Efficiency of a Reduced Herbicide Rate for *Brachiaria brizantha* Control in Sugarcane[1]

Eficiência de Subdoses de Herbicidas no Controle de ***Brachiaria brizantha*** *em Cana-de-Açúcar*

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ABSTRACT - At different growth stages, weeds present different sensitivities to herbicides. Thus, the registered herbicide rate may be reduced under specific conditions, while maintaining satisfactory weed control. This study evaluated the efficiency of reduced rates of the formulated herbicide mixture Velpar K WG® (hexazinone + diuron) + Volcane® (MSMA) for *Brachiaria brizantha* control at different growth stages. Optimum weed control efficiency was obtained when applying 50% of the recommended rate in younger plants (plants with one to four leaves). In late applications, it is necessary to increase the herbicide rates and, under these conditions, 90% of the recommended rate for (diuron + hexazinone) + MSMA was estimated to be the most economical one.

Keywords: *Saccharum* spp., hexazinone, diuron, MSMA

RESUMO - Em estádios diferentes de crescimento, as plantas daninhas apresentam sensibilidade diferenciada aos herbicidas. Desse modo, as doses registradas dos herbicidas podem ser reduzidas em condições específicas, mantendo-se o controle satisfatório das plantas daninhas. Neste trabalho, avaliou-se a eficiência de subdoses da mistura dos herbicidas formulados Velpar K WG® (hexazinone + diuron) + Volcane® (MSMA) no controle de Brachiaria brizantha em diferentes estádios de crescimento. Ótima eficiência de controle da espécie daninha foi obtida com aplicação de 50% da dose recomendada, quando os herbicidas foram aplicados em plantas mais jovens (plantas com uma a quatro folhas). Em aplicações tardias, comprovou-se a necessidade de aumentar a dose para obter controle eficiente; nessas condições, a dose econômica ótima estimada foi de 90% da dose recomendada da mistura dos herbicidas (diuron + hexazinone) + MSMA.

Palavras-chave: *Saccharum* spp., hexazinone, diuron, MSMA.

INTRODUCTION

The competition caused by weeds is a major factor limiting sugarcane production; this crop presents a low competitive ability at the beginning of its cycle due to its slow initial growth and wide spacing between planting rows. Without weed control, the yield may be reduced by 40%, depending on the species and density (Kuva et al., 2003). The *Brachiaria* genus is among the weed species commonly found in sugarcane fields. *B. decumbens* is a species that is highly competitive with the crop, resulting in a limitation of the stalk yield of 1.0 t ha^{-1} for each 3.7 g m^{-2} of dry matter produced (Kuva et al., 2003).

Among the available weed control methods, those most widely used in sugarcane crops include chemical suppression. These stand out because of their high efficiency, speed, and lower operational costs. However, the misuse of such products can cause serious environmental impacts (Mitchell et al., 2005).

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Thus, an alternative is to reduce the rate of application, since satisfactory weed control is often achieved by using less than the usually recommended rate presented on the product label (Boström & Fogelfors, 2002). This is because, for all herbicide formulations, the recommended rates by the manufacturer are usually set to provide efficient control over a wide range of environmental and management conditions (Devlin et al., 1991). Therefore, if these products are applied at the appropriate times and conditions, they may provide satisfactory control, even at rates below the recommendations (Boström & Fogelfors, 2002). This characterizes the economically optimal rate, which is the one that provides the greatest economic return, with a reduction in both production costs and environmental impacts.

In integrated weed management, which combines the use of complementary weed control methods, herbicides should be used when chemical control is extremely needed. Hence, post-emergence herbicide applications should be performed. Rizzardi & Fleck (2004) observed control of 95% of *Sida rhombifolia* with the use of 1.25 L ha^{-1} of the commercially formulated bentazon + acifluorfen mixture, applied at the 2-leaf stage. However, with six leaves, the control was around 87% with a rate of 2.0 L ha^{-1}.

