Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v35i1.15440

Photosynthetic activity of coffee after application of glyphosate subdoses

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ABSTRACT. Farmers use non-selective herbicides, such as glyphosate, in directed applications to control weeds in coffee crops. Despite the precautions used during the application of herbicides, there are usually reports of poisoning in plantation areas. Moreover, it is fundamental to understand the effects of glyphosate on photosynthetic processes. The present study aimed to evaluate the characteristics associated with the photosynthetic activity in coffee cultivars subjected to doses of glyphosate. The experiment was conducted in a greenhouse using three varieties of coffee (*Coffea arabica*), including Acaiá (MG-6851), Catucaí Amarelo (2 SL) and Topázio (MG-1190), and three subdoses of glyphosate (0.0, 115.2 and 460.8 g ha^{-1}) in a 3 x 3 factorial scheme. Herbicide application led to reduced internal carbon, ratio between internal and environmental carbon, carbon consumption and photosynthetic rate at 15 days after application (DAA) in the fourth leaf. In the same leaf at 45 DAA, the carbon consumption of the cultivars was even less. Despite low carbon concentrations, no difference in consumption and photosynthetic rate was observed in the last leaf. Glyphosate caused metabolic damage with transitory effects on the photosynthetic rate; the Acaiá cultivar was the most tolerant. These transitory effects may result in irreversible and prolonged damage to crop growth.

Keywords: herbicide, EPSPs, *Coffea arabica*, photosynthetic rate, drift.

Atividade fotossintética do cafeeiro após aplicação de subdoses de glyphosate

RESUMO. Para o controle de plantas daninhas em lavouras cafeeiras, os produtores utilizam herbicidas não-seletivos, como o glyphosate, empregado em aplicações dirigidas. Apesar de todos os cuidados com a aplicação, são constatados casos de intoxicação em plantas, sendo de fundamental importância o conhecimento dos efeitos sobre os processos fotossintéticos. Objetivou-se com este trabalho avaliar as características associadas à atividade fotossintética entre cultivares de cafeeiro submetidos a doses de glyphosate. O experimento foi conduzido em casa de vegetação utilizando-se três cultivares de cafeeiro (*Coffea arabica*): Acaiá (MG-6851), Catucaí Amarelo (2 SL) e Topázio (MG-1190) e, três subdoses do glyphosate (0,0; 115,2 e 460,8 g ha^{-1}), em esquema fatorial 3 x 3. Em função da aplicação do herbicida observou-se redução de carbono interno, razão carbono interno e do ambiente, consumo de carbono e taxa fotossintética, aos 15 DAA na quarta folha. Na mesma folha aos 45 DAA, constatou-se menor consumo de carbono pelos cultivares. Na última folha apesar de inferiores concentrações de carbono, não obteve-se diferença no consumo e taxa fotossintética. O glyphosate resulta em danos metabólicos com efeitos transitórios sobre a atividade fotossintética, sendo o cultivar Acaiá o mais tolerante. Este efeito transitório pode resultar em danos prolongados e irreversíveis no crescimento da cultura.

Palavras-chave: herbicida, EPSPs, *Coffea arabica*, taxa fotossintética, deriva.

Introduction

Although herbicides used for coffee plantations are applied in post-emergence (RONCHI et al., 2003), glyphosate, which is highly efficient and inexpensive, is commonly used. Glyphosate is applied to perennial cultures in such a way to avoid hitting the leaves. It is necessary to prevent drops from being carried by the wind and, consequently, from contacting the leaves of coffee plants. This process is also known as drifting of the product.

Glyphosate affects the shikimic acid pathway by inhibiting the synthesis of 5-enolpyruvoylshikimate-3-phosphate synthase. In this pathway, 5-enolpyruvoylshikimate-3-phosphate synthase is exclusively synthesized from aromatic amino acids, including phenylalanine, tyrosine and tryptophan, as well as many other secondary metabolites derived from these amino acids (GRAVENA et al., 2009). The visual consequences of glyphosate actions include chlorosis (FRANÇA et al., 2010a). Therefore, care should be taken with the following aspects of glyphosate application: spray pressure, bar height, operation speed, wind speed, temperature and relative humidity.

