Effect Of A Mixture of Diuron 80% Wp and Glufosinate Ammonium 150g./l Wsc (basta) in Controlling Weeds in Sugarcane

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ABSTRACT

Finding alternative herbicides have become imperative after termination of importation of Paraquat, which has been used for controlling weeds in sugarcane mixing with Diuron. This study evaluates the effect of herbicide Glufosionate Ammonium 150g./l WSC (Basta) mixed with Diuron 80% WP on weed control in sugarcane.

A series of field experiments was conducted at the Sugarcane Research Institute (SRI), Uda Walawe and in farmers' fields at Sevanagala, Sri Lanka during 2013-2014. The effect on weed control of three dosage rates of Basta (1.4l/ha, 1.7l/ha and 1.9l/ha) each mixed with Diuron 80% WP (3.5 kg/ha) were examined and compared with Paraquat 65g/l EC 6l/ha mixed with Diuron 80% WP 3.5 kg/ha. In farmers' fields, the rates of the Basta mixed with Diuron3.5kg were revised to 0.75 l/ha, 1.0 l/ha, 1.25 l/ha and 1.5 l/ha. The effects of the herbicides on weed knockdown, residual activity and crop phytotoxicity were evaluated by rating visually and counting live weeds. The visual ratings were presented with their standard error values and weed count data were analysed by ANOVA procedure.

All treatments of Diuron + Basta mixtures provided a more than 90% weed knock down and satisfactory residual control beyond 7 – 8 weeks after planting (WAP). Therefore, Basta could be used as an alternative herbicide to Paraquat, in Diuron + Paraquat treatment. Diuron 80 WP 3.5kg/ha is recommended to mix with Basta at the rates of 0.75 – 1.5l/ha for early and late post-emergence application to control weeds in sugarcane. If weeds are matured or more grasses are present, Diuron, the rate recommended has to be mixed with a higher dosage rate of Basta, i.e.,1.5 l/ha to get satisfactory weed knock down. The minor scorching and discoloration of crop when Basta was applied at higher dosage rates of 1.25 l/ha and 1.5 l/ha, mixed with Diuron were negligible and disappeared within 2 – 3 weeks.

Keywords: Basta, Diuron, Glufosionate Ammonium, Sri Lanka, Sugarcane, Weed control

INTRODUCTION

Weeds account for a10% – 70% yield loss in sugarcane, and in some instances, it may rise up to 100%. Weeds control accounts for 10% – 12% of the cost of sugarcane production (Witharama, 2001). As early growth of sugarcane occurs at a fairly slow pace, it take about 3 – 4 months to develop canopy to cover the ground under irrigation, and this period could extend up to 4 – 5 months under rain-fed. As a result of the slow development of crop canopy, a substantial amount of sunlight is transmitted to the ground during early stages of crop growth inducing a heavy weed growth along with the crop. Thus, to raise a successful crop, it is essential to keep sugarcane fields weed free until the crop develops full canopy cover, and this period is considered as critical for weed competition in sugarcane (Witharama, 2001).

Adoption of integrated weed management is the best strategy for effective control of weeds in sugarcane (Witharama, 2000). Application of inexpensive post-planting and residual herbicides with other mechanical control options is effective and economical to ensure a long-lasting weed control. Among

the effective post planting herbicides with residual actions, a mixture of Diuron and Paraquat has proved to be superior to the other herbicides.

The importation of Paraquat has been discontinued in Sri Lanka due to its extremely high mammalian toxicity. Thus, there was a necessity of an alternative herbicide to be used with Diuron. The Sugarcane Research Institute (SRI) started evaluation of several new herbicides and herbicide mixtures to explore their crop safety, knock down effect and residual activity on weeds in sugarcane. The objective of the experiments reported herein was to evaluate the effects of Glufosinate Ammonium 150g./l WSC (Basta) as a mixing partner of Diuron 80% WP, as an alternative to Paraquat, in controlling weeds in sugarcane in terms of crop safety, knock down effect and residual activity. The specific objectives were to find out the most effective dosage of Basta to be mixed with Diuron, appropriate time of application and its effect on controlling different weed species.

MATERIALS AND METHODS

Experimental Procedure

Basta containing 150g Glufosinate ammonium per liter, a post-emergent herbicide developed by Bayer Crop Science to control grasses, broad-leaved weeds and Cyperus species was selected to test its effect in controlling weeds in sugarcane, as a mixing partner of pre-emergent residual herbicide Diuron. The experiments were conducted in three stages from 2013 to 2014 at the research farm of SRI, Uda Walawe and in sugarcane farmers' fields at Sevanagala, Sri Lanka. Initially, the herbicide treatments selected based on the rates recommended by manufacturer were tested after spraying in observational plots at early post-emergence stage of weeds but before emergence of crop and late post-emergent stages to both crop and weeds to find out their effects on weed control. The effective herbicide treatments were subsequently tested in a replicated experiment for detail investigation on weed knock down, residual activity and crop damage after spraying again at early and late post-emergent stages of the crop and weeds. The final sets of experiments were conducted in farmers' fields at Sevanagala to test them at pilot scale to further confirm the findings of the replicated experiments.