Holm et al. (2000), while studying various herbicides for wild oat control in wheat crops, found that rate reductions were dependent on the physicochemical characteristics of the products. This study demonstrated higher efficiency of control in areas with younger and smaller weed populations. In some cases, reduced rates can inhibit the weed competition effect causing a partial suppression, while not fully controlling the population (Rizzardi & Fleck, 2004). However, one must take care that these species will not produce viable seeds in order to avoid increases in the soil seed bank, which will hamper the management of subsequent crops. Even if this is a questionable effect, in the management of weeds in corn, the use of reduced herbicide rates and the economic harm level were not associated with an increase in the weed seed bank (Sikkema et al., 2007).

For better efficiency in weed management, the integration between the population levels and rates of herbicides, in which dosing would increase accordingly with the weed population, is a viable possibility (Kim et al., 2002). Another possibility could be to improve the efficiency of reduced dosing with synergistic herbicide mixtures, as observed with the mixture of mesotrione and ametryn. This mixture effectively controls weeds that are slightly susceptible to single herbicides, such as *B. plantaginea* and *B. horizontalis* (Carvalho et al., 2010).

Lower herbicide rates will reduce crop production costs, thus increasing profits. This reduction will lead to less environmental pollution, especially from pre-emergence herbicides. Some herbicides have the potential to leach into the soil, reaching underground water, and contaminate them. Several studies have observed the herbicides ametryn, hexazinone, and tebuthiuron, among others, in surface or groundwater (Pfeuffer & Rand, 2004; Mitchell et al., 2005). The above mentioned herbicides are widely used for weed management in Brazilian sugarcane fields.

This work aimed to evaluate the efficiency of reduced herbicide rates of the formulated herbicide mixture Velpar K WG® (hexazinone + diuron) + Volcane® (MSMA) in *B. brizantha* control at different growth stages, aiming at a reduction not only in the environmental impact but also in the production costs.

MATERIAL AND METHODS

The experiment was conducted in field conditions (latitude 20°45'14" S and longitude 42°52'53" W) in a Yellow-Red Argissol (Kandiustalf). Sugarcane planting was conducted using the conventional one-year old system, with plowing and harrowing, followed by furrowing spaced in 1.4 m between rows.

The planting of the variety RB867515 was performed at a density of 18 buds per meter. Fertilization was performed in the furrow, according to the soil analysis results and recommendations for the crop, using 500 kg ha^{-1} of an 8-28-16 NPK formulation plus 160 kg ha^{-1} of KCl in post-emergence.

The experimental units were composed of five rows with 5.0 m long, with a total area of

35.0 m^2. The experimental design was randomized blocks with four replications. Treatments were allocated in a factorial design; factor A was composed of the commercial formulation mixture of the herbicides Velpar K WG® (diuron + hexazinone) + Volcane® (MSMA) at rates of 50.00, 62.50, 75.00, 87.50, and 100.00% of the recommendations (1.00 + 1.00; 1.25 + 1.25; 1.50 + 1.50; 1.75 + 1.75 and 2.00 + 2.00 kg or L ha^{-1} of the commercial product, respectively). Factor B was the timing of herbicide application, which was performed at three moments: when *B. brizantha* was at the two to four leaves stage; the intermediate stage, four leaves to one tiller; and the late stage, with one to four tillers. In addition, an untreated control and another plot in which *B. brizantha* was controlled by roughing were included.

The two commercial herbicide formulations were mixed directly into the spray tank. The applications were performed using a precision sprayer, pressurized with CO_2, comprised of a bar containing four spray nozzles (XR TeeJet® series 110.02), calibrated to apply 200 L ha^{-1} of herbicide. Climatic conditions at the time of the applications were as follows: first application - temperature 29 °C, relative humidity 59.3% and wind speed 3.53 m s^{-1}; second application - temperature 29.8 °C, relative humidity 63% and wind speed 3.9 m s^{-1}; third application - temperature 27.5 °C, relative humidity 63% and wind speed 4.46 m s^{-1}.

