

Efficacy of Herbicides against Broad-spectrum Weed Floras and Their Effect on Non-target Soil Micro-organisms and Productivity in Sugarcane (*Saccharum* sp.)

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RK and SB designed the study. Authors SG and RP performed the statistical analysis and wrote the protocol. Author MM wrote the first draft of the manuscript. Authors SG and MM managed the analyses of the study. Author RK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Weeds pose a major challenge at the initial stages of sugarcane and when uncontrolled cause high yield losses. This study was undertaken to define a better and cost-effective weed management strategy. Field experiment was carried out at District Seed Farm (C Unit) of Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India (22°97'N latitude and 88°43'E longitude with the 9.75 meters above the mean sea level) under natural weed infestations in sugarcane in 2017–2018 and 2018–19. The objective was to evaluate the efficacy of herbicides on weed florae, non-target soil organisms and productivity of sugarcane (cv. CoS 98231). The pattern of nutrient uptake by weed species was also itemized. The treatments were comprised of four doses of Atrazine 50% WP (1.0, 2.0, 3.0 and 4.0 kg a.i. ha⁻¹), Trifloxysulfuron-Na (10% OD) 30 g a.i. ha⁻¹ and weedy check within a randomized complete block design, replicated four times. The results revealed that among the tested herbicides, the utmost dose of Atrazine was most efficient against grassy as well as broadleaf weeds. The higher weed control efficiency (> 60%) and cane yield (85.41 t ha⁻¹) were recorded from

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treatment received Atrazine 4000 g a.i. ha⁻¹ followed by its lower doses. Owing to an efficient controller of diversified weeds same herbicide treated plot removed the least amount essential primary nutrients irrespective of all weed species. Herbicides did not show any phytotoxicity symptoms on sugarcane throughout the observation period. Based on overall performance, the Atrazine 50% WP (4000 g a.i. ha⁻¹) may be considered as the best substitute for others post-emergent herbicide against the complex weed floras in sugarcane.

Keywords: Bio-efficacy; atrazine; weed management; soil microbes; sugarcane.

1. INTRODUCTION

Sugarcane is the most important sugar crop in India occupying an area of 5.03 million ha with an average productivity of 70.86 t ha⁻¹ [1]. India ranks second (after Brazil) in the world in cane-sugar production with annual production of 30.5 million tonnes [2]. Sugarcane is grown mainly in the Northern, Eastern, and Southern India. Sugarcane is a long-duration crop and requires a large number of labourers for multiple weeding. The critical period of weed interference in spring-planted sugarcane in India ranged between 30 and 90 days after planting (DAP), and the yield reductions due to composite/mixed stand of weeds (grassy, broad-leaved, and sedges) varied from 26% to 75% in unweeded control (UWC) plots [3], therefore management of weeds during this period is of great important. This lower productivity is mainly due to heavy weed infestation in the early growth stage and poor weed management practices [4]. Initial slow growth and wider row spacing provide ample opportunity for weeds to occupy the vacant spaces between rows and offer serious crop-weed competition [5].

Generally, in Eastern India, The age-old weed management practices followed in sugarcane cultivation such as hand weeding, inter-row tillage etc. are both cost and labour-intensive and uneconomical. Now a days there is increasing paucity of manual labourers for weeding in sugarcane for their drift from village to cities make delayed and ineffective weed management in Sugarcane, where weed menace is more visible to farmers. In some states, even higher wages are charged for the labourers to be engaged for weeding than for normal farming works. Chauhan et al. [6] reported that the paucity of labourers coupled with higher rates of wage has made hand weeding impractical or less practical in weed management practices. As alternative weed management in agricultural lands is rapidly shifting towards chemical methods because herbicides are the most effective and economically acceptable [7,8]. As

farmers continue to realize the usefulness of herbicides, larger quantities would be applied to the soil. But the residual of these compounds can be contaminated groundwater by leaching, or if immobile, they would persist on the top soil and become harmful to microorganisms, plants, wildlife and even humans [9]. Soil microorganisms degrade herbicides, deriving energy and nutrients for cellular metabolism [10]. The effect of herbicides on microorganisms has also rarely been studied in sugarcane.