Description of the experimental sites

Soil type and climatic conditions

The soil in the experimental area is predominantly well–drained Reddish Brown Earths (RBE) (Alfisol to Ustalf) with a sandy clay-loam texture. The area is characterised by a bimodal pattern of rainfall distribution, with about 1,300 mm average annual precipitation. About, two-thirds of the annual rainfall is received during September to February (Maha season). There is a small peak of rainfall during March to May (Yala season), but it is erratic. The ambient air and soil temperatures are high and range from 280C to 320C.

Weed spectrum

A considerably heavy weed growth was observed in the experimental locations. The weed flora was dominated with annual grasses and annual broad-leaved weeds.

Observational experiment

In the observational experiment, Diuron at the rate of 3.5kg/ha mixed with three different dosage rates of the herbicide Basta, i.e., 1.4 l/ha, 1.7 l/ha and 1.9 l/ha, were sprayed separately in 0.1ha plots few days after sporadic emergence of sugarcane crop of Co 775, and the weeds were at 2-4 leaf stage (15 Days After Planting – DAP). A tank mixture of Diuron 80% WP 3.5kg/ha and Paraquat 65g/l EC 6l/ha was applied as the standard treatment. The effects of the same set of treatments were evaluated in observational plots after spraying at late post-emergence stage, 28 DAP.

Replicated experiments

Two identical experiments, one for early post-emergence application at 15 DAP and the other for late post-emergence application at 28 DAP, were conducted to test the effects of Diuron 80% WP at the rate of 3.5kg/ha mixed with the same three dosage rates of Basta, i.e., 1.4 l/ha, 1.7 l/ha and 1.9 l/ha . A tank mixture of Diuron 80% WP and Paraquat 65g./l EC at the rates of 3.5 kg. and 6l/ha respectively was applied as the standard treatment. An untreated and un-weeded treatment was included as control. The two experiments were laid out in randomised complete block design with four replicates adopting a plot size of 9m long 6 cane rows.

Experiments conducted in farmers' fields at Sevanagala

Three farmers' fields at Sevanagala planted with the start of Maha season were selected for the study. Each field with an extent of 0.75 hectare was divided into five equal-sized blocks and Diuron 80% WP at the rate of 3.5kg/ha mixed with four dosage rates of Basta, i.e., 0.75 l/ha, 1.0 l/ha, 1.25 l/ha and 1.5l/ha were sprayed to four randomly-selected blocks. It was noted in the previous studies that Diuron 80% WP at the rate of 3.5kg/ha mixed with the tested three dosage rates of Basta, i.e., 1.4 l/ha, 1.7 l/ha and 1.9 l/ha had given a fairly high weed control and hence the mixing rates of Basta with the same rates of Diuron was revised in this experiment to reduce cost and find out the effective and more economical range. The remaining block was sprayed with the standard treatment Diuron 80% WP + Paraquat 65g/l at the rates of 3.5kg/ha and 6l/ha respectively.

Establishment and maintenance of the experiments

Land preparation, planting and crop management were carried out as per SRI recommendations (SRI, 1991). Seed beds were prepared by making ridges and furrows with a tractor-mounted ridger with the center spaced at 1.4m to make furrows of 17 cm to 22 cm deep. Stem cuttings (setts) of the sugarcane variety Co 775 with three internodes were planted in the furrows. The planting was coincided with the commercial planting periods for sugarcane in the area, i.e, (i) Observational experiment on February 05, 2013 (ii) Replicated experiment on April 10, 2013 (iii) Farmer' field experiments during October / November 2013. The crops were raised under supplementary irrigation. Tank mixtures of herbicides were applied by a hand-operated knapsack sprayer fitted with single, poly-jet nozzle. The herbicides were directed sprayed in between the cane rows by walking operator on the ridges. The swath-width (45cm above the ground) was 1.5m; spraying pressure was approximately 2 – 3 bars. The sprayer was calibrated before spraying, the application rate was 300l/ha.

Assessments

Assessment criterion

The effects of the herbicide treatments on weed knockdown, residual activity and crop phytotoxicity were evaluated. The weed control and crop damages were assessed visually and graded on a 0 to 100 scale and the ratings were summarised according to the Table 1.

Table 1 The scale used for evaluating weed control and crop damage visually

Scale	Degree of weed control	Degree of crop damage
0 – 10	No weed control	Non / Minor crop damage
10 – 30	Poor weed control	Less crop damage
30 – 60	Moderate weed control	Significant crop damage
60 – 90	Satisfactory weed control	Severe crop damage
90 – 100	Complete weed control	Complete crop damage

Weed knock down and residual activity of the herbicide treatments were also assessed by counting the number of live weeds at regular intervals before and after introducing the herbicide treatments.