Despite all of the precautions taken by directed application, cases of contamination have been reported (RONCHI; SILVA, 2004). Many studies related to the simulation of drifting with subdoses of glyphosate applied in cultures have been reported on the following crops: corn (BROWN et al., 2009; REDDY et al., 2010), eucalyptus (MACHADO et al., 2010; TUFFI SANTOS et al., 2007), cotton (YAMASHITA; GUIMARÃES, 2005, 2006), fruits (GRAVENA et al., 2009; PROCÓPIO et al., 2009; WAGNER JÚNIOR et al., 2008), vegetables (FIGUEREDO et al., 2007; RIGOLI et al., 2008) and physic nuts (COSTA et al., 2009).

França et al. (2010a) assessed the growth of coffee plants submitted to subdoses of glyphosate, and they reported that plants recover their growth in the aerial part and that the visual symptoms of intoxication decreases after 120 days of application. However, visual symptoms of damage are not always correlated with losses in yield. Some herbicides may not cause visual symptoms in plants but can affect the growth and development of plants during the culture cycle (CARVALHO et al., 2009). However, damage to plants can be assessed by indirect influence over variables associated with photosynthesis (TAIZ; ZEIGER, 2006).

Knowledge on the effects of photosynthetic activities is important because these effects are responsible for the accumulation of all organic matter of plants, and any factor that interferes with photosynthesis will affect plant development (LOPES et al., 2009). According to Barela and Christoffoleti (2006), reduced culture yield can be a consequence of reduced photosynthetic rates of plants depending on the degree of intoxication caused by the herbicide. Thus, the present work aimed to assess the characteristics associated with the photosynthetic activity of coffee cultivars submitted to subdoses of glyphosate.

Material and methods

The experiment was conducted in a greenhouse using three coffee cultivars, including (*Coffea arabica*) Acaiá (MG-6851), Catucaí Amarelo (2 SL) and Topázio (MG-1190), treated with three subdoses of glyphosate. The seedlings of the coffee cultivars were produced by direct sowing in polyethylene bags. At the stage of five pairs of completely expanded leaves, the plants were transplanted to vases containing 10 L of substrate composed of a sample of sifted soil and aged manure (3:1). The soil sample was achieved from a typical distrofic Red-Yellow Latosol with a sand/clay texture. The chemical analysis of the soil presented the following results: pH (water) of 4.7; organic matter rate of 2.4 dag kg^{-1}; P and K contents of 2.3 and 48 mg dm^{-3}, respectively; and Ca, Mg, Al, H+Al and $CTC_{effective}$ contents of 1.4, 0.4, 0.6, 6.27 and 2.52 cmol dm^{-3}, respectively. Simple superphosphate (100 g per vase) was used to supply P_2O_5, and dolomitic limestone was used to increase the saturation per base to 60%. After transplanting the seedlings, the vases remained in a greenhouse under an aspersion irrigation system until the treatments were applied. Potassium chloride (31.48 g per vase) and urea (10 g per vase) were added 30 and 60 days after transplantation (RIBEIRO et al., 1999).

The experiment was installed in a (3 x 3) factorial scheme with the first factor corresponding to the coffee cultivars and the second factor corresponding to the subdoses of glyphosate. The experiment was set up in a randomized block design with four replications. Subdoses of 0, 115.2 and 460.8 g ha^{-1} of glyphosate were tested, which corresponded to 0, 8.0 and 32.0%, respectively, of the recommended commercial dose for weed control (1.440 g ha^{-1}). The experimental parcels consisted of a vase containing a plant. At 120 days after transplantation in September 2008 when the coffee plants had approximately 21 pairs of leaves and six plagiotropic branches, glyphosate was applied in a way that it would not reach the upper third of the coffee plants using a pasteurized coastal pulverizer, which was pressurized with CO_2 and calibrated for a constant pressure of 250 kPa. The pulverizer was equipped with a bar and two fan-like pulverization tips (TT110.02) spaced 50 cm from each other, which provided a spray application of 200 L ha^{-1}. During application, the air temperature (25.3°C ± 1), relative air humidity (80% ± 3) and wind velocity (2 km h^{-1}) were measured. After the application of glyphosate, the plants remained outside the greenhouse for 24 hours with the leaves protected from irrigation or rain water to avoid removal of the product.

