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Formation of Seedlings of *Coffea canephora* Pierre ex Froehner and Weed Control Under Application of Herbicides Oxyfluorfen and Pendimethalin

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Abstract

One of the most relevant factors for the formation of coffee crops is to use quality seedlings. However, the competition of weeds for nutrients and water from the soil can negatively affect your obtaining. Thus, the control of weeds in nursery is often dependent on the use of herbicides, considering that the manual activity is costly. In this way, this work aimed to evaluate the effectiveness of weed control and the effects on the development of clonal seedlings of coffee (*Coffea canephora* Pierre ex Froehner) by application of herbicides oxyfluorfen and pendimenthalin in nursery conditions. The experiment was conducted under a completely randomized design in factorial scheme 2 × 5, two herbicides: Pendimethalin and Oxifluorfen in five doses: corresponding to 0, 1, 2, 4, 8 L.ha^{-1} of commercial products. Was evaluated during the experiment the emergence of weeds and to end (140 days), were evaluated: seedling Height, stem diameter, leaf area, number of sheets, number of roots, root length, root volume, dry mass of roots and shoot dry matter. There was significant effect for seedling height, shoot dry matter and total dry mass, in which the pendimethalin caused damage to seedlings in comparison to oxyfluorfen. The use of the herbicides Pendimethalin and Oxyfluorfen obtained satisfactory control of weeds with application of 1080g and 648 g a.i. ha^{-1}, respectively.

Keywords: amazon, coffee, doses, weeds

1. Introduction

The genus *Coffea* comprises at least 124 species of which only *C. arabica* and *C. canephora* Pierre ex a. Froehner are widely disseminated, and commercially known as Arabica and Robusta/Conilon (Davis, Tosh, Ruch, & Fay, 2011). World coffee production in 2018 reached a volume of approximately 9.89 million tons (ICO, 2018), Brazil being the largest producer with about 3.7 million tons, 37.4% of the total produced (CONAB, 2018).

As this is a perennial crop, one of the most important factors in the formation of the coffee crop is the use of quality seedlings, with good development. Thus, weed interference affects the cultivation of coffee plants due to competition exerted, promoting limitations in the exploration of this crop (Ronchi & Silva, 2006).

In the commercial production of clonal seedlings of *C. canephora*, is common the use of plastic bags as containers and soil of subsurface horizons, as substrate (Espindula et al., 2015), which can contain a seed bank several weed species, causing a competition in the formation of clonal seedlings of *C. canephora*. The coffee seedlings show slow growth and are highly susceptible to competition with weeds, which have greater efficiency in nutrient absorption (Ronchi, Terra, & Silva, 2007; Lemes, Carvalho, Souza, & Alves, 2010; Fialho et al., 2010).

The weed control in coffee seedling nurseries is usually done manually, however, demand greater labor and sometimes unsatisfactory results, mainly in high-capacity production nurseries (Piva, Maciel, & Mendonça, 2009). In this way, the adoption of chemical control with pre-emergent herbicides provides optimization and efficiency in the control of weeds, however, the recommended doses are usually for adult coffee growing, generating the need for information for plants in the initial stage.

The phytotoxicity of herbicides in plants of coffee can vary with some features, how to growth and plants size (França et al., 2010; França et al., 2013), leaf age and the stage of growth, that will influence directly the absorption and metabolism of the product (Salgado et al., 2011). Young plants are sensitive to certain active ingredients of herbicides that interfere in the accumulation of biomass of the aerial part and of the root system, negatively influencing the growth characteristics of the seedling (Oliveira, Freitas, & Vieira, 2009).

Are scarce, in literature, references of chemical control of weeds in nursery conditions for the culture of the coffee and, especially if the application of selective herbicides usually recommended for adult crops causes phytotoxic effects on development of seedlings in nursery stage. Thus, the present study aimed to evaluate the effectiveness of weed control by application of herbicides oxyfluorfen and pendimenthalin and the effects in the development of clonal seedlings of *C. canephora*.

