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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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Analysis of Consecutive-day Maximum Rainfall at Udawalwe, Sri Lanka

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ABSTRACT

Understanding on magnitude and distribution of rainfall is a basic prerequisite in designing drainage structures for effective management of soil and water resources, but available information on this aspect is limited in sugarcane growing areas of Sri Lanka. Annual one-day and two to five consecutive- day maximum rainfall at Uda Walawe was assessed for return periods 2, 5, 10, 20, 30, 50 and 100 years. The analysis was carried out using popular probability distribution functions, i.e. Gamma, Gumbel Max,Weibull, and Normal distributions. The goodness-of-fit for each probability distribution was evaluated by Chi-square test. Above probability distribution functions were fitted to annual maximum rainfall data at Uda Walawe for annual one-day as well as two to five consecutive-day maximum rainfall, and the probability of receiving rainfall maximum for different return periods were assessed.

The analysis found that a maximum of 95.8mm in 1 day, 122.5mm in 2 days, 142.9mm in 3 days, 151.7mm in 4 days and 163.2mm in 5 days are expected to occur in every two years at Uda Walawe. Similarly, the probable maximum rainfall values for 5 consecutive days for 5-, 10- 20-, 30-, 50-, and 100-year return periods are 163.2, 187.3, 203.2, 218.8, 227.5, 238.2 and 253.0 mm respectively. The analysis further revealed that, considerably heavy rainfall events are occurred during 1st and 2nd inter-monsoon rainy periods at Uda Walwe. Except one-day maximum rainfall for two-and 5-year recurrence interval, all rainfall events can be classified under "very heavy rainfall" of more than 115mm/day. The area has a 100% probability to occur "heavy rainfall" event that is beyond 75mm/day in any return period from 2,5,10,20,50 and 100 years.

Keywords: Consecutive-day rainfall, Drainage, Probability distribution, Return period, Sugarcane

INTRODUCTION

A thorough understanding of magnitude and distribution of rainfall is vital for the management of soil and water resources, particularly for designing drainages requirements. Drainage requirements basically depends upon amount of excess water in a field which in turn vary with climate, land use, extent of the area, intensity and frequency of rainfall (Patel, 2005). Weak drainage system often creates ill-drained conditions. Improper surface drainage system cause for excessive soil erosion, particularly during intense rainy seasons in undulating terrain in addition to yield reduction.

Since rainfall is a natural phenomenon, its intensity and amount received cannot be controlled, rainfall-runoff water should be removed exclusively by a proper drainage system. The amount and rate of rainfall-runoff depends on intensity of rainfall, soil infiltration and initial soil moisture content. Drainage designers commonly use two methods to determine amount of runoff. They are; (1) selecting a "drainage discharge" using directly-measured discharge data or (2) selecting a "design rainfall" from a long-term time-series rainfall data and transforming corresponding runoff discharge data via a rainfall runoff transformation (Oosterbaan, 1994). Due to non-availability of directly-

-measured and accurate rainfall-runoff data, second method is usually used in most cases. Estimation of the drainage parameters in an agricultural land requires the knowledge of the probable maximum rainfall that can be occurred throughout the cropping period and probabilities of rainfall maximums (Bhattacharya, 1982). Frequency analysis for 1-5 consecutive-days annual maximum rainfall is usually used to estimate probable maximum rainfall (Kapil, 2014; Barkotulla,2009;. Shivastava et al, 2008; Patle, 2005; Bhakar, 2006; Umarfarooque, 2011). One-day and two to five-day maximum rainfall data corresponds to various return periods are then taken for rainfall runoff estimations (Shivastava, 2008). Drainage structures sufficient to meet the hydrologic requirements of the area is then designed by performing a frequency analysis for previously-decided extreme rainfall levels over different return periods (Oosterbaan, 1994). But a large volume of data is needed to do this analysis by direct method. On the other hand, rainfall is a natural phenomenon and extreme events are not very often. In order to overcome these limitations, scientist are using various probability distribution functions for frequency analysis. A number of probability distribution functions, i.e., Weibuill's, Gammbel's, Gamma, Log Normal and Normal distributions have been well recognized for maximum rainfall probability analysis (Barkotulla, 2009). Further, this frequency analysis method can be used to determine the future expectations of such extreme rainfall events (Kapil, 2014) and are used for designing drainage requirements for various purposes.

The objective of this analysis is to determine annual one-day and two to five consecutive-day maximum rainfall levels and the probabilities of occurring them corresponding to various return periods; 2, 5, 10, 20, 30, 50 and 100 years to be used in designing drainage requirements for sugarcane lands in Uda Walawe area.

METHODOLOGY

Basis of the analysis

Daily rainfall data collected at Uda Walawe agro met station from 1992 to 2014 was used for the analysis. This daily rainfall data was summarized into 1-day and 2 to 5 consecutive-day maximum rainfall levels for each year. Appropriate probability functions were identified as described below by performing goodness-of-fit test. This annual 1-day maximum rainfall and 2 to 5 consecutive-day maximum rainfall data were used for probability analysis. The probable maximum rainfalls were estimated for 2-, 5-, 10-, 20-, 50- and 100-year return periods.

Selecting probability function

A probability function, which is more relevant to the existing data set has to be defined before performing statistical analysis using various probability distribution functions. Kapil (2014) used Gama (3p), Normal and Log normal (3p) distributions to analyze 1- and 2-5-day maximum rainfall in Gujarat, India. Bharkar (2006) and Barkotulla (2009) in Bangladesh have used the same methods to estimate probability of extreme rainfall events. Shivastava *et al.* (2008), used Weibull, Gumbel and Log normal distributions to design drainage parameters in sugarcane fields in India. However, such information is not available to select an appropriate distribution function for rainfall data at Uda Walawe.

Goodness-of-fit test

The goodness-of-fit test is usually used to select the most suitable probability distribution function in estimating extreme rainfall events (Kapil (2014) which ensures a realistic estimation of maximum rainfall data to have a reasonable accuracy. Therefore, Gamma, Gambel, Weibull, and Normal distributions were evaluated by conducting a goodness-of-fit test at critical level of 0.05 () to determine most suitable probability distribution function for annual maximum and two to 5 consecutive-day maximum rainfall analysis. The details of each of the above models are given below:

1. Gamma distribution:

$$f(x) = \frac{(x-y)^{\alpha-1}}{\beta^{\alpha}\tau\,(\alpha)} \exp(-(x-\gamma)/\beta$$

where, α - continuous shape parameter, β - continuous scale parameter, γ - continuous location parameter and τ– Gamma function

2. Gambel distribution (extreme value type 1 distribution):

$$f(x) = \frac{1}{\propto} \exp\ (\text{-z-exp(-z)})$$

where z=(x-μ)/σ, μ is the location parameter, and σ is the distribution scale (σ>0)

3. Weibull distribution (extreme value type 3 distribution):

$$f(x) = \frac{\propto}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\propto-1} \exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$$

where, α - shape, β – scale parameters and location (shift) parameter γ

4. Normal distribution:

$$f\,(x) = \frac{\exp\left(-1/2\left(\frac{x-y}{\propto}\right)^{2}\right)}{\propto\sqrt{2\pi}}$$

where, is continuous scale parameter and y is continuous location parameter

The observed and the estimated values are compared by Chi-square test (Patle, 2005; Srivasthava, 2008). Probability distribution function that has the lowest Chi-square value was selected as best-fitted distribution.

Estimating probable maximum rainfall

The analytical needs for hydraulic engineering designing is usually fulfilled by analysing the rainfall data up to hundred years return period (Umarfarooque, 2011). Therefore, this analysis estimated the probable maximum rainfall for 2-, 5-, 10-,20-, 50- and 100-year return periods based on 1- and 2-5 consecutive-day annual maximum rainfall in Uda Walawe.

Probability of occurrence of a maximum rainfall event

The probability of any incident for a considered recurrence interval is given by,

p = 1/T ……………equation 01

where, p- probability, T- recurrence interval (Oosterbaan, 1994)

Probability within a period of N years is given by,

$p_N = 1 - (1\text{-}p)^N$……… equation 02

where, p- probability, p_N -probability for N years

RESULTS AND DISCUSSION

A summary of annual 1-day and 2 to 5 consecutive-day maximum rainfalls for the period of 22 years from 1992 to 2014 is given in Table 1.

The summarized maximum values of annual 1-day and 2 to 5 consecutive-day total rainfall presented in Table 1 were fitted to 4 different probability functions, i.e., Gamma, Gambel, Weibul, and Normal distributions. The calculated Chi-Square values for testing goodness-of-fit and the corresponding ranking order for each probability function used are given in Table 2. The bolded values indicate best-fitted probability factions that have the lowest Chi-Square values in relation to each annual one-day and two to 5 consecutive- day maximum rainfalls.