The *B. brizantha* populations were obtained by seeding 10 days before sugarcane emergence, so that the two species emerged at the same time. The seeding rate was 10 kg of seeds ha^{-1}, resulting in an average population of 23 *B. brizantha* plants per m^2.

Control of *B. brizantha* was assessed at 7, 21, 35, and 49 days after herbicide application (DAH). For this, a percentage scale was used, where zero corresponded to no effect and 100% control meant total plant destruction.

One year later, the stalk yield was evaluated. For this, a stalks count was performed in the three central rows, disregarding 0.50 m at the beginning and end of each plot. This was followed by the random collection of 30 stalks from the inside area of the plots, which were subsequently weighed. With the average weight and number of stalks per unit area, the yield was estimated in t ha^{-1}.

The stalks yield loss was calculated in relation to the treatment with the highest herbicide rate, for each application time, and expressed in t ha^{-1} and USD ha^{-1}. For economic losses, an average harvest price of $27.00 USD per ton of stalks was used as the calculation basis.

The optimal economic rate (OER) was considered as the rate at which the curve of lost yield in USD ha^{-1} intercepted the cost of control (Rizzardi & Fleck, 2004). For these authors, the OER was the herbicide rate at which the yield monetary loss equaled the cost of control, determined by using the recommended rate on the herbicide label, plus the application costs.

Data was submitted to an analysis of variance. When significant, the effects of the moment of herbicide application were compared by Tukey's test. The rate effects were compared by regression analysis. The choice of a model was based on statistical significance (F test), the adjusted coefficient of determination, and the biological significance of the model. All tests were performed at 5% probability.

RESULTS AND DISCUSSION

There was a significant interaction between factors for all the variables studied. Regarding the time of application, especially at lower rates, a greater degree of control was observed at treatments where herbicide was applied at early stages of development (two to four leaves), especially 7 DAH (Table 1). Rizzardi & Fleck (2004) found similar results when studying weed control in soybeans. Post-emergent herbicides have greater efficiency when applied to young plants (Dieleman et al., 1996).

The more susceptibility of young plants may due to more translocation of herbicides via plasmodesma. In older plants, the translocation of herbicide can be reduced in the plasmodesma, because the size exclusion limit can be reduced to approximately 50 times lower in these plants. This information

Table 1 - The *Brachiaria brizantha* control, in terms of developmental stages and rates of the formulated herbicide Velpar K WG® (diuron + hexazinone) and Volcane® (MSMA) mixtures

Herbicides rates (kg or L ha^{-1})	Application stage	Control (%)				Stalks yield (t ha^{-1})
		7 DAH[4/]	21 DAH	35 DAH	49 DAH	
0.00	Early[1/]	0.00 a[5/]	0.00 a	0.00 a	0.00 a	53.34 a
	Intermediate[2/]	0.00 a	0.00 a	0.00 a	0.00 a	57.55 a
	Late[3/]	0.00 a	0.00 a	0.00 a	0.00 a	54.75 a
1.00 + 1.00	Early[1/]	88.30 a	99.00 a	97.50 a	94.00 a	86.48 a
	Intermediate[2/]	50.00 b	93.00 b	91.30 b	79.50 b	93.68 a
	Late[3/]	79.00 a	99.00 a	97.50 a	82.50 b	63.43 b
1.25 + 1.25	Early[1/]	94.50 a	99.30 a	97.50 a	94.30 a	101.93 a
	Intermediate[2/]	58.80 b	94.30 b	94.50 b	88.30 b	74.67 b
	Late[3/]	93.80 a	99.80 a	99.00 a	98.00 a	82.96 b
1.50 + 1.50	Early[1/]	95.00 a	99.80 a	99.30 a	95.80 a	92.23 a
	Intermediate[2/]	67.50 b	94.80 b	98.30 a	96.30 a	69.77 b
	Late[3/]	94.30 a	100.00 a	99.80 a	98.30 a	82.35 ab
1.75 + 1.75	Early[1/]	94.80 a	100.00 a	97.80 a	98.50 a	90.90 a
	Intermediate[2/]	70.00 b	98.300 a	99.00 a	96.30 a	89.44 a
	Late[3/]	97.50 a	100.00 a	100.00 a	99.00 a	91.18 a
2.00 + 2.0	Early[1/]	94.80 a	100.00 a	99.50 a	98.00 a	110.37 a
	Intermediate[2/]	70.00 b	100.00 a	98.00 a	97.30 a	103.39 ab
	Late[3/]	94.80 a	97.80 a	99.80 a	98.00 a	94.60 b
Weeded	Early[1/]	100 a	100 a	100 a	100 a	98.18 a
	Intermediate[2/]	100 a	100 a	100 a	100 a	94.17 ab
	Late[3/]	100 a	100 a	100 a	100 a	89.34b
VC (%)		9.52	2.58	2.14	3.77	14.96

