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Mesotrione and Tembotrione Applied Alone or in Tank-Mix with Atrazine on Weed Control in Elephant Grass

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Abstract**—**The experiment was carried out in Valença, Rio de Janeiro State, Brazil, to evaluate the selectivity and weed control of carotenoid biosynthesis inhibiting herbicides applied alone or in combination with atrazine in elephant grass crop. The treatments were as follows: mesotrione (0.072 and 0.144 kg ha^{-1} + 0.5% v/v mineral oil - Assist®), tembotrione (0.075 and 0.100 kg ha^{-1} + 0.5% v/v mineral oil - Aureo®), atrazine + mesotrione (1.25 + 0.072 kg ha^{-1} + 0.5% v/v mineral oil - Assist®), atrazine + tembotrione (1.25 + 0.100 kg ha^{-1} + 0.5% v/v mineral oil - Aureo®), atrazine + mesotrione (1.25 + 0.072 kg ha^{-1}), atrazine + tembotrione (1.25 + 0.100 kg ha^{-1}) and two controls (hoed and unhoed check). Two application rates of mesotrione with the addition of mineral oil or the tank mixture of atrazine plus mesotrione, with or without the addition of mineral oil, did not provide injuries capable to reduce elephant grass forage yield. Tembotrione was phytotoxic to elephant grass when applied with mineral oil. Atrazine and tembotrione in a tank-mix, with or without mineral oil, were also phytotoxic to elephant grass. All treatments provided satisfactory weed control.

Keywords**—**Forage, Napier grass, pasture, *Pennisetum purpureum,* weeds.

I. Introduction

THE majority of Brazil's milk and meat production is based on the use of pasture. Thus, the search for forage species with high productivity and forage quality for cattle feeding has great importance. Elephant grass (*Pennisetum purpureum* Schum.) is suitable for this purpose and widely used in cattle raising, mainly for cutting, grazing and silage production [20], [12]. In addition to an excellent animal feed, elephant grass can also be used as raw material for the production of bio-gas, bio-oil, charcoal [25], [18], and alcohol [23], as well as for the generation of electricity [14].

Elephant grass is known for high productive potential in tropical and subtropical regions; when properly managed, it can produce from 30 to 50 t/ha/year of dry matter [16]. In addition, elephant grass is resistant to drought, diseases and pests [22]. However, one of the major limitations on the implementation and conduct of elephant grass fields is related to weed interference [4]. There is a lack of research on weed management in elephant grass, as most studies consider this species to be a weed rather than a crop [7], [13], [10].

Proper weed management during elephant grass implantation is very important, because the culture is sensitive in its early stages of growth (3-6 weeks after planting) [5]. Normally, elephant grass is installed during the rainy season in Brazil (November to January), which coincides with high temperatures, favoring the emergence and establishment of various weeds, especially grasses. These weeds, mainly *Brachiaria* species, demand special attention by growers at the moment of elephant grass crop implantation and conduction [2].

Herbicides are the most commonly used method to control weeds. Carotenoid biosynthesis inhibiting herbicides, particularly those that inhibit the 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme, are noteworthy and commonly used on corn [6], [24]. HPPD-inhibiting herbicides have become popular among corn growers because of their broad-spectrum of weed control, flexible application timing, tank-mix compatibilities, and crop safety [3], [27].

Another herbicide widely used on corn is atrazine [19]. It can be applied to a crop before, during or after planting of the seeds, or even after crop emergence. It is most often used at low rates in tank-mixes to improve broad-spectrum weed control [3].

The development of methods for weed control by means of selective herbicides is an important practice in order to expand elephant grass cultivation in tropical and subtropical regions.

The objectives of this work were to evaluate the selectivity and weed control of carotenoid biosynthesis inhibiting herbicides alone or in combination with atrazine in elephant grass crop.

II. Materials and Methods

A. Study Areas

The experiment was conducted in experimental area in the municipality of Valença, Rio de Janeiro State, Brazil (22°22'06.53"S, 43°42'00.48"W).

B. Experimental Implantation

The experiment was implanted under field conditions in a soil classified as Red-Yellow Argisol. The samples were collected at 0-20 cm depth and the results of the chemical and textural analyses were as follows: pH (H_2O) = 5.1, P = 9.6 mg dm^{-3}, K = 90 mg dm^{-3}, Ca^{2+}= 2.4 $cmol_c$ dm^{-3}, Mg^{2+} = 2.3 $cmol_c$ dm^{-3}, Al^{3+} = 0.0 $cmol_c$ dm^{-3}, H + Al = 3.3 $cmol_c$ dm^{-3}, SB = 4.93 $cmol_c$ dm^{-3}, CEC (t) = 4.93 $cmol_c$ dm^{-3}, CEC ($T_{pH = 7.0}$) = 8.23 $cmol_c$ dm^{-3}, V = 60%, C organic = 1.94 dag kg^{-1}, clay = 18%, silt = 16%, sand = 66%.