Table 1: Annual one-day maximum rainfall and 2 to 5 consecutive-day maximum rainfall in Uda Walawe

Year	**Annual 1-day maximum rainfall (mm)**	**Consecutive 2-day maximum rainfall (mm)**	**Consecutive 3-day maximum rainfall (mm)**	**Consecutive 4-day maximum rainfall (mm)**	**Consecutive 5-day maximum rainfall (mm)**
1993	101.8	169.5	169.5	176.4	201.8
1994	78.7	85.7	86.9	103.3	110.3
1995	76.7	125.4	180.3	180.3	180.3
1996	107.0	134.5	146.0	150.8	161.7
1997	130.0	165.0	165.0	210.2	236.2
1998	81.6	107.9	116.2	123.8	145.4
1999	71.0	85.0	111.8	140.8	147.8
2000	65.5	110.2	139.2	147.8	154.6
2001	98.5	98.5	99.9	131.6	164.9
2002	81.0	87.6	109.1	128.5	146.5
2003	131.0	133.3	154.3	154.3	180.3
2004	151.5	154.0	163.2	169.8	176.8
2005	107.0	107.7	161.6	162.8	164.5
2006	71.5	96.7	117.7	122.2	155.0
2007	91.0	117.5	133.8	135.5	177.0
2008	120.2	130.2	151.4	161.4	173.3
2009	75.7	90.2	119.8	119.8	144.8
2010	120.0	153.1	153.3	158.1	159.7
2011	110.4	149.5	154.0	157.6	166.2
2012	143.7	179.3	209.3	214.7	223.0
2013	83.6	142.3	171.9	171.9	173.3
2014	100.0	103.6	129.9	143.7	146.1
Average	99.9 ®1.1	123.9®1.3	142.9®1.3	153.0®1.2	167.7®1.2

The results of Chi-squire values (Table 2) revealed that, Gumbel Max,Weibull, Normal, Weibull and Gumbel Max were best-fitted models for probability analysis of annual maximum rainfall for one, two, three, four and five consecutive days respectively. These probability functions could be considered as the most suitable probability functions for rainfall analysis for Uda Walawe area.

Table 2: The Chi-square values calculated by goodness-of-fit test for annual one-day maximum and 2-5 consecutive-day maximum annual rainfall data for different probability distribution functions

Probability	**Chi-Square**	**Rank**
1- day max		
Gamma	2.3221	3
Gumbel Max	**0.94342**	**1**
Normal	2.4676	4
Weibull	1.0612	2
2 consecutive-day max		
Gamma	0.64778	2
Gumbel Max	1.7582	4
Normal	0.65993	3
Weibull	**0.54983**	**1**
3 consecutive-day max		
Gamma	2.3423	3
Gumbel Max	2.6547	4
Normal	**1.2175**	**1**
Weibull	2.2573	2

Probability	**Chi-Square**	Rank
4 consecutive-day max		
Gamma	0.14015	2
Gumbel Max	1.561	4
Normal	0.26694	3
Weibull	**0.09916**	**1**
5 consecutive-day max		
Gamma	0.18913	2
Gumbel Max	**0.15716**	**1**
Normal	1.0156	4
Weibull	0.9926	3

Table 3 shows a considerable variation of monthly probabilities of annual maximum rainfall received at Uda Walawe. The second inter-monsoon from September to October period has the highest probability of 54.5% to occur one-day maximum rainfall. However, the highest probability of occurrence of two to five consecutive-day maximum rainfall is 54.8%, in the 1st inter monsoon period from March to April.

As estimated by the best-fitted probability distribution function, the maximum rainfall of 95.8mm in 1 day, 122.5mm in 2 consecutive days, 142.9mm in 3 consecutive days, 151.7 mm in 4 consecutive days and 163.2 mm in 5 consecutive days are expected to be occurred in Uda Walawe in every two -year intervals (Table 4). Similarly, probable maximum rainfall values for 5 consecutive days for 5-, 10-, 20-, 30-, 50-, and 100-year return periods are 163.2, 187.3, 203.2, 218.8, 227.5, 238.2 and 253.0 mm respectively. These values could be used in designing of drainage system in Uda Walawe sugarcane-growing areas. Normally, rainfall beyond 50 mm/day is considered as a heavy precipitation. Liesl (2009) classified daily rainfall levels for 3 classes as significant rainfall (RF>50mm), heavy rainfall (RF>75mm), and very heavy (RF> 115mm). Accordingly, except for one-day maximum rainfall values estimated for 2- and 5-year recurrence intervals, all rainfall events could be classified as "very heavy rainfall" events. All combinations (Table 4) have exceeded the level of "heavy rainfall" events. Though,

Table 3: Monthly probabilities of annual maximum rainfall occurs at Uda Walawe using the above selected best-fit models

	Annual 1 day	**2 consecutive days**	**3 consecutive days**	**4 consecutive days**	**5 consecutive days**
March	0.0	13.6	9.1	9.1	9.1
April	0.0	4.5	4.5	13.6	13.6
May	0.0	13.6	13.6	9.1	18.2
June	0.0	0.0	9.1	13.6	0.0
July	0.0	4.5	4.5	4.5	0.0
August	18.2	13.6	0.0	4.5	9.1
September	36.4	9.1	4.5	4.5	0.0
October	18.2	4.5	13.6	13.6	13.6
November	4.5	9.1	4.5	4.5	0.0
December	4.5	13.6	9.1	9.1	13.6
January	0.0	9.1	18.2	9.1	22.7
February	18.2	4.5	9.1	4.5	0.0

Table 4: Variations of probable maximum rainfall for 2-, 3-, 10-, 20-, 30-, 50- and 100-year return periods for one and 2-5 consecutive days

	Return period (recurrence interval) in years						
	2	**5**	**10**	**20**	**30**	**50**	**100**
1- day max	95.8	117.7	132.2	146.1	154.4	164.2	177.7
2-day max	122.5	146.4	157.9	166.9	171.5	176.5	182.7
3-day max	142.9	167.7	180.7	191.5	197.2	203.5	211.6
4-day max	151.7	172.7	182.5	190.0	193.9	198.0	203.0
5-day max	163.2	187.3	203.2	218.8	227.5	238.2	253.0

Uda Walawe area is under the low country dry zone and is considered as low rainfall receiving area in Sri Lanka, the above analysis has clearly shown that this annual maximum rainfall levels is a significant factor that has to be considered in designing drainages. It's importance further increases, as undulating terrain is prominent in the area and hence soil erosion (Joshua, 1977) will be high due to slope of the topography. Samran, S. and Wichai, S (2000) proposed to use 125mm maximum rainfall is sufficient for drainage designing in tropical areas. Except one day maximum for 2 and 5 year return period and, 2 consecutive day maximum for 2 year return period, all other rainfall maximum values at Uda Walawe are extremely beyond to this limit. This gives evidence that due considerations has to be paid in drainage designing under the conditions at Uda Walawe, to the fact that the heavy intensity rainfall has lower effectiveness to infiltration but high to surface runoff and ultimately results in heavy soil erosion in undulating terrain.

CONCLUSION

The study revealed that, Gumbel Max, Weibull, Normal, Weibull and Gumbel Max were best-fitted models for probability analysis of annual maximum rainfall in Uda Walawe for one-day maximum, two consecutive-day maximum, three consecutive-day maximum, four consecutive-day maximum and five consecutive-day maximum respectively.

Except one-day maximum rainfall for 2- and 5-year recurrence intervals, all the events can be classified as very heavy rainfall events. The consideration of this fact is essential in drainage designing in Uda Walawe area. As field conditions are changed by 5-10 years periodically due to re planting of sugarcane, drainage structure within the cultivating area (farmer field) should be designed considering at least the maximum rainfall of 10-year return periods. Major drainage structures like, culverts, diversions, bridges, flood controlling structures etc that are established outside to farmer fields would be designed according to the 30-, 50- or 100-year recurrence intervals which is basically depends upon the financial availability and lifetime expectation of the entire project.

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The Effects Of High-grade Eppawala Rock Phosphate As A Phosphorous Substitute On Yield And Quality Of Sugarcane In Sri Lanka

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ABSTRACT

This study evaluates the possibility of incorporating High-Grade Eppawala Rock Phosphate (HERP) as an alternative to Triple Super Phosphate (TSP), a Phosphorous (P) fertiliser for sugarcane cultivation in Sri Lanka. A field trial was carried out with 6 treatments comprising of different levels of TSP and HERP in a Randomised Complete Block Design (RCBD) with 3 replicates at Kowul-Ara, Sevanagala from October 2007 to August 2011 using the sugarcane variety Co 775. Soil, leaf and cane yield and quality parameters, such as brix, Pol and fibre percent of cane were measured. The analysis of variance was performed on cane yield and sugar yield to study the effects of TSP:HERP treatment combinations on cane and sugar yields. The initial soil P was deficient, but was not reflected in the leaf P content or in cane and sugar yields. Further, the cane yields and sugar yields at the different levels of TSP and HERP were not significantly different. The residual P level has declined over the years, and therefore, further investigations on the critical level of P and the fate of P in HERP are required to confirm the possibility in substituting TSP with HERP.