[1/, 2/, 3/] *Brachiaria brizantha* in the two to four leaves stages, six leaves to one tiller and one to four tillers, respectively, [4/] days after the herbicides' application; [5/] Means followed by the same letters in the column, within each rate do not differ inwardly, by Tukey's test at 5% probability.

strongly suggests that plasmodesmatal reduction in size exclusion limited is one of the great responsibilities due to the lower susceptibility of older plants to herbicides (Concenço & Galon, 2011).

Differences in the control of *B. brizantha* were higher with lower rates, when the weed stage was essential to the efficiency of the herbicide. At higher rates, the herbicide showed greater control, independent of the application time (Table 1). At later evaluations, 21 and 35 DAH, control showed smaller differentials between the times of application, with a tendency to similar control values.

It is noteworthy that diuron + hexazinone have residual effects in soil which controls new fluxes of emergence of *B. brizantha*. Therefore, effective control remained the same up to the last evaluation, conducted 49 DAH. Even in the early applications, the lowest rates tested were sufficient to promote the efficient control of the *B. brizantha* emergence up to the last evaluation time, with control values above the 90% mark.

Regarding the application time versus crop yield, there was a trend toward greater stalk yield with early applications, when both crop and weed species were at the early stages of development, independently of the dosages used. Conversely, there was a lower yield when herbicides were applied later, when *B. brizantha* had one to four tillers (Table 1). These results can be attributed to the interference caused by weeds in the early stages of crop growth, because in the treatments in which the application was made late, the crop and weeds stayed together for a longer time (Holm et al., 2000).

Weed interference is more serious at the early stages of crop growth. At this stage, one of the most limiting factors in the environment is light, often not by shading, but by changes in light quality and the consequent interference in the initial development of the crops (Merroto Jr. et al., 2009). For greater competitive ability in crops, the spacing between plants can be reduced (Stougaard & Xue, 2005).

The greatest loss in the stalk yield in herbicide-treated areas with *B. brizantha* at more developed stages could not be attributed to the lower efficiency of control, because differences were only observed at lower rates and in the early stages (Table 1); yield differences between application times were noted for all the tested rates.

The timing of herbicide application in post-emergence interferes with yield and economic performance (Berti et al., 1996). According to these authors, with early treatment the proportion of controlled weeds and the economic losses they generate are small. However, early control with herbicides lacking pre-emergent control can enable the emergence of weeds after treatment, which can lead to an economic impact.

A sugarcane stalk yield comparison was conducted between treatments at the lowest and highest rates of the herbicide mixture [(diuron + hexazinone) + MSMA] and the experiment controls, including the infested plots and the interference-free (weeded) plots, within each time point. There was no difference in the stalk yield between manual weeding and the highest rate of the herbicide (2.00 kg or L) at all time points (Table 2). The yield was lower when *B. brizantha* was not controlled.

When comparing *B. brizantha* control treatments with manual weeding and no control at all, the yield was limited to 45.67, 38.89, and 38.72% for the first, second, and third control stages, respectively. These results demonstrate the yield losses resulting from the competition exerted by the weeds when control was performed late.