Assessment of weed control

Weeds species appeared in 50 x 50 cm quadrat in ten randomly selected places in each experimental location were counted to estimate frequencies of occurrence of different weed species before experiments begun. After initiating experiments, apparent weeds knock down and crop phytotoxicity were rated visually one, two and three weeks after herbicide application according to the scale given in the Table 1. The density and species composition of weeds which appeared before herbicide application and in regular intervals after the application were also recorded. In the replicated experiments, weed appeared in five randomly-selected places on the ridges in each treatment plot were counted by placing 50 x 50 cm quadrat to estimate weed density. In farmers' fields, weeds on ridges were counted in ten random places in blocks treated with each herbicide treatment. The residual activity of the treatments was assessed in terms of their effect on weed control in comparison with the control at 3, 4, 6, 8 and 12 weeks after application of herbicide treatments.

Assessment of crop damage

Crop damage or phytotoxicity as burning/discoloration or stunting including the death of plants were assessed in each plot visually using a scale from 0 to 100 (Table 1). Phytotoxicity assessments are reported only when there were observable toxicities.

Data analysis

The weed species count data recorded in all three experimental locations before the experiments begun was used to estimate frequency of occurrence of common weeds, according to the following equation.

$$F_K = \frac{\sum^{n} Yi \times 100}{30}$$

Where

F_k – Frequency value of species K

Yi – Presence (1) absence of (0) of species k in the sampling place i

30 – Total numbers of places sampled in three experimental locations

After initiating experiments, the visual ratings given for weed control and crop damage by three assessors were averaged and presented with their standard error values. The mean rating values were subjected to ANOVA for comparison.

The weed counts of different species in each sampling point were categorised under three major weeds types; grasses, broad-leaved weeds and sedges. The total counts of each species belonged to one category in one sampling point were added and the density, i.e. number of plants of each weed type per square meter was estimated. Then the estimated densities of grasses, broad-leaved weeds and sedges in five sampling points were added separately and divided by five to estimate average density of each weed type in each treatment plot. The total weeds densities in each treatment plot were estimated by adding average densities of grasses, broad leaved weeds and sedges in each treatment plot. Total weed densities and densities of individual weed type; grasses, broad-leaved weeds and sedges were subjected to ANOVA procedure for comparison. In the case of farmers' field experiment, total weed densities were presented with their standard error values for comparison.

RESULTS AND DISCUSSION

Weed spectrum

A considerably heavy weed growth was observed in the experimental locations and

occurrence of some weeds that were common in sugarcane plantations was very high. The commonly-observed weeds are shown in Table 2. Grasses and broad-leaved weeds were dominant. The most aggressive weed species were Isachnae globosa followed by Agerotum conyzoides. Among sedges, Cyperus rotundus was frequently distributed in the experimental sites.

Observational experiment

In the initial experiments conducted to observe effectiveness of the herbicide, it was noted that weed knock down one week after spraying (1 WAS) was over 85% after early post emergent application and was over 60% after late post emergent application of all tested herbicide treatments (Diuron 3.5kg/ha mixed with Basta, i.e., 1.4 l/ha, 1.7 l/ha and 1.9 l/ha). Also, residual effects of all Diuron + Basta treatments were fairly high and stand above satisfactory weed control levels until 6 to 8WAS similar to that of the Diuron + Paraquat treatment.

Phytotoxicity symptoms on crop were not appeared when Diuron was mixed with Basta at the rates between 1.4 to 1.9l/ha and was applied at early post emergent stage. In the case of application at late post-emergent stage, the phytotoxicity showed by all tested Diuron + Basta treatments on sugarcane was minor and negligible and lower than that of the standard herbicide Diuron + Paraquat mixture and entirely disappeared in another one to two weeks' time.

Since the weed control observed in all herbicide treatments in this experiment was above the satisfactory level and the phytotoxicity was minor, the data is not presented. The same treatments were subsequently tested in a replicated experiment for detailed investigation.

Table 2. Common weeds grown in association with sugarcane in the experimental sites at the SRI farm and in the Sevanagala farmers' fields

Weed category	Vernacular name	Scientific name	Observed Frequency
Grasses	Batadalla	*Isachnae globosa*	0.96
	Digitaria	*Digitaria spp*	0.68
	Gini	*Panicum maximum*	0.57
	Pututhana	*Dactylocteniumae gyptium*	0.50
Broad leaved	Hulunthala	*Agerotum conyzoides*	0.92
	Gatakola	*Sperma cocehispida*	0.80
	Hingura	*Mimosa invisa*	0.79
	Maha Galkura	*Corchorus* spp.	0.29
	Gatathumba	*Leucas zeylanica*	0.28
	Heendiyaberiliya	*Commelina bengalensis*	0.27
	Kapumkeeriya	*Euphobia hirta*	0.20
	Godamaruk	*Echinochloa colona*	0.12
Sedges	Kaladuru	*Cyperus rotundus*	0.36

Note: Frequency indicates the relative presence of a species in each 50 x 50 cm sampling area; if a species was present in all sampling points, then the observed frequency was 1.0.