At 15 and 45 days after application (DAA), the percentage of coffee plant intoxication caused by glyphosate was evaluated using a scale of 0 to 100 where 0% corresponded to no visible symptoms and 100% corresponded to plant death. At the same times after application, the leaf area, CO_2

concentration of the substomatal chamber (*C*i; μmol mol^{-1}) and photosynthetic rate (*A*; μmol m^{-2} s^{-1}) were measured. The CO_2 consumed by the plant (*ΔC*; μmol mol^{-1}) and the ratio between the internal and environmental concentration of CO2 (*C*i/*C*a) were also calculated from the reference values of CO_2 in the evaluation chamber. The physiological assessments were performed when the last and fourth leaves completely expanded (counting from the base of the plant) using an infrared gas analyzer (IRGA; brand ADC, model LCA PRO; Analytical Development Co. Ltd., Hoddesdon, UK).

The data were submitted to variance analysis by the F test ($p \leq 0.05$). The interaction was then unfolded and submitted to Tukey's test at 5% probability resulting in comparison among the three cultivars and three dosages at 15 and 45 DAA.

Results and discussion

An interaction between the cultivars and subdoses of glyphosate occurred for the assessed variables depending on the sampled leaf and time of evaluation. Although non-significant, the results of each assessment were unfolded and presented in a standardized manner.

A difference was observed in the following photosynthetic characteristics when comparing the cultivars in the fourth leaf 15 days after application (DAA): internal carbon (*C*i); carbon consumption (*ΔC*); ratio between internal carbon and atmosphere carbon (*C*i/*C*a); and photosynthetic rate (*A*). The Topázio cultivar presented higher averages of *C*i and *C*i/*C*a, and a similar difference was observed without the application of glyphosate. When considering the effect of the subdoses, only the Acaiá cultivar had different *C*i values from the Topázio cultivar with the herbicide application of 115.2 g ha^{-1} (Table 1). Moreover, the *ΔC* and *A* averages of the Acaiá cultivar were higher than the averages of the other cultivars. Without the glyphosate application, lower values of *ΔC* and *A* were observed only for the Topázio cultivar. After the application of the highest subdose, the Catucaí Amarelo cultivar presented lower values representing approximately 52 and 49% of the *ΔC* and *A* values, respectively, of the Acaiá cultivar (Table 1).

The application of glyphosate led to decreased values of *C*i and *C*i/*C*a with decreases of 115.2 g ha^{-1}. In contrast, the *C*i and *C*i/*C*a values of the Acaiá cultivar did not differ with herbicide application. The *ΔC* and *A* values did not present differences between the zero subdose and intermediate subdose. However, the highest subdose differed negatively from the others as well as in the values of each cultivar (Table 1).

Table 1. Internal carbon (*C*i), consumption of CO_2 (*ΔC*), ratio of internal carbon and atmosphere carbon (*C*i/*C*a) and photosynthetic rate (*A*) measured in the fourth leaf (completely expanded) of three coffee cultivars (*Coffea arabica*) treated with different glyphosate subdoses at 15 days after application.

Treatments	*C*i - μmol mol^{-1}			
	----------Sub-doses - g ha^{-1}----------			Mean
Cultivars	0	115.2	460.8	
Acaiá	275.00 bA	268.80 bA	281.60 aA	275.13 b
Catucaí Amarelo	292.80 bA	279.40 abA	259.00 bB	277.07 b
Topázio	326.60 aA	291.40 aB	264.60 abC	294.20 a
Mean	298.13 A	279.87 B	268.40 C	CV(%)=4.43
	ΔC - μmol mol^{-1}			
Acaiá	32.00 aA	29.00 aA	25.00 aB	28.67 a
Catucaí Amarelo	30.20 aA	27.40 aA	13.00 cB	23.53 b
Topázio	25.00 bA	25.40 aA	20.80 bB	23.73 b
Mean	29.07 A	27.27 A	19.60 B	CV(%)=9.50
	*C*i/*C*a			
Acaiá	0.74 bA	0.73 aA	0.76 aA	0.74 b
Catucaí Amarelo	0.79 bA	0.75 aAB	0.70 bB	0.75 b
Topázio	0.87 aA	0.78 aB	0.71 abC	0.78 a
Mean	0.80 A	0.75 B	0.72 B	CV(%)=4.62
	A - μmol m^{-2} s^{-1}			
Acaiá	10.04 aA	9.53 aA	8.10 aB	9.22 a
Catucaí Amarelo	9.33 aA	8.82 abA	4.00 bB	7.38 b
Topázio	7.74 bAB	8.24 bA	7.07 aB	7.69 b
Mean	9.04 A	8.87 A	6.39B	CV(%)=7.54

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to Tukey's test at 5% probability.

