EFFICACY OF HERBICIDES APPLIED TO *Digitaria horizontalis* PLANTS UNDER DIFFERENT WATER CONDITIONS[1]

*Eficácia de Herbicidas Aplicados em Plantas de **Digitaria horizontalis** Submetidas a Diferentes Condições Hídricas*

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ABSTRACT - This project aimed to relate the control efficiency of ACCase inhibiting herbicides applied post-emergence to *Digitaria horizontalis* plants under different soil water contents. The experiments were conducted in a greenhouse, with the application of three different herbicides (fluazifop-p-butyl, haloxyfop-methyl, and sethoxydim + mineral oil Assist). The experimental design used for each herbicide was completely randomized, with four replications, consisting of a 3 x 4 factorial, with the combination of water management strategies (-0.03, -0.07 and -1.5 MPa) and four doses of these products (100%, 50%, 25%, and 0% of the recommended dose). Herbicide application was made at two vegetative stages, 4-6 leaves and 2-3 tillers. The visual phytotoxicity evaluations were performed at 14 days after application and the plant dry weight at the end of the study was evaluated. The control efficiency was not affected by water management strategies when applied to the recommended dose of the herbicides in early stages of plant development (4-6 leaf stage). In late applications (2-3 tiller stage) the plants held under drought stress showed less phytotoxicity.

Keywords: crabgrass, chemical control, water restriction, weed.

*RESUMO - Este projeto objetivou relacionar a eficiência de controle de herbicidas inibidores da ACCase aplicados em pós-emergência em plantas de **Digitaria horizontalis** submetidas a diferentes teores de água no solo. Os experimentos foram conduzidos em casa de vegetação, com a aplicação de três diferentes herbicidas (fluazifop-p-butil, haloxyfop-methyl e sethoxydim + óleo mineral Assist). O delineamento experimental utilizado para cada herbicida foi inteiramente casualizado, com quatro repetições, constituído de um fatorial 3 x 4, sendo a combinação de três manejos hídricos (-0,03, -0,07 e -1,5 MPa) e quatro doses desses produtos (100, 50, 25 e 0% da dose recomendada). A aplicação dos herbicidas foi feita em dois estádios vegetativos: 4-6 folhas e 2-3 perfilhos. As avaliações visuais de fitotoxicidade foram realizadas aos 14 dias após a aplicação e avaliou-se a matéria seca das plantas ao final do estudo. A eficiência de controle não foi influenciada pelos manejos hídricos quando se aplicou a dose recomendada de todos os herbicidas na fase inicial de desenvolvimento das plantas (estádio de 4-6 folhas). Em aplicações tardias (estádio de 2-3 perfilhos), as plantas mantidas sob estresse hídrico apresentaram menor fitotoxicidade.*

Palavras-chave: capim-colchão, controle químico, restrição hídrica, planta daninha.

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INTRODUCTION

Weeds affect crop development and this interference is influenced by factors related to cultivation, such as species or variety, spacing and planting density, sowing timing and the extension of the period of coexistence between the crop and the weeds, and also by the own characteristic factors of the weeds, such as specified composition, density, and distribution (Pitelli, 1985), besides the allelopathic effects provided by these weeds to the crops (Muniz et al., 2007; Borghi et al., 2008; Tejeda-Sartorius & Rodríguez-González, 2008).

Currently, the use of herbicides is an essential and common practice in agricultural areas because of the extensive farming and the high cost of labor (Vieira, 2010). The effectiveness of a herbicide depends on several factors, such as physical and chemical characteristics and the applied dose, the species to be controlled (own structural characteristics), the development stage and the biology features of the weed, application techniques, the soil moisture, and environmental factors at the time of herbicide application - i.e. temperature, air humidity, rainfall, solar radiation, and wind (Victoria Filho, 1985).

According to the studies of Zannata et al. (2008) the effectiveness of herbicides is reduced when applied to plants developed under conditions of water deficit due to low absorption and translocation of the product. Prolonged periods of drought can cause leaf thickening, increased density of the cuticle, and greater leaf pubescence, as well as tissue dehydration, disturbing the diffusion (Kogan & Bayer, 1996) and leading to reduced absorption and translocation of herbicides.