Replicated experiment

Weed and crop growth before herbicide application

The estimated weed densities and their observed growth stages before herbicides application are reported in the Table 3. Most weeds emerged within the first 1-2 weeks after planting (WAP). They were tiny and tender at the stage of early post-emergence application (2 WAP) but were grown-up and mature when herbicides were applied at late post-emergent stage (4WAP). The recently-emerged sugarcane settlings were scattered in the fields as spikes when the herbicides were sprayed at early post-emergent stage, but the majority of the emerged settlings were at 3 – 5 leaves stage when herbicides were applied at late post-emergent stage.

Table 3 Mean density, height and number of leaves per plant of weeds one day before herbicide application

Parameters	2WAP	4WAP
Density (number/m^2)	175 – 280	201 – 263
Height (cm/plant)	1 – 5	6 – 14
Leaves(number/plant)	2 – 4	8 – 20

The minimum and maximum values of density, height and numbers of leaves per plant were based on the mean values in each plot.

Early post-emergence application

Visual observations

The weed knockdown, according to the ratings given for weed control 1 week after spraying (WAS) was over 95 in the plots applied with different rates of Diuron + Basta and Diuron + Paraquat treatments. As appeared in the ratings recorded at 3WAS, 2 months after spraying (MAS) and 3MAS, the levels of residual effects of all Diuron + Basta treatments were also fairly high and over 81, almost same as that of the Diuron + Paraquat treatment. Since the observed weed control levels in all herbicide treatments were above the satisfactory level, the ratings recorded at 3WAS and 2MAS were not presented in the Table 4. These levels of weed control by all herbicide treatments are adequate to keep weed competition at a minimum during the critical period of growth of sugarcane. The suppression of Cyperus rotundus was more in the treatments which, Diuron was mixed with higher dosage rates of Basta (1.7 and 1.9l./ha) than lower dosage (1.4l./ha) or Paraquat (6l/ha).

The phytotoxicity of Diuron + Basta treatments on sugarcane was minor and negligible (the ratings 4 - 6) and lower than rating (14) recorded in standard herbicide Diuron + Paraquat treatment (Table. 4). Only phytotoxicity found 1WAS was slight yellowing of sugarcane leaves. But, the symptoms have entirely disappeared in a week time showing a rapid recovery.

Table 4. Visual ratings given for weed control (WC) and crop damage (CD) after different time periods of herbicide application at early post-emergent stages

Treatment*	Weed Control				Crop Damage	
	1WAS		3MAS		1WAS	
	WC	SE	WC	SE	CD	SE
Basta 1.4l	95	3.5	81	5.2	4	1.3
Basta 1.7l	96	1.3	84	3.0	4	2.4
Basta 1.9l	95	3.5	87	1.7	6	1.3
Paraquat 6l	98	1.4	83	2.8	14	3.8
Control	0	0.0	0	0.0	0	0.0

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat

Each rating is an average of three scores given by three assessors

Effect on weed densities

The reduction of live weed densities from 217 – 280 /m^2 before herbicide application to 46 – 92 / m^2 3 WAS (ranging from 67% to 82%) further confirm a fairly high weed knock down in all herbicide treatments of Diuron mixed with different dosage rates of Basta (Table 5). The weed knock down increased ($P \leq 0.05$) with increasing the dosage rates of mixing Basta from 1.4l to 1.9l per hectare and vice versa. However, weed knock down was relatively inferior (67 and 68%) if Diurom was mixed with lower dosage rates of Basts (1.4 and 1.7l/ha.) and not comparable with that of the estimated 96% in Diuron + Paraquat treatment. Weed knock down similar to the Diuron + Paraquat treatment was observed after early post-emergence application of a mixture 3.5 kg Diuron with and1.9l Basta per hectare.

Effect on different weed species: The estimated weed densities before spraying herbicide treatments occupied with more broad-leaved weed species (150 – 250 plants/m2) than grasses (8 – 38 plants/m^2). The only sedge species found was Cyperous rotundus with the densities ranging 6 – 15 no / m^2.

There was no differential effect of the tested herbicide treatments on individual weed species but the herbicide treatments had a significant effect in controlling them when considering under three major weed types, i.e. grasses, broad-leaved weeds and sedges ($P \leq 0.05$) (Table 6). The reduction of densities of grass species due to standard herbicide treatment, Diuron + Paraquat mixture was over 98%. The reduction of grass (over 68%) reported in Diuron 3.5kg.+ Basta 1.9l /ha treatment was similar to the reduction of grass in the standard herbicide treatment. Control of grass was negligible and similar to the untreated control treatment after application of Diuron mixed with lower dosage rate (1.4l./ha.) of Basta. Thus, there was a decreasing trend of controlling grasses with decreasing rate of Basta 1.9l to 1.4l./ha mixed with Diuron. This indicates that Diuron has to be mixed with a higher dosage rate of Basta to control weeds, if weed flora is dominated with more grasses.