Thus, higher availability/concentration of CO_2 was observed in the substomatic spaces for photosynthetic activity for the highest *C*i and *C*i/*C*a values. However, this cultivar showed lower values of *ΔC* and *A* without glyphosate application and in the averages of all subdoses. The higher availability/concentration of CO_2 in the Topázio cultivar was also higher in the absence of the product. Thus, it is an intrinsic characteristic of the cultivar in the handling conditions of the experiment. With the application of glyphosate, the *C*i and *C*i/*C*a values were reduced in the cultivars, but the *C*i and *C*i/*C*a values of the Acaiá cultivar did not change with the application of different glyphosate subdoses.

A greater effect of glyphosate subdoses has been reported in eucalyptus plants 21 days after application (MACHADO et al., 2010). Lassiter et al. (2007) observed a sharp decrease in the yield of peanuts with the yield decreasing by 140 g ha^{-1}. However, the yield of physic nut plants is decreased by 45.0 g ha^{-1} when submitted to simulated drift of glyphosate (COSTA et al., 2009).

Lower *ΔC* and *A* values occur because of the restriction of CO_2 in locations of carboxylation or possible metabolic limitations of the plant. Therefore, the low values of *A* are assumed to be related to the metabolic and non-stomatic limitations or restriction of CO_2. When submitted to low temperatures, coffee genotypes also have low *A* values due to the limitation of the lower metabolism of plants (PARTELLI et al., 2009).

Photosynthetic rates affect culture yields. Therefore, a reduced yield can be expected with glyphosate application because the cultivars obtained lower *A* and *ΔC* values even under conditions without carbon restriction for photosynthesis. However, Galon et al. (2009) observed no direct correlation between dry matter and photosynthetic rate in sugarcane because the accumulation time of dry matter is from the time of plant emergence until the time of assessment and the photosynthetic analysis is punctual and depends on environmental conditions.

In the assessment of the last leaf at 15 DAA, the *C*i and *C*i/*C*a values were lower in the Acaiá and Catucaí Amarelo cultivars with the application of 115.2 g ha^{-1}, and a reduction in these values was observed in the Topázio cultivar with the application of the highest subdose (460.8 g ha^{-1}), which made the cultivars even. These variables also had lower averages in the Acaiá cultivar compared with the other cultivars. In contrast to the assessment of the fourth leaf, the last leaf did not present differences in the averages of *C*i and *C*i/*C*a. Only the Topázio cultivar presented lower values with the highest subdose (Table 2).

Table 2. Internal carbon (*C*i), consumption of CO_2 (*ΔC*), ratio of internal carbon and atmosphere carbon (*C*i/*C*a) and photosynthetic rate (*A*) measured in the last leaf (completely expanded) of three coffee cultivars (*Coffea arabica*) treated with different glyphosate subdoses at 15 days after application.

Treatments	*C*i - μmol mol^{-1}			
	----------Sub-doses - g ha^{-1}----------			Mean
Cultivars	0	115.2	460.8	
Acaiá	274.80 aA	283.40 bA	275.20 aA	277.80 b
Catucaí Amarelo	302.80 aA	291.00 bA	289.00 aA	294.27 ab
Topázio	297.60 aAB	323.69 aA	286.80 aB	302.67 a
Mean	291.73 A	299.33 A	283.67 A	CV(%)=6.64
	ΔC - μmol mol^{-1}			
Acaiá	24.00 abA	24.4 aA	23.80 aA	24.07 a
Catucaí Amarelo	16.00 bA	25.40 aA	20.80 aA	20.73 a
Topázio	31.40 aA	11.00 bB	27.80 aA	23.40 a
Mean	23.80 A	20.27 A	24.13 A	CV(%)=32.70
	*C*i/*C*a			
Acaiá	0.74 aA	0.77 bA	0.74 aA	0.75 b
Catucaí Amarelo	0.82 aA	0.78 bA	0.78 aA	0.79 ab
Topázio	0.80 aAB	0.87 aA	0.77 aB	0.81 a
Mean	0.78 A	0.81 A	0.76 A	CV(%)=6.60
	A - μmol m^{-2} s^{-1}			
Acaiá	7.65 abA	7.74 aA	7.68 aA	7.69 ab
Catucaí Amarelo	5.08 bA	7.21 aA	6.29 aA	6.19 b
Topázio	10.06 aA	9.39 aA	8.89 aA	9.45 a
Mean	7.60 A	8.11 A	7.62 A	CV(%)=24.22

