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Response of Non-Irrigated Peanut to Multiple Rate Delayed Flumioxazin Applications

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Abstract: Flumioxazin is crucial for peanut weed management across the United States with over 75% of growers applying it to control troublesome weed species. For maximum peanut yield, it is essential that weed control is maintained during weeks three through eight after planting. Peanut injury due to flumioxazin PRE applied has been noted under unfavorable moisture or weather conditions, but also due to delays in application as growers plant hundreds of hectares on their farms. Research in Georgia (GA) investigated the response of non-irrigated peanut to flumioxazin PRE applied from 0 to 107 g ai/ha at 0 to 14 d after planting for cultivar Georgia-16HO. Trends during the 2020 through 2022 growing seasons indicated that as rate and time after planting of application increased, injury increased. Over 50% injury was noted in Tift County and 24% in Sumter County during the 2021 growing season. Peanut pod yield decreased while flumioxazin rate increased and time of application after planting was delayed in Tift County, but no differences were noted in Sumter County, potentially due to soil adsorption of the herbicide. Yield differences of up to 800 kg/ha were noted when comparing no herbicide being applied to the full application rate. The recorded injury coincided with large amounts of rainfall at both locations. It was also noted that peanut may be most sensitive to flumioxazin application injury between days seven and ten after planting.

Keywords: flumioxazin; peanut; rate response; application timing; injury

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1. Introduction

Peanut (*Arachis hypogaea* L.) has become an important source of oil and protein over time. South America is the origin of the peanut, though the name has been changed numerous times [1]. The Incan civilization referred to peanut as *ynchic* and was changed by the Spanish conquistadors to *mani*, which is still used in many Spanish speaking countries such as Cuba [1]. As exploration and religious missionary expeditions increased, the names of peanut also began to increase and included *mandi*, *manobi*, *manduiss*, *mandubi*, *amendois*, and *tlalcacuatl* (German, French, Spanish, Spanish, Portuguese, Nahuatl, respectively). Wild-types *Arachis ipaensis* (Krapov. and W.C. Gregory) and *Arachis duranensis* (Krapov. and W.C. Gregory) are the parents of *Arachis hypogaea* (L.) which is the commercially grown peanut and contains two subspecies: *Arachis hypogaea* sp. *hypogaea* (L.) and *Arahcis hypogaea.* sp. *fastigiata* (L.) [2]. The runner and virginia-type peanut belong to the sp. *hypogaea* and the spanish and valencia type peanut belong to the sp. *fastigiata*. The difference between the subspecies is whether flowers are produced along the main stem (sp. *fastigiata*) or not (sp. *hypogaea*) [3]. The introductory time and place in the United States has never been fully identified for peanut due to lack of written records. The commonly accepted introduction was through Portuguese and Spanish traders en route to Africa. The traders would then bring cargo to the United States where peanut was used as a food supply due to the non-perishing properties. The American Civil War played a major role in the distribution and popularity of peanut as soldiers needed easily transportable food that was high in protein and nutrients. The Department of Agriculture reported an annual increase in peanut production of 200 to 300% between 1865 to 1870, with 37 states planting peanut in 1889 [4]. This distribution led to peanut primarily being grown in the Southeast, the East coast, and the Southwest [2,4,5].

Peanut producers in GA averaged 4600 kg/ha with 1.49 billion kg produced in the 2020 growing season representing over half of the total United States supply. Each peanut growing region has a dominant market-type produced. Georgia predominately produces runner-type peanut as compared to the Spanish, Valencia, or Virginia-types of peanut grown in Texas and Oklahoma, New Mexico and West Texas, and mid-Atlantic coast, respectively.

