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Phytotoxicity of herbicides applied in post transplanting of seedlings of yellow passion fruit[1]

Fitotoxicidade de herbicidas aplicados em pós transplantio de mudas de maracujá amarelo

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Abstract - Brazil is the world's leading producer of passion fruit. However, for this crop, there are no records of herbicides for weed control. Thus, the aim of this study was to evaluate the effects of herbicide application after transplanting of yellow passion fruit seedlings during growth and phytotoxicity of the crop. Twenty-one herbicides with different mechanisms of action were tested by application at 35 days after transplanting (DAT). Phytotoxicity of the crop by the herbicides was evaluated at 63 DAT, and assessments of damage to seedlings were held at 70 days DAT. No herbicide caused damage to the root system of the passion fruit plants. The herbicides glyphosate, imazapic, metsulfuron-methyl and glufosinate-ammonium reduced plant height gain. The herbicides atrazine, linuron, metribuzin, diuron, tebuthiuron and bentazon reduced leaf dry matter, stem dry matter and total dry matter of the plants. Fluazifop-p-butyl reduced height gain and leaf dry matter. Herbicides that caused the greatest damage to seedling growth also caused the greatest phytotoxicity. The herbicides oxadiazon, fenoxaprop-ethyl, tembotrione, chlorimuron-ethyl and isoxaflutole did not hinder growth and did not intoxicate the seedlings; they were the most promising for use in the total area.
Keywords: *Passiflora edulis*; selectivity; weeds

Resumo - O Brasil é o principal produtor de maracujá do mundo, todavia, para esta cultura não existe registro de herbicidas no controle de plantas daninhas. Sendo assim, o objetivo deste experimento foi avaliar os efeitos da aplicação de herbicidas após o transplantio de mudas de maracujá amarelo no crescimento e intoxicação da cultura. Foram testados 21 herbicidas de diferentes mecanismos de ação aplicados aos 35 dias após transplantio (DAT). Aos 63 dias DAT foram avaliadas as intoxicações causadas pelos herbicidas na cultura, e aos 70 dias DAT foram realizadas as avaliações dos danos causados às mudas. Nenhum herbicida causou danos ao sistema radicular das plantas de maracujá. Os herbicidas glifosate, imazapic, metsulfuron-methyl e amonio-glufosinate, causaram reduções no ganho em altura das plantas. Os herbicidas atrazine, linuron,

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metribuzin, diuron, tebuthiuron e bentazon reduziram a matéria seca da folha, caule e total das plantas. O fluazifop-p-butil reduziu o ganho em altura e a matéria seca de folhas. Os herbicidas que causaram os maiores danos no crescimento das mudas, também causaram maiores intoxicações. Os herbicidas oxadiazon, fenoxaprop-ethyl, tembotrione, chlorimuron-ethyl e isoxaflutole não prejudicaram o crescimento e não intoxicaram as mudas, sendo os mais promissores para aplicação em área total.

Palavras-chaves: *Passiflora edulis*; seletividade; plantas daninhas

Introduction

Commercial cultivation of passion fruit in Brazil is based on a single species (*Passiflora edulis*), popularly known as yellow or sour passion fruit, which is present in over 97% of orchards, because it offers good quality, vigor, productivity and yield as juice (Panasonichigh and Brückner, 2001; Ferreira, 2005).

Passion fruit crops stand out among those of other tropical fruits, as they are considered to be an interesting agricultural alternative for small farms. Passion fruit plants are the ones that have attracted most small farmers because they offer rapid economic return, as well as the opportunity for better income distribution throughtout the year (Meletti et al., 2011). Brazil is the largest producer of passion fruit, with an average yield of 14.6 t ha^{-1} (IBGE, 2013), below the potential presented by the crop, which is more than 50 t ha^{-1} (Meletti et al. 2011).