Keywords: Co 775, High-grade Eppawala Rock Phosphate, Phosphorous, Sri Lanka, Sugarcane, Triple Super Phosphate

INTRODUCTION

Phosphorous (P) is an essential element in sugarcane crop development, particularly for the formation of a vigorous and a healthy root system in both plant and ratoon crops. It has been estimated that sugarcane crop of 100 t ha^{-1} removes 50-53 kg of P from soil (Dharmawardhena, 1999). To replenish the soil, the inorganic P fertiliser recommended for sugarcane-growing areas in Sri Lanka is Triple Super Phosphate (TSP). This costs a considerable amount of valuable foreign exchange. With the discovery of apatite deposit at Eppawala in Sri Lanka in 1971, investigations have been carried out to study its suitability for coconut plantations (Loganathan and Fernando, 1977).

The availability of Phosphorous to plants depends mainly on the solubility of the fertiliser and fixation of the released P in the soils. Super Phosphate is a soluble fertiliser and its P availability depends only on the fixation (Loganathan and Fernando, 1977). The P in rock phosphate is found in insoluble form and is available to plants very slowly (Horgarth and Allsopp, 2000). Eppawala Rock Phosphate (ERP), the phosphate fertiliser produced at Eppawala, Sri Lanka, has an average total P_2O_5 content of 28 % and citrate soluble P_2O_5 content of 4 %. Over the years, the product has been improved to High-grade Eppawala Rock Phosphate (HERP) by selective mining. The HERP contains 40 % total P_2O_5 and a citrate soluble P_2O_5 content of 6-7 % (FAO, 2011). On the other hand, TSP with a P_2O_5 content ranging from 44% to 52% has water soluble P content greater than 85 % (Johnston and Richards, 2003). If the P requirement of sugarcane crop could be provided by HERP, the cost of P fertiliser could be reduced considerably. This study was designed to investigate the possibility of using HERP as a source of P for sugarcane to minimise cost of sugarcane production in Sri Lanka.

MATERIALS AND METHODS

A field experiment was conducted with six treatment combinations (Table 1) in a randomised complete block design (RCBD) with 3 replicates. Except for the treatment without P, all treatments contain the recommended level of P provided by different combinations of TSP and HERP as shown in Table 1. Each plot was 10 m long with 5 rows prepared 1.2 m apart. The trial with the test crop Co 775 was established at Kowul-Ara, Sevanagala area (6° 36' N, 80° 87' E) in October 2007 and continued up to August 2011.

Soil and climate

The soil of the selected field site is classified as Reddish Brown Earths (Order - Alfisols, Sub order - Ustalfs, Great group - Rhodustalfs) and its texture ranges from sandy loam to sandy clay loam. The area receives an annual rainfall of about 1450 mm (900 mm at 75 % expectancy) with a distinct bimodal distribution. The average annual minimum and maximum temperatures are 22 ± 1.4 °C and 33 ± 1.4 °C respectively (Panabokke, 1996).

Field operations

The land was ploughed as per recommendations for commercial sugarcane planting. The crop was planted according to the conventional method under irrigated conditions (SRI, 1991). The plots were fertilised according to the recommendations of N, P and K for Sevanagala, by varying only the source of P as indicated in Table 1. The crop was maintained up to third ratoon crop.

Measurements and analyses

The plant crop and ratoon crops were harvested after 11-12 months each year. During harvesting, six cane stalks were sampled from each plot to determine cane juice quality, i.e., % brix and pol and fibre. The parameter, pure obtainable cane sugar (POCS) was calculated based on brix, pol and fibre contents. Sugar yield was estimated by multiplying POCS with cane yield. The soil available P and leaf P was measured by Olsen method and the wet digestion method respectively. The analysis of variance was carried out to determine the effects of the P source on cane and sugar yields using ANOVA procedure of SAS software system (Version 9.1.3). The costs and returns of the above-mentioned fertiliser levels were estimated at current prices of fertiliser (unsubsidised) and the farm-gate prices of sugarcane. The net income of each combination of TSP and HERP was estimated to determine the most profitable levels of the two P sources.

RESULTS AND DISCUSSION

The pH and the available P content of the initial soil was 6.63 and 1.75 µg/g respectively. According to Horgarth and Allsopp (2000), the most suitable pH range for availability of P in soil is between 5.5 and 7 and less than 10 µg/g of soil available P is considered deficient for sugarcane. Thus the soil pH is favourable for P availability, but the soil is deficient in P for the growth of

Table 1. Treatment levels with TSP:HERP percentages and rates (kg ha^{-1}).

Treatment	TSP (%)	HERP (%)	TSP (kg ha^{-1})	HERP (kg ha^{-1})
1	0	0	0	0
2	100	0	130	0
3	75	25	98	40
4	50	50	65	79
5	25	75	33	118
6	0	100	0	158

sugarcane. However, the plant did not show any P deficiency as the third leaf P of all the treatments (Table 2) showed a value greater than 0.19 % which is the critical level for sugarcane according to Horgarth and Allsopp (2000).

Table 2 Third leaf P content of each treatment of the plant crop

Trt. No.	TSP:HERP (%)	Third leaf P (%)
1	0 : 0	0.23 c
2	100 : 0	0.33 a
3	75 : 25	0.30 ab
4	50 : 50	0.30 ab
5	25 : 75	0.28 b
6	0 : 100	0.29 ab

Note: Means with the same letters are not significantly different at 5% probability.

Effects of TSP:HERP ratios on yield and quality of sugarcane

The mean results for plant crop and three ratoon crops indicated that neither the level nor the source of P (TSP:HERP) significantly affect the cane yield and quality of the sugarcane variety Co 775 (Table 3). This indicates that the same level of added P at different ratios of TSP and HERP produced a similar cane yield having the similar quality as that for without adding any P at all. Though the variation of mean cane yields and sugar yields of Co 775 from plant to ratoon crop 3 were not significant, the highest mean cane and sugar yield in plant crop and three ratoon crops were observed in the treatment applied with 98 kg ha^{-1} of TSP and 40 kg ha^{-1} of HERP provided with 75 % and 25 % of the requirement respectively.

Since the cane and sugar yields of the treatments were not significantly different (Table 3), the residual available P of treatment 2 (100 % TSP) was compared with that of treatment 6 which is 100 % HERP (Table 4).

According to Table 4, it shows that the residual available P content was significantly lower in treatment 6 (100 % HERP) than that in treatment 2 (100 % TSP). Further, the initial available P has declined from 1.75 µg/g to 0.608 µg/g over 4 years with the addition of 100 % HERP. Thus, in the plots applied with HERP, the soil residual P content has declined over the years. This could be due to the slow release of the P contained in HERP. This could lead to depletion of P in sugarcane-growing soils in the long run.

Table 4. Residual available P of treatments 2 and 6 after harvest of the 3rd ratoon.

Trt. No.	TSP:HERP (%)	Residual available P (µg/g)
2	100 : 0	3.869 a
6	0 : 100	0.608 b

Note: a and b denote significant difference of the two means at 5% probability.

Table 3. Variation of cane and sugar yields at different combinations of TSP and HERP from plant crop to ratoon crop 3.

Trt. No.	TSP:HERP (%)	CY ($t\ ha^{-1}$)					SY ($t\ ha^{-1}$)				
		P	R1	R2	R3	Mean	P	R1	R2	R3	Mean
1	0 : 0	102	84	71	63	80	13	15	10	8	11.8
2	100 : 0	102	104	68	63	81	13	17	9	8	11.1
3	75 : 25	115	101	99	69	96	15	17	14	9	13.7
4	50 : 50	107	73	85	63	83	13	12	12	7	11.4
5	25 : 75	101	77	78	62	80	13	13	11	8	11.5
6	0 : 100	101	86	82	71	85	10	14	12	9	11.5

According to Table 4, it shows that the residual available P content was significantly lower in treatment 6 (100 % HERP) than that in treatment 2 (100 % TSP). Further, the initial available P has declined from 1.75 µg/g to 0.608 µg/g over 4 years with the addition of 100 % HERP. Thus, in the plots applied with HERP, the soil residual P content has declined over the years. This could be due to the slow release of the P contained in HERP. This could lead to depletion of P in sugarcane-growing soils in the long run.

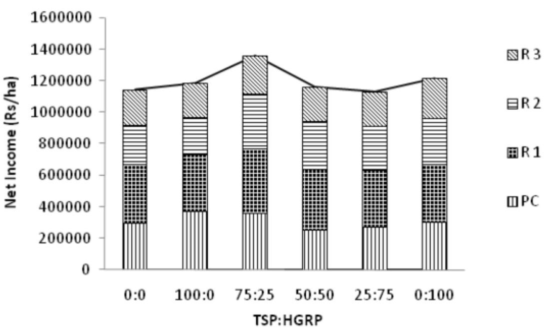

Figure 1. Variation of net income based on cane yield at different TSP:HERP levels

The economics of TSP:HERP ratios

The economic analysis based on cane yield (currently payments are made on cane yield) showed that all treatments have similar cumulative net incomes received (Figure 1).