Evaluating the control of *B. brizantha* with reduced rates of the herbicide mixture, (diuron + hexazinone) + MSMA, at 7 DAH, increased weed control as rates were increased when these herbicides were applied during the intermediate application period *(B. brizantha* with six leaves per tiller). In the remaining application periods, herbicide rates had no effect on weed control, with control over 90% (Figure 1). The rapid control effect is due to the mechanism of action of MSMA; this is a contact effect type of herbicide (Procopio et al., 2010). The less effective control when applied to *B. brizantha* at the intermediary stage may be due to a lower relation between shoot and root system, with proportionally less surface area for the absorption of the herbicide.

The control evaluated 21 DAH showed a positive linear relationship between herbicides rates and *B. brizantha* control. An exception when the herbicides were applied to weeds at later stages of development, where there was no difference between the rates and *B. brizantha* control, with 99.15% control maintained regardless of the rate applied (Figure 1). These results demonstrate the efficiency of weed control with reduced rates of herbicides. Moreover, lower herbicide

Table 2 - Sugarcane stalks yield, according to the method of control for the *Brachiaria brizantha* at different developmental stages

Control type	Control stage		
	Early	Intermediate	Late
Infested control	53.34 c[2/]	57.55 b	54.75 b
Herbicides - 1.00 kg or L[1/]	86.48 b	93.68 a	63.43 b
Herbicides - 2.00 kg or L[1/]	110.37 a	103.39 a	94.60 a
Weeded control	98.18 ab	94.17 a	89.34 a
VC (%)	17.13	14.98	10.56

[1/] Herbicides mixture: Velpar K WG® (diuron + hexazinone) + Volcane® (MSMA); [2/] Means followed by the same letters in the column do not differ by the Tukey's test at 5% probability.

rates decrease the weed control costs and the environmental damage caused by these products (Kim et al., 2006).

At 35 DAH, *B. brizantha* control remained stable as the rate of the herbicides was increased, when applied early. At the other stages, an exponential response of weed control was observed as the herbicide rate was increased, with the biggest differences in control at the lower rates and more stable responses at the higher rates (Figure 2).

Similar results were observed 49 DAH, where the first application period presented a positive linear relationship between herbicide rates and *B. brizantha* control. However, even when using the lowest rate (half the recommended dose), the control of this weed species was greater than 90%, which is considered efficient, considering that the climatic conditions were suitable for the application. At the other application stages, a nonlinear relationship was observed between the herbicide rates and control, with greater efficiency at higher rates (Figure 2).

The lower control values observed 35 and 49 DAH were due to the uncontrolled regrowth of the plants and by the new flux of *B. brizantha* emergence, which occurred after herbicide application. The latter case can be observed in the treatments with early implementation, where control was greater after application, but the control's effect lessened over time, especially for the lower rates of treatment. This may be due to the minimal residual effects of the herbicides, because with half the