The control of *Digitaria sanguinalis* with 30 g ha^{-1} of haloxyfop-methyl was of 92% for non-stressed plants and 8% for those in water stress (Peregoy et al., 1990). According to Levene & Owen (1995), plants in water stress (*Xanthiumstrumarium* and *Abutilon theophrasti)* showed more vertically oriented leaves than non-stressed plants. This fact could potentially reduce exposure of the leaf area and, consequently, decrease the retention of the droplet. Corroborating these results, Pereira et al. (2010) found that *Urochloa plantaginea* plants under water stress were not effectively controlled by herbicides that inhibit ACCase when applied during late stage.

The aim of this study was to compare the control efficiency of ACCase inhibiting herbicides applied post-emergence to *Digitaria horizontalis* plants when subjected to water stress, determining the soil water potential which could impair the efficiency of these herbicides.

MATERIAL AND METHODS

The studies were carried out from January to March 2009 with the following characterization of the climate during this period in the greenhouse (average): Minimum average temperature of 20.3 °C, maximum average temperature of 29 °C, air humidity at 76.1%, and evapotranspiration of 3.07 $mmonth^{-1}$, which was daily monitored through a Class A Tank.

The species used was *D. horizontalis*, grown in plastic pots with 2 L, maintained in a greenhouse. The description of soil texture was classified as average through the sieve analysis (65.6% sand, silt 6.7, 27.7 clay). Soil fertilization was performed according to chemical analysis (Table 1).

The soil, before planting, was dried in air, turned over twice a week until constant weight. Richards' pressure plate was used to obtain the water retention curve (Klar, 1984).

Table 1 - Chemical analysis of soil used in the study. Botucatu-SP, 2009/2008

pH	MO	P resin	H+Al	K	Ca	Mg	SB	CTC	V
($CaCl_2$)	(g dm^{-3})	(mg dm^{-3})	(mmol dm^{-3})						(%)
4.6	7	3	22	0.2	2	2	4	26	15

From the results of water retention, three minimum water potentials were established (Ψs): -0.03, -0.07, and -1.5 MPa, with 13, 10, and 8% soil moisture, respectively, compounding the water management, evaluated by pots weighing. Upon reaching the approximation of the potential defined for each treatment, the transpired water replacement was done until reaching mass of maximum water potential of soil water retention (-0.01 MPa/14% soil moisture). The water management strategies were initiated in the development stage of two leaves on each plant.

A backpack sprayer was used, equipped with application bar containing four spray nozzles of plan type XR11002VS, with a solution consumption of 200 L ha^{-1}.

Herbicide application was performed during weed development (4-6 leaves and 2-3 tillers). Three different herbicides were applied (fluazifop-p-butyl, haloxyfop-methyl, and sethoxydim + mineral oil Assist) and the experimental design used for each product was completely randomized, with four replications, consisting of a 3 x 4 factorial, with the combination of three water managements (-0.03, -0.07, and -1.5 MPa) and four doses of these products (100, 50, 25, and 0% of the recommended dose). According to the manufacturers of each product, 100% of recommended dose of each herbicide in grams of active ingredient per hectare is (g a.i. ha^{-1}): sethoxydim, 184; haloxyfop-methyl, 60; and fluazifop-p-butyl, 125.

The effects of chemical treatments on the plants were visually evaluated 14 days after application through a percentage score scale in which "0" indicates no control and "100" indicates the plant's death (SBCPD, 1995). At the end of the evaluations, the plants were dried in forced ventilation of air at 60 °C until constant weight and then the dry mass of the samples were determined.

The experimental design used in the studies was completely randomized with four replications. The results of phytotoxicity were subjected to analysis of variance by "F-test ", and the dry plant mass to linear regression models and polynomial, with the treatment averages compared by Tukey test at 5% probability.

RESULTS AND DISCUSSION

At 14 DAA, when applying 100% of the recommended dose of different herbicides on plants at 4-6 leaf stage, it was observed that all of them were effective in weed control of crabgrass, regardless of water management strategy, which shows that the full doses of these herbicides are not influenced by the efficiency levels of water stress (Tables 2, 3, and 4).