Many biotic and abiotic factors have the potential to severely hinder peanut growth and development resulting in decreased quality or yield. Drought or excessive rainfall, disease, weeds, insect pressure, and damaging winds during the season are examples of stresses peanut can encounter during a growing season. One factor that must be adequately controlled is the weed species population. Weeds can harbor disease and insects as well as compete with peanut for space, water, nutrients, and sunlight [6,7]. Everman et al. [8] indicated that peanut yields decreased as competition time with broadleaf or grass weed species increased. The investigators indicated that it was weed species specific as to how much yield could be lost if not controlled by a certain time in the growing season. Data indicated yield was affected if control was not maintained by 8 to 10 weeks after planting for broadleaf weed species and 5 to 8 weeks for grass weed species. Weed control is primarily accomplished through chemical applications due to their availability, ease of use, and effectiveness. Herbicides can be applied before (PRE) or after (POST) crop emergence to provide season long weed control.

An effective and widely used PRE herbicide in peanut production is flumioxazin (2-[7-fluoro-3,4-dihydro3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione). Flumioxazin was applied by growers across the entire peanut Southeastern growing region with 74, 64, 62, and 58% of Georgia, North Carolina, Florida, Alabama, and South Carolina hectares treated in 2018, respectively [9]. Flumioxazin at 107 g ai/ha provides residual control of broadleaf species including pigweeds (*Amaranthus* sp.), Florida beggarweed (*Desmodium tortuosum* Sw.) DC., and kochia (*Kochia scoparia* L.) Schrad., and suppression of grass species barnyardgrass (*Echinochloa crus-galli* L.) Beauv., large crabgrass (*Digitaria sanguinalis* L.), and Italian ryegrass (*Lolium perenne* L. spp. *multiflorum* Lam.) Husnot [10]. The mechanism of action of flumioxazin will affect the plant chlorophyll and heme production by preventing proper function of the protoporphyrinogen oxidase (PPG oxidase) [11]. Flumioxazin will bind to the PPG oxidase and prevent the conversion of protoporphyrinogen IX into protoporphyrin IX causing an overflow of protoporphyrinogen IX to leak from the chloroplast into the cell cytoplasm. Once in the cytoplasm, the protoporphyrinogen IX will be converted into protoporphyrin IX and begin to accumulate light energy. As this occurs, the protoporphyrin IX will begin to develop triplet and singlet oxygen species that will interact and degrade lipids and proteins, leading to leaky membranes and allow rapid desiccation of cells. Flumioxazin can be absorbed either through foliage or roots but has limited foliar translocation due to rapid onset of necrosis on treated foliage [11]. Hurdle et al. [12] reported that peanut seed germination was affected more by cool temperatures than direct exposure to flumioxazin due to rapid root metabolism. It has been noted that injury can be caused by overhead irrigation or rainfall by splash from water droplets carrying flumioxazin onto green plant matter [13]. The registration label states that flumioxazin should not be applied more than 2 days after planting due to potential injury [10]. As growers are now planting large peanut hectarages in this region of the world with approximately 81 ha/farm [9], timely PRE herbicide applications can be challenging. Thus, flumioxazin applications can be delayed as growers expand peanut production on their respective farms.

Flumioxazin has been extensively researched under irrigated field conditions with respect to weed control and peanut response [14–17], but this leaves peanut growers with little information about the response of non-irrigated peanut to flumioxazin. Therefore, research was conducted to evaluate peanut physiological response under non-irrigated conditions to flumioxazin rate and timing of application.

2. Materials and Methods

2.1. Site Description

Non-irrigated peanut field experiments were conducted in Tift county, Georgia (31.49 N, −83.52 W) and the Southwest Research and Education Center in Sumter County, Georgia (32.03 N, −84.37 W) from 2020 through 2022. Soil type in Tift County consisted of Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 7% clay, 84% sand, 9% silt, and 0.8% OM. Sumter County soil properties consisted of a Greenville sandy loam (Clayey, kaolinitic, thermic Rhodic Kandiudults) with 18% clay, 65% sand, 17% silt, and 0.7% OM.