Experiment was installed on October 30, 2015. Before elephant grass planting, the experimental area was plowed and

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barred. Elephant grass (cultivar "BRS Capiaçu") was planted in furrows spaced 1.0 m long with 20 cm depth. Stems (40 cm long) were distributed within the furrows and fertilized with 200 kg ha^{-1} (mono-ammonium phosphate) [4].

Four furrows of 5 m long were implanted in each plot. Side-dressing was performed at 30 days after planting with 40 kg ha-1 of nitrogen (urea). The herbicide doses were applied on November 19, 2015, when the elephant grass plants were approximately 0.25 m tall. Treatments were applied using a backpack sprayer, CO_2 pressurized (2 kgf cm^{-2}) to deliver a volume equivalent to 140 L ha^{-1} [4]. The sprayer boom (1.5 m length) comprised four flat fan nozzles (Magnojet BD 110 02), spaced 0.5 m apart. The environmental conditions during herbicide spraying were temperature, 27 °C; relative humidity, 68%; and wind speed, 2 m s^{-1}. The predominant weed species and their densities at the time of herbicide applications were: *Brachiaria plantaginea* (3.0 plants m^{-2}), *Ipomoea cordifolia* (2.0 plants m^{-2}), *Cyperus esculentus* (4.0 plants m^{-2}) and *Commelina benghalensis* (3.0 plants m^{-2}).

C. Treatments and Experimental Design

A completely randomized block design with four replicates was used. The treatments applied were as follows: mesotrione (0.072 and 0.144 kg ha^{-1} + 0.5% v/v mineral oil - Assist®), tembotrione (0.075 and 0.100 kg ha^{-1} + 0.5 % v/v mineral oil - Aureo®), atrazine plus mesotrione (1.25 + 0.072 kg ha^{-1} + 0.5% v/v mineral oil - Assist®), atrazine plus tembotrione (1.25 + 0.100 kg ha^{-1} + 0.5% v/v mineral oil - Aureo®), atrazine plus mesotrione (1.25 + 0.072 kg ha^{-1}), atrazine plus tembotrione (1.25 + 0.100 kg ha^{-1}) and two controls (hoed and unhoed check).

D. Measurements of Elephant Grass and Weeds

Phytotoxic effects of herbicide treatments on the elephant grass and the weed control were evaluated on a scale of 0% to 100% at 10, 20 and 30 days after treatments (DAT). The value zero corresponded to no symptoms of phytotoxicity on elephant grass plants or no weed control, and 100% to complete elephant grass death or complete weed control [21]. All weed species were cut on the soil surface within a quadrat (0.5 x 0.5 m) to determine aboveground fresh matter weight at 30 DAT. Green color indices were evaluated on elephant grass leaves at 23 DAT using a SPAD-502 chlorophyll meter (Konica Minolta, Japan). The harvest and determination of forage yield were performed on February 15, 2016, approximately 110 days after elephant grass establishment. Plants were cut within a quadrat (1.0 x 1.0 m) at the soil surface to quantify the aboveground biomass. Harvested plants were weighed, placed in a forced-air ventilation oven at 65 °C for 72 h; and subsequently reweighed. The values of fresh and dry matter weight of elephant grass were converted to kg ha^{-1} [4].

E. Statistical Analysis

The percentage of phytotoxicity and the weed control percentages were normalized by square root transformation of (x + 1) to perform analysis of variance tests [4]. Data were subjected to analyses of variance, and the mean values were compared using the Scott-Knott test ($P \leq 0.05$). Statistical analyses were performed using SAEG software [17].

III. Results and Discussion

The application of two doses of mesotrione with the addition of mineral oil or the tank mixture of atrazine plus mesotrione, with or without the addition of mineral oil, was highly selective to elephant grass plants (Table I).