Table 5.Mean live weed densities (Plants/m^2) in the fields one day before herbicide applications and 3weeks after herbicide application (3WAS) at early post-emergence stage and weed control (WC) as percentage of initial weed densities

Treatment*	Total Weed Density				WC %
	Before spraying		3WAS		3WAS
	Density**	SE	Density***	SE	
Basta 1.4l	280	77.4	92 ^{b}	25.9	67
Basta 1.7l	206	35.1	65^{bc}	10.1	68
Basta 1.9l	262	43.2	46^{cd}	6.8	82
Paraquat 6l	217	28.4	10 ^{d}	4.2	96
Control	175	11.5	171 ^{a}	5.9	2
CV %	28.8		35.2		

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat

** Mean weed density values between treatments are not significantly ($P \geq 0.05$) different

*** Mean weed density values with same letters in each column are not significantly ($P \geq 0.05$) different.

The broad leaved weed densities were significantly reduced ($P \leq 0.05$) in all three tested dosages of Diurn and Basta mixtures and more or less similar to the Diuron + Paraquat treatment (Table 6). In contrast, the effect of herbicide treatment on Cyperus rotundus showed different trend. The least density was recorded in control treatment perhaps due to suppression of Cyperus rotundus by free growing other weed species. More Cyperus rotundus in herbicide-treated plots could be attributed with poor control of this species by the applied herbicide treatments coupled with higher growth of them in absence of interference from other species as they have successfully controlled by the tested herbicide treatments.

Table 6. Mean weed densities (Plants /m^2) of grasses, broad leaved weeds and sedges at 3weeks after herbicide spraying at early post emergence stage

Treatment*	3 Weeks After Spraying		
	Grasses	Broad leaved	Sedges
Basta 1.4l	57 ^{a}	27^{b}	08^{ab}
Basta 1.7l	30^{b}	15^{b}	21^{a}
Basta 1.9l	23^{bc}	09 ^{b}	13^{ab}
Paraquat 6l	01^{c}	01^{b}	08^{ab}
Control	74^{a}	93^{a}	03^{b}
CV%	40.4	64.8	74.7

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat

Mean weed density values with the same letters in each column are not significantly ($P \geq 0.05$) different.

Effect on sugarcane germination

There were no significant differences ($P \geq 0.05$) of germination counted 1 MAP between different herbicide treatments and control plots. The mean number of settlings appeared was 5.0±0.5with a range of 4 – 6 numbers per one meter furrow length. The herbicide treatments were applied at 2WAP so that, none of the treatment had any impact of sugarcane germination or damaging the crop. This finding further confirmed minor or negligible crop phytotoxicity observed at subsequent stages (Table 4).

Late post-emergence application

Visual observations

Considerably higher densities of grown-up and mature weeds (201 – 263 plants/ m^2) were observed in all treatment plots before spraying. Even then, the all herbicide treatments gave fairly high knockdown effect as evident from appreciably high degree of weed control rated over 86, three WAS herbicide treatments (Table 7). The apparent knockdown effect of weeds between treatments containing Diuron and different rates of Basta and standard Diuron + Paraquat treatment were almost similar. As appeared in the ratings recorded at 2 MAS and 3MAS, the residual effects of all Diuron + Basta treatments were also fairly high and rated values were over 72 and above satisfactory weed control level and similar to the Diuron + Paraquat treatment. Since the values in all herbicide treatments were above the satisfactory weed control level, the ratings recorded at 2MAS are not presented in the table. This level of residual weed control by all herbicides treatments is quite adequate to keep weed competition at a minimum during the critical period of growth of sugarcane. It was, however noted that the suppression of Cyperus rotundus was more in all tested rates of Basta mixed with Diuron than the standard Diuron + Paraquat mixture.

Phytotoxicity showed by Diuron + Basta treatments on sugarcane was minor and negligible, the ratings were below 10 and lower than standard herbicide treatment Diuron + Paraquat mixture if applied at lower dosage rates. Even though, the observed crop damage in the plots treated with Diuron mixed with higher dosage rate of Basta (1.9l/ha.) was comparatively high and closure to the standard

Diuron + Paraquat treatment, the symptoms entirely disappeared in 1-2 weeks' time. Only phytotoxicity found at 3WAS was slight yellowing and partial scorching of sugarcane leaves (Table. 7).