CONCLUSION

Though the soil is deficient in P, it is not reflected either in the leaf P content or in cane and sugar yields. Application of P in either form of fertiliser also does not have any effect on the yield and quality of sugarcane. Since the residual P level in the HERP applied plots has declined over the years, further investigations on the critical level of P and the fate of P in HERP after application to sugarcane fields are required to confirm the possibility in substituting TSP with HERP.

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Krismat 75 WG, A Novel Herbicide for Early and Late Post-Emergence Weed Control in Sugarcane

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ABSTRACT

A series of field experiments was conducted at the Sugarcane Research Institute (SRI), Uda Walawe, Sri Lanka from 2013 to 2014 to evaluate the effects of herbicide Krismat 75 WG on weeds control in sugarcane. Initially, the Krismat, at the rates 0.5, 1.0 and 1.5 kg/ha was tested after early-post emergent (15 days after planting – DAP) and the late-post emergent (28 DAP) applications. Subsequent studies were conducted to test Krismat at higher rates (2.0, 4.0 and 6.0 kg/ha) at late post-emergent stages. The effects of the herbicide on weed knock down, residual activity and crop phytotoxicity was evaluated by rating visually and counting live weeds. The data were analysed by ANOVA procedure.

The knock down of grasses and broad-leaved weeds was over 90% after early-post emergent application of Krismat at rates 0.5, 1.0 and 1.5 kg/ha. Satisfactory residual weed control was observed only at the rate 1.5 kg./ha., until six weeks after spraying (WAS). In the late-post emergent application, knock down of broad-leaved weeds was over 82% at the rates 0.5 and 1.0 kg/ha and was 100 % at the rate 1.5 kg/ha. The knock down of grass was less, 38% and 45% at 0.5 and 1.0 kg/ha respectively. The residual effect of the rates 0.5, 1.0 and 1.5 kg/ha did not exceed satisfactory level beyond 4 WAS. In contrast, application of Krismat at higher rates (2, 4 to 6 kg/ha) at late post-emergence stage gave weed knock down over 85 - 90% and residual control until 4 – 6 WAS. The phytotoxicity of Krismat on sugarcane was minor and negligible.

Thus, the herbicide Krismat can be safely and effectively applied to control annual grasses and broad-leaved weeds in sugarcane. The rates of application should be 2-4 kg/ha of the commercial formulation and the period of application could be within two to four weeks after planting.

Keywords: Krismat 75 WG, post-emergence, residual effect, sugarcane, weed knock down

INTRODUCTION

Yield losses due to weed growth in sugarcane plantations vary from 6% to 75% and sometimes up to 100% depending on types of weeds, degree and duration of competition (Witharama, 2000). As the early growth of sugarcane occurs at a fairly slow pace, it takes about 3-4 months to develop a good canopy cover under irrigation, and this period could further extend up to 4-5 months under rain-fed. Thus, to raise a successful crop, weeds in sugarcane plantations have to be kept controlled until the crop develops a full canopy cover. Usually, this critical period of weed/crop competition extends from 21 to 90 days after planting (DAP) and control measures have to be adopted before weed competition begins at 21 DAP (Witharama, 2001). Several control options such as manual, mechanical, cultural and chemical methods are available to control weeds in sugarcane. However, adoption of integrated weed management is the best solution in which the use of herbicide has been inevitable.

A number of herbicides have been recommended as pre- and post-emergent application for effective control of weeds (Witharama, 2000). Application of post-planting residual herbicides along with mechanical control options has been an effective strategy of obtaining lasting weed control during the critical period of crop weed competition. Among the effective post-planting herbicides with residual action, mixture of Diuron and Paraquat was proved to be superior to other herbicides in terms of the knock-down effect and residual activity and had been widely used to control weeds in sugarcane. However, since the importation of Paraquat is no longer allowed, finding alternative herbicides for more economical control of weeds in sugarcane has become necessary. The Sugarcane Research Institute (SRI) started field studies to screen several new herbicides and Krismat 75 WG was found to be promising. This paper presents the results of the experiments conducted with Krismat 75 WG to find out its effect on weed knock-down, residual activity and phytotoxicity on sugarcane to recommend the optimum time and rates of application for effective control of weeds in sugarcane.

MATERIALS AND METHODS

Experimental procedure

Krismat 75 WG, a mixture of Ametryn (731.5 g/kg) and Ttrifloxysulfuron (18.5 g/kg), a selective post-emergence herbicide developed by Syngenta for control of grasses, broad-leaved weeds and Cyperus species was selected to test its effect on controlling weeds in sugarcane. Initially, two field experiments; one for early-post emergence application (Experiment I) and the other for late-post emergence application (Experiment II) were conducted at the research farm of the Sugarcane Research Institute (SRI), Uda Walawe. The two experiments were laid as randomised complete block design with four replicates adopting a plot size of 9m long 6 cane rows and three different dosage rates of Kristmat as 0.5kg, 1 kg and 1.5 kg/ha were tested. In the Experiment I, herbicide treatments were applied few days after sporadic emergence of sugarcane, and the weeds were at 2-4 leaf stage (15 days after planting – DAP). The same treatments were evaluated in the Experiment II, but sprayed at 28 DAP when weeds were grown up and matured. In the both experiments I and II, a tank mixture of Diuron and Paraquat was applied as the standard treatment and an untreated control was also included for comparison. Since, phytotoxicity appeared on crop due to the Kristmat at the rates tested above was negligible, subsequent experiments were conducted to test higher dosage rates of Kristmat (2, 4 and 6 kg /ha) after spraying each treatment in an extent of about 0.1 hectare at late-post emergence stage (Experiment III). The treatment details of the three experiments are given in the Table 1.

Description of the experimental sites

The soil in the experimental area is predominantly well–drained Reddish Brown

Table 1. Details of herbicide treatments evaluated after early and late post emergence application and in the pilot project (Field studies I, II & III)

Treatments	Rate of application- kg or l/ha	
	Experiments I & II	Experiment III
Krismat 75 WG	0.5 kg	2 kg
Krismat 75 WG	1.0 kg	4 kg
Krismat 75 WG	1.5 kg	6 kg
Praquat 65 SL + Diuron 80% WP	6l + 3.5 kg	6l + 3.5 kg
Control	No weeding	No weeding

Experiment I: Early post emergence application at 15 DAP

Experiment II: Late post emergence application at 28 DAP

Experiment III: Pilot project spraying at late post emergence stage with higher rates

Earths (RBE) (Alfisol to Ustalf). 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 28^0 C to 32^0C.

Weed spectrum

A considerably heavy weed growth was observed in the experimental locations and weed pressure was very high from several weeds that were common to the sugarcane plantations. The commonly-observed weeds are shown in Table 2.

Establishment and maintenance of the experiments

The all field trials were established at the research farm of the Sugarcane Research Institute (SRI) at Uda Walawe. 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 centre spaced at 1.4m to create furrows of 17 to 22 cm deep. The sugarcane variety (Co 775) stem cuttings with three internodes (setts) were planted in the furrows. The planting was coincided with the commercial planting periods for sugarcane in the area; the experiments I & II on April 10, 2013 and the experiment III 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 the operator on the ridges. The swath-width (45cm above the ground) was 1.5m; the spraying pressure was approximately 2 – 3

Assessments

Assessment criterion

The effects of the herbicides 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. The ratings were summarised according to the Table 3.

Table 2. Common weeds grown in association with sugarcane in the experimental area

Grasses	Broadleaves	Sedges
Panicum maximum	*Ageratum conizoides*	*Cyperus rotundus*
Elusine indica	*Amaranthus viridis*	*Cyperus iria*
Isachne globosa	*Ipomea triloba*	*Fimbrystylis miliaceae*
Dactyloctenium aegptium	*Acanthospermum hispidum*	
Echinocloa colona	*Euphobia heterophyla*	
	Euphobia hirta	
	Cleome rutidosperma	
	Waltheria indica	
	Boraria laevis	

Table 3.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

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

Assessment of weed control

Visual observations were made and species composition of weed flora was recorded before herbicide application in all locations where investigations were carried out (Table 2). The weeds knock down was rated according to the scale given in Table 3, one, two and three weeks after herbicide application in each of the experiment I and II. The residual activity was assessed as the effect of herbicide treatments on weeds in comparison with untreated control at 4, 6, 8 and 12 weeks after spraying (WAS). The density and species composition of weeds which appeared before herbicide application and after regular intervals 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 density. In the case of the experiment III, weeds were counted in ten random places on the ridges in each treatment plot.

