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Development of lawns in response to applications of imazapic alone or combined with imazapyr[1]

Desenvolvimento de gramados em resposta à utilização de imazapic isolado ou em associação com imazapyr

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HIGHLIGHTS:

The imazapic applied alone or in tank mixture with imazapyr can be used as a growth regulator of lawns with Tifton 419 grass.
The herbicide imazapic applied alone or in a tank mixture with imazapyr can control the growth of lawns with Zoysia grass.
Some doses of imazapic applied alone or combined with imazapyr can affect the visual aspect of lawns with Zoysia grass.

ABSTRACT: Successive mowings are the major maintenance cost of lawns. These costs have led to the search for alternatives to mechanical management. This study aimed to determine the effects of imazapic herbicide doses applied alone or combined with imazapyr as a growth regulator of Tifton 419 and Zoysia grasses. The experimental design was randomized blocks with four replicates, and the treatments consisted of four doses of herbicide imazapic applied alone (35; 70; 105 and 140 g a.i. ha^{-1}) and three doses of imazapic + imazapyr mixture (7.875 + 2.625; 15.57 + 5.25 and 23.625 + 7.875 g a.i. ha^{-1}) in two sequential applications on both grass lawns. Visible injury symptoms, canopy height, height and number of inflorescences, and total dry matter of clippings were determined. Applications of imazapic alone or combined with imazapyr effectively reduced all morphological variables of Tifton 419 grass. Imazapic applied alone or mixed with imazapyr provided adequate control of growth and quantity of dry matter of Zoysia grass clippings. Still, with some application doses of this herbicide, the number of inflorescences present in the lawns increased.

Key words: *Cynodon dactylon* × *C. transvaalensis*, *Zoysia japonica*, bermuda grass, zoysia grass

RESUMO: Operações sucessivas de corte são os principais custos na manutenção de gramados. O dispêndio com os cortes leva à busca por alternativas para o manejo mecânico. O presente estudo teve por objetivo estudar os efeitos de doses do herbicida imazapic aplicado isolado ou em associação com imazapyr, como regulador de crescimento das gramas Tifton 419 e Esmeralda. Adotou-se o delineamento experimental de blocos casualizados, com quatro repetições e os tratamentos constituíram de quatro doses do herbicida imazapic isolado (35; 70; 105 e 140 g i.a. ha^{-1}) e três doses da associação de imazapic + imazapyr (7,875 + 2,625; 15,57 + 5,25 e 23,625 + 7,875 g i.a. ha^{-1}) em duas aplicações sequenciais para ambas as espécies. Avaliaram-se os sintomas visuais de injúria, a altura do dossel, a altura e o número de inflorescências e a matéria seca total das aparas. As aplicações de imazapic isolado ou em associação com imazapyr foram efetivas na redução de todas as variáveis morfológicas da grama Tifton 419. O imazapic aplicado isolado ou associado ao imazapyr proporcionou controle satisfatório do crescimento e da quantidade de matéria seca das aparas da grama Esmeralda, no entanto, algumas doses desse herbicida aumentaram o número de inflorescências presentes nos gramados.

Palavras-chave: *Cynodon dactylon* × *C. transvaalensis*, *Zoysia japonica*, grama bermuda, grama esmeralda

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Introduction

Tifton 419 (*Cynodon dactylon* (L.) Pears. × *C. transvaalensis* Burtt-Davy) and Zoysia grass, also known as Japanese or Korean lawn grass (*Zoysia japonica* Steud.), are adapted to the climate of Brazil; which are used in residential, industrial, and public lawns, as well as airports, parks, square gardens, roadsides, and sports fields (Santos & Castilho, 2018; Amaral et al., 2019; Gazola et al., 2019).

Successive mowings are the main source of lawn maintenance costs, which, together with the large number of clippings produced and the repetitive operations of piling up the residues and transporting them, have become the main factors of rejection to the use of this technique. Also, the constant removal of nutrients that must be replaced increases the costs of this activity even more (Marchi et al., 2013a). Therefore, both the costs with successive mowings and the visual and physiological lawn quality have led to the search for alternatives to mechanical management (Marchi et al., 2014).