Neither there was a decrease of the control percentages when the dose of the herbicides was reduced by 50%, compared to the full dose applications, in plants grown in soil with minimum stresses of -0.03 and -0.07 MPa soil water. In plants under severe water

Table 2 - Percentage of control plants of *D. horizontalis* at the stage of 4-6 leaves subjected to different managements water, 14 days after application of the herbicide fluazifop-p-butil. Botucatu-SP, 2008/2009

Water management (MPa)	Percentage of the dose of herbicide			
	0	25	50	100
-0.03	0.00 aC	57.50 aB	99.75 aA	100.00 aA
-0.07	0.00 aC	58.75 aB	97.75 aA	100.00 aA
-1.5	0.00 aD	57.50 aC	65.00 bB	100.00 aA
$F_{Water\ Management}$ (W)	29.414**			
F_{dose} (D)	1777.644**			
F (W) x (D)	28.138**			
CV (%)	6.0			

Means followed by same letter in the column and capital on the line, do not differ by Tukey test (p>0.05). ** significant value for the test "F" (p≤0.01).

Table 3 - Percentage of control plants of *D. horizontalis* at the stage of 4-6 leaves subjected to different managements water, 14 days after application of the herbicide haloxyfop-methyl. Botucatu-SP, 2008/2009

Water management (MPa)	Percentage of the dose of herbicide			
	0	25	50	100
-0.03	0.00 aC	58.75 aB	97.50 aA	100.00 aA
-0.07	0.00 aC	52.50 aB	95.00 aA	100.00 aA
-1.5	0.00 aD	23.75 bC	88.25 aB	98.75 aA
$F_{Water\ Management}$ (W)	19.928**			
F_{dose} (D)	891.465**			
F (W) x (D)	10.308**			
CV (%)	9.1			

Means followed by same letter in the column and capital on the line, do not differ by Tukey test (p> 0.05). ** significant value for the test "F" (p ≤ 0.01).

Table 4 - Percentage of control plants of *D. horizontalis* at the stage of 4-6 leaves subjected to different managements water, 14 days after application of the herbicide sethoxydim. Botucatu-SP, 2008/2009

Water management (MPa)	Percentage of the dose of herbicide			
	0	25	50	100
-0.03	0.00 aC	94.50 aB	98.25 aAB	100.00 aA
-0.07	0.00 aC	42.50 bB	96.50 abA	100.00 aA
-1.5	0.00 aC	92.00 aB	92.50 bB	96.75 aA
$F_{Water\ Management}$ (W)	152.849**			
F_{dose} (D)	4135.794**			
F (W) x (D)	136.388			
CV (%)	3.7			

Means followed by same letter in the column and capital on the line, do not differ by Tukey test (p> 0.05). ** significant value for the test "F" (p ≤ 0.01).

stress (-1.5 MPa of water management), it was observed an average reduction of 10% (application of the herbicides sethoxydim and haloxyfop-methyl) and 35% (herbicide fluazifop-p-butyl) in phytotoxicity symptoms, and this product presented the worst result when applied to this dose amount.

Applying half the recommended dose of sethoxydim did not reduce its effectiveness in relation to other doses used in plants without water stress (-0.03 MPa of water management), and in plants grown in soil with minimum stress of -1.5 MPa the observed control was of 92%, which may also be attributed to the reactions of plants to severe water restriction. In other treatments, phytotoxicity has averaged 55%, except for applications with the herbicide haloxyfop-methyl, which averaged only 23.7% in plants under higher water stress.

It can be inferred, based on these results, that the weed species *D. horizontalis* is susceptible to all products used after 14 days of application at the recommended dose, and unaffected by the water conditions imposed to the plants, when it is done on plants in an early development stage.

In applications of the commercial dose to *Digitaria ciliaris* weed species, 15 days after emergence, the control at 28 DAA provided by the herbicide fluazifop-p-butyl was of 87.5%, and by sethoxydim was of 99.0% (López Ovejero, et al., 2005), corroborating the results found herein.

