x + 7.637$, ($R^2$=0.04); for Sorbyx: $y = -5.77x^2 +1.4x + 47.12$, ($R^2$=0.06); and for No surfactant: $y =-21.44x^2+ 0.85x + 79$, (R^2= 0.18); where y = smutgrass biomass (% of untreated control), and x = rainfall accumulation volume (mm).

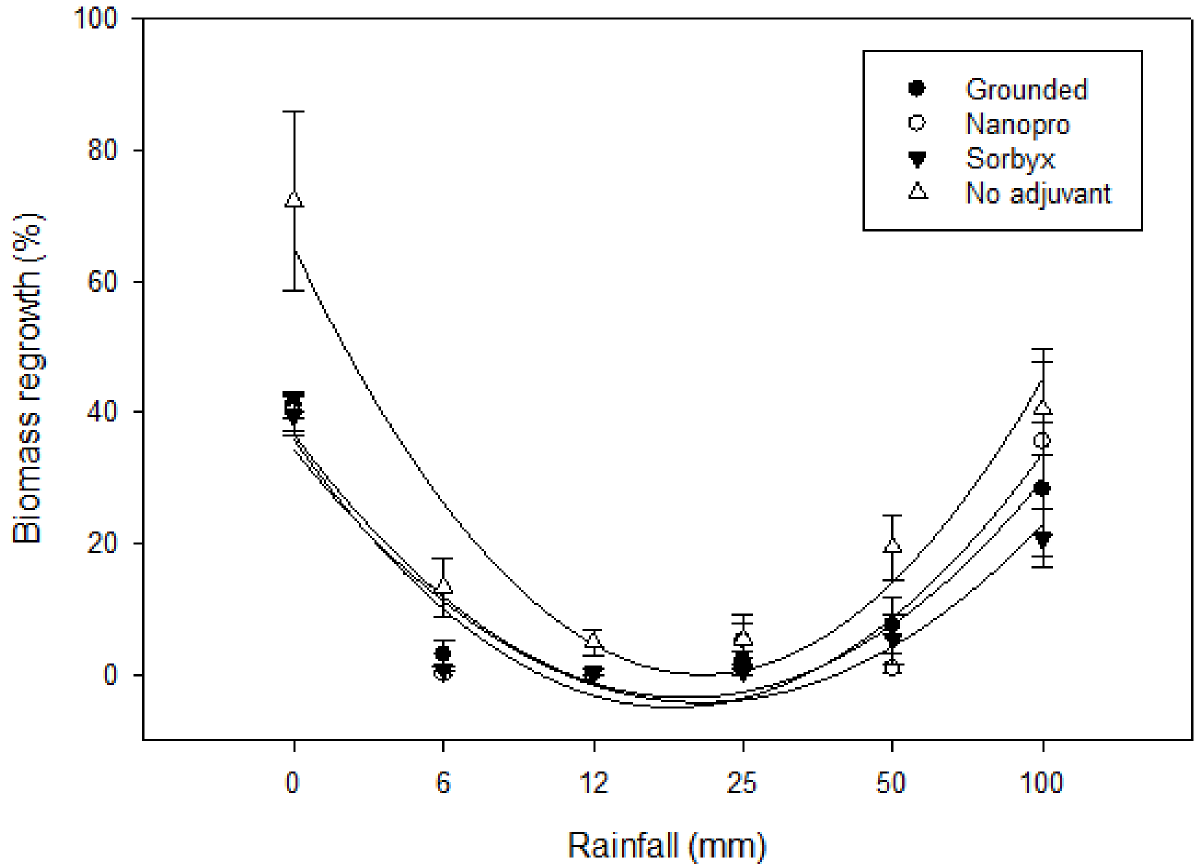

Figure 3-3. Biomass regrowth (% of untreated) of giant smutgrass 60 days after treatment (DAT) in response to increasing rainfall accumulation volumes (0, 6, 12, 25, 50, and 100mm) for each surfactant including with hexazinone alone (No surfactants). Predicted lines are plotted with the mean and standard error. The predicted model for Grounded: $y = -30.63x^2 + 0.79x + 36.56$, ($R^2$=0.6); for Nanopro: $y = -32.21x^2 + 6.36x + 35.86$, ($R^2$=0.53); for Sorbyx: $y = -32.21x^2 + 6.36x + 34.35$, ($R^2$=0.74); and for No surfactant: $y = -47.68x^2 + 8.74x + 65.12$, ($R^2$= 0.64); where y= smutgrass regrowth biomass (% of untreated control), and x = rainfall accumulation volume (mm).

MANAGEMENT AND IMPLICATIONS

Without continuous agitation, the addition of liquid UAN fertilizer to hexazinone has little to no impact on smutgrass control; however, research comparing non-agitated spray solution vs. agitated spray solution has not been investigated. Therefore, considering the results of this research, UAN does not increase smutgrass control, but it could help bahiagrass recovery following hexazinone applications. This could be important in providing increased bahiagrass biomass as well as a competitive ability over smutgrass regeneration from seed.

As research has shown that rainfall is a requirement for hexazinone activity, the addition of soil surfactants significantly enhanced hexazinone efficacy and further broadened the rainfall range, allowing efficacy at lower and higher rainfall amounts compared to hexazinone without a surfactant. Both the greenhouse and field experiments especially in Ona, showed that surfactant addition is beneficial and could be valuable practice for improving hexazinone efficacy.

Percent Completion: 100%

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Principal Investigator:	Sellers,Brent Alan
Award Begin Date:	10/30/2023
Award End Date:	07/31/2024
UF FEIN:	59-6002052

Sponsor Award ID:	58
Award Title:	Utility of Liquid Nitrogen Fertilizer and Soil Surfactants for Smutgrass Control with Hexazinone
Award Amount:	$34,419.00

Invoice #	I000130450
UF Award #	AWD15793
Primary Project #	P0324584
Primary Department:	60780000
Current Invoice Amount:	$21,021.93

Description	Current	Cumulative
Personnel - Salary	$10,913.95	$15,319.58
Personnel - Fringe Benefits	$1,283.19	$1,803.05
Tuition	$3,252.38	$9,757.13
Domestic Travel	$3,320.07	$3,320.07
Direct Cost	$18,769.59	$30,199.83
Facilities and Administrative Costs	$2,252.34	$3,623.97
Total	$21,021.93	$32,823.80

For billing questions, please call 352.392.1235
Brown,Katrina Adel brownk3@ufl.edu
Please reference the UF Award Number and Invoice Number in all correspondence

By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil, or administrative penalties for fraud, false statements, false claims or otherwise. (U.S Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812).

Payment History	
Cumulative Invoices:	$32,823.80
Payments Received:	$12,801.87
Outstanding Balance:	$21,021.93
Note: Outstanding balance includes current invoice amount	

Katrina Brown

Certifying Official

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Project ID	Deptid	Department Name	Current	Cumulative
P0324584	60780000	AG-RCREC-ONA	$21,021.93	$32,823.80