2. Material and Methods

The experiment was conducted in nursery for clonal seedlings of coffee (*C. canephora*), in the municipality of Rolim de Moura-Rondônia (11°34′57.7″ S and 61°46′00″ W). According to Köppen, the climate of the region is of type Aw (humid equatorial), with well-defined dry season in the year (June to September), minimum temperature of 24 °C, maximum 32 °C, with average annual precipitation of 2250 mm and with relative humidity around 85%.

The stakes, propagative parts of *C. canephora*, for seedling formation were obtained from orthotropic branches removed from plantations with good phytosanitary and nutritional aspects. The techniques for seedling production followed the recommendations for coffee in the Brazilian Amazon (Espindula et al., 2015). Plastic bags were used as containers (11 cm wide × 20 cm high) and, as substrate, soil of subsurface horizons was used, which were removed below the first 10 cm.

The experiment was conducted under a completely randomized design, in a 2 × 5 factorial scheme with four replications, the first factor being the pre-emergent herbicides Pendimethalin and Oxyfluorfen; And The second factor, the herbicide doses, being 0, 1, 2, 4, 8 L ha^{-1} of the commercial products, which corresponds to 0, 400, 800, 1600, 3200 g a.i. ha^{-1} of the Pendimethalin and 0, 240, 480, 960, 1920 g a.i. ha^{-1} of the Oxyfluorfen. Each experimental unit consisted of 10 coffee seedlings, totaling 400 seedlings in the experiment.

The herbicides and their respective doses were applied 20 days before the insertion of the stakes in the containers with soil and in pre-emergence of weeds. For application was used pressurized sprayer with CO_2, equipped with nozzle model TT 110.02, operating at a height of 40 cm of the target, calibrated to apply the equivalent to 305 L. ha^{-1} of the solution.

For the production of clonal seedlings, micro sprinkler irrigation systems were used, associated with timers that controlled the irrigation for a defined time. The time of activation and waiting of the irrigation system was determined by the importance of maintaining the moisture with small droplets in the leaves of the coffee seedlings.

To verify the selectivity of the herbicides and the respective doses, were evaluated at the end of the experiment, after 140 days after herbicides application, the variables: seedling height (cm), stem diameter (mm), leaf area estimation (cm^2), number of leaves, number of roots, length of roots (cm), root volume (cm^3), dry mass of roots (g $plant^{-1}$), shoot dry matter (g $plant^{-1}$), total dry mass (g $plant^{-1}$). For the count of the number of leaves was considered fully expanded leaves. Plants height and roots length were obtained by means of graduated ruler. For height, it was measured from the beginning of the sprouting to the maximum leaf development, and the root length of the initial point of root emission in the stakes up to the maximum vertical expansion. The stem diameter was measured by means of a manual caliper, at the bottom of the Orthotropic branch of the coffee seedling. In seedlings with more than one Orthotropic branch, the average between the branches was calculated.

The root volume was determined using a graduated cylinder, containing a known volume of water and, when adding the roots, the volume of displaced water was measured, and this value was equivalent to the volume occupied by the roots. The leaf area was estimated by means of the non-destructive methodology for seedlings, described by Partelli et al. (2006), in which the measurements of the central rib length of the leaves were used.

Leaf area (LA) was calculated from Equation:

$$L\hat{A} = 0.2027 \times CRL^{2.1336} \quad (1)$$

where, $L\hat{A}$ = leaf area estimation (cm²); CRL = central Rib Length (cm).

Then, all the material was individually wrapped in paper bags and led to the forced air circulation greenhouse (65 °C) until a constant mass was obtained to determine the shoot dry matter (SDM) and root dry matter (RDM), using an analytical scale of precision and subsequent calculation for total dry matter (TDM), being SDM + RDM = TDM.

To verify the efficiency of the herbicides in weed control, the weeds that emerged were observed during the experiment. Identification by gender or species was performed. To interpret the efficiency data in weed control, the total density of plants that occurred in each treatment was calculated. The value of 100% of weed infestation was attributed to treatments without herbicide application. Based on this referential value, estimates of percentage control of weeds (relative control) were calculated for the other treatments.

The relative control (CR) was calculated from Equation:

$$RC\ (\%) = 100 - (HT \times 100)/TWH \quad (2)$$

where, RC = relative control in percentage; HT = plant density in herbicide treatment; TWH = plant density in the treatment without herbicide.