Similar results were found by Vieira et al. (2010) with ametrine herbicide application at a dose of 2400 g a.i. ha^{-1}, which provided an efficient control of the access of *D. nuda*, averaged at 90% after 7 DAA and 100% after 14 DAA. In a study on the herbicides efficacy, controlling the species *Digitaria* spp., Dias et al. (2007) found that the herbicides from the chemical groups of triazines (ametrine) and isoxazolines (isoxaflutole) also have excellent levels of control.

Figures 1, 2, and 3 show the dry masses of weeds tested in different water management strategies, with and without herbicide application at the stage of 4-6 leaves at 14DAA.

It was observed that the control plants (without application of the products), kept in 13% minimum soil moisture, presented higher dry weight. This mass decreases as the reduced amount of water, with 48% and 62% in plants grown in soil with a minimum of 10 and 8% moisture, respectively. This reduction in dry weight was probably due to reduction of leaf area, as well as the number and thickness of roots and leaves, which may explain the results with greater control in plants without water stress, due to their larger contact area with the product, opened stomata, and less thick cuticle.

With application of 100% of the recommended herbicide flluazifop-p-butyl (Figure 1), the plant dried mass reduced on average 92% in all water management strategies applied to them. With the application of 50% and 25% of the recommended dose, there was a decrease of 88% to 69% and 81% to 56% of the plants grown in soil with minimum of 13 and 10% humidity, respectively, compared with the plants without herbicides. The reduction in dry weight was lower in plants under severe water stress (8% soil moisture), with an average of 57% in reduced doses of herbicide, with no differences between them.

The same behavior was observed in dry mass of plants applied with reduced doses of herbicides haloxyfop-methyl (Figure 2) and sethoxydim (Figure 3). A reduction of the dry mass of plants was noted on average 90% with the implementation of the recommended dose of herbicide haloxyfop-methyl, regardless of

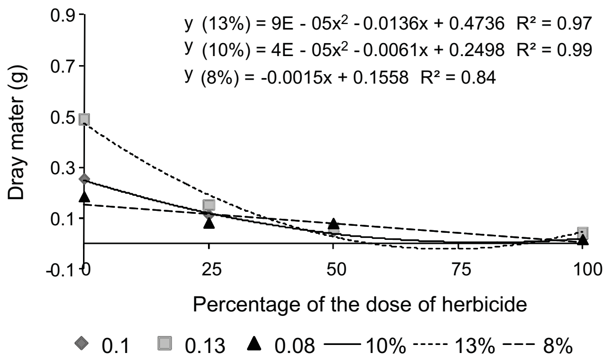

Figure 1 - Dry mass of plants of *D. horizontalis* under different water management strategies with application of the herbicide fluazifop-p-butyl, in four different doses, after 14 days on plants at 4-6 leaf stage. Botucatu-SP, 2008/2009.

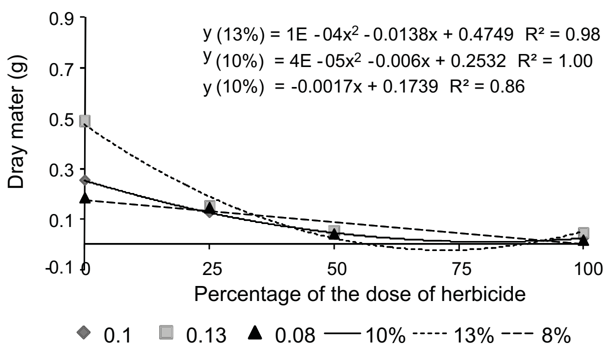

Figure 2 - Dry mass of plants of D. horizontalis under different water management strategies with application of the herbicide haloxyfop-methyl, in four different doses, after 14 days on plants at 4-6 leaf stage. Botucatu-SP, 2008/2009.