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to Tukey's test at 5% probability.

In the absence of herbicide application, the Catucaí Amarelo cultivar had lower values for *ΔC* and *A* compared with the Topázio cultivar. Moreover, a lower average was observed in the Catucaí Amarelo cultivar compared with the Topázio cultivar. With the application of glyphosate, a reduction was observed only in the *ΔC* value in the Topázio cultivar, and the application of an intermediary subdose caused no differences in the *ΔC* and *A* values (Table 2).

The height of the coffee plants was severely impaired by the application of glyphosate, but only the highest applied dose of 460.8 g ha^{-1} had an effect after 120 days of application of the product (FRANÇA et al., 2010a).

At 45 DAA when the fourth leaf was assessed, the *C*i, *C*i/*C*a and A variables did not differ regardless of the cultivar and subdose applied. On the other hand, the *ΔC* average was inferior in the Catucaí Amarelo cultivar, including all subdoses used. However, no decrease in *ΔC* values was observed in the Catucaí and Topázio cultivars with increased application doses of the product. However, the Acaiá cultivar had a reduced *ΔC* value with the application of glyphosate without differing from the Topázio cultivar. Moreover, this reduction in the Acaiá cultivar may have affected the *ΔC* average of the cultivars in the subdoses (Table 3).

Table 3. Internal carbon (*C*i), consumption of CO_2 (*ΔC*), ratio of internal carbon and atmosphere carbon (*C*i/*C*a) and photosynthetic rate (*A*) measured in the fourth leaf (completely expanded) of three coffee cultivars (*Coffea arabica*) treated with different glyphosate subdoses at 45 days after application.

Treatments	*C*i - μmol mol^{-1}			
	----------Sub-doses - g ha^{-1}----------			Mean
Cultivars	0	115.2	460.8	
Acaiá	265.80 aA	285.60 aA	285.80 aA	279.07 a
Catucaí Amarelo	265.60 aA	258.00 aA	277.20 aA	266.93 a
Topázio	262.60 aA	277.20 aA	285.40 aA	275.07 a
Mean	264.67 A	273.60 A	282.80 A	CV(%)=11.14
	ΔC - μmol mol^{-1}			
Acaiá	22.00 aA	17.80 aB	18.60 aB	19.47 a
Catucaí Amarelo	13.00 bA	12.20 bA	11.20 bA	12.13 b
Topázio	19.60 aA	18.80 aA	18.20 aA	18.87 a
Mean	18.20 A	16.27 B	16.00 B	CV(%)=10.31
	*C*i/*C*a			
Acaiá	0.72 aA	0.77 aA	0.78 aA	0.76 a
Catucaí Amarelo	0.72 aA	0.70 aA	0.75 aA	0.72 a
Topázio	0.71 aA	0.76 aA	0.77 aA	0.75 a
Mean	0.72 A	0.74 A	0.77 A	CV(%)=11,17
	A - μmol m^{-2} s^{-1}			
Acaiá	6.43 aA	5.62 aA	5.76 aA	5.94 a
Catucaí Amarelo	5.29 aA	5.17 aA	5.33 aA	5.26 a
Topázio	4.97 aA	5.59 aA	5.74 aA	5.43 a
Mean	5.56 A	5.46 A	5.61 A	CV(%)=24.58

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to Tukey's test at 5% probability.