2.2. Experimental Setup

Experimental design was a randomized complete block in a split-plot arrangement with 4 replications. Plots measured 1.9 m by 9.1 m with main plots being herbicide application timings at 0, 3, 5, 7, 10, and 14 days after planting (DAP) and sub-plots of flumioxazin at 0, 27, 54, and 107 g ai/ha which translate into a 0, 0.25, 0.5, and 1.0× rates [10]. Herbicide treatments were applied using TeeJet TTI 11,002 nozzles at 187 L/ha and 207 kPa. Herbicides were activated by natural rainfall (Table 1) and not supplemented by overhead irrigation. The cultivar Georgia-16HO [18] were planted on 18 May 2020, 11 June 2021, and 25 May 2022, in a single row manner for 18 seed/m in Tift County. Phorate (diethoxy-(ethylsulfanylmethylsulfanyl)-sulfanylidene-λ5-phosphane) [19] was applied at 454 g ai/ha along with a *Bradyrhizobium* sp. *Arachis* inoculant at a product rate of 141 L/ha. All plots were treated with diclosulam (N-(2,6-dichlorophenyl)-5-ethoxy-7-fluoro-[1,2,4]triazolo[1,5-c]pyrimidine-2-sulfonamide) (Indianapolis IN USA, 46268) at 27 g ai/ha and pendimethalin (3,4-dimethyl-2,6-dinitro-N-pentan-3-ylaniline) (Research Triangle Park NC USA 27709) at 906 g ai/ha. For Sumter County, Georgia-16HO was planted in single-rows to achieve a population of 18 seed/m on 2 June 2020, 18 May 2021, and 10 May 2022. All plots received a blanket application of diclosulam and pendimethalin at the same rates as the Tift County location. Acephate (N-[methoxy(methylsulfanyl)phosphoryl]) (Valent U.S.A. Walnut Creek, CA USA 94596) was applied to peanut in Sumter County at 819 g ai/ha. Peanut were planted when rainfall was predicted to occur withing a one to five DAP. All plots were maintained under University of Georgia agronomic recommendations [20,21] for non-irrigated peanut production.

Table 1. Temperature and Rainfall [a] for Sumter and Tift Counties in Georgia for 2020, 2021, and 2022.

		Maximum Temperature [b]		Minimum Temperature [b]		Rainfall [c]	
Year	**Month**	**Sumter**	**Tift**	**Sumter**	**Tift**	**Sumter**	**Tift**
		°C				cm	
2020	May	NA	29.4	NA	19.9	NA	6.6
	June	30.9	30.8	20.2	20.8	7.3	12.9
	July	32.8	33.7	21.8	22.3	9.7	4.7
	Aug.	32.7	33.3	21.8	22.5	16.3	11.6
	Sept.	28.4	29.4	19	20.1	16.8	13.3
	Oct.	26.6	28.3	14.8	17.3	7.3	1.4
	Season	30.3	30.8	19.5	20.5	57.4	50.5
2021	May	30.2	NA	16.3	NA	0.3	NA
	June	30.6	31.1	20.1	21.4	20.1	11.8
	July	31.4	31.7	21.4	22	14.4	20.7
	Aug.	31.6	31.9	21.8	22.5	18.6	14.9
	Sept.	29.3	30.4	18.2	19.2	14.3	9
	Oct.	27.1	27.8	16.6	16.9	10.6	5.1
	Season	30	30.6	19.1	20.4	78.3	61.5
2022	May	29.9	31.6	17.4	19.3	11.2	0.2
	June	33.8	34.2	21.3	21.8	5.1	9.9
	July	32.3	32.9	22.3	22.3	19.8	14.2
	Aug.	31.4	32.2	21.5	21.9	13.2	20.7
	Sept.	29.0	29.6	17.9	18.6	8.3	6.3
	Oct.	24.9	25.1	9.3	10.7	4.0	2.6
	Season	30.2	30.9	18.3	19.1	61.6	53.9

[a] Temperature and rainfall data from http://www.weather.uga.edu/ (accessed on 24 December 2024). [b] Average of daily values for time period listed. [c] Sum of daily values for each time period listed.