Passion fruit is an annual crop, whose vegetative cycle varies according to the place of production, ranging from 12 months in the state of Pará, to ten months in Bahia, and to seven to nine months in São Paulo (Araújo et al., 2005). Thus, this crop is subject to the occurrence of several weed cycles during the year, and this is one of the main reasons for Brazil's low average productivity. Improper weed management can lead to reduced productivity and quality of passion fruit, as weeds compete against the crop for nutrients and water (Souza et al., 2002).

The main training system used for passion fruit plants is by means of espaliers, which allow greater interrow spacing, thus enabling favorable conditions for the development of weeds next to the planting rows. The fact that the root system of the crop is concentrated at 20 cm soil surface layer may hinder the use of manual or mechanical weeding, as they may damage the roots and facilitate the entry of pathogens (Ogliari et al., 2007).

The most frequently used method for weed control in most crops is chemical control, whose success depends on herbicide selectivity, which is the measure of the differential response of plant species to the application of a particular molecule (Oliveira Jr. et al., 2001). However, there is still little research on herbicide application on passion fruit crops, and currently there are no products registered by the Ministry of Agriculture, Livestock and Food Supply (MAPA, 2015) for use of this control method.

Some producers use paraquat and / or glyphosate for weed control in passion fruit plantations, with directed applications between the rows, keeping the soil covered with the remaining straw. Research conducted by Lima et al. (1999), by checking the selectivity of herbicides diuron, oxyfluorfen, alachlor and metolachlor + atrazine, applied before transplanting of yellow passion fruit seedlings, found that only atrazine + metolachlor, at rates of 6.0 and 12.0 kg ha^{-1}, caused injury to seedlings, while the others were promising for use in the field. However, there are no studies in the literature evaluating the use of herbicides after transplanting for application in the total area.

Therefore, this study aimed to evaluate the effects of herbicide application after transplanting of yellow passion fruit seedlings on growth and phytotoxicity of the crop.

Material and Methods

The experiment was conducted at Diogo Alves de Melo experimental station, Federal University of Viçosa (UFV), Viçosa-MG. Yellow passion fruit seeds (FB200 yellow master) were sown in Bioplant® substrate and grown in a greenhouse for 60 days until they had 6 to 8 fully developed leaves, when they were then transplanted to pots (6 L) in open field. Typical Dystrophic Acrisol with medium texture was used as a substrate (Embrapa, 2015). It had been previously sieved and fertilized. Table 1 shows the results of chemical and physical analyses.

Table 1. Results of chemical and physical analyses of the red-yellow typical Distrophic Acrisol. Viçosa (MG), 2015.

pH	P	K	Ca	Mg	Al	H + Al	SB	(t)	(T)	V	m	OM
H_2O	mg dm^{-3}		---------------------- cmol$_c$dm^{-3} -----------------------							----- % ---		Dag kg^{-1}
5.8	7.2	98	2.3	1.4	0.0	3.8	3.98	3.98	7.78	51	0	2.98
Granulometry (%)	Clay = 24					Silt = 17				Sand = 59%		

Analysys performed at the Soil Analysis Laboratory of Viçosa, according to the methodology of the Brazilian Agricultural Research Corporation - EMBRAPA (1997); (t) = effective cation exchange capacity; (T) = total cation exchange capacity; V = base saturation; m = Saturation by Al^{+3}; OM = organic matter.

For the purposes of nutrient adequacy of the substrate, pre-planting and topdressing fertilizations were performed according to the recommendations for the crop (CFSEMG, 1999). At 20 days after transplanting of the seedlings, additional topdressing fertilization was performed. Drip irrigation was performed daily, while respecting the needs of the crop on the dates required by climatic conditions (Figure 1).