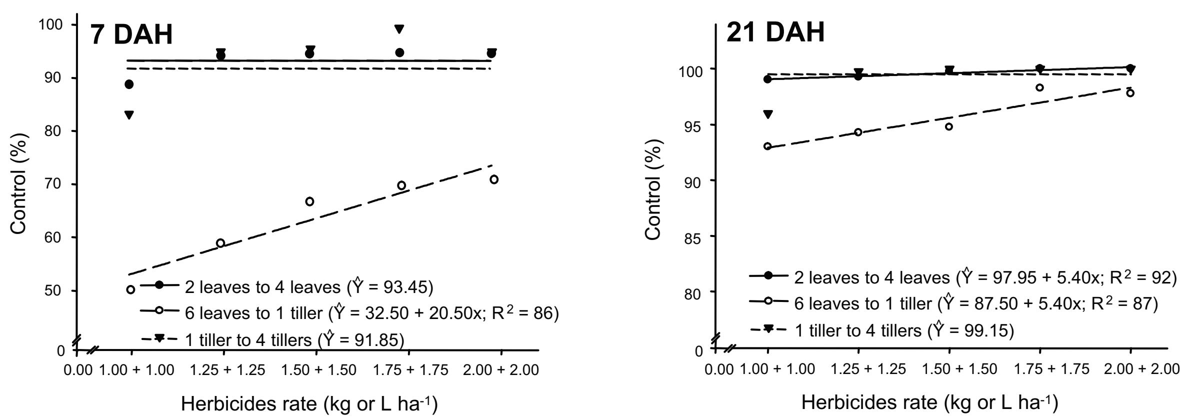

***Figure 1** - Brachiaria brizantha* control at 7 and 21 days after herbicides application in the function of rates of the formulated herbicides Velpar K WG® (diuron + hexazinone) + Volcane® (MSMA), and the developmental stages of the *B. brizantha.*

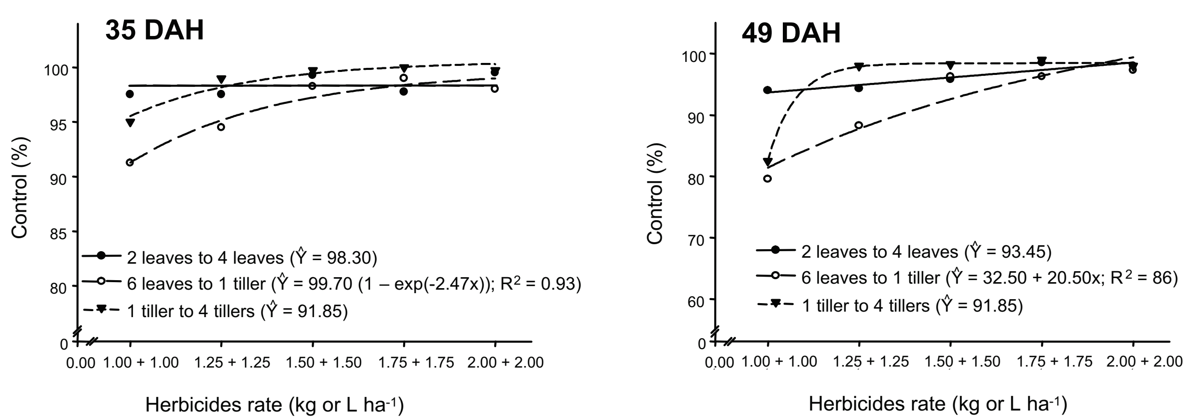

***Figure 2** - Brachiaria brizantha* control at 7 and 21 days after herbicides application in the function of rates of the formulated herbicides Velpar K WG® (diuron + hexazinone) + Volcane® (MSMA), and the developmental stages of the *B. brizantha.*

recommended rate, herbicide residuals in the soil are lessened and are, therefore, not able to control weed emergence for an extended period after application.

The stalk yield was not affected by increasing the herbicide rate in the first two application periods; in such cases, the optimal economic rate (OER) was 50% of the recommended herbicide rate. However, there was a positive linear relationship between the herbicide rate and crop yield in the application when *B. brizantha* had one to four tillers (Figure 3). This demonstrates that even half the recommended rate of the combined herbicide (diuron + hexazinone) + MSMA can provide efficient control of weed species, provided it is used in the early stages of growth.

With late application, it was possible to calculate the OER of herbicides, correlating the losses in stalk yield with the cost for each herbicide dose applied. The cost of control ranged from 56.00 USD ha^{-1} to 95.00 USD ha^{-1} for the lowest and highest rates, respectively, considering the cost of applying an herbicide to control post-emergent plants, and another for pre-emergent plants, plus the application cost.

