Selectivity of Clomazone and S-Metolachlor Applied after Cassava Pruning[1]

Seletividade do Clomazone e do S-Metolachlor Aplicados Após a Poda da Mandioca

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ABSTRACT - The objective of this work was to evaluate the selectivity of clomazone in two formulations and S-metolachlor applied on shoots of different sizes after pruning of 'Baianinha' cassava. The experiment was arranged in a randomized block design in a factorial 5 x 2 (5 treatments x 2 sizes of shoots after pruning – 10 and 33 cm) with four replications. The herbicides evaluated were: clomazone (encapsulated suspension – 900 g h^{-1}), clomazone (encapsulated suspension – 1,080 g ha^{-1}), clomazone (emulsifiable concentrate 900 g ha^{-1}), S-metolachlor (1,920 g ha^{-1}) and an untreated control. During the experiment, all plots were kept free of weed interference by hand weeding. It was concluded that both the formulations of clomazone and S-metolachlor were selective when applied on both the shoot sizes evaluated. However, the application of S-metolachlor on 33 cm shoots gave higher selectivity to 'Baianinha' cassava plants.

Keywords: *Manihot esculenta*, microencapsulated, weed, clomazone, S-metolachlor.

RESUMO - Objetivou-se neste estudo avaliar a seletividade do clomazone em duas formulações e do S-metolachlor aplicados em diferentes tamanhos de brotos depois da poda da mandioca Baianinha. O delineamento experimental utilizado foi o de blocos ao acaso, em esquema fatorial 5 x 2 (5 tratamentos x 2 tamanhos de brotos após a poda – 10 e 33 cm), com quatro repetições. Os herbicidas avaliados foram: clomazone (suspensão de encapsulado 900 g ha^{-1}), clomazone (suspensão de encapsulado 1.080 g ha^{-1}), clomazone (concentrado emulsionável 900 g ha^{-1}), S-metolachlor (1.920 g ha^{-1}), além da testemunha sem aplicação. Durante a condução do experimento, todas as parcelas foram mantidas livres da interferência das plantas daninhas por meio de capinas manuais. Concluiu-se que ambas as formulações do clomazone e o S-metolachlor apresentaram-se seletivas quando aplicadas em ambos os tamanhos de brotos avaliados; no entanto, a aplicação do S-metolachlor em brotos de 33 cm proporcionou maior seletividade às plantas de mandioca Baianinha.

Palavras-chave: *Manihot esculenta*, microencapsulado, planta daninha, clomazone, S-metolachlor.

INTRODUCTION

Cassava (*Manihot esculenta*), having originated from Brazil and being cultivated in over 90 countries, is a plant very tolerant to drought and low soil fertility, commonly grown and consumed by small farmers in areas of poor soils and where the weather conditions are often unfavorable to other cultures (Doretto, 1993; Sagrilo et al., 2002). However, it is one of the main economic sources of carbohydrates in the tropical regions, playing a key role in human and animal nutrition and in the industrial processing of flour and starch (Albuquerque et al., 2008).

In Brazil, the state of Paraná stands out among the major cassava growing states, having a cultivated area of about 179.6 thousand hectares and production of 4.1

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million tons of roots in the 2011/2012 harvest, with an average yield of 22.6 t ha^{-1} (IBGE, 2012). However, despite cassava yield in the state of Paraná is 55.9% higher than the national average (14.5 t ha^{-1}), it still is below the potential crop yields. Cassava growers in this region report that the disturbance caused by weeds reduces significantly the crop yields, and weeds control is extremely difficult because of the high cost of weeding and the lack of options for selective herbicides for the culture.

Another important issue with regard to the cassava management is pruning of the varieties produced for the industry. Such varieties have a cycle of 18 to 24 months, and the plants are often pruned during the period of physiological rest or dormancy (10 to 12 months after planting), especially after the occurrence of frosts, in order to diminish the source of inoculums of pests and diseases, to facilitate cultural practices or to obtain stem cuttings or new planting areas (Takahashi, 1998). According to Andrade et al. (2011), cassava plants prunig during the dormant period increases the production of roots, which tend to present more dry mass and lower flour production at the end of the cycle. Likewise, Sagrilo et al. (2002) observed that the second stage of the physiological rest of the varieties Mico, IAC 13 and IAC 14 was more beneficial to harvest than a single growing cycle due to the increased production of tuberous roots (92.5%), dry mass (125.0%), and starch (144.0%). These are important characteristics for the starch industry.