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 0 to 100 scale (Table 3). Phytotoxicity assessments are reported only when there were observable toxicities.

Data analysis

The visual ratings given for weed control and crop damage by three assessors were averaged and presented with their standard error values and those values were compared with the levels given in Table 3. Also the rated values were subjected to ANOVA procedure for comparison.

Weed counts of different species in each sampling point were categorised under three major weeds types; i.e. grasses, broad-leaved weeds and sedges. The total numbers of each weed specie belonged to one category i.e. grasses, broad-leaved weeds and sedges in one sampling point were added and converted to number per square metre to estimate density. 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 types; grasses, broad- leaved weeds and sedges were subjected to ANOVA procedure for mean comparison.

RESULTS AND DISCUSSION

Early post-emergence application

At the time of herbicide application, weeds were tiny and tender with 2 – 4 leaves; densities ranged between 175 – 280 plants/m^2. The recently-emerged sugarcane settlings were sporadically scattered in the fields as spikes.

Effect on weed knock down and crop phytotoxicity

Weed knock down as appeared from the ratings given for weed control were above the satisfactory level (60%) in all herbicide treatments except Kristmat 0.5 kg/ha at 3 weeks after spraying (WAS). Degree of weed knock down increased with increasing the rate of application (Table 4). However, the effect of weed knock down was not satisfactory and was not comparable with that of the standard treatment, Diuron and Paraquat mixture.

The phytotoxicity of Krismat on sugarcane, as appeared from the rated crop damage was minor and negligible (the ratings 2 - 4) and lower than rating (16) recorded in standard herbicide Diuron + Paraquat treatment (Table. 4). The only phytotoxicity found at 1WAS was slight yellowing of sugarcane leaves. But the symptoms have entirely disappeared in a week time, showing a rapid recovery.

According to the counted live weeds left behind 3 WAS, there was an over 90% reduction of densities of grasses, broad-leaved weeds and total and the effect is not significantly different between different rates of Krismat applied from 0.5 to 1.5 kg/ha and Diuron + Paraquat treatment (Table 5). However, in the case of sedges dominated by *Cyperus rotundus*, there was no significant reduction ($P \geq 0.05$) of densities either due to Krismat treatments or standard treatment compared with the control. This indicates an appreciably higher effect of tested rates of Krismat on the knock down of grasses and broad-leaved weeds when applied at early post-emergence stage of weeds and poor control of *Cyperus rotundus*.

Residual effect

The residual effect of Krismat at the rates tested in comparison with the control treatment appeared to be fairly poor. The over satisfactory weed control was appeared only until six weeks when Krismat was applied at the rate of 1.5 kg/ha. On the other hand, standard treatment provided an appreciably high level of lasting residual effect for almost 12 weeks after application of the treatment. The level of weed control provided by Diuron/ Paraquat mixture is fairly adequate to keep the weed competition at a minimum during the critical period of crop growth.

Table 4. Visual ratings (%) given for weed control at 1 and 3 WAS and crop damage at 1 WAS herbicide treatments at early post-emergence stage

Treatment	Weed Control 1 WAS		3 WAS		Crop damage 1 WAS	
	Rating	SE	Rating	SE	Rating	SE
Krismat 0.5kg /ha	75^{a}	0.63	47^{a}	2.5	2.5	2.5
Krismat 1.0kg / ha	77^{a}	5.0	64^{b}	4.7	2.5	2.5
Krismat 1.5kg /ha	80^{a}	3.13	77^{b}	6.3	3.8	3.8
Paraquat 6l + Diuron 3.5kg/ha	94^{b}	1.88	100^{c}	0.0	15.6	3.1
Control	0.0	0.0	0.0	0.0	2.5	2.5

Means followed by the same letter in each column are not significantly different ($P \geq 0.05$).

Table 5. Mean live weed densities (Plants / m^2) of grasses, broad-leaved weeds, sedges and their totals before and 3 WAS at early post-emergence stage

Treatment	Grasses		Broad leaves		Sedges		Total	
	Before	3WAS	Before	3WAS	Before	3WAS	Before	3WAS
Krismat 0.5kg /ha	104	3b	146	11b	14	7	263	22b
Krismat 1.0kg /ha	96	9b	174	15b	19	11	289	35b
Krismat 1.5kg / ha	75	0b	188	5b	22	5	285	9b
Paraquat 6l + Diuron 3.5kg/ha	106	0b	204	3b	12	7	321	10b
Control	82	35a	143	80a	12	13	237	128a
CV %	29	163	24	144	61	54	14	119

Means followed by the same letter in each column are not significantly different ($P \geq 0.05$).

It was noted that Krismat exhibited a differential degree of residual control of different weed species. The rates adopted in the present study effectively controlled all broad-leaved weeds for about 6 weeks after application, but failed to give a lasting control of grasses and Cyperus rotundus.

Late post-emergence application

At the time of herbicide application, weeds were grown-up and mature. Sugarcane germination has been completed and the emerged settlings, the majority at 3 – 5 leaves stage, were appeared along the planted furrows with 3 – 5 inches inter settling spacing.

Effect on weed knock down and crop phytotoxicity

Weed knock down 1 WAS, rated visually was above the satisfactory level (60%) only when Kristmat was applied at the rates of 1.0 and 1.5 kg / ha (Table 7). Effect of Krismat at low dosage rates (0.5 kg/ha) failed to knock down mature weeds satisfactorily. However, the effect on weed knock down was not satisfactory and was not comparable with that of the standard treatment, Diuron + Paraquat mixture.

Similar to the early post-emergence application, the phytotoxicity of Krismat on sugarcane was minor and negligible (the ratings 2–5) even on young sugarcane settlings. In contrast, the phytotoxicity on young sugarcane settlings as appeared burning of leaves due to Diuron + Paraquat treatment was significantly ($P \leq 0.05$) higher (rating 20) and also took several weeks to recover inducing mild stress condition over crop and perhaps retardation of growth. This high tolerance of sugarcane settlings to the rates tested in this experiment allows increasing the rate of application of Kristmat to get higher level of weed control (Table. 7).

Table 6. Visual ratings (%) given for weed control at 4, 6, 8 and 12 WAS herbicide treatments at early post-emergence stage

Treatments	Weed control ratings			
	4 WAS	6 WAS	8 WAS	12 WAS
Krismat 0.5kg / ha	50[a]	33[a]	25[a]	2[a]
Krismat 1.0kg / ha	60[b]	50[b]	40[b]	10[b]
Krismat 1.5kg/ha	65[b]	60[b]	53[b]	19[b]
Paraquat 6l + Diuron 3.5kg/ha	97[c]	95[c]	86[c]	86[c]
Control	0	0	0	0

Means followed by the same letter in each column are not significantly different ($P \geq 0.05$).

Table 7. Visual ratings (%) given for weed control and crop damage 1 WAS at late post- emergence stage

Treatment	Weed control		Crop damage	
	Rating	SE	Rating	SE
Krismat 0.5kg / ha	59[b]	6.4	2.5[b]	1.5
Krismat 1.0kg /ha	64[b]	5.2	2.5[b]	1.5
Krismat 1.5kg / ha	68[b]	4.5	5.0[b]	2.3
Paraquat 6l + Diuron 6 l + 3.5kg/ha	95[a]	3.8	20[a]	4.2
Control	0	0.0	na	Na

Means followed by the same letter in each column are not significantly different ($P \geq 0.05$).

The effect on weed knock down of herbicide treatments to reduce density of different weed species were non-significant ($P \geq 0.05$) perhaps due to heterogeneity of occurrence and distribution of weeds species, as evidenced by the corresponding higher CV% values. However, the knock down of total weed densities were 62%, 71% and 92% when Kristmat was applied at the rates of 0.5, 1.0 and 1.5 kg./ha respectively and comparatively higher than the observed 42% in Diuron + Paraquat treatment. Moreover, Kristmat showed differential knock-down effect on different weed species. The knock down of grasses was over 83% when Krismat was applied at the rate of 1.5 kg/ha, according to the mean weed density values before and 3 WAS (Table 8). However, knock down of grasses was less than 50 % if Krismat was applied at lower dosage rates of 1.0 kg/ha and negligible if applied at 0.5 kg/ha. The knock down of broad-leaved weeds by Krismat was more as there is an over 82% reduction both at the rates of 0.5 and 1.0 kg / ha and 100 % if applied at 1.5 kg / ha. The knock down of grasses and broad-leaved weeds were 38% and 45% respectively in Diuron + Paraquat treatment and less than the effect of Kristmat when applied at the rates of 1.5 kg/ha. This indicates that, Krismat 75 WG even at lower dosage rates (0.5 & 1.0 kg/ha) are sufficient to knock down broad-leaved weeds but relatively higher dosage rates are required to knock down grasses. However, there is no an appreciable knock down of *Cyperus rotundus*, due to Krismat treatment in the rates tested here.