Very few herbicides are selective when applied at post-emergence to sugarcane. Triazines like atrazine and recently, trifloxysulfuron found to be effective post-emergent herbicides for sugarcane. Atrazine is very effective against annual grasses and broad-leaf weeds but when supplemented with hoeing operation give better control for perennial weeds [11]. Atrazine was first registered in Europe in the year 1959 [12]. Trifloxysulfuron, inhibiting acetolactate/acetohydroxy acid synthase (ALS/AHAS) is effective against annual broad-leaved and sedge weeds [13,14] for weed control in sugarcane. Therefore, this study was undertaken to optimize the dose of Atrazine 50% WP against broad spectrum weed flora to boost the sugarcane productivity without hampering the soil quality.

However, the efficacy of herbicides is dose-dependent and also site-specific. It varies, depending on soils (mainly, soil texture, organic matter, pH) and climate (mainly, rainfall, temperature). The sugarcane-growing Eastern and Northern India fall under the Indo-Gangetic Plains (IGP), having alluvial soil and almost similar climate. The recommendation accrued from this study in lower IGP (~ Eastern India) would largely be applicable to the upper IGP (Northern India) as well.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiments were carried out at the District Seed Farm (C Unit), Bidhan Chandra Krishi

Viswavidyalaya, West Bengal, India (22°97' N latitude and 88°43' E longitude with the 9.75 meters above the mean sea level) and topographically the land was medium in slope having deep tube well facility under natural weed infestations in sugarcane 2017–2018 and 2018-2019. The soil was sandy clay loam (sand 64.8%, silt 10.4%, and clay 24.8%) with a pH of 7.3 and an electrical conductivity of 0.296 ds m⁻¹. It contained 0.66% organic C, 315.2 kg available N ha⁻¹, 41.6 kg available P₂O₅ ha⁻¹ and 156.4 kg available K₂O ha⁻¹. The climate of the study site was sub-tropical. The average maximum temperature starts falling from July and reaches minimum in January. Weekly maximum and minimum temperatures fluctuated between 39.8 to 21.0°C and 29.3 and 9.0°C during 2017-2018 and 2018-2019 respectively. The mean monthly rainfall and relative humidity are higher in July - August and lowers in December. The annual rainfall during the experimental period was 1289.0 mm and 1420.50 mm in 2017-18 and 2018-19 respectively. Relative humidity ranged from 25% to 98% in 2017-18 and 35% to 95% in 2017-18 and 2018-19 respectively.

2.2 Herbicidal Treatments

Six weed control treatments including Atrazine 50% WP at four different dosages of (1.0, 2.0 3.0 and 4.0 kg a.i. ha⁻¹) and Trifloxysulfuron-Na (10% OD) 30 g a.i. ha⁻¹ along with weedy check were laid out in a randomized complete block design with four replications. Herbicides were applied using a knapsack sprayer fitted with a flat fan nozzle (Sukun Agencies India, Mumbai, Maharashtra) with a volume rate of 400 L water ha⁻¹ at 15 DAP of sugarcane. The gross and net plots (i.e. area actually harvested for yield) were 5 m × 4.8 m and 5 m × 3.2 m, respectively.

2.3 Crop Planting/Sowing and Agro-Practices

The field was dry cultivated using a tractor-drawn rotavator and levelled using a wooden leveller. Carbofuran 3G @ 30 kg ha⁻¹ was applied during final land preparation to avoid termite infestation on young sugarcane seedlings. Three-budded setts/cuttings of sugarcane (Cv. CoS 98231), cut from the top one-third portion of sugarcane stalks were dipped in SAAF @ 2g l⁻¹ (Carbandazim 12% + Mancozeb 63% EP) for 30 minutes to prevent any fungal infection before planting with a sett rate of 6.0 t ha⁻¹ on 30th March in 2017 and 25th March in 2018, the setts were planted end-to-end in 10 cm deep furrows, leaving 5 cm gap between two setts in 80 cm row-to-row distance

and covered immediately by soil. Total number of four lines were opened in each plot and two plots were separated by 1 m bund. A recommended dose of 180 kg N, 90 kg P₂O₅ and 45 kg K₂O ha⁻¹ in the form of urea, single superphosphate, and muriate of potash, respectively, was applied to sugarcane. Full doses of P and K were applied as basal, whereas N was applied in three equal splits: at planting, 75 DAP (tillering stage) and 120 DAP (grand growth stage). Irrigation was provided to furrows. Eight irrigations to sugarcane were provided throughout the growing periods. Other recommended practices were followed for raising the crops.