The use of selective herbicides that provide a regulating effect of plant growth without detriment to the visual quality of lawns can be a very interesting management tool due to the dual purpose to be attained (Maciel et al., 2011; Queiroz et al., 2017).

In this context, the present study aims to study the effects of imazapic herbicide applied alone or combined with imazapyr on the vegetative growth and inflorescence of Tifton 419 and Zoysia grasses.

Material and Methods

The experimental phase of the present research comprised two studies carried out in experimental areas of the Núcleo de Pesquisas Avançadas em Matologia - NUPAM of the Departamento de Produção Vegetal of the Faculdade de Ciências Agronômicas of Botucatu/UNESP, at the geographic coordinates of 22° 07' 56" S and 74° 66' 84" W Gr., 762 m of altitude.

The lawns, approximately 14 months old, were formed with Tifton 419 and Zoysia grass carpets in areas equipped with a sprinkler irrigation system. The soil was classified as Oxisol with moderate A horizon and clayey texture.

Before the implantation of the lawns, 2.6 t ha^{-1} of limestone was added to the soil. Furthermore, soil samples were collected and analyzed in the laboratory, and the chemical characteristics are described in Table 1.

The treatments (Table 2) were arranged in a randomized block experimental design with four replicates. Each plot had a total area of 3.75 m^2 (1.5 x 2.5 m).

In addition to a control plot without herbicide application, a 0.5 m^2 strip alongside the experimental blocks served as a lateral control to better visualize the injury effects caused by the chemical treatments tested.

The lawns were mowed two days before applying the treatments to a height from 3.0 to 5.0 cm above the ground using a motorized mower with rotating blades.

The first herbicide application was performed using a CO_2-pressurized sprayer with a spraying boom containing two flat jet nozzles (TP 8002 VS), spaced 0.50 cm apart, at a constant pressure of 2.0 bar and set to deliver 200 L ha^{-1} of the solution.

During the herbicide applications, the plots were laterally protected with plastic canvas to avoid possible drifts of the sprayed solution to the neighboring plots. When the herbicide was applied, the weather conditions were partially cloudy sky, mean air temperature of 23 °C, mean relative air humidity of 57%, with a southeast wind at a mean speed of 2.0 m s^{-1}.

The second herbicide application was made 14 days after the first application (DAFA) and optimized the growth regulator action in both species studied, as proposed by Marchi et al. (2013a). This 14-DAFA interval was determined when the mean height of the experiments reached 70% of the mean height of the control. All the experimental plots were mowed again to a height from 3 to 5 cm, aiming to optimize the growth regulator action. Then the second dose of the growth regulator was applied, according to the methodology mentioned above.

The effect of the treatments was evaluated weekly by observing visible symptoms of injuries and the height of the lawn canopy until the time when the plants' height in both treated and non-treated (control) plots remained unaltered.

The injuries were evaluated visually using a scale from 0 (total absence of injury) to 100% (plant death). The grass height was expressed in centimeters and determined by direct

Table 1. Chemical characteristics of the soil in the 0-0.20 m layer

$pH_{(CaCl2)}$ (0.01 mol L^{-1})	OC (g kg^{-1})	P (mg kg^{-1})	Ca	Mg	K	Al	Al + H	CEC	V	Fe_2O_3 (g kg^{-1})
			($mmol_c$ kg^{-1})						(%)	
5.9	15	12	27	13	9.6	0.3	32.9	82.9	60	176

OC - Organic carbon

Table 2. Doses of imazapic alone and combined with imazapyr on lawns with Tifton 419 (*Cynodon dactylon*) and Zoysia (*Zoysia japonica*)

Treatment	Tifton 419		Zoysia	
	Doses (g a.i. ha^{-1})			
	1st Application	2nd Application	1st Application	2nd Application
Imazapic	35	35	35	35
Imazapic	70	70	70	70
Imazapic	105	105	105	105
Imazapic	140	140	140	140
Imazapic + Imazapyr	7.875 + 2.625	7.875 + 2.625	7.875 + 2.625	7.875 + 2.625
Imazapic + Imazapyr	15.57 + 5.25	15.57 + 5.25	15.57 + 5.25	15.57 + 5.25
Imazapic + Imazapyr	23.625 + 7.875	23.625 + 7.875	23.625 + 7.875	23.625 + 7.875
Control	---	---	---	---

measurement of the plant's canopy height using a graduated ruler.