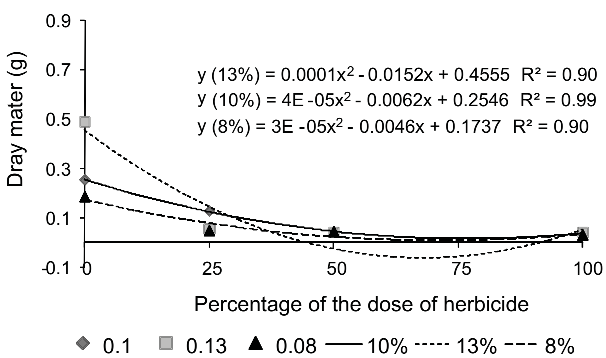

Figure 3 - Dry mass of plants of *D. horizontalis* under different water management strategies with application of the herbicide sethoxydim, in four different doses, after 14 days on plants at 4-6 leaf stage. Botucatu-SP, 2008/2009.

the used water management. With the application of sethoxydim, there was influence of water management in the dry weight of plants, with a 91% reduction in plants grown without water stress (water managements at 13%) and an average of 83% in plants grown in soils with minimum of 10 and 8% moisture.

The results of dry mass with treatment application corroborate the results of phytotoxicity, which are directly proportional; the higher the phytotoxicity, the greater the reduction in dry weight and higher efficiency of control. It is noteworthy that this increased control efficiency with herbicide application is observed in plants without water stress.

Tables 5, 6, and 7 present the control evaluations performed at 14 DAA, on the plants with herbicide application in the 2-3 tiller stage. The highest control percentages were observed in plants grown in soils with minimum stresses of -0.03 and -0.07 MPa, reaching 100% efficiency with the implementation of the recommended herbicide haloxyfop-methyl.

By applying this same product in plants grown under severe water stress (-1.5 MPa of water management systems), the control efficiency was reduced by 21.75%. On the other hand, the control provided by the herbicides sethoxydim and fluazifop-p-butyl was on average 88% and did not differ from control plants grown in soil with minimum stress of -0.07 MPa.

Table 5 - Percentage of control plants of *D. horizontalis* at the stage of 2-3 tillers under different water managements, 14 days after application of fluazifop-p-butil. Botucatu-SP, 2008/2009

Water management (MPa)	Percentage of the dose of herbicide			
	0	25	50	100
-0.03	0.00 aC	81.75 aB	95.25 aA	96.25 aA
-0.07	0.00 aB	76.25 aA	81.25 cA	82.50 cA
-1.5	0.00 aC	75.75 aB	87.50 bA	88.75 bA
$F_{Water\ Management}$ (W)	283.131**			
F_{dose} (D)	1794.517**			
F (W) x (D)	4.004**			
CV (%)	5.5			

Means followed by same letter in the column and capital on the line, do not differ by Tukey test (p> 0.05). ** significant value for the test "F" ($p \leq 0.01$).

Table 6 - Percentage of control plants of *D. horizontalis* at the stage of 2-3 tillers under different water managements, 14 days after application of haloxyfop-methyl. Botucatu-SP, 2008/2009

Water management (MPa)	Percentage of the dose of herbicide			
	0	25	50	100
-0.03	0.00 aC	23.75 bB	93.75 aA	100.00 aA
-0.07	0.00 aD	25.00 abC	83.75 bB	100.00 aA
-1.5	0.00 aD	30.75 aC	68.75 cB	78.25 bA
$F_{\text{Water Management}}$ (W)	32.961**			
F_{dose} (D)	1785.633**			
F (W) x (D)	22.251**			
CV (%)	7.2			

Means followed by same letter in the column and capital on the line, do not differ by Tukey test (p> 0.05). ** significant value for the test "F" ($p \leq 0.01$).

Table 7 - Percentage of control plants of *D. horizontalis* at the stage of 2-3 tillers under different water managements, 14 days after application of sethoxydim. Botucatu-SP, 2008/2009

Water management (MPa)	Percentage of the dose of herbicide			
	0	25	50	100
-0.03	0.00 aC	73.75 aB	87.50 aA	92.25 aA
-0.07	0.00 aC	75.00 aB	78.75 bB	88.75 aA
-1.5	0.00 aD	60.75 bB	70.00 cA	87.50 aA
$F_{\text{Water Management}}$ (W)	33.102**			
F_{dose} (D)	2001.789**			
F (W) x (D)	8.627**			
CV (%)	5.3			

Means followed by same letter in the column and capital on the line, do not differ by Tukey test (p> 0.05). ** significant value for the test "F" ($p \leq 0.01$).