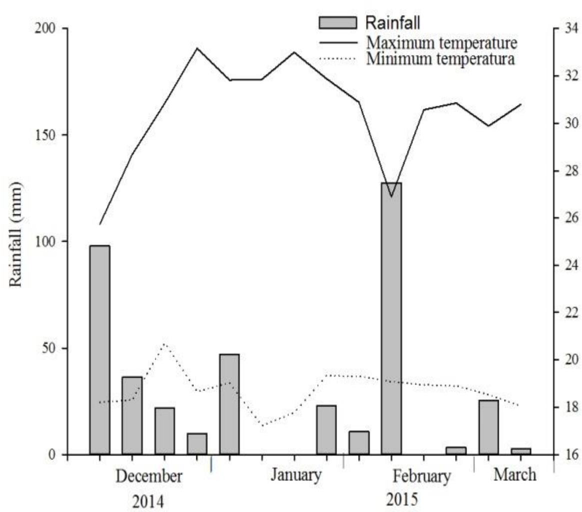

Figure 1. Rainfall and maximum and minimum temperatures per week during the period of the experiment. Viçosa (MG), 2015.

The experimental design was a randomized block with four replications. The treatments consisted of 21 herbicides with different mechanisms of action and a control without herbicide application. The experimental units were composed of pots containing a single seedling. Table 2 shows the mechanisms of action, trade name, common name, and rate of active ingredient.

Herbicide application was performed at 35 days after transplanting in pots in the open field, using a CO2-pressurized, backpack sprayer with constant pressure, fitted with a flat fan, positioned at 0.50 m away from the seedlings, at a height of 0.50 m above the ground with a speed of 1 m s^{-1}, applied in the range of 0.50 m wide, resulting in a spray volume of 150 L ha^{-1}. Initial plant height was assessed on the day of application by using a scale ruler.

At 28 days after herbicide application (DAA), an assessment was made of phytotoxicity of the crop caused by the herbicides, with a scale ranging from 0 (no toxicity) to 100 (plant death), according to the modified EWRC scale (1964).

At 70 days after transplanting, final plant height was measured, and height gain was calculated, based on data on initial and final height. Plant material was collected and separated into leaves (for determination of leaf area), stems and roots. Then, the material was dried in a forced air circulation oven at 65° C to constant weight to determine the dry matter of the plant parts.

Table 2. Classification of herbicides and their rates applied on passion fruit plants. Viçosa (MG), 2015.

Mechanism of action	Commercial product	Common name (a.i)	Dose a.i (g ha^{-1})
Photosystem II Inhibitors	Totril®	Ioxynil-octanoato	335
	Atranex® 500 SC	Atrazine	2000
	Afalon® SC	Linuron	720
	Sencor® 480	Metribuzin	360
	Diuron Nortox® 500 SC	Diuron	1600
	Combine® 500 SC	Tebuthiuron	1000
	Basagran® 600	Bentazon	720
Protox Inhibitors	Flex®	Fomesafen	225
	Goal® BR	Oxyfluorfen	480
	Ronstar® 250 BR	Oxadiazon	750
Photosystem I Inhibitors	Gramoxone® 200	Paraquat	300
EPSP Synthase Inhibitors	Roundup Original®	Glyphosate	720
Acetolactato sintase Inhibitors	Plateau®	Imazapic	105
	Ally®	Metsulfuron-methyl	1,98
Glutamine Synthetase Inhibitors	Finale®	Amonio-glufosinate	300
ACCase Inhibitors	Podium® EW	Fenoxaprop-ethyl	88
	Fusilade® 250 EW	Fluazifop-p-butil	125
Carotenoid Biosynthesis Inhibitors	Soberan®	Tembotrione	75,6
	Fordor® 750 WG	Isoxaflutole	75
PPO and ACCase Inhibitors	Fusiflex®	Fomesafen + Fluazifop-p-butil	200 + 200
ALS Inhibitors	Classic®	Chlorimuron-ethyl	17,5

The morphological data were submitted to analysis of variance, and the means, when significant, were grouped by the Scott-Knott test at 5% probability of error. Data on phytotoxicity percentage were analyzed descriptively using the standard deviation.