The *ΔC* is related to plant metabolism. Therefore, lower values of *ΔC* result in slower metabolism. Thus, lower *ΔC* values can be the result of a slower metabolism and may cause an indirect effect on photosynthesis due to the effect of herbicide on metabolism and, consequently, on plant growth. A previous study has assessed the growth of coffee plants after the application of glyphosate subdoses and has reported that plant height and aerial foliage are decreased at 45 DAA (FRANÇA et al., 2010a).

The N, P, K, Zn e Cu contents were lower after 45 days after application of glyphosate (FRANÇA et al., 2010b). In other hand, this study has shown that the Mg and S contents did not differ and the Ca contents increased with the increase of glyphosate subdoses.

In relation to the last leaf at 45 DAA, the averages of the *Ci*/*Ca* ratio and *Ci* in the cultivars decreased with the application of the product. These variables in the Catucaí Amarelo cultivar also demonstrated lower values in the pulverization at the highest subdose. Despite the reduced availability of carbon, however, the ΔC and *A* values were not reduced by herbicide application, and no difference was observed among the cultivars.

The joint analysis of the leaves revealed that the lowest *A* value found with the highest subdose at 15 DAA was not observed at 45 DAA. In that period, no difference was observed between the untreated leaves and the leaves that received herbicide application (Table 4). The metabolic effects caused by the application of glyphosate subdoses are fast and transitory. Gravena et al. (2009), simulated glyphosate drift in rangpur lime (limão cravo) plants, and they observed that the effects are also transitory and that the plants do not have severe metabolic damage.

Table 4. Internal carbon (*Ci*), consumption of CO_2 (ΔC), ratio of internal carbon and atmosphere carbon (*Ci*/*Ca*) and photosynthetic rate (*A*) measured in the last leaf (completely expanded) of three coffee cultivars (*Coffea arabica*) treated with different glyphosate subdoses at 45 days after application.

Treatments	*Ci* - µmol mol^{-1}			
	----------Sub-doses - g ha^{-1}----------			Mean
Cultivars	0	115.2	460.8	
Acaiá	278.60 aA	250.00 aA	246.00 aA	258.20 a
Catucaí Amarelo	278.40 aA	253.00 aAB	231.20 aB	254.20 a
Topázio	274.40 aA	254.80 aA	268.00 aA	265.73 a
Mean	277.13 A	252.60 B	248.40 B	CV(%)=10.38
Cultivars	ΔC - µmol mol^{-1}			
Acaiá	22.20 aA	18.40 aA	18.60 aA	19.73 a
Catucaí Amarelo	19.80 aA	16.80 aA	20.40 aA	19.00 a
Topázio	20.00 aA	19.40 aA	18.40 aA	19.27 a
Mean	20.67 A	18.20 A	19.13 A	CV(%)=14.60
Cultivars	*Ci*/*Ca*			
Acaiá	0.76 aA	0.68 aA	0.67 aA	0.70 a
Catucaí Amarelo	0.76 aA	0.69 aAB	0.63 aB	0.70 a
Topázio	0.74 aA	0.69 aA	0.72 aA	0.72 a
Mean	0.75 A	0.69 B	0.67 B	CV(%)=10,26
Cultivars	*A* - µmol m^{-2} s^{-1}			
Acaiá	6.92 aA	6.41 aA	6.11 aA	6.48 a
Catucaí Amarelo	6.25 aA	5.13 aA	6.04 aA	5.81 a
Topázio	6.53 aA	6.19 aA	5.07 aA	5.93 a
Mean	6.57 A	5.91 A	5.74 A	CV(%)=18.14

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to Tukey's test at 5% probability.

Glyphosate has fast absorption followed by fast translocation through the phloem (CASELEY; COUPLAND, 1985). Citrus plants recover rapidly after treatment with glyphosate (GRAVENA et al., 2009). In the present study, the damage reflected by the *A* values did not exist at 45 DAA. However, the transitory effect on the photosynthetic rate can lead to prolonged and irreversible damage to the growth and yield of coffee plants.