There was no difference observed in the efficiency of controlling with the application of sethoxydim in commercial dose, regardless of the water management used. With the application of the herbicide fluazifop-p-butyl, the greatest control reduction was observed in plants growing in soil with minimum 10% humidity. This fact can be explained by the high water restriction imposed on plants and their consequences - impaired development, yellowing, leaf curl, and death - masking the effect of the herbicide.

Differences in plants responses to the application of herbicides were observed when under water stress, since in this current work, the species *D. horizontalis* presented minor symptoms of intoxication with the application of the haloxyfop-methyl herbicide, while in *U. plantaginea* plants, the herbicide with minor efficiency was the sethoxydim, according to Pereira et al. (2010).

The application of 50% of the commercial dose of the fluazifop-p-butyl herbicide did not reduce weed control, regardless of the water management used. This data has also been observed in plants grown without water stress (-0.03 MPa of water management systems) with the use of other products. The best control percentages were observed in plants without water stress, reaching up to 95%.

A control reduction was also noted, on average, of 18 and 10% in plants grown in soils with minimum stress of -0.07 and -1.5 MPa, with the application of the sethoxydim and haloxyfop-methyl herbicides, respectively.

Phytotoxicity was not affected by the application of ¼ of the recommended dose of fluazifop-p-butyl herbicide in plants grown in soil with minimum of 10 and 8% moisture. On plants without water restriction (water managements of -0.03 MPa) there was a 15% reduction compared to the treatments with application of 100% of the dose.

The largest control reduction was observed in applications of haloxyfop-methyl herbicide in plants grown in soil with minimum of 10% humidity. There were no effect differences among plants grown in soils with minimum stresses of -0.03 and -1.5 MPa. This fact can be explained by the high water restriction imposed on the plants and their consequences, such as inferior development, yellowing, leaf curl, and death, masking the effect of the herbicide.

Given the above, it can be inferred that the effect of herbicides was higher on plants without water restriction and with applications in early development. There are reports in the literature where changes in the morphology of plants due to water restriction, such as the low density of stomata and higher amount of waxes, would be potential barriers to the penetration of herbicides (Procópio et al., 2003), and also the lower hydration of the leaves cuticle of plants that developed in drought.

In the right conditions of soil moisture, over 90% of *Avena fátua* plants treated with 140.0 g ha^{-1} of fenoxaprop-ethyl were controlled; however, less than 70% of plants in water stress were controlled (Xie et al., 1993). Researchers report the lowest leaf area as one of the responsible factors for lower efficacy of the applied product.

Figures 4, 5, and 6 present the weed dried mass subjected to different water management strategies, with and without herbicide application, in the 2-3 tiller stage at 14 DAA. Among the control plants (without herbicide use), the ones grown in a soil without water restriction, i.e. maintained the minimum potential of soil water of -0.03 MPa (water management at 13%), presented the largest dry mass. As the water content in soil decreases, dry weight is also reduced. This reduction was of 38% and 76% in dry mass of the plants maintained in soil with a minimum of 10% and 8% moisture content (-0.07 and -1.5 MPa), respectively, when compared to the plants masses that have not suffered water restriction.

It was observed that the different soil moisture influences on herbicide performance, reflecting the plants dry mass. In applications of the commercial dose of all herbicides, the lowest reductions in dry mass were on plants maintained in soils with a minimum of 8% moisture (water managements of -1.5 MPa), averaging 69%. In plants grown in soils with minimal stress of -0.03 and -0.07 MPa (13 and 10% humidity), the reduction in dry mass,

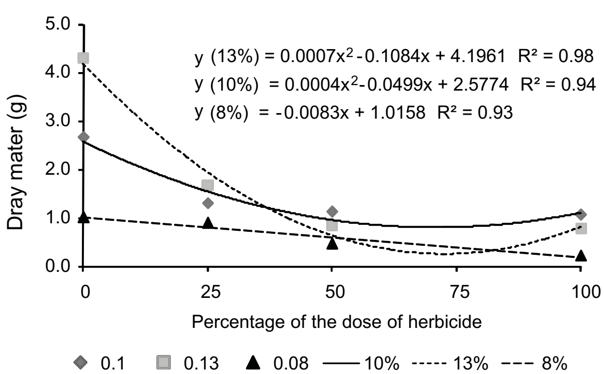

Figure 4 - Dry mass of plants of *D. horizontalis* under different water management strategies with application of the herbicide fluazifop-p-butyl, in four different doses, after 14 days on plants at the 2-3 tiller stage. Botucatu-SP, 2008/2009.