2.3. Data Collection

Data collected included percent injury compared to the non-treated control (NTC) on a 0 to 100% scale (0% indicating no injury and 100% representing plant death), plant width, plant population, percent weed control (0% indicating no control and 100% as total weed control) and yield [22–25]. Plant widths were measured from leaf tip to leaf tip of the outermost fully expanded leaves [15], and plant population was randomly selected from 1 m of row per plot [26]. Data collection occurred at 10, 14, 18, 22, 25, 29, 32 and 37 DAP in Tift County and 14, 17, and 23 DAP in Sumter County in 2020. Data collection occurred 13, 19, and 31 DAP in Tift County and 20, 23, 29, and 36 DAP in Sumter County for the 2021 season. Data were collected 12, 19, 22, and 28 DAP in Tift County and 17, 23, 30, 35, and 43 DAP in Sumter County. Prominent weed species included broadleaf species of morningglory (*Ipomoea* sp.), sicklepod (*Senna obtusifolia* L.), pigweed (*Amaranthus* sp.), and Florida beggarweed (*Desmodium tortuosum* Sw.) DC. As these are common summer species, data for weed control was combined for presentation. The control ratings were taken at every collection timing, but only the first three ratings after the respective application were used for consistency across all applications timings. Previous peanut plant physiological measurements including stomatal conductance to water vapor (GSW), electron transport (ETR), quantum yield of PSII (ΦPSII), and net assimilation rate (Anet) have been conducted with flumioxazin [15].

2.4. Data Analysis

Data were combined to include the first three ratings of each respective rate and application timing. Data were subjected to ANOVA utilizing PROC GLIMMIX in SAS

Studio 3.8 (SAS Institute Inc., Cary, NC, USA). When appropriate, herbicide rate, application timing, and rate by timing interactions were further analyzed with means separated by Tukey's HSD set at $\alpha = 0.05$ [27,28].

3. Results and Discussion

Initial analysis indicated that year and location were significant preventing data combination across year or location ($p < 0.05$). Therefore, data are presented by location and year. Data utilized for analysis are the first three collections after each respective application timing to maintain consistency across all treatments for percent injury compared to the NTC, plant width, plant population, and yield consisting of the harvested measurement. There were no stand count differences noted during the duration of the trial for any treatments ($p > 0.05$).

3.1. Visual Injury

Injury compared to the non-treated control indicated numerous differences increasing as application time after planting increased, regardless of rate in 2020 (Table 2). For Sumter County, flumioxazin applied at 107 g ai/ha 14 DAP resulted in the greatest amount of injury resulting in less than 7% injury. For Tift County, plants treated with either 54 or 107 g ai/ha at 10 or 14 DAP sustained the greatest amount of injury ranging from 20 to 40% (Table 2). Injury noted included overall plant stunting, necrotic lesions, and discolored petioles which was been previously reported [16,29–32].

Table 2. Effects of multiple application rates and timings of flumioxazin on peanut injury compared to the non-treated control at Sumter and Tift Counties in Georgia from 2020 to 2022.

Timing	Rate	Sumter County						Tift County					
		2020		2021		2022		2020		2021		2022	
DAP	g ai/ha	%											
0	0 [a]	0	c	0	d	0	f	0	d	0	e	0	f
	27	0	c	4	cd	0	f	0	d	1	e	0	f
	54	0	c	5	cd	1	f	0	d	0	e	0	f
	107	1	bc	7	cd	1	f	0	d	3	e	1	f
3	0	0	c	0	d	0	f	0	d	0	e	0	f
	27	0	c	6	cd	0	f	0	cd	0	e	0	f
	54	1	bc	5	cd	0	f	1	cd	5	e	0	f
	107	0	c	6	cd	3	ef	1	cd	30	b–d	1	f
5	0	0	c	0	d	0	f	0	d	0	e	0	f
	27	1	bc	10	a–d	1	f	0	cd	3	e	0	f
	54	0	bc	11	a–d	1	f	1	cd	6	e	3	f
	107	0	c	11	a–d	5	d–f	1	cd	31	b–d	3	f
7	0	0	c	0	d	0	f	0	d	0	e	0	f
	27	1	bc	4	cd	4	d–f	2	cd	16	c–e	2	f
	54	0	c	7	b–d	4	d–f	2	cd	30	cd	3	f
	107	2	bc	10	a–d	11	c–e	4	cd	51	ab	9	e
10	0	0	c	0	d	0	f	0	d	0	e	0	f
	27	0	c	19	a–c	2	f	12	bc	12	de	15	de
	54	4	a–c	25	a	6	d–f	20	b	36	a–c	24	c
	107	3	a–c	23	a–c	20	b	40	a	52	a	40	a