Effect on Weed Density

The knock down of weeds was 44%, 63% and 81% at 2WAS and were 97%, 76% and 99% at 3WAS due to application of Diuron mixed with Basta at the rates of 1.4l, 1.7l and 1.9l/ha respectively. The weed knock down after spraying Diuron + Paraquat treatment was 93% at 2 WAS and 49% at 3 WAS (Table 8). The degree of weed knock down increased with increasing mixing rates of Basta from 1.4l to 1.9l / ha. However, weed knock down was relatively inferior in the plots applied with Diuron mixed with lower dosage rates of Basta (1.4 l/ha.) and not comparable with the standard herbicide treatment Diuron + Paraquat mixture. More weed control similar to the standard Diuron + Paraquat mixture was observed after late post-emergence application of Basta at the rates of 1.7 and 1.9l/ha. Therefore, unlike in early post-emergence application, Diuron has to be mixed with higher dosage rates of Basta (1.7 to 1.9l. / ha.) to get satisfactory knock down of grown-up and mature weeds.

The total weed densities recorded at 3WAS were different, as least weed density reported was from the control plots (Table 8). Profusely-growing vigorous plants take competitive advantage and occupy more spaces while suppressing weak neighbouring plants in a free-growing weed population making few grown-up weeds to occupy in a unit area. This could be attributed to low densities of mature weeds in the controlled plots. In contrast, the highest weed density was recorded in the plots treated with standard herbicide Diuron + Paraquat. The plots treated with Diuron + Basta mixtures reported low weed densities, the least density recorded was from the plots treated with Diuron mixed with higher dosage rate of Basta (1.9l./ha.). This phenomenon could be attributed to the mode of action of the tested herbicides. Paraquat, being a post-emergence contact herbicide, kills only the above-ground parts of the weeds if contact with the active chemical. Therefore, higher weed densities reported at 3WAS in Diuron + Paraquat treated plots may be due to regeneration of partially knock down weeds which were not completely smeared with the herbicide and intact underground parts of knock down weeds. The herbicide Basta has contact

Table 7.Visual ratings given for weed control (WC) and crop damage (CD) after different time periods of late post-emergence application

Treatment	Weed Control				Crop Damage	
	3WAS		3MAS		3WAS	
	WC	SE	WC	SE	CD	SE
Basta 1.4l	86	6.9	72	5.7	6	3.2
Basta 1.7l	89	2.4	72	5.5	9	3.2
Basta 1.9l	86	2.5	74	5.8	10	2.0
Paraquat 6l	95	1.7	82	4.4	11	1.3
Control	0	0.0	8	7.5	0	0.0

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat
Each rating is an average of three scores given by three assessors

action and limited systemic effect having capacity to kill whole plant after entering in to a plant so that available propagators for subsequent regeneration were less. However, those aspects were not investigated detail in this study.

Effect on different weed species

Similar to the early post-emergence experiment, the densities of broad- leaved weeds (119 – 169 plants /m^2) were more than grasses (56 – 82 plants / m^2) before spraying herbicides (Table 9). At 2 WAS, there was a significant ($P \leq 0.05$) knock down of grasses and broad-leaved weeds in the herbicide-treated plots compared with the control. The weed knock down has increased with increasing rate of mixing Basta with Diuron, from 1.4 to 1.9 l/ha. However, the knock down of grasses even Diuron was mixed with higher dosage rates of Basta (1.7 and 1.9 l/ha) was inferior to the Diuron + Paraquat mixture. In the case of broad-leaved weeds and sedges, the knock down was similar to the Diuron + Paraquat mixture if Diuron is applied mixing higher dosage rate of Basta (1.7 and 1.9l./ha.). This is in contrast to the results reported under early post-emergence application as an appreciable weed knock down was observed even Diuron was applied mixing with lower dosage rate of Basta. This indicates that Diuron mixed with lower dosage rates of Basta are sufficient to kill young immature weeds but Diuron mixed with higher dosage rates have to be applied to control grown-up mature weeds.

Densities of three categories of weed species recorded at 3 WAS show differential response. Similar to the total weed densities (Table 8) the low densities of grasses, broad-leaved weeds and sedges observed in the control plots at 3 WAS may be due to suppression of weak plants due to profuse growth of vigorous individuals occupying more space (Table 9). The effect of different herbicide treatments on the density of grasses were non-significant at this stage and the values were similar to the control treatment. Occurrence of broad-leaved weeds too do not showed regular pattern, perhaps due to heterogeneous distribution of those species in the fields. Relatively, more broad-leaved weeds were observed in Diuron + Paraquat treatment at this stage. However, according to the visual ratings reported in Table 7, the weed control was quite satisfactory in all herbicide treatments compared with control at this stage

Table 8.Total weed densities (Plants /m^2) in the fields one day before, 2 weeks after herbicide application (WAS), 3WAS and weed control (WC %) as percentage of initial weed density at 2 WAS in late post-emergence sprayed experiment

Treatment*	Weed Density				WC	Weed Density	
	Before spraying**		2WAS***		2WAS	3WAS***	
	Density	SE	Density	SE	%	Density	SE
Basta 1.4l	201	23.8	113^{b}	6.8	44	6^{b}	1.6
Basta 1.7l	210	28.0	77^{c}	11.6	63	51^{ab}	31.6
Basta 1.9l	263	11.6	50^{c}	9.4	81	3^{b}	1.3
Paraquat 6l	254	39.0	17^{d}	7.4	93	129^{a}	53.9
Control	202	40.1	188^{a}	16.1	7	3^{b}	0.9
CV %	28.9		23.2			156.8	