Results and Discussion

The herbicides belonging to the groups of derivatives of glycine (glyphosate and imazapic), sulfonylureas (metsulfuron-methyl) and phosphinic acids (glufosinate-ammonium) caused a minor increase in the height of the treated plants, and the latter also caused a drastic reduction in leaf area (Table 3). The results observed in the plants treated with metsulfuron-methyl are attributed to the fact that this molecule causes symptoms in meristematic tissues first, where they found high amounts of amino acids, thus halting plant growth (Shaner and Singh, 1993).

The dry matter values of plant parts (leaves, stem and total area) were affected by most of the herbicides, and the photosystem II inhibitors caused most damage to plants (atrazine, linuron, metribuzin, diuron, tebuthiuron, bentazon). The herbicides that inhibit the photosystem II, such as triazines, ureas and uracil, block electron transport in the photosystem and generate chlorophyll molecules that are more energy-charged. As a result, they form a chain reaction, form free radicals, and lead to peroxidation of lipid membranes, causing damage to plants (Gronwald, 1994; Vidal, 1997).

Fluazifop-p-butyl adversely affected height gain and dry matter of passion fruit leaves. This herbicide belongs to the group of ACCase inhibitors which act by inhibiting the enzyme Acetyl-CoA carboxylase (ACCase), preventing lipid synthesis and halting the growth of the treated plants (Rendina et al., 1989; Gronwald, 1991; Ohlrogge and Browse, 1995). The selectivity of these herbicides to dicotyledonous species generally lies in the type of enzyme and its compartmentalization in the cell. Grass species have only cells with a form of ACCase both in the cytoplasm and in the stroma of the chloroplasts; by contrast, in dicotyledonous species, the form present in the cytoplasm would be equivalent to that of grasses, while the one present in chloroplasts would be insensitive to the action of these herbicides and account for all lipid synthesis when the cytoplasmic enzyme is inhibited (Sasaki et al., 1995).

Table 3. Height gain, stem, leaf and total dry and leaf area for passion fruit plants at 35 DAA. Viçosa (MG), 2015.

Herbicides	Variáveis									
	Height gain		Stem dry matter		Leaf dry matter		Total dry matter		Leaf area	
	(cm)				(g plant^{-1})				(cm²)	
Without herbicide	**102,58**	**A**	**19,90**	**A**	**21,18**	**A**	**56,15**	**A**	**1.934,50**	**A**
Atrazine	79,60	B	10,64	B	12,90	B	34,90	B	1.301,00	B
Fomesafen + Fluazifop-p-butil	73,33	B	9,27	B	12,13	B	29,57	B	1.167,33	B
Bentazon	64,33	B	11,27	B	12,33	B	36,33	B	1.161,00	B
Tebuthiuron	52,25	B	10,53	B	11,18	B	30,88	B	1.090,00	B
Amonio-glufosinate	23,20	C	9,56	B	7,10	B	23,84	B	522,60	C
Linuron	67,50	B	12,00	B	14,13	B	38,15	B	1.218,25	B
Oxyfluorfen	57,75	B	11,93	B	14,65	B	36,38	B	1.360,50	B
Ioxynil-octanoato	**85,25**	**A**	**14,10**	**A**	**17,08**	**A**	**41,35**	**A**	**1.655,50**	**A**
Fluazifop-p-butil	78,50	B	12,78	B	22,65	A	50,95	A	1.644,75	A
Fomesafen	70,75	B	14,15	A	18,93	A	44,33	A	1.649,00	A
Diuron	87,00	A	10,88	B	13,85	B	34,35	B	2.150,50	A
Metribuzin	68,25	B	10,83	B	15,93	B	37,60	B	1.593,50	A
Oxadiazon	**92,75**	**A**	**14,73**	**A**	**21,88**	**A**	**47,08**	**A**	**1.961,75**	**A**
Paraquat	70,00	B	15,68	A	15,90	B	41,10	A	1.440,00	B
Fenoxaprop-ethyl	**85,00**	**A**	**13,75**	**A**	**19,10**	**A**	**44,03**	**A**	**1.573,08**	**A**
Tembotrione	**93,25**	**A**	**13,78**	**A**	**16,98**	**A**	**47,13**	**A**	**1.656,75**	**A**
Glyphosate	2,25	C	10,70	B	21,65	A	40,10	A	1.155,50	B
Metsulfuron-methyl	8,75	C	10,15	B	20,50	A	40,73	A	1.401,25	B
Imazapic	19,75	C	13,38	A	20,68	A	41,58	A	1.356,50	B
Chlorimuron-ethyl	**96,00**	**A**	**15,75**	**A**	**17,78**	**A**	**44,95**	**A**	**1.550,00**	**A**
Isoxaflutole	**103,25**	**A**	**14,25**	**A**	**21,35**	**A**	**47,73**	**A**	**1.889,00**	**A**
CV (%)	28,65		28,52		24,81		18,43		22,99	