Table 2. *Cont.*

Timing	Rate	Sumter County						Tift County					
		2020		2021		2022		2020		2021		2022	
DAP	g ai/ha	%											
14	0	0	c	0	d	0	f	0	d	0	e	0	f
	27	3	a–c	8	b–d	12	b–d	8	cd	11	de	14	e
	54	5	ab	16	a–d	15	bc	22	b	18	c–e	20	cd
	107	7	a	24	ab	28	a	37	a	20	c–e	33	b

[a] Rate reflects the percentage of the full labelled application rate. 0 = 0 g ai ha, 0.25 = 27 g ai ha, 0.5 = 54 g ai ha, 1 = 107 g ai ha. Application time indicates days after planting (DAP) the herbicide application was made. Values followed by the same letter within the same column are not significantly different at the 5% probability level. Data were subjected to PROC GLIMMIX in SAS Studio 3.8 with means separated by Tukey's HSD. Data were separated by year and location.

In 2021, the maximum damage occurred on peanut treated with 54 g ai/ha applied 10 DAP (Table 2) when compared to the NTC in Sumter County. The lowest injury sustained was 4% for peanut treated with 27 g ai/ha when applied at planting as compared to the NTC. In Tift County, peanut injury was greater than in Sumter County that year (Table 2). The maximum injury noted was 52% on peanut treated with 107 g ai/ha of flumioxazin applied 10 DAP. This treatment was different from all others except peanut treated with 107 or 54 g ai/ha at 7 or 10 DAP, respectively. The trend was similar as in Sumter County with plants treated with less flumioxazin closer to planting sustaining less injury.

In 2022, peanuts treated with 107 g ai/ha applied 14 DAP noted the greatest amount of injury at 28% (Table 2) in Sumter County. This was followed up with peanut injury treated 10 DAP at the full rate with 20% injury. As in 2021, the trend noted that as rate and application time after planting increased, injury also increased. Peanut sustained up to 40% injury in Tift County during the same period (Table 2). Plants treated with any rate at either 10 or 14 DAP noted injury of 15 to 40%. All other treatments caused <10% injury.

Overall, both locations experienced high injury levels with late applications of flumioxazin. Previous research has shown that applying flumioxazin at 105 g/ha caused significant injury when applied at 6, 8, and 10 days after planting (DAP) [9]. These findings illustrate the high risk of delayed flumioxazin applications in peanuts and emphasize the importance of applying it within the recommended window of 0 to 2 DAP.

3.2. Weed Control

In 2020, the greatest amount of weed control in Sumter County was achieved when flumioxazin was applied at 54 or 107 g ai/ha closer to peanut planting (Table 3). Greater than 71% control was observed when applied at the full rate at planting or 7 DAP. The least amount of weed control was provided by flumioxazin applied at all rates 14 DAP. Weed species including morningglory, sicklepod, pigweed and Florida beggarweed were controlled except for yellow nutsedge, which was managed through hand weeding and late post-emergence (POST) applications. Applications of 54 or 107 g ai/ha near planting achieved some control, with 107 g ai/ha reaching 74% control. Less than 6% control was achieved when applied at 14 DAP. Other studies indicated that flumioxazin was ineffective in controlling yellow nutsedge during the early season [31].

Table 3. Effects of multiple application rates and timings of flumioxazin on weed control compared to the non-treated control in peanut at Sumter and Tift Counties in Georgia from 2020 to 2022.