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat

** Mean weed density values between treatments are not significantly ($P \geq 0.05$) different

*** Mean densities with the same letters in each column are not significantly ($P \geq 0.05$) different.

Table 9. Mean weed densities (Plants / m^2) of grasses (GR), broad leaved weeds (BL) and sedges (SED) one day before herbicides applications and 2 and 3 weeks after herbicide application (WAS) in late post emergence sprayed experiment

Treatment*	Before spraying**			2 WAS***			3 WAS***		
	GR	BL	SED	GR	BL	SED	GR	BL	SED
Basta 1.4l	73	120	7	65 ^{b}	26 ^{b}	23 ^{ab}	3	0 ^{b}	3 ^{ab}
Basta 1.7l	56	151	3	27 ^{c}	18^{bc}	32 ^{a}	14	21 ^{ab}	15 ^{ab}
Basta 1.9l	82	169	12	25 ^{c}	8b^{c}	18 ^{b}	3	0 ^{b}	1 ^{b}
Paraquat 6l	82	159	12	0 ^{d}	1 ^{c}	16 ^{b}	15	72 ^{a}	43 ^{a}
Control	69	119	15	93 ^{a}	82 ^{a}	13 ^{b}	2	0 ^{b}	1 ^{b}
CV%	28	33	119	27	44	42	166	185	198

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat
** Differences of mean weed densities between treatments are not-significant ($P \geq 0.05$)
*** Means densities with same letters in each column are not significantly ($P \geq 0.05$) different.

so that level of weed control achieved was adequate to keep weed competition at minimumduring the critical period. Even there were more weeds within 50 x 50 cm quadrat, in herbicide-treated plots at 2 and 3 WAS, those were recently germinated or regenerated small plants. But in the control plots, the weed were grown up and mature bushes which required a wider space to occupy one so number per unit area is less. In contrast, there was a significant reduction of species of sedges, i.e.,*Cyperus rotundus* in Diuron + Basta treatments than Diuron + Paraquat treatment. The suppression of Sedges was more with increasing the rate of mixing Basta with Diuron. This again may be due to regeneration of the partially knocked-down weeds and intact under-ground parts of the knocked-down weeds due to contact action of Paraquat in the standard herbicide treatment.

Experiments Conducted at Sevanagala Farmers' Fields

Weed and crop growth before herbicide application

Similar to Uda Walawe, a higher weed densities ranging from 79 – 646 plants/m^2 was observed in the farmers' fields in Sevanagala too but stages of crop and weed growth were not uniform not only between different fields but also between different locations within a field. There were immature and moderately mature weeds and emerged young sugarcane settlings at different growth stages between 1 – 2 months in farmers' fields at the time of spraying.

Visual Ratings

The observed weed knock down in the field 1 at 1WAS was below the satisfactory level (Ratings 54 – 55) when Diuron was applied mixing lower dosage rates of 0.75 and 1.0l/ha Basta (Table 10). Even the rating reported for Basta 1.25l./ha (68) was above the satisfactory level, its weed control was inferior to the standard Diuron + Paraquat treatment (Rating 73). However, the weed knock down was superior to the standard herbicide treatments at this stage when Diuron was applied mixing Basta at the rate of 1.5l./ha (Rating 81). The weeds were moderately matured at the time of herbicide application to this field. Low vulnerability of mature weeds to the applied herbicide treatments delayed their knock down after application of lower dosage rates of Basta mixed with Diuron. As a consequence, the owner of this field had deliberately sprayed Paraquat to kill the partially knock down weeds without prior notice. Therefore, this field was not evaluated further 1 WAS to assess weed control efficacy.

Table 10. Visual ratings given for weed control after different time periods of herbicide application in Sevanagala farmers' fields

Treatment*	Field No.1		Field No. 2				Field No. 3			
	1WAS		1WAS		1MAS		3WAS		1MAS	
	WC	SE	WC	SE	WC	SE	WC	SE	WC	SE
Basta-0.75l/ha	55	2.9	93	1.7	88	2.5	93	1.7	93	2.5
Basta – 1.0l/ha.	54	3.8	92	1.7	88	2.5	88	3.3	85	5.0
Basta-1.25l/ha	68	2.5	92	1.7	90	0.0	93	1.7	93	2.5
Basta-1.5/ha	81	1.3	93	1.7	93	2.5	83	6.0	88	2.5
Paraquat 6l/ha.	73	4.3	92	3.3	93	2.5	88	3.3	93	2.5

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat
Each rating is an average of three given by three assessors