The number of inflorescences was determined by sampling using a 0.25 m^2-metal square placed in the plots' center. The inflorescence height was determined using a graduated ruler by measuring the distance from the ground to the inflorescence extremity, considering only the highest inflorescence in each plot's center.

Total dry matter of clippings was determined by collecting the plant mass-produced in the plots after cutting the grass at 3 cm of height using a powered mower. The samples were placed in paper bags and kept in a forced-air circulation oven at 65 ºC for three days to constant weight when they were weighed in a 0.01 g precision scale (Bel® Model: S2202H).

The values obtained for all variables cited were analyzed by F-test, and the means of the treatments were grouped by the Scott-Knott test at $p \leq 0.05$, using the statistical software AgroEstat (Barbosa & Maldonado Jr., 2015).

Results and Discussion

The Tifton 419 grass exhibited low sensitivity to imazapic since at seven days after the second application (DASA), injury levels below 5.0% were observed, even with the highest dose of the herbicide applied alone. The imazapic with imazapyr mixture also caused low levels of injury on Tifton 419 lawn grass, and the values found at 7 DASA were lower than 7%, irrespective of the herbicide dose applied (Table 3).

The injury symptoms observed at 7 DASA for the imazapic doses applied alone or mixed with imazapyr showed a decline at 21 DASA, with values below 4.3% (Table 3). On the subsequent evaluation (28 DASA), it was observed total recovery of the *C. Dactylon* plants for all treatments assessed, and no visible symptom of injury was recorded in this period (Table 3).

Table 3. Visible injury caused by the application of imazapic alone and combined with imazapyr on lawns with Tifton 419 (*Cynodon dactylon*) and Zoysia (*Zoysia japonica*)

Treatment	Injury (%) DASA[1]			
	7	14	21	28
	Tifton 419 grass			
Imazapic 35 + 35	3.2 c	2.5 d	0.8 d	0.0
Imazapic 70 + 70	2.5 c	1.7 e	0.0 e	0.0
Imazapic 105 + 105	5.0 b	3.3 c	3.2 c	0.0
Imazapic 140 + 140	0.0 d	0.0 f	0.0 e	0.0
Imazapic + Imazapyr 7.9 + 2.6	4.5 b	2.5 d	0.0 e	0.0
Imazapic + Imazapyr 15.6 + 5.2	7.0 a	4.3 b	3.8 b	0.0
Imazapic + Imazapyr 23.6 + 7.9	7.0 a	6.2 a	4.3 a	0.0
Control	0.0 d	0.0 f	0.0 e	0.0
F Treatment	99.50**	101.69**	156.39**	-
F Block	0.38^{ns}	2.66^{ns}	2.03^{ns}	-
CV (%)	15.10	16.21	20.25	-
	Zoysia grass			
Imazapic 35 + 35	15.0 c	6.0 a	0.0 c	0.0
Imazapic 70 + 70	15.3 c	0.0 b	0.0 c	0.0
Imazapic 105 + 105	16.0 c	7.0 a	0.0 c	0.0
Imazapic 140 + 140	16.2 c	5.8 a	0.0 c	0.0
Imazapic + Imazapyr 7.9 + 2.6	19.0 c	6.3 a	1.5 b	0.0
Imazapic + Imazapyr 15.6 + 5.2	26.8 b	5.0 a	0.0 c	0.0
Imazapic + Imazapyr 23.6 + 7.9	32.5 a	7.0 a	2.5 a	0.0
Control	0.0 d	0.0 b	0.0 c	0.0
F Treatment	42.06**	29.69**	52.00**	----
F Block	0.40^{ns}	4.98*	2.33^{ns}	----
CV (%)	16.68	23.23	53.45	----

ns, **, * - Not significant and significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test, respectively; Means followed by the same letter in column belong to the same group by the Scott-Knott test at $p \leq 0.05$; \[1] DASA - Days after the second application

All doses of the imazapic herbicide applied alone caused significant visible injuries on the Zoysia grass plants in the first evaluation, at 7 DASA. The lowest level of injury found was 15%, resulting from the application of 35 + 35 g a.i. ha^{-1} of imazapic. The toxic effect caused by the herbicide did not remain constant as the herbicide doses increased, with toxic values between 15.3 and 16.2% (Table 3).