Residual effect

The residual effect of Krismat at the rates tested was below the satisfactory level beyond 4 WAS. On the other hand, the standard Diuron + Paraquat treatment provided an appreciably high level of lasting residual effect even beyond 12 WAP and adequate to keep the weed competition at a minimum during the critical period of crop growth.

The above analysis indicates that Kristmat 75 WG could effectively be used to control annual grasses and broad-leaved weeds in sugarcane plantations by application at both early post- emergent and post-emergent stages. Moreover, increasing trend in the degree of weed control, both knock-down effect and residual effect on weeds, with increasing the rate of application from 0.5 to 1.5 kg/ha together with extremely high crop tolerance suggests that further increase of the rate of application may provide more effective level of weed control. This is quite evident from the results of the experiment III in which higher dosage rates of Krismat were tested after late post- emergence application.

Effect on cane yield

After early post-emergence application, cane yield was significantly ($P \leq 0.05$) less in

Table 8. Mean live weed densities (Plants / m^2) of grasses, broad-leaved weeds, sedges and the total weeds before and 3 WAS at late post emergence stage

Treatment	Grasses		Broad-leaved		Sedges		Total	
	Before	3WAS	Before	3WAS	Before	3WAS	Before	3WAS
Krismat 0.5kg / ha	56	46	116	17	1	3	173	65
Krismat 1.0kg / ha	50	28	158	28	6	4	213	61
Krismat 1.5kg / ha	66	11	145	0.63	7	4	218	16
Paraquat 6l + Diuron 2.5kg / ha	67	41	129	71	12	9	208	121
Control	48	36	123	49	8	3	179	88
CV	46		50		104		48	

Means followed by the same letter in each column are not significantly different at 5% probability.

Table 9. Visual ratings (%) given for weed control 4 and 8 WAS when herbicide treatments were applied at late post-emergence stage

Treatments	Weed control	
	4 WAS	8 WAS
Krismat 0.5kg / ha	37^{a}	10^{a}
Krismat 1.0kg / ha	35^{a}	09^{a}
Krismat 1.5kg / ha	54^{b}	14^{a}
Paraquat 6l + Diuron 3.5kg / ha	93^{c}	93^{c}
Control	0	0

Means followed by the same letter in each column are not significantly different P ≥ 0.05.

Krismat 0.5 and 1.0 kg/ha treatments than the Krismat 1.5 kg/ha and Diuron + Paraquat treatments. This may be due to differences of degree of weed-crop competition until clean weeding 16 weeks after planting (WAP). The least yield recorded in control plots is due to higher weed pressure over the crop in terms of degree and duration of competition. Likewise, there is an increasing trend of cane yield from 44 t/ha to 62 t/ha with increasing the rate of Krismat applied from 0.5 kg/ka to 1.5 kg/ha and Diuron + Paraquat treatment, again due to varying degree and duration of weed competition in the respective treatment plots (Table 10).

After late post-emergence application, cane yields in all treatment plots were comparatively low; perhaps due to the effect of weed/crop competitions until adoption of herbicide treatments, 28 DAP. Differences of yields in the plots applied with different herbicide treatments could be attributed to their different levels of weed control. The effect of Kristmat in controlling weeds is superior over the Diuron + Paraquat treatment when it was applied at late post-emergence stage. There is an increase in cane yield by 21% when Krismat was applied at the rates of 0.5 and 1.0 kg/ha rates and by 48 % when Krismat was applied at the rate of 1.5 kg/ha compared with control and Diuron + Paraquat treatment. This could be attributed to the level of weed control in terms of knock-down and residual effects and negligible crop damages reported in Krismat treatments applied at late post-emergence stage compared with that of the control and Diuron + Paraquat treatment (Table 10).

Effect of higher rates of Krismat 75 WG applied at late post-emergence stage

The visual ratings reported 1 WAS indicate appreciable knock-down of weeds over 85% to 90% when Krismat was applied at the rates from 2 to 6 kg /ha (Table 11). It was also noted that poorly controlled weed species after application of low rates of Krismat (0.5 to 1.5 kg/ha) were able to control successfully when higher rates were adopted. Further, comparatively higher rating values recorded at 4 and 8 WAS confirm high level of residual control of annual grasses and annual broad-leaved weeds after application of Krismat at higher rates of 2 – 6 kg / ha.

Table 10. Cane yield in different herbicide treatments and control in early post emergence and late post emergence sprayed experiments

Treatment	Early post-emergence		Late post-emergence	
	Yield (t/ha)	SE	Yield (t/ha)	SE
Krismat 0.5kg / ha	44b	1.39	40b	5.05
Krismat 1.0kg /ha	48b	6.14	43ab	4.03
Krismat 1.5kg / ha	60a	3.64	49a	1.92
Paraquat 6l + Diuron 3.5kg/ha	62a	4.02	35c	2.28
Control	30c	3.77	33c	11.54

Means followed by same letter in each column are not significantly different P=0.05.

Table 11. Visual ratings (%) given for weed control and crop damage after different time periods when Krismat was applied at higher dosage rates at early post emergence stage

Treatment	Weed control rating			Phytotoxicity rating	
	1 WAS	4 WAS	8 WAS	1 WAS	2 WAS
Krismat 2.0 kg / ha	85[a]	80[a]	65[a]	2.5	0
Krismat 4.0kg / ha	90[a]	88[a]	75[a]	4.4	0
Krismat 6.0kg / ha	90[a]	93[a]	80[a]	6.0	0
Control	0	0	0	0	0

Means followed by the same letter in each column are not significantly different $P \geq 0.05$.

The very high level of weed control accompanied with broad spectrum activity and presence of effective knock-down and residual effect on weeds showed by Krismat during the present investigations could be attributed to the different modes of action (inhibition of amino acid biosynthesis and photosynthesis light reaction) of the two chemical constituents, Ametryn and Trifloxysulfuron, in Krismat formulation (Thomson, 1986). Combination of two herbicides with different modes of action would also offer more opportunities for the management of resistance development in weeds that are sensitive to both herbicides independently (Preston, 2000).

The phytotoxicity showed by Krismat on sugarcane was almost negligible. The only phytotoxicity symptom found at 7 days after herbicide application was slight yellowing of the leaves of sugarcane (Table 11). But the symptoms have entirely disappeared in a week time showing a rapid recovery. Change in application time or increasing the rate of application have made no serious observable changes in phytotoxiciy except for slight yellowing of leaves in sugarcane. Thus, there is hardly any chances in reducing sugarcane yields due to toxicities when Krismat is applied at the rates from 0.5 kg/ha to 6kg/ha.

CONCLUSIONS

The herbicide Krismat can be safely and effectively applied to control annual grasses and annual broad-leaved weeds by knock-down and residual action in sugarcane for over two months after planting the crop. The appropriate rate of application would be 2 - 4 kg/ha of the commercial formulation (Krismat 75 WG) and the period of application could be varied between two to four weeks after planting (from early to late post-emergence stages). Broad-leaved species are more vulnerable and could easily be controlled by a low dosage rate whereas a high dosage rate has to be applied to control grasses species. Event though, there is a little suppression, the control of *Cyperus rotundus* is not satisfactory after application of this herbicide.

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Survival of the *Deltocephalus menoni* (Homoptera: Cicadellidae), the Vector of Sugarcane White Leaf Disease in Sri Lanka on Alternative Host Plants

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ABSTRACT

Deltocephalus (Recilia) *menoni* (Hemiptera: Cicadellidae) is the only identified insect vector of sugarcane White Leaf Disease in Sri Lanka. Field and laboratory experiments were conducted from January 2013to December 2014 in sugarcane-growing areas to study the ability of *D. menoni* to survive on other plant species presence in and near the sugarcane plantations to design the vector management programme. Field surveys were conducted in randomly-selected four disease-infected fields, 0.5ha each from each location. All available weeds in randomly-selected nine weedy spots with ten-metre long from each field were recorded and the weeds with frequency > 0.25 were identified up to species level. The available intercrops with the disease-infected sugarcane and other annual crop species adjacent to the disease fields were recorded in all study locations during *Yala* and *Maha*. Museum data and literature were collected. Field and laboratory studies were conducted using identified plant species to study the ability of the vector to survive on those plant species. The number of days of survival of the vector was recorded on each plant species and statistically compared with that on *Saccharum* hybrids. Two (02) wild relatives of the *Saccharum* hybrids, twenty nine (29) weed species, fourteen (14) intercrops and six (06) annual crops were recorded and identified during the field surveys. *Sorghum bicolor* and *Saccharum spontaneum* act as alternative host plants for *D. menoni*. Both plant species were feeding and breeding hosts. Hence, *D. menoni* has monophagy feeding habit; it prefers feeding on plant species belong to the family, Poaceae.