Means followed by the same capital letter in the column do not differ by the Scott-Knott test (p = 0.05). Treatments marked in **bold** were grouped together with the control treatment in all morphological variables.

Although the ACCase inhibitors are considered to be systemic graminicides, there are sensitive dicot species. Vidal, et al., (2000), as previously observed for passion fruit plants (Eudicotiledonea) found that fluazifop-p-butyl affects height gain and dry matter production of leaves in melon and cucumbers plants. This did not occur with the use of fenoxaprop-ethyl (also belonging to the group of ACCase inhibitors), which caused no change in growth or symptom of the seedlings, indicating that the damage caused by fluazifop-p-butyl is not inflicted by all the herbicides with this mechanism of action.

Phytotoxicity percentage assessments followed the same trend of growth assessments (Figure 2). With the exception of fluazifop-p-butyl, herbicides that caused damage in these variables, also caused phytotoxicity with values that ranged from 3.25 to 66.75%. Among the herbicides that do not affect plant growth (ioxynyl-octanoate oxadiazon, fenoxaprop-ethyl, tembotrione, chlorimuron-ethyl and isoxaflutole), ioxynyl octanoate was not selected because it caused toxicity greater than 25%, while for the other herbicides, when symptoms were evident, toxicity was less than 10% - considered as acceptable from an agricultural point of view, which shows that these molecules are potentially selective to passion fruit crops.