Hence, beginning with cassava pruning, a new period of development of the culture takes place, and the weeds interference can significantly impair the production and quality of the roots, requiring the adoption of control measures.

Weeds can compete for limiting environmental resources (mostly water, light and nutrients); release allelopathic substances and thus prevent sprouting of cassava shoots; host pests and diseases that are common to the culture; interfere with the crop yields (Pitelli, 1985). The level of disturbance of the weeds community with the cassava culture may decrease the production of roots and starch from 89.8 to 100% (Peressin, et al., 1998; Alabi et al., 2001; Chikoye et al., 2001; Johanns & Contiero, 2006; Albuquerque et al., 2008; Biffe et al., 2010).

Thus, chemical control appears to be an excellent alternative for the control of weeds in cassava cultures for allowing intervention in large areas with little dependence on manpower and due to its quick application (Silva et al., 2012; Silveira et al., 2012). However, in Brazil only ametryna+clomazone, clethodim, clomazone, isoxaflutole and metribuzin are registered herbicides for cassava cultures (Rodrigues & Almeida, 2005).

Among these herbicides, clomazone (carotenoid inhibitor) stands out as the herbicide more commonly used in the pre-emergence of the culture and is commercially available in two formulations (Emulsifiable Concentrate – EC and Encapsulated or Microencapsulated Suspension – ES), and the ES clomazone formulation was developed recently to minimize losses by volatilization, photodecomposition (photolysis), besides providing a slower release of the molecule into the environment and, as a consequence, maximizing the residual effect on the soils on the weeds seed bank (Webster et al., 1999; Bollich et al., 2000). Therefore, there are few studies on the differences of selectivity of the clomazone formulations in the different cycles of cassava growth.

According to Silva et al. (2012), there are several molecules of herbicides that allowed satisfactory research results on the control of weeds, being selective for cassava, but they are still pending on register. Among these products we can cite S-metolachlor, which showed to be selective and can be included in the weeds management programs (Silva et al., 2009; Biffe et al., 2010).

Thus, there is little information in the literature on the management of weeds during cassava pruning and on the influence of application of pre-emergence herbicides on crop yields after sprouting. Therefore, the hypotheses of this study are based on the fact that the reserves of starch in the cassava roots may provide a better tolerance to pre-emergence herbicides applied after pruning and the beginning of sprouting, as well as the kind of herbicide formulation may influence the selectivity.

Thus, the objective was to evaluate the selectivity of clomazone in two formulations and S-metolachlor applied in different sizes of shoots after pruning of 'Baianinha' cassava.

MATERIAL AND METHODS

The experiment was conducted at the IAPAR's Experimental Station in the municipality of Porto Mendes-PR. The area has been cultivated for 18 years in the no-tillage system, rotating with soybean in summer and maize in winter. Before the experiment, maize was cultivated (sowing in February/2010) with spacing of 0.9 m between rows and 4.0 plants per meter. After the maize has been harvested, the area was desiccated (Aug/2011) using glyphosate (Atanor 360) in a mixture with 2.4-D (Aminol 806), in dosages of 3.3 + 1.0 L ha^{-1} of the commercial products.

Planting of the 'Baianinha' variety was made in Sept 12/2010 in the no-tillage system, with the help of a mechanized planter with row spacing of 0.9 x 0.7 m. In the first cycle of the culture, the weeds were controlled with pre-emergent chemical control with application of sulfentrazone (Boral 500 SC), in the dosage of 1.0 L ha^{-1} of the commercial product, and 20 days after planting clomazone herbicide (Gamit 500 EC) was used at the dosage of 2.0 L ha^{-1} of the commercial product.

Chemical analysis of the soil indicated the following characteristics: pH ($CaCl_2$) = 5.6; organic matter (g dm^{-3}) = 22.6; P (mg dm^{-3}) = 4.0; H+Al, K, Ca, Mg, SB and CTC ($cmol_c$ dm^{-3}) = 4.61; 0.51; 8.09; 1.88; 10.48 and 15.09, respectively; and V% = 69.45; and the soil composition indicated 15.0% of sand; 30.0% of silt and 55.0% of clay.

The experimental design was randomized block in a 5 x 2 factorial design (5 treatments x 2 sizes of shoots after pruning) with four replications. The treatments evaluated in the experiment are described in Table 1. Data on average temperature (°C) and rainfall (mm) during the period of the experiment are described in Figure 1.