The data obtained were subjected to analysis of variance by the F test. For the significant results, the averages were compared using the Tukey test at a 5% of significance. For quantitative treatments, regression equations were adjusted. The analyses were performed with the computer program Sisvar 5.6 (Ferreira, 2011).

3. Results and Discussion

During the experiment, the weed species *Pteridium aquilinum*, *Cyperus* spp., *Brachiaria* spp., Digitaria spp., *Trema micrantha* and *Plantago tormentosa* were observed. However, the species that predominated in the treatments without herbicide application were *Cyperus* spp., *Digitaria* spp. and *Pteridium aquilinum*.

There was a significant effect for height, shoot dry matter and total dry mass of coffee seedlings, influenced by herbicide action, without significance for the effect of applied doses. There was no significant effect for any of the other variables or significant interaction between the herbicides and the doses (Table 1).

Table 1. Analysis of variance and regression for Root Length (RL), Stem Diameter (SD), Plant Height (PH), Number of Leaves (NL), Number of Roots (NR), Shoot Dry Matter (SDM), Root Dry Matter (RDM), Root Volume (RV), Leaf Area (LA) and Total Dry Matter (TDM) of *C. Canephora* seedlings under application of different doses of the herbicides Oxyfluorfen and Pendimethalin

Source of variation	Variables									
	RL	SD	PH	NL	NR	SDM	RDM	RV	LA	TDM
Herbicide (H)	0.26^{ns}	0.83^{ns}	7.94^{**}	4.00^{ns}	0.51^{ns}	6.87^{*}	4.14^{ns}	2.28^{ns}	1.08^{ns}	7.24^{*}
Doses (D)	0.71^{--}	0.41^{--}	1.30^{--}	0.18^{--}	0.34^{--}	0.87^{--}	0.57^{--}	0.10^{--}	0.71^{--}	2.75^{--}
Interacion HxD	0.13^{ns}	0.16^{ns}	0.57^{ns}	0.46^{ns}	0.53^{ns}	0.54^{ns}	0.14^{ns}	0.53^{ns}	1.70^{ns}	0.69^{ns}
Residue	3.15	0.12	12.02	1.36	1.96	0.31	0.07	2.85	52.68	0.53
CV (%)	10.07	13.34	13.34	13.79	16.79	27.26	32.6	36.72	17.98	24.50
Linear regression	0.16^{ns}	0.44^{ns}	0.82^{ns}	0.07^{ns}	0.00^{ns}	0.59^{ns}	0.29^{ns}	0.06^{ns}	0.30^{ns}	1.31^{ns}
Quadratic regression	0.45^{ns}	0.34^{ns}	0.88^{ns}	0.03^{ns}	0.00^{ns}	0.26^{ns}	0.00^{ns}	0.01^{ns}	0.46^{ns}	0.36^{ns}
Exponential regression	0.03^{ns}	2.89^{ns}	1.34^{ns}	0.09^{ns}	0.00^{ns}	1.55^{ns}	1.08^{ns}	1.30^{ns}	0.86^{ns}	3.85^{ns}

Note. ^{ns}, ** and * = non-significant, significant at the level of 1 and 5% probability, respectively, by the test F. CV: Coefficient of Variation. $^{--}$ The treatments are quantitative and the F test does not apply.

The herbicide Pendimethalin, compared to Oxyfluorfen, showed negative effects on height, shoot dry matter and total dry mass of seedlings. For seedling height, the application of the herbicide Pendimethalin promoted the reduction of 11.22% in the mean, compared with the application of Oxyfluorfen. For shoot dry matter, there was a reduction of 20.08% in the use of the herbicide Pendimethalin compared to Oxyfluorfen. The total dry mass followed this same behavior, reduced by the application of Pendimethalin in 18.90% (Table 2).

Table 2. Effects of Oxyfluorfen and Pendimethalin herbicides on plant height (PH), Shoot Dry Matter (SDM) and total dry mass (TDM) of coffee seedlings (*C. canephora*) with 120 days after stakes implantation

Treatments	PH	SDM	TDM
	cm	---------- g plant^{-1} ----------	
Oxyfluorfen	27.53 a	2.29 a	3.28 a
Pendimethalin	24.44 b	1.83 b	2.66 b
SMD	2.24	0.36	0.47

Note. Averages followed by the same letter in the column did not differ statistically by the Tukey test at level 5% of significance; SMD: Significant Minimum Difference.