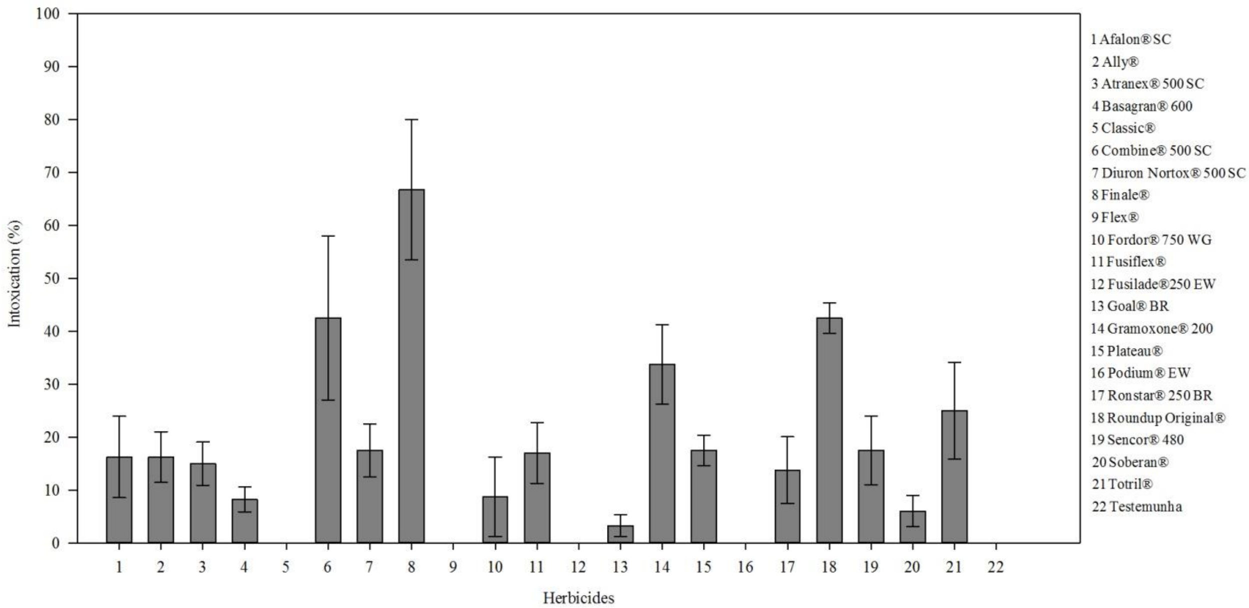

Figure 2. Phytotoxicity percentage of passion fruit plants treated with herbicide applications at 28 DAA. Viçosa (MG), 2015.

The herbicides tembotrione and isoxaflutole, belong to the group of carotenoid synthesis inhibitors; more particularly, molecules that act by inhibiting the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD), essential in carotenoid biosynthesis (Mitchell et al., 2001; Hawkes, 2007). Currently, in Brazil, tembotrione is registered only for corn, and isoxaflutole, for crops of eucalyptus and pine (MAPA, 2015). There is limited information available on the possible reasons for the selectivity of these herbicides to crops (Oliveira Jr., 2011).

Oxadiazon, belongs to the Group of PROTOX inhibitors, and the basis of selectivity of this herbicide in tolerant species is attributed to minimum absorption and translocation, sequestration of the herbicide or increase in concentration of the mitochondrial PROTOX enzyme, which reduces excess protoporphyrinogen in the cytoplasm (Higgins et al., 1988; Matsumoto et al., 1999; Warabi et al., 2001). In Brazil, this herbicide, is currently recommended for rice, irrigated rice, garlic, onions and sugar cane crops (MAPA, 2015).

Chlorimuron-ethyl, which belongs to the class of ALS inhibitors (Acetolactate Synthase), may inhibit the synthesis of branched-chain amino acids (valine, leucine and isoleucine), interrupting protein synthesis, which in turn interferes with DNA synthesis and cell growth (Petter et al., 2011). The selectivity of this group of herbicides in some crops, such as soybeans and wheat, is based primarily on the ability of plants to quickly metabolize the herbicide into non-toxic forms (Sweester et al., 1982). In Brazil, it is recommended for use in soybeans and in desiccation of areas (MAPA, 2015).

The herbicides glyphosate, imazapic, metsulfuron-methyl and glufosinate-ammonium caused reductions in plant height gain. Photosystem II inhibitors (atrazine, linuron, metribuzin, diuron, tebuthiuron and bentazon) were the key players in reducing dry matter accumulation of plant parts (leaves, stems and total area). Fluazifop-p-butyl affected height gain and leaf dry matter. Phytotoxicity percentage assessments usually followed the same trend in growth. The herbicides oxadiazon, fenoxaprop-ethyl, tembotrione, chlorimuron-ethyl and isoxaflutole proved to be the most promising for use in total area, and can be potentially used in studies on time, rates and method of application in the field and their effects on crop yield, with possibly different options of mechanisms of action for weed control in passion fruit.

Conclusions

The herbicides oxadiazon, fenoxaprop-ethyl, tembotrione, chlorimuron-ethyl and isoxaflutole proved to be the most promising for use in total area, as they were were highly selective to the passion fruit crop until 35 DAA.

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