Table 1 - Treatments evaluated in the experiment. Porto Mendes-PR, 2010-2012

Treatment	Dosage (g ha^{-1})	Shoot size (cm)
Control	---	10
Control	---	33
Clomazone[1/]	900	10
Clomazone[1/]	900	33
Clomazone[1/]	1.080	10
Clomazone[1/]	1.080	33
Clomazone[2/]	900	10
Clomazone[2/]	900	33
S-metolachlor[3/]	1.920	10
S-metolachlor[3/]	1.920	33

[1/] commercial product Gamit 360 ES (Encapsulate suspension); [2/] commercial product Gamit 500 EC (Emulsifiable Concentrate); [3/] commercial product Dual 960 EC (Emulsifiable Concentrate).

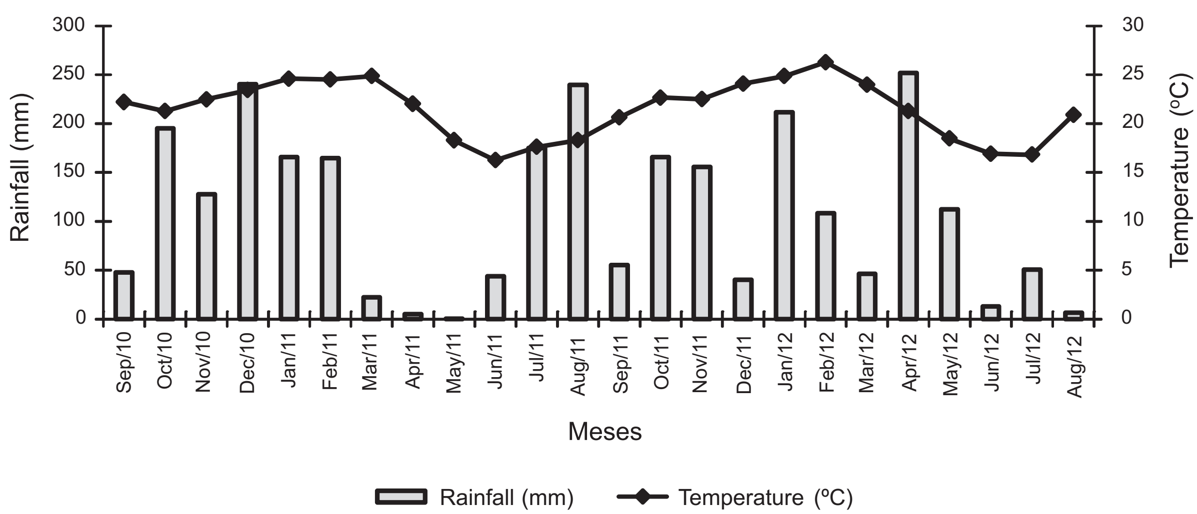

Figure 1 - Average temperature (°C) and rainfall (mm) during the experiment's period of time. Porto Mendes-PR, 2010-2012.

The plots consisted of 5 rows of cassava with space of 0.9 m and 7.0 m long (4.5 x 7.0 = 31.5 m^2). Total area of the experiment = 1,260 m^2. During the conduction of the experiment, all plots were kept free from the interference of weeds by means of manual weeding.

The application of the treatments was performed at the end of the first cycle of growth of 'Baianinha' cassava after management of stem cuttings. The first application was performed in Sept 28/2011, when the shoots had an average size of 10 cm, while the second application was made in Oct 18/2011, when the shoots had an average size of 33 cm.

A backpack sprayer was used, pressurized by CO_2 and equipped with a bar with four flat tips (Jet Model 110-LD-02), spaced in 50 cm, and the consumption of the solution was equivalent to 200 L ha^{-1} using pressure of 45 Lb pol^{-2}.

The applications were made in the late afternoon, and the first and second applications had the following conditions of temperature, relative humidity and wind speed: 26.1 and 23.3 ^oC; 50 and 54%; 2 and 4 km h^{-1}, respectively.

Evaluations of phytotoxicity in the cassava plants were made visually, using a scale of percentage of grades, in which 0 (zero) corresponds to no injury shown in the cassava plant and 100 (one hundred) to the death of the plants (SBCPD, 1995). The criteria used for the grades were: growth inhibition, amount and uniformity of injuries; plants' sprouting ability; and amount of dead plants. Evaluations were performed at the 7th and 21st days after the first and second application of the herbicides.

At the 57th and 37th days after the first and second applications, respectively, five plants at random at the three central rows of the plots were assessed to determine height (m). The evaluation was made using a graduated rule (2 m), and measures of the plant were taken from the soil to the apex.