Timing	Rate	Sumter County						Tift County				
		2020		2021		2022		---------	2021		2022	
DAP	g ai/ha	%										
0	0 [a]	0	f	0	b	0	d		0	b	0	b
	27	21	c–f	67	a	86	a–c		77	a	90	a
	54	41	a–e	74	a	90	a–c		86	a	96	a
	107	71	ab	75	a	95	a–c		81	a	94	a
3	0	0	f	0	b	0	d		0	b	0	b
	27	38	a–e	82	a	77	bc		60	a	93	a
	54	43	a–d	75	a	76	c		91	a	97	a
	107	48	a–c	74	a	93	a–c		88	a	79	a
5	0	0	f	0	b	0	d		0	b	0	b
	27	34	b–f	70	a	94	a–c		82	a	80	a
	54	46	a–c	64	a	97	a		69	a	82	a
	107	48	a–c	76	a	97	a		88	a	96	a
7	0	0	f	0	b	0	d		0	b	0	b
	27	43	a–d	83	a	89	a–c		59	a	97	a
	54	60	ab	89	a	91	a–c		83	a	98	a
	107	74	a	96	a	96	ab		93	a	95	a
10	0	0	f	0	b	0	d		0	b	0	b
	27	17	c–f	85	a	95	a–c		76	a	97	a
	54	18	c–f	79	a	95	a–c		73	a	95	a
	107	37	a–f	93	a	98	a		90	a	97	a
14	0	0	f	0	b	0	d		0	b	0	b
	27	6	d–f	64	a	96	ab		93	a	99	a
	54	3	ef	75	a	96	ab		73	a	97	a
	107	6	d–f	77	a	98	a		78	a	98	a

[a] Rate reflects the percentage of the full labelled application rate. 0 = 0 g ai ha, 0.25 = 27 g ai ha, 0.5 = 54 g ai ha, 1 = 107 g ai ha. Application time indicates days after planting (DAP) the herbicide application was made. Values followed by the same letter within the same column are not significantly different at the 5% probability level. Data were subjected to PROC GLIMMIX in SAS Studio 3.8 with means separated by Tukey's HSD. Data were separated by year and location.

Peanut treated with any rate of flumioxazin at any application timing provided greater control than the NTC (Table 3) at Sumter and Tift Counties in 2021. Weed control in Sumter County ranged from 64% to 96% with the greatest amount occurring in peanut treated with 107 g ai/ha at 7 DAP, and the least amount at 54 g ai/ha applied 5 DAP. The rate that provided the greatest amount of control only caused 10% injury while the treatment with the least was 11% injury. Similar control was recorded in Tift County, from 59 to 93% noted at the full rate of 107 g ai/ha applied at 7 DAP, but the least control was achieved by 27 g ai/ha when applied at that same time, excluding the NTC (Table 3).

In 2022, all herbicide treatments achieved >76% weed control, with maximum of 98% occurring at the full rate applied 10 DAP (Table 3) in Sumter County. Greater than 90% control was achieved by all treatments except, the 27 g ai/ha applied 0, 3, and 7 DAP along with the 54 g ai/ha applied 3 DAP and the NTC's. In Tift County, all treatments provided >79% weed control, with the trend indicating greater control as application time increased after planting.

3.3. Plant Widths

In 2020, peanut widths in Sumter County were different from those treated with 27 g ai/ha of flumioxazin 10 DAP, sustaining the greatest amount of stunting with plants measuring only 8 cm in diameter (Table 4). These plants were different than those treated with 0 flumioxazin at 14 DAP, 54 g ai/ha applied at planting, and 27 g ai/ha when applied at 0, 7, or 14 DAP. In Tift County, widths were 9 cm to 14 cm, with the lowest record for 105 g ai/ha at 10 DAP (Table 4).

Table 4. Effects of multiple application rates and timings of flumioxazin on peanut plant diameters at Sumter and Tift Counties in Georgia from 2020 to 2022.