However, weed knock down in the fields 2 and 3 were satisfactory as the ratings reported 1 WAS in the field No. 2 were over 92 and the ratings reported 3 WAS in the field No. 3 were over 83 in all levels of Diuron + Basta treatments and Diuron + Paraquat treatment (Table 10). Tender and fleshy weeds appeared in these fields at the time of herbicide spraying might have easily knocked down even after application of Diuron mixed with lower dosage rates of Basta. On the other hand, all Diuron + Basta treatments have shown higher levels of weed control at 1 MAS, the ratings were above 88 and 85 in the fields No. 2 and No. 3 respectively. The corresponding ratings of the standard Diuron + Paraquat treatment in the field No. 1 and 2 at 1 months after spraying (MAS) are 93 and 88 respectively. The age of crop at this stage was over 2 months after planting so that appreciably higher residual effect on weed control observed at this stage was sufficient to keep weed competition at a minimum level during critical period.

Effect on weed density

Weed density values reported in Table 11 further confirm the observed fairly high weed knock down (more than 90%) from the population appeared before spraying all herbicide treatments containing Basta and the standard Diuron + Paraquat treatment. Since weed control efficacy was not monitored after 1 WAS, weed density values at 2 WAS of the field number 01 was not presented in Table 11.

Table 11. Weed densities (Plants/m^2) in each field one day before spraying (DBS) and 2 weeks after spraying (WAS)

Treatment*	Field No.1		Field No. 2			Field No. 3		
	1 DBS		1 DBS		2WAS	1 DBS		2WAS
	Density	SE	Density	SE	Density	Density	SE	Density
Basta 0.75l/ha	309	20	133	17	1	460	40	0
Basta 1.0l/ha	287	38	79	28	5	646	38	3.2
Basta 1.25l/ha	238	17	107	27	4	300	37	0.4
Basta-1.5/ha	255	39	144	49	1	438	39	0
Paraquat 6l/ha	185	41	-	31	13	125	41	1.2

Note: * Diuron 3.5 kg./ha mixed with each of the dosage rate of Basta and Paraquat

On average, crops in the fields were at the stage of about 1 month after planting (MAP) in both farmers' field. Reduction of weed densities more than 93% in field No. 2 and more than 99% in the field No. 3 at 2 WAS represent the crop ages of 5 – 7weeks after planting. Thus, the weed control achieved in terms of residual effect is quite satisfactory in keeping weed competition below minimum during critical competition period.

The crop damages observed in the farmers' fields were negligible. The minor crop damages of slight yellowing and partial scorching of leaves after application of treatments having higher dosage of Basta mixed with Diuron, similar to the standard Diuron + Paraquat treatment recovered rapidly within a couple of weeks so that the data was not presented here.

CONCLUSIONS

The results of the three experiments have confirmed that the Diuron + Basta mixtures have provided an appreciably higher weed knock down effect as well as long-lasting residual effect similar to that of the standard herbicide treatment Diuron + Paraquat mixture. Therefore, Basta could be used as a mixing partner with Diuron as an alternative herbicide to Paraquat. However, a higher dosage rate of Basta (2 l. /ha.) has to be mixed with Diuron to get satisfactory weed knock down if weeds are mature at the time of spraying.

The effect of lower dosage rates of Basta mixed with Diuron on controlling grass was not satisfactory. Therefore, a higher dosage rate of Basta (2 l. /ha.) has to be mixed with Diuron if weed flora is dominated with more grasses species. A fairly high broad leaved weed control even after application of lower dosage rates of Basta (0.75 l. / ha.) mixed with Diuron suggests that mixing Basta at lower dosages rates with Diuron are sufficient to control weeds if population is dominated with more broad-leaved weeds. Suppression of *Cyperus rotundus*was was more in the treatments of Diuron mixed with higher dosage rates of Basta.

Phytotoxicity on crop due to this herbicide treatments was negligible if lower dosage rates of Basta were mixed. The crop injuries of slight yellowing and partial scorching of leaves were minor even when Diuron mixed with Basta at higher dosage rates of 1.4 and 1.9l/ha, were applied. Even though, those symptoms were less than the symptom appeared after application of standard Diuron + Paraquat treatment and also completely disappeared within 2 – 3 weeks after application showing rapid recovery. This minor crop injury too could be avoided by directed spraying herbicides in-between the cane rows and minimizing herbicide drifting over the crop canopy by using ploy jet nozzle.

Considering the above facts, the pre-emergent herbicide Diuron 80 WP 3.5kg./ha is recommended to mix with post-emergent herbicide Basta (Glufisinate Ammonium 150g./l) at the rates of 0.75 – 1.5l/ha for early and late post emergence application to control weeds in sugarcane. If weeds are mature and/or composition of species is dominated with more grasses, a higher dosage rate of Basta has to be added. On the other hand, application of a lower dosage rate of Basta is adequate to get a satisfactory weed control if the species composition of weed flora is dominated with more broad leaved weeds and or weeds are immature at the time of herbicide application.

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