Keywords: Alternative host, *Deltocephalus menoni, Saccharum* hybrids, Sri Lanka, Sugarcane, Vector, White Leaf Disease

INTRODUCTION

Management of alternative host plants can be used to reduce the vector populations and the disease incidences in some cropping systems (Weintraub and Wilson; 2010). *Deltocephalus* (Recilia) *menoni* (Hemiptera: Cicadellidae, Subfamily: Deltocephalinae) is the only confirmed insect vector responsible for spreading the White Leaf Disease (WLD) of sugarcane, which is the most serious Phytoplasma disease of sugarcane in Sri Lanka. The vector should be managed with integrated vector management strategies, as there is a significant relationship between the population levels of the vector and the disease incidence in commercial sugarcane plantations in the country (Seneviratne, 2008; Chanchala *et al.,* 2014). The feeding habits of the members of the subfamily Deltocephalinae ranges from monophagy to polyphagy (Weintraub and Wilson; 2010), and several number of plant families have been identified as feeding and breeding hosts of family Cicadellidae*viz.*,Solanaceae, Leguminaceae,Cucurbitaceae,Commelinaceae, etc. (Lamp *et al.*, 1994; Marques *et al.,* 2012; Eziashi *et al*., 2013). Therefore, those plants facilitate the survival and longevity of the Cicadellids which exist within the cropping areas even without their major hosts.

Several weed species, intercrops and other annual crops are present in and near the sugarcane plantations in Sri Lanka. Therefore, information on the ability of *D. menoni* to survive on those plant species are useful to design a vector management programme to reduce the crop losses due to WLD while protecting the sugarcane-growing environment for sustainable sugarcane production. Therefore, this study was conducted with following two objectives:

i. to identify the weed species(with more than 0.25 frequency), inter crops and other annual crops in and near the WLD-infected sugarcane plantations

ii. to study the ability of *D. menoni* to survive on identified weed species, inter crops and other annual crops

MATERIALS AND METHODS

i. Identification of weed species, inter crops and other annual crops in and near the WLD-infected sugarcane plantations

Field surveys were conducted in five locations,*viz.*, Research Farm, Sugarcane Research Institute (SRI) at Uda Walawe and commercial sugarcane plantations at Sevanagala, Pelwatte, Hingurana (in the dry zone-annual rainfall 1,300 – 1,600 mm) and Passara (intermediate zone- annual rainfall 1,750 – 2,500mm) of Sri Lanka from January 2013to December 2014.

Four WLD-infested sugarcane fields, 0.5 ha each, were selected randomly from each location and data were collected at monthly intervals. Randomly-selected nine (09) weedy spots each with ten metre (10m) length were marked using a rope in each field. All available weeds along the rope were recorded to calculate the frequencies of each species according to Witharama *et al.* (1997). Weed species with frequency above 0.25, were collected and preserved and the preserved specimens were identified up to species level using published literature and reference samples in the weed collection of SRI.

The available intercrops with the sugarcane during *Yala* (Mid-March- Mid September) and *Maha* (Mid-September-Mid March) seasons of the year were recorded in all study locations. The annual crop species which were cultivated near the disease-infected sugarcane fields were also recorded and identified.

ii. Studying the ability of *Deltocephalus menoni* to survive on identified weed species, inter crops and other annual crops

Studies were conducted in four steps,*viz.*,collection of museum data, literature survey, field studies and laboratory tests.

Collection of museum data

The available specimens of leaf hopper species in the museum of the Horticultural Research and Development Institute, Gannoruwa, Sri Lanka were checked to identify whether the *D. menoni* has been recorded on other plant species.

Literature survey

Literature on the host range of the *D. menoni* was collected from the peer-reviewed journals and the previous records available in the Sugarcane Research Institute, Uda Walawe.

Field studies

All insects presence on weeds (frequency > 0.25), intercrops and other annual crops were collected at three-month intervals at Uda Walawe and Sevanagala. Five plots of 25m x 10m size were selected randomly from each plant species in both locations. The all insects presence in those plots was collected using sweep net as 500 sweeps per plot. The insects collected were checked for the presence of *D. menoni*. At the same time, five plants from each species in each location were enclosed separately using a sweep net and each plant was observed for the presence of the *D. menoni* within the enclosure.

Laboratory tests

Adults of *D. menoni* were collected using a sweep net and a pooter from the sugarcane plantations below six months old in the research farm, Uda Walawe. The collected insects were reared in insect-rearing cages in the laboratory of SRI at Uda Walawe according to the protocol developed by Senevirathne (2008).

Studying surviving ability of the vector on test plant species

No choice tests were conducted to study surviving ability of the vector by arranging test plants in Completely Randomised Design (CRD) with three replicates. Young and healthy plants from each selected weed species were uprooted from the natural environment, and they were planted in plastic pots (Diameter: 12cm) with sterilised soil after confirming the absence of living insects, cocoons and eggs of any insect species.

Seeds or vegetative propagative materials of the recorded intercrop and annual crop species were planted in pots in the same way. The potted plants were acclimatised under laboratory conditions (26-27 ^{0}C, 70-72% RH with 12h photoperiod) for a period of one week and were placed in the insect-proof laboratory cages. The potted sugarcane plants of the variety SL 96 328 were used as the control. Five adult vectors (Female: Male - 3:2) were introduced to the each potted plant in insect-proof cages.

Studying feeding of the vector on test plant species

Three plants from each selected plant species were grown in insect-proof cages. Leaf or leaf portion from each plant encircled with Para film sachet and water-starved young female vector was introduced to each sachet. Each vector left in sachet for a 6-hour period for feeding and feeding amount measured using following two tests.

i. Honey dew in sachet collected with the bromocresol green-treated filter papers and strained area (blue) measured using squire millimetre grid printed on transparent paper.

ii. Cut the portion of leaves where insect fed on and dipped the cut leaves in staining solution of 0.1% erythrosine dye for 10-15 min. Then, the leaf portions were examined under a microscope and stained (pink/red) stylet sheaths were counted in each plant species.

Data collection and analysis

Studying surviving ability of the vector on test plant species

The vectors in the cages were observed at twelve-hour intervals for a one month period. The maximum number of days of survival of the vector on each plant species was determined. After two weeks of adult introduction, the cages were regularly monitored to observe the emergence of the nymphs. The maximum number of days of survival of the vector on each plant species and number of nymphs emerged from the each plant and their ability to survive on particular plant species were also recorded. The average number of nymphs survived on each plant species was compared with that on sugarcane plants, by using Dunnett's test at 0.05 probability levels using SAS (for windows 9.0) software.

Studying feeding of the vector on test plant species

The honey dew-stained area in each species and the number of stylet sheaths on test leaf bits were also compared with those on sugarcane plants, by using Dunnett's test at 0.05 probability levels using SAS (for windows 9.0) software.

RESULTS AND DISCUSSION

I. Identification of weed species, inter crops and other annual crops in and near the WLD-infected sugarcane plantations

According to the results, two (02) wild relatives of the *Saccharum* hybrids, twenty nine (29) weed species with frequencies more than 0.25, fourteen (14) intercrops and six (06) annual crops were recorded and identified during the field surveys in the year 2013 in all study locations (Table 1).

I. Ability of *Deltocephalus menoni* to survive on identified weed species, inter crops and other annual crops

According to the museum data and literature survey, there were no any records on alternative host plants for *D. menoni* in Sri Lanka. Also *D. menoni* was not recorded in the collected insects during the field studies on the identified weeds, intercrops and crop species at Uda Walawe and Sevanagala.

The results of laboratory tests indicated that *D. menoni* survived 15 days on *Saccharum* hybrids, 13 days on *Saccharum spontaneum* and *Sorghum bicolor* and 1-4 days on other plant species. The maximum number of survival days of the vector on all other plant species were significantly lower with the *Saccharum* hybrids (Table 1) except *Saccharum spontaneum* and *Sorghum bicolor*.

The amount of honey dew produced by *D. Menoni* after feeding on *Saccharum spontaneum* and *Sorghum bicolor* was significantly higher than that on other test species. The average honey dew production of *D. menoni* on *Saccharum spontaneum* (12.5mm^2) and *Sorghum bicolor*(6.48mm^2)was lower than that on *Saccharum* hybrid (19.41 mm^2), but significantly higher than that on other test species. There was no honey dew recorded on most of the test species. The amounts recorded on some test species were not significant compared to that on sugarcane.

Stylet sheaths were observed on *Saccharum spontaneum* (3), *Sorghum bicolor* (2), *Zea maise*(9), *Hemidesmus indicus*(7)and *Achyranthes aspera*(5).There was less number of stylet sheeths on *Saccharum spontanium* and *Sorghum bicolor* which act alternative hosts to *D. menoni* and higher number of stylet sheaths on *Zeamaise, Hemidesmus indicus and Achyranthes aspera* which are do not act as hosts. Higher number of stylet sheaths on those plants is a result of trying of the vector to feed, but failure to feed on that species. These results indicate that *Saccharum spontaneum* and *Sorghum bicolor* act as alternative feeding hosts of *D. menoni.* In Taiwan, several weed species have been identified as alternative host plants for the insect vector of WLD; *Matsumuratettix hiroglyphicus* (Matsumara) (Yang and Pan, 1979).