TABLE I
PERCENTAGE OF PHYTOTOXICITY ON ELEPHANT GRASS PLANTS AT 10, 20 AND 30 DAYS AFTER APPLICATION OF THE TREATMENTS, VALENÇA, RIO DE JANEIRO STATE, BRAZIL

Treatments	Doses	Days		
	(kg ha^{-1})	10	20	30
Mesotrione	0.072+0.5% oil	0.0 D[1]	0.0 D	0.0 C
Mesotrione	0.144+0.5% oil	0.0 D	0.0 D	0.0 C
Tembotrione	0.075+0.5% oil	98.0 A	100.0 A	100.0 A
Tembotrione	0.100+0.5% oil	98.2 A	100.0 A	100.0 A
Atrazine + Mesotrione	1.25+0.072+0.5% oil	0.0 D	0.0 D	0.0 C
Atrazine + Tembotrione	1.25+0.100+0.5% oil	87.7 B	98.0 B	100.0 A
Atrazine + Mesotrione	1.25+0.072	0.0 D	0.0 D	0.0 C
Atrazine + Tembotrione	1.25+0.100	14.7 C	54.2 C	65.0 B
Hoed Check	-	0.0 D	0.0 D	0.0 C
Unhoed Check	-	0.0 D	0.0 D	0.0 C
Coefficient of Variation (%)	-	1.2	0.8	0.3

[1]Mean values followed by different letters are significantly different ($P \leq 0.05$) by Scott–Knott.

The response of millet (Cultivar 'ADR-300'), submitted to the dose of 60 g ha^{-1} of mesotrione, was evaluated [8]. The results also indicated selectivity of this herbicide to millet, since there was no damage to plant growth. Other studies conducted by [1] revealed the possibility of using mesotrione in sorghum. Several genotypes were submitted to post-emergence applications at doses of 0, 52, 105, 210, and 315 g ha^{-1}. The results showed 17 mesotrione-tolerant sorghum hybrids, and, when grown under field conditions, the symptoms of injury did not correlate with crop yield. Mesotrione (50 and 100 g ha^{-1}) and the mixture of atrazine plus mesotrione (1000 + 50 g ha^{-1}) were evaluated in six sorghum hybrids [26]. These treatments were selective for the sorghum crop, demonstrating that they were an option for post-emergence application.

The two doses of tembotrione with the addition of mineral oil caused total death of the plants, already in the second evaluation, at 20 DAT (Table I). Characteristic symptoms were the appearance of bleached leaves and stunted plants. Herbicides of this chemical group act in some enzymatic sites of the route of synthesis of carotenoid pigments [15]. The blocking synthesis of these pigments is responsible for the characteristic symptom of depigmentation or "albinism" due to the lack of chlorophyll protection from photodegradation. Growth ceases in absence of the production of green photosynthetic pigments and symptoms of necrosis and plant death begin to appear. Tembotrione (100.8 g ha^{-1}) was applied alone and in a tank-mix with atrazine (1,500 g h^{-1}) on three sorghum cultivars [9]. These treatments were highly detrimental to cultivars, with percentages of phytotoxicity varying from 98% to 100%.

Atrazine and tembotrione in a tank-mix plus mineral oil provided high values of phytotoxicity and plant death at 30 DAT (Table I). Reductions in the percentage of phytotoxicity were observed for atrazine plus tembotrione without mineral oil, ranging from 14% to 65%. However, these values were still high and were not enough to avoid losses in forage yield (Table II).

TABLE II
SPAD INDICES (SPAD) ON ELEPHANT GRASS PLANTS, FRESH MATTER WEIGHT (FMW) (KG HA^{-1}) AND DRY MATTER WEIGHT (DMW) (KG HA^{-1}) OF ELEPHANT GRASS, VALENÇA, RIO DE JANEIRO STATE, BRAZIL

Treatments	Doses (kg ha^{-1})	SPAD	FMW	DMW
Mesotrione	0.072+0.5% oil	56.3 A[1]	159.300.0 A	44.720.19 A
Mesotrione	0.144+0.5% oil	56.2 A	177.125.0 A	43.239.14 A
Tembotrione	0.075+0.5% oil	18.4 D	53.800.0 C	14.598.98 C
Tembotrione	0.100+0.5% oil	30.4 C	64.850.00 C	17.496.23 C
Atrazine + Mesotrione	1.25+0.144+0.5% oil	53.3 A	165.750.0 A	46.533.98 A
Atrazine + Tembotrione	1.25+0.100+0.5% oil	30.9 C	79.400.0 C	21.460.32 C
Atrazine + Mesotrione	1.25+0.144	53.9 A	180.050.0 A	49.079.70 A
Atrazine + Tembotrione	1.25+0.100	46.7 B	119.600.0 B	34.635.12 B
Hoed Check	-	53.4 A	163.600.0 A	44.557.86 A
Unhoed Check	-	50.1 B	69.600.0 C	19.920.53 C
Coefficient of Variation (%)	-	7.1	12.8	17.9

[1]Mean values followed by different letters are significantly different ($P \leq 0.05$) by Scott–Knott test.