The combination of imazapic with imazapyr initially also caused high levels of injury to the plants of the *Z. japonica* species, and the values found at 7 DASA were higher than 19% and lower than 32.5% of the injury, with higher values as the herbicide doses increased (Table 3).

After the evaluation, at 7 DASA, there was a significant recovery of the Zoysia grass plants treated with imazapic applied alone or combined with imazapyr. The visible injury symptoms at 21 DASA were observed only when the doses of imazapic + imazapyr mixture were applied, with values between 1.5 and 2.5%. It is worth noting that at 28 DASA, there was a total recovery of the *Z. japonica* lawns for all treatments in this experiment (Table 3).

Regarding the visual aspect of the lawns, it can be seen that the imazapic herbicide applied alone or combined with imazapyr can be indicated for use as a growth regulator in lawns planted with *C. dactylon* and *Z. japonica* grasses, considering that there was the total recovery of both species at 28 DASA and, for some treatments, at 21 DASA.

However, the visible injury data indicate that Zoysia grass plants are more sensitive to the imazapic herbicide applied alone or mixed with imazapyr than the Tifton 419 grass. It was found that the visible injury symptoms caused by the herbicides on the lawn with Zoysia exceeded 15% and reached maximum values of 32.5% at 7 DASA, while the injuries on the Tifton 419 grass, in this same period, were below 7%, even with the application of the highest doses of the herbicide alone or combined with imazapyr (Table 3).

It should be noted that the main injury symptoms observed in Tifton 419 and Zoysia grasses are characterized by a change in the green-yellow color of the lawn to purple. In general, formulations of the imidazolines chemical group's herbicides can initially cause chlorosis in young leaves, and the symptoms can advance to an intense purple with subsequent evolution to necrosis of these leaves (Shaner, 2014; Piveta et al., 2018).

It is worth noting that toxicity levels below 7%, as observed in the Zoysia lawn grass at 14 DASA (Table 3), are acceptable for lawns because irrigation or use of grass colorants may reduce the time of disappearance of phytotoxicity symptoms. Another alternative could be the application of extra doses of nitrogen-based fertilizers because this element is vital for the chlorophyll synthesis and restores the green color of grasses (Costa et al., 2010; Marchi et al., 2013a). These alternatives become viable because, as mentioned earlier, successive mowing operations, especially during the spring and summer months, are the biggest cost factor for lawn maintenance. Also, the huge number of clippings resulting from the cuttings and the labor cost of disposing of these clippings, the costs with

fuel and the machines themselves, further increase mowing cost (Marchi et al., 2013b).

Concerning the mean height of the grass, it can be seen that sequential applications of imazapic doses higher than 35 + 35 g a.i. ha^{-1} and all doses of the imazapic + imazapyr mixture provided a satisfactory growth control of Tifton 419 grass by 49 DASA (Table 4). All treatments cited did not reach the critical cut limit of 70% of the mean height of the control lawn (non-treated), which is considered crucial when decisions are made on possible reapplications of growth regulators on lawns (Costa et al., 2010).

The vertical vegetative growth of Zoysia grass was also significantly affected by all doses of herbicide imazapic applied alone or mixed with imazapyr, from 7 DASA, compared with the control (Table 5). Furthermore, all treatments in this study provided satisfactory control of the lawn grass plants by 92 DASA (Table 6), as they did not reach the critical cut limit of 70% of the mean height of the control grass lawn (Costa et al., 2010), and resulted in a reduction of the plant height from 41.4 to 50.3% (Table 5).