During the laboratory experiments, we observed that the vector in the rearing cages with *Cleome viscosa* (Cleomaceae) always evaded the *Cleome* plants and confined to the side walls of the rearing cages in all replicates. Also all the introduced vectors died within the 24 hours. The characteristic odour and the hairy nature of leaves and stem of the *Cleome viscosa* may be the reasons for the above behaviour of the vector on this plant.

Furthermore, we observed a searching behaviour of the vector on *Panicum maximum* (Poaceae) plants for feeding in addition to the resting behaviour on it. Also, they survived for four days on *Panicum*

Table 01: Maximum insect survival days, honey dew excretion, number of salivary sheaths and population build-up of D. *menoni* on test plant species and *Saccharum* hybrids

	Scientific name	Family	maximum number of	honey dew	Number of salivary	Population
1	*Saccharum* hybrids	Poaceae	15	19.22	1	30
Wild relatives of *Saccharum* hybrids						
2	*Saccharum officinarum*	Poaceae	13	13.33***	2.33	21
3	*Erianthus arundinaceous*	Poaceae	3***	1.00***	0.00 ***	0.00 ***
Weed species						
4	*Achyranthes aspera*	Amaranthaceae	2 ***	0.00 ***	4.66	0.00 ***
5	*Amaranthus viridis*	Amaranthaceae	2***	0.33 ***	0.00 ***	0.00 ***
6	*Aerva lanata*	Amaranthaceae	2***	0.66***	0.00 ***	0.00 ***
7	*Hemidesmus indicus*	Apocynaceae	2***	0.25***	0.00 ***	0.00***
8	*Asparagus racemosus*	Asparagaceae	1***	0.00 ***	0.00 ***	0.00 ***
9	*Tridax procumbens*	Asteraceae	2***	0.00 ***	0.00 ***	0.00 ***
10	*Cyanthillium cinereum*	Asteraceae	2***	0.00 ***	0.00***	0.00 ***
11	*Micania scandeus*	Asteraceae	2***	0.00 ***	0.00 ***	0.00 ***
12	*Calyptocarpus vialis*	Asteraceae	2***	0.41***	0.00 ***	0.00 ***
13	*Emilia sanchipolia*	Asteraceae	1***	0.00 ***	0.00 ***	0.00 ***
14	*Cleome viscosa*	Cleomaceae	1***	0.00 ***	0.00 ***	0.00 ***
15	*Commelina benghalensis**	Commelinaceae	1***	0.00 ***	0.00 ***	0.00 ***
16	*Cyperus rotundus*	Cyperaceae	1***	0.00 ***	0.00 ***	0.00 ***
17	*Euphorbia heterophylla**	Euphorbiaceae	1***	0.00 ***	0.00 ***	0.00 ***
18	*Euphorbia hirta*	Euphorbiaceae	1***	0.00 ***	0.00 ***	0.00 ***
19	*Acalypha indica*	Euphorbiaceae	1***	0.00 ***	0.00 ***	0.00 ***
20	*Alysicarpus vaginalis*	Fabaceae	1***	0.00 ***	0.00 ***	0.00 ***
21	*Phaseolus lathyroides**	Fabaceae	3***	0.16 ***	0.00 ***	0.00 ***
22	*Mimosa pudika*	Fabaceae	2***	0.91***	0.00 ***	0.00 ***
23	*Desmodium triflorum*	Fabaceae	3***	0.00 ***	0.00 ***	0.00 ***
24	*Ocimum sanctum*	Lamiaceae	3***	0.00 ***	0.00 ***	0.00 ***
25	*Leucas zeylanicus*	Lamioideae	3***	0.00 ***	0.00 ***	0.00 ***
26	*Sida acuta*	Malvaceae	3***	0.00 ***	0.00 ***	0.00 ***
27	*Urena lobata*	Malvaceae	2***	0.00 ***	0.00 ***	0.00 ***
28	*Abutilon Indicum*	Malvaceae	3***	0.00 ***	0.00 ***	0.00 ***
29	*Boerhavia coccinea*	Nyctaginaceae	2***	0.00***	0.00 ***	0.00 ***
30	*Phylanthus viridis*	Phyllanthaceae	1***	0.00 ***	0.00 ***	0.00 ***
31	*Scorpia dulcis*	Plantaginaceae	1***	0.00 ***	0.00 ***	0.00 ***

32	*Imperata cylindrica*	Poaceae	1***	0.91 ***	0.00 ***	0.00 ***
33	*Panicum maximum*	Poaceae	1***	0.00 ***	0.00 ***	0.00 ***
34	*Dectyloctenium aegyptinm*	Poaceae	2***	0.00 ***	0.00 ***	0.00 ***
35	*Eleusine indica*	Poaceae	2***	0.00 ***	0.00 ***	0.00 ***
36	*Borreria spp.**	Rubiaceae	2***	0.00 ***	0.00 ***	0.00 ***
37	*Hedyatis corymbosa*	Rubiaceae	3***	0.00 ***	0.00 ***	0.00 ***
38	*Cardiospermum microcarpum*	Sapindaceae	2***	0.33 ***	0.00 ***	0.00 ***
Intercrop species						
39	*Citrullus lanatus*	Cucurbitaceae	4***	0.00 ***	0.00 ***	0.00 ***
40	*Cucumis sativus*	Cucurbitaceae	3***	0.00 ***	0.00 ***	0.00 ***
41	*Cucurbita maxima*	Cucurbitaceae	2***	0.00 ***	0.00 ***	0.00 ***
42	*Benincasa hispida*	Cucurbitaceae	2***	0.00 ***	0.00 ***	0.00 ***
43	*Vigna radiata*	Fabaceae	3***	0.00 ***	0.00 ***	0.00 ***
44	*Vigna unguiculata*	Fabaceae	3***	0.00 ***	0.00 ***	0.00 ***
45	*Glycine max*	Fabaceae	3***	0.00 ***	0.00 ***	0.00 ***
46	*Vigna unguiculata* sub sp sesquipedalis	Fabaceae	2***	0.00 ***	0.00 ***	0.00 ***
47	*Vigna mungo*	Fabaceae	2***	0.00 ***	0.00 ***	0.00 ***
48	*Arachis hypogaea*	Fabaceae	3***	0.00 ***	0.00 ***	0.00 ***
49	*Zea maize*	Poaceae	2***	0.75 ***	8.33***	0.00 ***
50	*Capsicum annum*	Solanaceae	2***	0.33 ***	0.00 ***	0.00 ***
51	*Abelmoschuse sculentus*	Malvaceae	2***	0.00 ***	0.00 ***	0.00 ***
52	*Sesamum indicum*	Pedaliaceae	3***	0.00 ***	1.33	0.00 ***
Associated annual crop species						
53	*Ipomea batata*	Convolvulaceae	3***	0.75 ***	0.00 ***	0.00 ***
54	*Oryza sativa*	Poaceae	2***	0.00 ***	0.00 ***	0.00 ***
55	*Sorgum bicolor*	Poaceae	13	0.00 ***	0.00 ***	18 ***
56	*Vetiveria zizanioides*	Poaceae	2***	6.48 ***	0.00 ***	0.00 ***
57	*Chrysopogon zizanioides*	Poaceae	3***	0.00 ***	0.00 ***	0.00 ***
58	*Eleusine coracana*	Poaceae	3***	0.00 ***	0.00 ***	0.00 ***

maximum plants. This may be due to the more or less similar morphological characters of the *Panicum maximum* plants and *Saccharum* hybrids which belong to same family Poaceae.

CONCLUSIONS

Saccharum spontaneum and *Sorghum bicolor* act as alternative host plants for *Deltocephalus menoni*. Both plant species feeding and breeding hosts. But these two species showed lesser preference by *Deltocephalus menoni* for feeding and breeding than *Saccharum* hybrids. Three plant species; *Saccharum* hybrids, *Saccharum spontaneum* and *Sorghum bicolor* belong to family Poaceae. Hence, *D. menoni* has monophagy feeding habit, i.e., it prefers feeding on plant species belonged to the same family. Therefore, cultivating or maintaining *Saccharum spontanium* (Wild cane) and *Sorghum bicolor* should not be allowed to practice around fallowing fields and nursery areas since vector can survive on particular plant species and they can serve harbours to migrating vectors from the infected areas to healthy or newly-established sugarcane plantations. *Cleome viscosa* acts as a repellent to the *D. menoni* and most of other test plant species acts as resting sites for the vector. Behaviour of *D. menoni* on *Saccharum spontaneum* and *Sorghum bicolor was* also similar to that on sugarcane hybrids.

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