TABLE III
PERCENTAGE OF WEED CONTROL ON ELEPHANT GRASS PLANTS AT 10, 20 AND 30 DAYS AFTER APPLICATION OF THE TREATMENTS AND FRESH MATTER WEIGHT OF WEEDS (G 0.25 M^{-2}) (FMW) AT 30 DAT. VALENÇA, RIO DE JANEIRO STATE, BRAZIL

Treatments	Doses (kg ha^{-1})	Days			FMW
		10	20	30	
Mesotrione	0.072+0.5% oil	62.5 D[1]	50.0 E	77.2 E	1.47 B
Mesotrione	0.144+0.5% oil	78.2 C	62.5 C	87.2 C	0.90 B
Tembotrione	0.075+0.5% oil	98.7 A	99.5 A	100.0 A	0.62 B
Tembotrione	0.100+0.5% oil	99.5 A	100.0 A	100.0 A	1.04 B
Atrazine + Mesotrione	1.25+0.072+0.5% oil	57.2 E	50.2 E	85.0 D	1.01 B
Atrazine + Tembotrione	1.25+0.100+0.5% oil	99.5 A	100.0 A	100.0 A	0.61 B
Atrazine + Mesotrione	1.25+0.072	60.7 D	58.2 D	84.7 D	0.98 B
Atrazine + Tembotrione	1.25+0.100	87.2 B	89.2 B	95.5 B	0.96 B
Hoed Check	-	100.0 A	100.0 A	100.0 A	0.26 B
Unhoed Check	-	0.0 F	0.0 F	0.0 F	2.44 A
Coeficient of Variation (%)	-	1.8	0.9	0.5	54.2

[1] Mean values followed by different letters are significantly different ($P \leq 0.05$) by Scott–Knott test.

All treatments of mesotrione plus mineral oil or a tank mixture of atrazine plus mesotrione, with or without the addition of mineral oil, resulted in SPAD index values statistically equal to the hoed check (Table II). These same treatments were not reflected in forage yield losses, whose values of fresh and dry matter weights were similar to those reached in the hoed check. On the other hand, treatments with tembotrione plus mineral oil and atrazine plus tembotrione with and without mineral oil resulted in low SPAD index values. This fact reinforced the results obtained with visual evaluations of phytotoxicity. Elephant grass growth and development, which were adversely affected which reflected in forage yield losses.

Even though tembotrione has been registered for corn in post-emergence applications [19], [11], some sweet corn genotypes are sensitive to it [3]. The corn hybrid 'Merit' cultivar presents low tolerance to tembotrione applied alone or in a tank mixture with atrazine.

Weed interference in elephant grass can be measured when comparing the two checks (Table II). The reduction of elephant grass fresh and dry matter weights was evident as a result of weed interference. The unhoed check yielded 42.5%

and 44.7% less fresh and dry matter weights when compared to the hoed check, respectively.

Weed control in all mesotrione treatments ranged from 77% to 87% at 30 DAT (Table III).

Although the lowest dose of this herbicide resulted in 77% weed control at 30 DAT, there was no loss on forage yield in function of weed interference. The mixture of atrazine to mesotrione (0.072 kg ha^{-1}) provided improvements in weed control. The percentages of control ranged from 77% to 85% at 30 DAT when mesotrione was applied alone or in a tank-mix with atrazine, respectively. The importance of using atrazine in a tank-mix with other herbicides is due to the increase in spectrum of weed control [28]. The authors observed that in-tank mixing of atrazine with HPPD-inhibiting herbicides provided increases in the number and weight of ears of sweet corn of 9% and 13%, respectively, when compared to these herbicides applied alone.

The best weed control treatments were tembotrione alone or in combination with atrazine; the percentages ranged from 95% to 100% at 30 DAT. All herbicide treatments reduced the fresh matter weights of weeds, differing statistically from the unhoed check.

This research provides alternatives to weed control in elephant grass fields. Different herbicide options that are feasible for use in elephant grass can facilitate the increases in cultivated areas and forage supplies, mainly in tropical and subtropical regions.

IV. Conclusions

This research provides alternatives to weed control in elephant grass fields.

Mesotrione with the addition of mineral oil or in mixture with atrazine with or without mineral oil were tolerated by elephant grass. All treatments with tembotrione were phytotoxic to elephant grass, regardless the addition of mineral oil or not. The control of weeds was efficient with the application of all treatments.

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