The sharp reductions of plants' height of Tifton 419 and Zoysia grass species observed in Tables 4 and 5 can be associated with the fact that imidazoline-family herbicides are amino-acid inhibitors, acting mainly in inhibiting acetolactate synthase (ALS), a common enzyme in the biosynthesis of three aliphatic amino acids: valine, leucine, and isoleucine. Such inhibition action interrupts protein synthesis, interfering with DNA synthesis and cell growth (Marinho et al., 2018).

Additionally, herbicides from this class are easily absorbed by the roots and leaves and quickly carried to the plant tissues through xylem and phloem, directly affecting the growth and development of susceptible plants (Refatti et al., 2017).

The apparent recovery of the plant height was observed at 49 DASA for the herbicide dose of 35 + 35 g a.i. ha^{-1} of imazapic applied on the Tifton 419 grass (Table 4), which can be explained by the fact that nonstructural carbohydrates such as glucose, fructose, sucrose, and amides can be stored and used as reserve energy for stress tolerance and regeneration after the first symptoms of injury (Brighenti et al., 2019).

It is also worth noticing that at 49 and 92 DASA, all treatments tested with Tifton 419 and Zoysia grasses, respectively, maintained the lawn grass height below the maximum limit of 10 cm allowed for lawns located in central road verges and grass strips along highways (Marchi et al., 2013a). Therefore, it can be assumed that imazapic herbicide application has great potential for use as growth regulators for Tifton 419 and Zoysia grasses for approximately 60 days.

The sequential application of imazapic alone and its combination with imazapyr also provided high efficiency in reducing the grass height and the number of inflorescences of Tifton 419 until 49 DASA. For these variables, all treatments tested in this study were lower than the control (non-treated) (Table 6).

For all herbicide application doses, values between 66.7 and 94.2% of reduction of the number of inflorescences were achieved, especially with the herbicide dose of 70 + 70 g a.i.

Table 4. Mean height of Tifton 419 grass (*Cynodon dactylon*) at 7, 14, 21, 28, 35, and 49 DASA according to the application of imazapic herbicide alone and combined with imazapyr

Treatment	Grass height (cm) DASA[1]						
	7	14	21	28	35	49	(%)[2]
Imazapic 35 + 35	4.1 a	5.0 b	5.2 b	6.0 b	8.5 b	8.6 b	28.3
Imazapic 70 + 70	4.4 a	4.6 b	5.1 b	5.7 b	6.5 c	7.0 b	41.7
Imazapic 105 + 105	3.9 a	4.5 b	4.6 b	5.5 b	7.0 c	7.1 b	40.8
Imazapic 140 + 140	4.2 a	5.0 b	5.4 b	6.1 b	6.2 c	6.5 b	45.8
Imazapic + Imazapyr 7.9 + 2.6	4.5 a	4.1 b	5.1 b	6.7 b	6.7 c	7.3 b	39.2
Imazapic + Imazapyr 15.6 + 5.2	4.1 a	4.2 b	5.4 b	5.6 b	6.3 c	6.8 b	43.3
Imazapic + Imazapyr 23.6 + 7.9	4.3 a	4.4 b	5.0 b	5.5 b	6.2 c	7.1 b	40.8
Control	4.6 a	8.0 a	8.4 a	9.9 a	11.3 a	12.0 a	-
F Treatment	0.33^{ns}	12.82**	5.08**	4.41**	5.71**	4.05**	-
F Block	1.41^{ns}	1.72^{ns}	4.02*	1.15^{ns}	1.35^{ns}	1.68^{ns}	-
CV (%)	19.21	14.61	18.83	21.98	24.79	25.17	-

ns, **, * - Not significant and significant at $p \leq 0.01$ and $p \leq 0.05$, by F test, respectively; Means followed by the same letter in column belong to the same group by the Scott-Knott test at $p \leq 0.05$; [1] DASA - Days after the second application; [2] Reduction calculated at 49 DASA in comparison with the control

Table 5. Mean height of Zoysia grass (*Zoysia japonica*) at 7, 14, 21, 28, 63, and 92 DASA according to the application of imazapic herbicide alone and combined with imazapyr