There were fewer losses in stalk yield (t ha^{-1}) and economic yield (USD ha^{-1}) when the herbicide rates were increased (Figure 4). The OER is calculated to obtain the maximization of profit (Rizzardi & Fleck, 2004). According to Dieleman et al. (1996), the choice for the

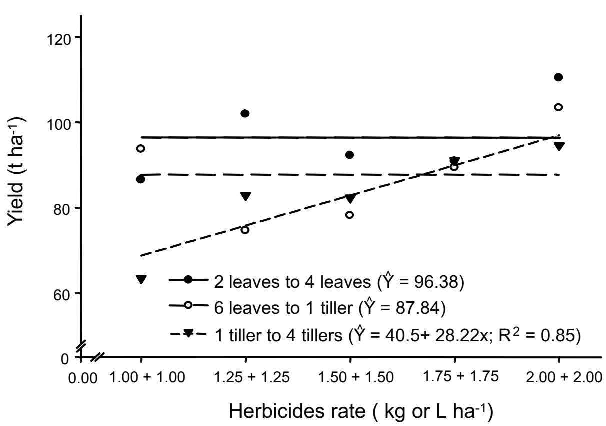

Figure 3 **-** Sugarcane stalks yield in the function of *Brachiaria brizantha* control timing and herbicides Velpar K WG® (diuron + hexazinone) + Volcane® (MSMA) rates.

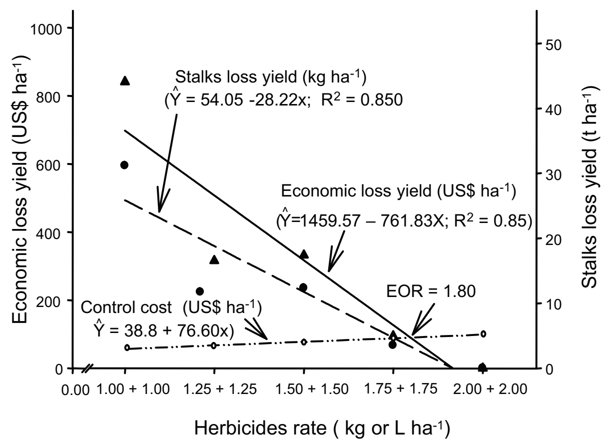

Figure 4 **-** Stalks loss yield of sugarcane, and economic optimum rate (EOR) for the *Brachiaria brizantha* control, depending on the rates of commercial herbicides Velpar K WG® (diuron + hexazinone) + Volcane® (MSMA) on late application (*B. brizantha* with one to four tillers).

best rate to be applied can be successfully incorporated in the development of an integrated management program for weed control in order to achieve efficient control, low costs, and to lessen the environmental impact.

The results of the present study show that the optimal economic rate for *B. brizantha* control was 90% of the recommended rate (1.8 kg or L ha^{-1}) for the combination of the herbicides (diuron + hexazinone) + MSMA used in *B. brizantha* control at the stage of development from one to four tillers (Figure 3). These results corroborate those by Rizzardi & Fleck (2004) when studying the control of *Sida* spp. and *Bidens pilosa* in soybean crops, with lower rates than those prescribed by the label in the commercially formulated mixture of acifluorfen + bentazon. The use of lower rates may reduce the weed competitive ability, even in the absence of their control, as reported by Murphy & Lindquist (2002).

Studies defining the best timing and herbicide rates, combined with others when evaluating weed the interference and determining levels of economic damage, are the basis for achieving the integrated management of weeds in sugarcane fields. The use of mathematical models has also been proposed to estimate the herbicide rate, considering the species, populations, and some environmental factors, such as soil nutrient levels and water availability (Kim et al., 2002, 2006, Wagner et al., 2007). With these models, it is possible to estimate herbicide rates that provide effective weed control, reduce production costs, and especially mitigate the environmental impact caused by these products.

B. brizantha is easily controlled at the stage of two to four leaves, in which only half of the recommended rate of the combined herbicide (diuron + hexazinone) + MSMA is needed to achieve its control. With the late control of *B. brizantha*, there is an impairment of the crop yield. Reinfestation may occur when lower rates of these herbicides are applied. For the control of *B. brizantha* at the stage of one to four tillers, there is a need to increase the herbicide rate, being the estimated optimal economic rate, under the conditions of this study, which is equal to 90% of the recommended rate of herbicide mixture.

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