Timing	Rate	Sumter County						Tift County					
		2020		2021		2022		2020		2021		2022	
DAP	g ai/ha	cm/plant											
0	0 [a]	10	ab	13	a	13	a–c	13	a–c	16	a–c	16	b–f
	27	10	a	12	a	13	ab	13	a–c	16	a	17	b–f
	54	10	a	12	a	12	b–d	14	ab	15	a–e	17	b–f
	107	10	ab	12	a	11	b–e	13	a–c	14	a–f	17	a–e
3	0	9	ab	13	a	13	bc	13	a–c	16	ab	18	a–e
	27	10	ab	12	a	13	a–c	14	a	16	ab	17	a–f
	54	10	ab	12	a	13	a–c	13	a–c	14	a–e	18	a–d
	107	10	ab	12	a	12	b–d	13	a–c	12	c–g	16	c–g
5	0	10	ab	12	a	13	bc	13	a–d	15	a–d	16	c–g
	27	10	ab	13	a	13	b–d	13	a–c	15	a–d	17	b–f
	54	10	ab	12	a	12	b–d	13	a–d	16	a–d	16	c–g
	107	10	ab	12	a	12	b–d	12	a–d	11	e–g	16	b–f
7	0	10	ab	13	a	13	a–c	13	a–c	16	ab	18	a–d
	27	10	a	13	a	12	b–d	13	a–c	14	a–g	16	c–g
	54	10	ab	11	a	11	b–e	13	a–c	12	d–g	17	a–f
	107	10	ab	13	a	11	de	11	b–e	10	g	15	Fg
10	0	9	ab	13	a	13	b–d	14	ab	16	ab	18	a–c
	27	8	b	12	a	12	b–d	11	c–e	13	a–g	15	d–g
	54	10	ab	11	a	11	c–e	10	de	12	b–g	15	e–g
	107	10	ab	12	a	10	e	9	e	10	fg	14	G
14	0	10	a	13	a	14	a	14	a–c	16	ab	19	A
	27	10	ab	12	a	13	a–c	12	a–d	14	a–e	19	Ab
	54	10	ab	12	a	12	b–d	11	b–e	13	a–g	17	a–e
	107	10	ab	12	a	10	e	11	b–e	13	a–g	16	c–g

[a] Rate reflects the percentage of the full labelled application rate. 0 = 0 g ai ha, 0.25 = 27 g ai ha, 0.5 = 54 g ai ha, 1 = 107 g ai ha. Application time indicates days after planting (DAP) the herbicide application was made. Values followed by the same letter within the same column are not significantly different at the 5% probability level. Data were subjected to PROC GLIMMIX in SAS Studio 3.8 with means separated by Tukey's HSD. Data were separated by year and location.

In 2021, no differences in plant width were observed for Sumter County. In contrast, plant widths in Tift County varied from 10 to 16 cm (Table 4). Overall, the trend noted plants treated with less flumioxazin closer to planting sustained the least amount of stunting. Differences in Tift County determined that all treatments were similar except plants treat-ed with 0 or 27 g ai/ha that had greater stands at 14 plants/m row than peanut treated with 107 g ai/ha applied at seven or 10 DAP at 11 plants/m row. Plants treated with 107 g ai/ha at 14 DAP were not different from any treatment and contained 13 plants/m row. In 2022, plant widths were 10 cm to 14 cm over the three ratings in Sumter County (Table 4). Plants treated with no flumioxazin, or 27 g ai/ha had the greatest plant widths, regardless of application time. As rate increased, plant width decreased with the smallest plants being treated with the full rate of flumioxazin applied 10, 14, and 7 DAP, respectively. In Tift County, widths ranged between 14 cm and 19 cm over the three ratings. The trend noted that as rate increased, plant width decreased regardless of application timing. Plants treated with 107 g ai/ha at 7 and 10 DAP noted the smallest plants at <15 cm. Overall, plant widths were reported to decrease on rates from 105 g ai/ha and up [9,32].

3.4. Yield

Yield was only significant for Tift County in 2020 (Table 5). The trend of increased injury observed with flumioxazin applications at 54 or 107 g ai/ha at 10 or 14 DAP led to the yield decrease. The lowest yielding plot was treated with 107 g ai/ha 14 DAP yielding only 3468 kg/ha on average. This was different than peanut treated with 0, 27, or 107 g ai/ha applied at planting as well as 27 g ai/ha when treated at 10 DAP. Yield differences were noted, ranging from 5092 kg/ha to 4059 kg/ha. The highest-yielding plots all achieved 4604 kg/ha on average.

Table 5. Effects of multiple application rates and timings of flumioxazin on peanut pod yield at Sumter and Tift Counties in Georgia from 2020 to 2022.