By the time of harvest of the cassava roots (Aug 24/2012 – 23 months cycle), the plants from the three central rows of the plots were harvested, disregarding one plant at each end of the row. After weighing the roots, yields were determined (t ha^{-1}). From each plot a sample of 5.0 kg of roots were collected to determine the percentage of starch, using the method of hydrostatic scale as proposed by Grossman & Freitas (1950).

The results obtained were submitted to the analysis of variance by F test, and the averages statistically analyzed by the LSD average test at 5% probability. The percentage data of phytoxicity were transformed into arcsine $\sqrt{x/100}$.

RESULTS AND DISCUSSION

The mean percentages of phytotoxicity and plants height after application of herbicides in different sizes of shoots after pruning of 'Baianinha' cassava are presented in Table 2. There was interaction between the herbicides and the shoots size in the first evaluation of phytotoxicity of the cassava plants. It was observed that at the 7th day, only clomazone (900 g ha^{-1}) in the formulation of the emulsifiable concentrate and S-metolachlor (1,920 g ha^{-1}) provided symptoms of phytotoxicity in the plants of 4.3 and 37.5%, respectively, when applied in the 10cm shoots. These symptoms can be considered of mild and moderate intensity. The formulation of clomazone encapsulated suspension caused less injury than the emulsifiable concentrate formulation, regardless the dosage used in the initial stage of development of the shoots of 'Baianinha' cassava.

These results were not present in the applications with more developed shoots. However, despite the herbicides have caused phytotoxicity when applied in 33cm shoots, the symptoms were considered very mild (< 3.0%), which indicated more tolerance of the culture when the shoots are more developed, considering especially S-metolachlor (1,920 g ha^{-1}).

Clomazone and S-metolachlor show more sorption to colloids in clay soils than in sandy soils, and can be absorbed by the humic substances present in organic matter (Mervosh et al., 1995; Kirksey et al., 1996; Cumming et al., 2002; Vasilakoglou & Eleftherohorinos, 2003; Ferri et al., 2005). Thus, there is often the need to increase dosage so that the

Table 2 - Phytotoxicity (% of plant injury) and height (m) of 'Baianinha' cassava plants after application of herbicides to different shoot sizes after pruning. Porto Mendes-PR, 2010-2012

Treatment		Phytotoxicity (%)				Height (m)[3/]	
		7th day		21st day			
Dosage		Shoot sizes					
(g ha^{-1})		10 cm	33 cm	10 cm	33 cm	10 cm	33 cm
Control	---	0.0 (0.0) cA	0.0 (0.0) bA	0.0	0.0	1.12	1.12
Clomazone[1/]	900	0.0 (0.0) cB	1.5 (6.9) aA	0.0	0.0	1.14	1.12
Clomazone[1/]	1,080	0.0 (0.0) cB	2.0 (8.0) aA	0.0	0.0	1.12	1.12
Clomazone[2/]	900	4.3 (9.9) bA	2.0 (8.0) aA	0.0	0.0	1.15	1.12
S-metolachlor	1,920	37.5 (37.7) aA	2.8 (9.4) aB	0.0	0.0	1.08	1.11
$F_{Treatments}$ (T)		81.634**		---		1.292^{ns}	
F_{Shoots} (B)		10.989**		---		0.107^{ns}	
$F_{(T) \times (B)}$		51.501**		---		1.114^{ns}	
F_{Blocks}		1.245^{ns}		---		0.148^{ns}	
CV (%)		36.32		---		3.45	
d.m.s.		4.212		---		0.056	

Means followed by the same lowercase and uppercase in the row do not differ statistically by the 'LSD' test ($p > 0.05$). The percentage values of phytoxicity were converted into arcsine $\sqrt{x/100}$ (in brackets); ** significant at 1% probability; ^{ns} non-significant; [1/] commercial product Gamit 360 ES; [2/] commercial product Gamit 500 EC; [3/] Shoots measuring 10 cm long (57 days after application) and shoots measuring 33 cm long (37 days after application).

herbicides have a higher residual effect on the weeds seed bank, particularly in clay soils such as of the present study (55.0% of clay); however, selectivity to cultures should be maintained even with higher dosages.

The injuries caused by clomazone corresponded to the occurrence of small chlorotic spots on the leaf blade while S-metolachlor caused curling, shrinking or stunting of the leaf surface and subsequent formation of chlorotic and necrotic areas. But the phytotoxicity symptoms disappeared completely from the 21st day in all treatments for both sizes of shoots under analysis. According to Bollich et al. (2000), clomazone may cause chlorosis (bleaching), stunting, late maturity, and stand reduction, depending on the soil characteristics, the application dosage and environmental conditions.