Similar results were found by Alcântara (2000), evaluating the selectivity of herbicides for freshly planted coffee trees, observed that the application of the herbicide Pendimethalin (1500 g a.i. ha^{-1}) reduced the gain in height and dry weight in 37% and 36% In relation to the witness, respectively. Ahmed and Chauhan (2015), also observed damage in the yield of rice (*Oryza sativa* L.) with the application of Pendimethalin in doses above 800 g a.i. ha^{-1}, consequence of the toxicity caused by the herbicide.

For the herbicide Oxyfluorfen, other authors observed that even causing some level of toxicity, the herbicide did not compromise the evaluated parameters. Ronchi and Silva (2004) observed that the application of Oxyfluorfen (480 g a.i. ha^{-1}) directly on the coffee plants at 21 days after transplanting to the field, caused slight toxicity (26.3%), however without compromising seedling growth, evaluated at 130 days after transplanting. Silva et al. (2017) also found no significant effect on the dry matter of coffee seedlings by Oxyfluorfen application, although mild phytotoxicity, but not affecting plant development.

The herbicide Oxyfluorfen has no effect on the root tissue and is not translocable, being essentially of contact (Rodrigues & Almeida, 2011), explaining the best performance for the evaluated parameters, since the application was performed in the soil without coming into direct contact with the coffee seedlings, that were inserted in the containers with soil 20 days after the application of the herbicide. Gonçalves et al. (2009) in the culture of *Jatropha curcas* L. and Velho and Dal Magro (2015) in the Culture of broccoli (*Brassica oleracea* var. *Italica*) observed that the use of oxyfluorfen via soil without direct application in the plants did not cause phytotoxic effects. The selectivity of an herbicide is related, among other factors, to the spatial localization of the herbicide in relation to the plant, which consists of the selectivity of herbicides obtained by the physical positioning of this plant, a factor that results in the separation between sensitive plant tissues and the herbicide (Santos et al., 2011).

The herbicide Pendimethalin has a half-life time between 72 to 172 days (Weber, 1990), and unlike Oxyfluorfen, it has effects on the root system. Meristematic roots become atrophied and present reduced water and nutrient absorption capacity (Vidal & Fleck, 2001), characteristics evidenced by the negative effect on height, shoot dry matter and total dry mass.

To control the weeds that occurred in the experiment, the herbicides did not differ statistically and there was also no significant interaction between the doses and herbicides. The regression analysis was performed for the quantitative factor (table 3). The exponential equation was used to represent the behavior of herbicide doses for weed control.

Table 3. Analysis of variance and regression for weed control in the production of coffee seedlings, subjected to different doses of the herbicides Oxyfluorfen and Pendimethalin

Source of variation	Weed Control
Herbicides (H)	3.97^{ns}
Doses (D)	94.33^{--}
Interaction (HxD)	1.74^{ns}
Residue	123.33
CV (%)	18.66
Linear regression	313.9**
Quadratic regression	61.274**
Exponential regression	179.35**

Note. ^{ns}, ** and * = non-significant, significant at the level of 1 and 5% probability, respectively, by the test F. CV: Coefficient of Variation. $^{--}$ The treatments are quantitative and the F test does not apply.

The results of weed control at 140 days after herbicide application showed control efficiency for the predominant species. It is also observed that the minimum control index (80%) Established by Frans et al. (1986) was achieved with the application of 3.30 L ha^{-1} of the herbicide Pendimethalin and 2.17 L ha^{-1} of Oxyfluorfen, corresponding to 1330 and 525 a.i. ha^{-1} of the herbicides, respectively (Figure 1).