Timing	Rate	Sumter County						Tift County					
		2020		2021		2022		2020		2021		2022	
DAP	g ai/ha	kg/ha											
0	0 [a]	4669	a	4998	a	6823	a	4886	b	2737	a	3527	A
	27	4672	a	4929	a	7232	a	4697	b	3592	a	2839	A
	54	4450	a	4720	a	6964	a	4568	b	3792	a	3108	A
	107	4556	a	4874	a	7613	a	4508	b	4088	a	3258	A
3	0	4589	a	4799	a	7148	a	5092	a	4974	a	2779	A
	27	4299	a	5336	a	6922	a	4804	ab	4114	a	2899	A
	54	4202	a	5095	a	7162	a	4448	b	5515	a	3228	A
	107	4408	a	4406	a	7077	a	4059	b	3504	a	2421	A
5	0	4374	a	4883	a	7105	a	4862	ab	4156	a	3168	A
	27	4278	a	5385	a	7077	a	4204	b	3226	a	2959	A
	54	4200	a	4781	a	7021	a	4568	b	3409	a	3198	A
	107	4528	a	4578	a	7176	a	5046	a	5212	a	3497	A
7	0	4322	a	5188	a	7387	a	4499	b	3826	a	3557	A
	27	4322	a	4872	a	7317	a	4996	ab	4926	a	3048	A
	54	4463	a	4656	a	7500	a	4506	b	2947	a	3078	A
	107	4394	a	3947	a	7119	a	4834	ab	3564	a	2959	A
10	0	4402	a	5452	a	7683	a	4073	b	4862	a	3467	A
	27	4644	a	5139	a	7218	a	4521	b	5651	a	4393	A
	54	4299	a	4593	a	7119	a	4742	b	5152	a	4513	A
	107	3970	a	4446	a	7162	a	4363	b	4518	a	4662	A
14	0	4370	a	4857	a	7260	a	4596	b	3919	a	4095	A
	27	4282	a	5512	a	7218	a	4635	b	4114	a	3796	A
	54	4320	a	4749	a	7035	a	4631	b	5257	a	3885	A
	107	3439	a	4518	a	7021	a	4477	b	4636	a	3676	A

[a] Rate reflects the percentage of the full labelled application rate. 0= 0 g ai ha, 0.25= 27 g ai ha, 0.5= 54 g ai ha, 1= 107 g ai ha. Application time indicates days after planting (DAP) the herbicide application was made. Values followed by the same letter within the same column are not significantly different at the 5% probability level. Data were subjected to PROC GLIMMIX in SAS Studio 3.8 with means separated by Tukey's HSD. Data were separated by year and location.

4. Conclusions

Flumioxazin has been noted to cause injury in the form of necrotic lesions at points of contact on leaves and overall plant stunting. Injury can be exacerbated in unfavorable conditions such as cool, wet soils which can be observed shortly after application. Though peanut is generally planted in May, new cultivars can be planted earlier when these unfavorable conditions may occur. The label states that flumioxazin should not be applied more than two DAP to avoid injury, but some growers may attempt to apply flumioxazin outside of this application window. This study indicated that applications at the full or half rate after peanut has emerged may reduce plant width and yield, while causing greater visual injury. Contrary to this, weed control increased as rate increased when applied at seven DAP, but would directly expose emerged or nearly emerged peanut to flumioxazin.

Though growers may have interest in making delayed flumioxazin applications for increased weed control or necessity, this decision may prove detrimental for peanut yield. A trend was noted in which as the flumioxazin rate and timing after planting increased, yield decreased. This may be due to necrotic lesions on the leaf surface reducing photosynthetic efficiency, nutrient transport, transpiration, increasing plant susceptibility to disease pathogens, or reducing plant competitiveness. These factors may delay peanut growth and development, subjecting sensitive growth stages to weather extremes. Pollination during high temperatures paired with reduced available moisture may reduce pollen viability, inhibit peg penetration into the soil profile, and reduce pod growth and development. Growers should observe weather reports and apply flumioxazin when conditions are optimal and according to label instructions to avoid injury.

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