The plants submitted to glyphosate application showed visual symptoms of intoxication. At 15 DAA with 115.2 g ha^{-1} of glyphosate, 2.92% toxicity was found, and the visual damage was about 4 times greater compared with the dose of 460.8 g ha^{-1} (Table 5). When considering the average toxicity of each cultivar, the Topazio cultivar was the most sensitive to the herbicide. Moreover, the leaf area evaluated at the same time showed no effect from the application of the product. Studies on the following crops have visually assessed the intoxication few days after glyphosate treatment and have assessed the effect on leaf area only after 40 days of application: coffee plants (FRANÇA et al., 2010a), physic nut plants (COSTA et al., 2009) and eucalyptus plants (MACHADO et al., 2010). Despite the physiological and visual short-term damage caused by this herbicide, the leaf area was not damaged (Tables 1 and 5).

Table 5. Phytotoxicity (%) and leaf area (cm^2) of three coffee cultivars (*Coffea arabica*) treated with different glyphosate subdoses at 15 days after application.

Treatments	Phytotoxicity - %			
	----------Sub-doses - g ha^{-1}----------			
Cultivars	0	115.2	460.8	Mean
Acaiá	0.00 aA	2.50 aA	12.50 aB	5.00 a
Catucaí Amarelo	0.00 aA	3.75 aA	11.25 aB	5.00 a
Topázio	0.00 aA	2.50 aA	10.00 aB	4.17 b
Mean	0.00 A	2.92 B	11.25 C	CV(%)=35.58
	Leaf area - cm^2			
Acaiá	1079.57 aA	1079.64 aA	1075.24 aA	1078.15 a
Catucaí Amarelo	1101.32 aA	1109.34 aA	1069.54 aA	1093.40 a
Topázio	1026.19 aA	1024.63 aA	1034.75 aA	1028.52 a
Mean	1069.03 A	1071.20 A	1060.84 A	CV(%)=12.36

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to Tukey's test at 5% probability.

The visual effect of glyphosate was also observed after 45 days of application but only with application of the highest dose (Table 6). In contrast to the leaf area at 15 DAA, the leaf area at 45 DAA decreased with the increased dose resulting in a 44% reduction in leaf area (Table 6). Glyphosate inhibits 5-enolpyruvylshikimate-3-phosphate synthase, which affects the shikimate metabolic pathway, thus preventing the formation of essential amino acids and secondary metabolites. In addition, this pathway is responsible for the formation of phenolic compounds, which can represent up to 35% of plant biomass (BOUDET et al., 1985). Thus, one should always take care when glyphosate is applied on coffee crops because contact of this herbicide with the leaves results in further damage to the plant.

Table 6. Phytotoxicity (%) and leaf area (cm^2) of three coffee cultivars (*Coffea arabica*) treated with different glyphosate subdoses at 45 days after application.

Treatments	Phytotoxicity - %			
	----------Sub-doses - g ha^{-1}----------			
Cultivars	0	115.2	460.8	Mean
Acaiá	0.00 aA	0.00 aA	11.25 aB	3.75 a
Catucaí Amarelo	0.00 aA	1.25 aA	12.50 aB	4.58 a
Topázio	0.00 aA	0.00 aA	13.75 aB	4.58 a
Mean	0.00 A	0.42 A	12.50 B	CV(%)=25.45
	Leaf area - cm^2			
Acaiá	4666.26 aA	4222.70 aB	2699.93 aC	3862.96 a
Catucaí Amarelo	4491.26 aA	4253.20 aA	2764.93 aB	3836.46 a
Topázio	4580.13 aA	4223.54 aA	2244.22 bB	3682.63 a
Mean	4579.22 A	4233.15 B	2569.69 C	CV(%)=6.51

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other according to Tukey's test at 5% probability.

Conclusion

Therefore, we concluded that glyphosate drift in coffee plants can result in damage to coffee plant metabolism with transitory effects on photosynthetic activity and prolonged effects on leaf area. The photosynthetic activity of all tested cultivars was sensitive to glyphosate, and a more tolerant cultivar was not considered in this study. Glyphosate drift had greater effects on the fourth leaf that received the application of the herbicide, which was reflected by the greater difference between the treatments in the studied variables. In general, glyphosate treatment causes visual and physiological transitory damage, which results in irreversible and prolonged damage to crop growth.

Acknowledgements

The authors would like to thank FAPEMIG (Fundação de Amparo a Pesquisa do Estado de Minas Gerais) for the financial support and provision of the resources for this research work as well as CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for the research grant provided for the first author.

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Received on December 5, 2011.
Accepted on March 20, 2012.