Treatment	Grass height (cm) DASA[1]						
	7	14	21	28	63	92	(%)[2]
Imazapic 35 + 35	3.4 b	3.4 b	3.7 b	4.4 b	6.1 b	7.6 b	47.6
Imazapic 70 + 70	3.2 b	3.3 b	3.4 b	3.7 b	5.9 b	8.0 b	44.8
Imazapic 105 + 105	3.1 b	3.2 b	3.3 b	3.9 b	6.6 b	8.5 b	41.4
Imazapic 140 + 140	3.5 b	3.6 b	3.9 b	5.0 b	8.1 b	8.5 b	41.4
Imazapic + Imazapyr 7.9 + 2.6	3.4 b	3.9 b	4.9 b	5.6 b	7.2 b	7.4 b	49.0
Imazapic + Imazapyr 15.6 + 5.2	3.2 b	3.6 b	3.9 b	4.2 b	6.4 b	7.3 b	49.6
Imazapic + Imazapyr 23.6 + 7.9	3.5 b	3.5 b	3.7 b	4.1 b	6.2 b	7.2 b	50.3
Control	10.7 a	10.9 a	11.1 a	12.0 a	13.8 a	14.5 a	-
F Treatment	50.38**	41.20**	24.95**	26.08**	15.76**	9.28**	-
F Block	2.19NS	3.38**	3.59**	8.23**	3.93*	3.88*	-
CV (%)	17.37	18.43	22.10	20.07	17.39	18.38	-

**, * - Significant at $p \leq 0.01$ and $p \leq 0.05$, by F test, respectively; Means followed by the same letter in column belong to the same group by the Scott-Knott test at $p \leq 0.05$; [1] DASA - Days after the second application; [2] Reduction calculated at 92 DASA in comparison with the control

Table 6. Height and number of inflorescences and total dry matter of clippings (TDMC) produced by Tifton 419 grass (*Cynodon dactylon*) at 49 DASA and, by Zoysia grass (*Zoysia japonica*) at 92 DASA, as a result of the second application of imazapic alone and combined with imazapyr

Treatment	Inflorescence			TDMC	
	Height (cm)	Number (m^{-2})	(%)\1	(g m^{-2})	(%)\1
		Tifton 419 grass			
Imazapic 35 + 35	1.10 b	10.0 c	88.4	142.52 b	64.8
Imazapic 70 + 70	1.57 b	5.0 c	94.2	123.58 b	69.5
Imazapic 105 + 105	2.07 b	10.0 c	88.4	96.27 b	76.2
Imazapic 140 + 140	1.97 b	28.7 b	66.7	100.87 b	75.1
Imazapic + Imazapyr 7.9 + 2.6	2.07 b	11.2 c	87.0	180.98 b	55.3
Imazapic + Imazapyr 15.6 + 5.2	3.17 b	6.2 c	92.8	121.52 b	70.0
Imazapic + Imazapyr 23.6 + 7.9	2.10 b	23.7 b	72.5	87.15 b	78.5
Control	7.80 a	86.3 a	-	405.36 a	-
F Treatment	63.87**	80.73**	-	23.00**	-
F Block	1.41^{ns}	0.94^{ns}	-	0.64^{ns}	-
C.V. (%)	19.48	26.56	-	27.73	-
		Zoysia grass			
Imazapic 35 + 35	6.3 b	63.7 d	36.3	175.34 b	79.5
Imazapic 70 + 70	6.0 b	60.3 d	39.7	256.64 b	70.0
Imazapic 105 + 105	5.8 b	132.5 b	-32.0	122.93 b	85.6
Imazapic 140 + 140	4.9 b	66.3 d	33.7	125.58 b	85.3
Imazapic + Imazapyr 7.9 + 2.6	5.8 b	122.5 b	-22.5	188.31 b	78.0
Imazapic + Imazapyr 15.6 + 5.2	5.6 b	62.5 d	37.5	133.97 b	84.3
Imazapic + Imazapyr 23.6 + 7.9	6.3 b	166.2 a	-66.2	134.81 b	84.2
Control	10.2 a	100.0 c	-	856.24 a	-
F Treatment	15.67**	51.11**	-	73.70**	-
F Block	1.02^{ns}	2.31^{ns}	-	4.88**	-
CV (%)	17.93	11.62	-	23.31	-