These results indicate that the initial shoots after management of cassava pruning represent a way of absorption of herbicides, as well as the absorption may be dependent on the herbicide and the formulation used, especially considering the early sprouting stages. It is also worth noting that the good recovery of 'Baianinha' cassava when applying mainly S-metolachlor can be explained by the weather conditions that were favourable to the plants development (Figure 1) and by the plant's ability to metabolize the molecules, probably due to the use of the starch stored in the roots, which represent a key source of energy for the plant, corroborating the study hypotheses.

Likewise, the herbicides did not reduce the height of the cassava plants, when applied in shoots of 10 and 33 cm long (Table 2).

Table 3 shows the data on roots yields and percentage of starch in the 'Baianinha' cassava plants after application of herbicides.

It was observed that there was no interaction between the treatments and the shoots size, and the herbicides did not differ statistically from the control samples considering root yields and starch percentage.

However, the results of phytotoxicity in this study indicate that applications of S-metolachlor (1,920 g ha^{-1}) in the early stages of development of the shoots of 'Baianinha' cassava should receive special attention in order to prevent stress of the plants, once the occurrence of high phytotoxicity ($\geq$ 37.5%) followed by long hot periods (hydric stress) may

Table 3 - Yields and percentage of starch in the 'Baianinha' cassava roots after application of herbicides to different sizes of shoots after pruning. Porto Mendes-PR, 2010-2012

Treatment		Yields (t ha^{-1})		Starch (%)	
Dosage (g ha^{-1})		Shoot sizes			
		10 cm	33 cm	10 cm	33 cm
Control	---	67.68	68.52	24.63	24.63
Clomazone[1/]	900	73.22	69.74	25.13	24.75
Clomazone[1/]	1,080	70.98	70.18	24.13	24.63
Clomazone[2/]	900	69.97	68.01	24.88	25.00
S-metolachlor	1,920	71.09	72.62	25.25	24.88
$F_{Treatments}$ (T)		0.292^{ns}		0.471^{ns}	
F_{Shoots} (B)		0.084^{ns}		0.005^{ns}	
$F_{(T) \times (B)}$		0.117^{ns}		0.202^{ns}	
F_{Blocks}		0.175^{ns}		0.859^{ns}	
CV (%)		12.02		4.68	

[ns] non-significant; [1/] commercial product Gamit 360 ES; [2/] commercial product Gamit 500 EC.

impact negatively the development of the plants, the root yields and starch contents (Cayón et al., 1997; Santisopasri et al., 2001).

Oliveira Jr. et al. (2001) mention that metolachlor (2,000 g ha^{-1}), when applied in pre-emergent 'Espeto' cassava, caused mild phytotoxicity at the 28th day after planting and caused reduction of 29.6 and 33.6% in the plants' height and in the production of roots, respectively in relation to the control weeded sample. Biffe et al. (2010) mention that S-metolachlor (1,920 g ha^{-1}), when applied at the pre-emergent cultivars of 'Fécula Branca' and 'Fibra' cultivars, showed to be selective, and may be used as a control tool of weds in cassava cultures.

S-metolachlor inhibits the cell division, being registered in Brazil for the control of weeds in pre-emergent cultures of soybean, beans, maize, sugarcane and cotton, while clamazone inhibits the synthesis of carotenoids and has register for the control of weeds in pre-emergent cultures of tobacco, rice, sugarcane, cassava, potato and cotton, and can also be used in irrigated rice plantations soon after the plants emergence (Rodrigues & Almeida, 2005). Thus, the potential use of both clomazone and S-metolachlor formulations also after the cassava pruning may explore the residual effect on the weeds seed bank in the soil, in isolate applications or mixed with other herbicides having distinct mechanisms of action.

The selection of other selective herbicides to cassava and that have different mechanisms of action, such as for example S-metolachlor, can contribute to the management of weeds and prevent the selection of biotypes that are resistant to the herbicides in cassava cultivation areas (Beckie, 2006; Beckie & Reboud, 2009; Mello et al., 2012; Vencill et al., 2012).

So, it can be concluded that the herbicides were selective to the 'Baianinha' cassava plants when applied to 10 and 33 cm shoots, and the application of S-metolachlor in 33 cm shoots showed more selectivity to the plants.

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