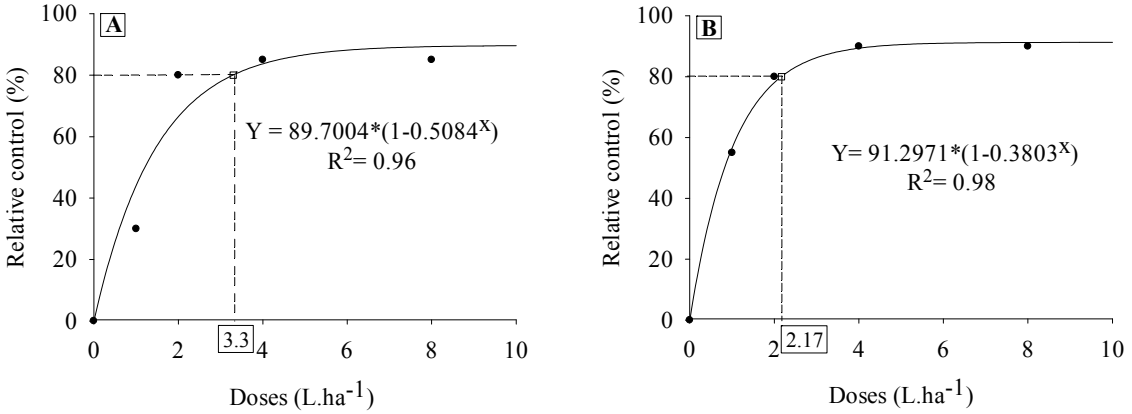

Figure 1. Relative weed control according to the doses of the herbicides Pendimethalin (A) and Oxyfluorfen (B). Dashed lines indicate the dose for the minimum control index established by Frans et al. (1986)

Among the predominant weed species occurring in the experiment, only *Digitaria* spp. has a recommended control with the application of the herbicides tested. However, similarly to the work, Piva et al. (2009) obtained excellent control of *Cyperus* spp. in coffee seedlings with application of the herbicide Oxyfluorfen. Just like Constantine and Bajwa (2015), who observed significant reductions in the density of *C. rotundus* with the application of Pendimethalin.

Several authors have demonstrated the efficiency of the herbicides Pendimethalin and Oxyfluorfen in weed control. For the Pendimethalin (930 g a.i. ha^{-1}), Steckel et al. (2002) reported 93% of control of *Amaranthus rudis* up to 28 days after application. Richardson et al. (2007) observed 96% of control of *A. hybridus* with Pendimethalin (690 g a.i. ha^{-1}) up to 56 days after application. Similarly, Ahmed and Chauhan (2015) observed control efficiency of *D. ciliaris* with application of Pendimethalin. For the herbicide Oxyfluorfen, Ibrahim et al. (2011) verified satisfactory control for grasses *Cynodon dactylon*, *D. cilliaris* and *Eleusine indica* and of the dicotyledons *Solanum nigrum*, *Solanum americanum*, *Ageratum conyziods*, *A. spinosus* and *Acanthospermum hispidum*. Costa et al. (2002) also observed efficiency of oxyfluorfen in the control of the species *I. grandifolia* for period 37 days after application, *B. decumbens* for 62 days after application and of *P. maximum* and *S. rhombifolia* for up to 95 days after application.

The satisfactory result in weed control by the herbicides Pendimethalin and Oxyfluorfen is due to their mechanisms of action. The mechanism of action of Pendimethalin consists of connecting the tubulin, the main component protein of the microtubules, which guide the chromosomes during the anaphase of mitosis. Thus, during cell division it does not occur to the division of chromosomes and the result is the formation of cells with abnormal number of chromosomes (Rizzardi et al., 2004).

Oxyfluorfen is an inhibitor of the enzyme protoporphyrinogen oxidase (PROTOX), which when applied in pre-emergence, acts on the Hypocotyl and epicotyl of the seedlings and in the foliar meristems, showing no action on the root tissues (Rodrigues & Almeida, 2011). This herbicide causes the death of plants when they come into contact with the treated soil layer, and quickly, sensitive tissues undergo necrosis and death, caused by lipid peroxidation (Oliveira Júnior, 2011).

4. Conclusions

The clonal coffee seedlings were more sensitive to the application of the herbicide Pendimethalin. The herbicide Oxyfluorfen caused lower negative effects for the clonal coffee seedlings in the experimental conditions evaluated.

The application of the herbicides Pendimethalin and Oxyfluorfen obtained good performance in the control of weeds existing in this experiment, with the use of 1080 g a.i. ha^{-1} and 648 g a.i. ha^{-1}, respectively.

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