ns, ** - Not significant and significant at $p \leq 0.01$ by F test, respectively; Means followed by the same letter in column belong to the same group by the Scott-Knott test at $p \leq 0.05$; DASA - Days after the second application; \1 Reduction calculated in comparison with the control

ha^{-1} of imazapic applied alone and the sequential application of 15.6 + 5.2 g a.i. ha^{-1} of imazapic mixed with imazapyr, which inhibited the reproductive development of the Tifton 419 grass plants almost totally (Table 6).

All treatments also achieved significant reductions of total dry matter of clippings of Tifton 419 grass compared with the control. Such reductions ranged from 55.3 to 78.5% concerning the treatment without herbicide application and were more intense for the dose of 105 + 105 g a.i. ha^{-1} of the herbicide imazapic applied alone and the sequential application of the 23.6 + 7.9 g a.i. ha^{-1} of imazapic combined with imazapyr (Table 6).

The sequential applications of imazapic alone or in tank-mixture with imazapyr reduced the height of the inflorescences produced by the Zoysia grass (Table 6). The dose of 35 + 35, 70 + 70 and 140 + 140 g a.i. ha^{-1} of imazapic applied alone, and the dose of 15.6 + 5.2 g a.i. ha^{-1} of imazapic mixed with imazapyr effectively inhibited the production of inflorescences in the Zoysia grass lawn, with reductions that ranged from 33.7 to 39.7% concerning the control (non-treated) (Table 6).

However, the doses of 105 + 105 g a.i. ha^{-1} of imazapic herbicide applied alone and the application of 7.9 + 2.6 and 23.6 + 7.9 g a.i. ha^{-1} of imazapic combined with imazapyr induced the Zoysia grass plants to produce a larger quantity of inflorescences than the control, resulting in higher increases that ranged from 22.5 to 66.2% in the number of inflorescences per m^2 (Table 6).

All treatments evaluated in this study provided significant reductions in the total dry matter of clippings generated by Zoysia grass compared to the control treatment. Such reductions varied from 70 and 85.6% concerning the treatment without herbicide applications (Table 6).

It is assumed that the significant reductions in the height and number of inflorescences of Tifton 419 grass for a long period (49 days) (Table 6) can be explained by the high values of the half-life of the herbicides in the soil, considering that the half-life of imazapic alone is estimated to last 40 to 120 days, while the imazapic and imazapyr mixture may have a long half-life, ranging from 30 to 200 days after application (DAA) (Bajrai et al., 2017; Matte et al., 2018; Yavari et al., 2019).

Concerning the increased number of inflorescences per m^2 produced by Zoysia grass after applying some doses of imazapic alone or combined with imazapyr, it can be inferred that the inflorescences were produced as an adaptative response of the plants to the stress caused by the herbicide doses applied. Such behavior has never been reported in the literature for the application of imidazoline-class herbicides on lawn grasses.

It is known that as all herbicides act in crucial plants' pathways or processes either as an inhibiting or stimulating agent, doses of any herbicide may modulate the plant composition, acting especially in an attempt to improve or increase seeds propagation to disseminate a generation free from the stresses caused (Brito et al., 2018).

Conclusions

1. The sequential applications of imazapic alone or mixed with imazapyr, irrespective of the herbicide doses tested, were effective in reducing the plant height, number and height of inflorescences, and the total dry matter of clippings produced by Tifton 419 grass.

2. All treatments tested in this study exhibited a satisfactory control of growth and quantity of total dry matter of Zoysia grass clippings. However, the doses of 105 + 105 g a.i. ha^{-1} of imazapic herbicide applied alone and the application of 7.9 + 2.6 and 23.6 + 7.9 g a.i. ha^{-1} of imazapic combined with imazapyr as a growth regulator increased the number of inflorescences in the lawns of this species. So, it cannot be recommended for areas designed for the practice of sports.

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