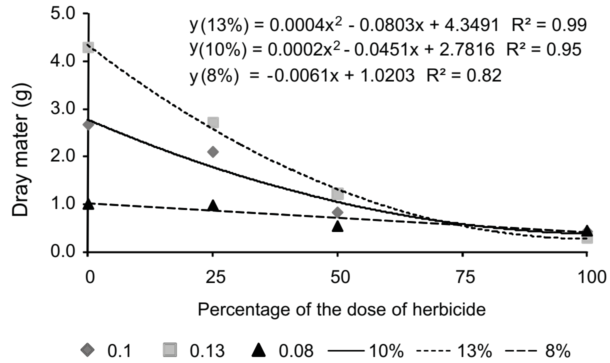

Figure 5 - Dry mass of plants of *D. horizontalis* under different water management strategies with application of the herbicide haloxyfop-methyl, in four different doses, after 14 days on plants at the 2-3 tiller stage. Botucatu-SP, 2008/2009.

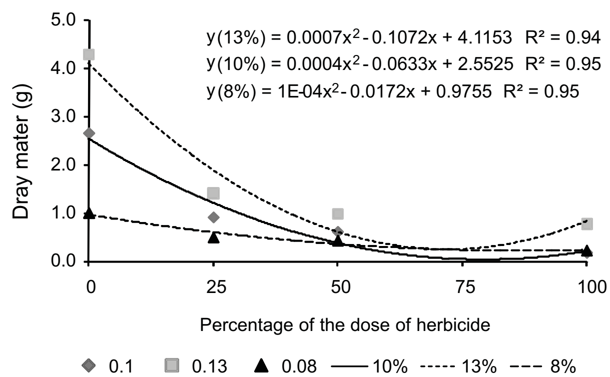

Figure 6 - Dry mass of plants of *D. horizontalis* under different water management strategies with application of the herbicide sethoxydim, in four different doses, after 14 days on plants at the 2-3 tiller stage. Botucatu-SP, 2008/2009.

compared with that of control plants, averaged 87%. Soil moisture had a greater influence on the plants dry mass with application of haloxyfop-methyl herbicide, where the plants grown in soil without water stress (water managements at 13%) had an average decrease of 93%. In the plants exposed to soil with high water restriction (water managements at 8%), the reduction was of only 55%. In applications of reduced doses of herbicides it is noticed a gradual behavior of plants dry mass and it is inversely proportional; the lower the applied dose, the higher was the plants dry masses, a fact noticed in the applications of all studied products.

Similar results were found by Zanatta et al. (2008), in which the water content in soil affected the efficiency of fomesafen herbicide on *A. hybridus* plants, but the level of influence varied with the applied dose. The application of the recommended herbicide provided a satisfactory control of this weed, regardless the soil moisture content, which did not occur when applied at lower doses.

Corroborating these results, Xie et al. (1993) reported that fenoxaprop-ethyl herbicide (150.0 g ha^{-1}) decreased by approximately 70% dry mass of non-stressed plants shoots, i.e. in adequate soil moisture, more than 90% of two strains of *Avena fatua*; however, the reduction in water-stressed plants was lower than 30%. Researchers report the lowest leaf area as one of the responsible factors for lower efficacy of the applied product, which directly contributes to lower dry mass.

Under the conditions in which this work was done, it can be concluded that the control efficiency was excellent with the application of the recommended dose of all herbicides in the early stages of development (4-6 leaves) of plants *D. horizontalis*, regardless the applied water management. In late applications (2-3 tiller stage) the water management strategies influenced the efficiency of these herbicides on the plants, and those grown under water stress showed less phytotoxicity. Haloxyfop-methyl herbicide had the best control for late application on plants exposed to water managements -0.03 and -0.07 MPa of soil water stress. The dry mass accumulation in plants of *D. horizontalis* grown in soil with minimum stress of -1.5 MPa was less influenced with the application of different herbicides.

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