2.4 Observations on Weeds

For weed count and weed biomass, four permanent quadrates (0.5 m x 0.5 m) were earmarked in each plot after sugarcane planting. Weed density was measured as the number of weeds per unit area at 15, 30 and 45 days after the application of herbicide from four permanent quadrates according to the weed species in situ. For taking dry weight, the destructed weed samples were first washed in clean tap water, then sun-dried and hot-air oven-dried at 70°C for 48 h, and weighed. Weed control efficiency (WCE), weed persistence index (WPI), treatment efficiency index (TEI), crop resistance index (CRI) and harvest index (HI) were worked out using following equations respectively:

$$WCE = \frac{WDM_c - WDM_t}{WDM_c}$$

Where,

WDM_c is the weed dry matter weight (g m⁻²) in control plot; WDM_t is the weed dry matter weight (g m⁻²) in treated plot.

$$WPI = \frac{WDM_t}{WDM_c} \times \frac{WC_c}{WC_t}$$

Where,

WC_c is weed count in control plot; WC_t = Weed count in treated plot

$$TEI = \frac{Y_t - Y_c}{Y_t} \times \frac{WDM_c}{WDM_t}$$

Where

Y_t is crop yield from the treated plot; Y_c is crop yield from the control plot; WDM_c is the weed dry matter weight (g m⁻²) in control plot; WDM_t is the weed dry matter weight (g m⁻²) in treated plot.

$$CRI = \frac{CDM_t}{CRM_c} \times \frac{WDM_c}{WDM_t}$$

Where

CDMt is crop dry matter (g m^{-2}) in treated plot;
CDMt is crop dry matter (g m^{-2}) in treated plot.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

2.5 Assessment of Crop Yield

Sugarcane was harvested from middle two row in each plot to avoid the border effect on 23rd January, 2018 and 25th January in 2019. The yield of sugarcane was determined on the basis of net plots ($\sim 5 \text{ m} \times 3.2 \text{ m}$) and converted to t ha^{-1} .

2.6 Microbiological Observations

Soil was collected at 15 days after herbicide application with an auger (5 cm diameter) from the mid-points between sugarcane rows in five locations per plot from a depth of 15 cm and bulked, having almost 200–250 g fresh weight. The colony-forming units (cfu) of fungi, bacteria, and actinomycetes were enumerated in Czapek's Dox medium, nutrient agar, and actinomycetes isolation agar (Hi media), respectively, following serial dilution technique and agar/pour plate method using a 1 mL soil solution for plating [15]. The microbes were incubated at 30°C after serial dilution and spreading of the soil solution on the respective plates. The populations of bacteria per plate were scored within 3 days, whereas the populations of fungi and actinomycetes were observed after an incubation period of 5–7 days [16].

2.7 Nutrient Assessment

The above ground parts of samples were dried in a hot air oven at $60 \pm 5^\circ\text{C}$ to constant weight, then ground and sieved through 0.5 mm sieve. The required quantity of samples was weighed out accurately and was subjected to acid extraction and N, P and K content was determined. Total Nitrogen, phosphorus and potassium content of the samples was determined by micro kjeldhal method [17], vanadomolybdate phosphoric yellow colour method [17] and flame photometric method [17], respectively and subsequently the nutrient uptake by weeds was computed on hectare basis as computed by Sunil et al. [18].

2.8 Statistical Analyses

Mean values of two years data on crops and weeds were jointly analyzed using the analysis of variance (ANOVA) technique as suggested by

Gomez and Gomez [19]. All the collected data were analyzed statistically by the analysis of variance (ANOVA) technique using the SAS Windows Version 9.3.

3. RESULTS AND DISCUSSION

3.1 Weed Population and Biomass

The experimental plots were infested with mixed weed flora where broadleaf weeds were the most dominating followed by grasses and sedges, irrespective of the dates of observations at 15, 30 and 45 DAA. Experimental results revealed that the weed control treatments had a significant effect on weed diversities; densities and biomass of weeds were significantly ($P=0.05$) higher in weedy check. Among the herbicides Atrazine 50% WP ($4000 \text{ g a.i. ha}^{-1}$) was the most effective against all major weed floras whereas the tested herbicides had no significant effect on *Cyperus* sp (Table 1). The density of *Commelina benghalensis* was highly reduced by the Atrazine with its maximum dose irrespective of the dates of observations (1.72, 2.85 and 4.27 g m^{-2} respectively). The same treatment significantly ($P=0.05$) reduced the densities of *Digitaria sanguinalis* (46.90% less than weedy check) at 15 DAA (Table 1).

The data from Table 2 also revealed that significantly ($P=0.05$) lowest dry matter (1.46 g m^{-2}) was accumulated by *Digitaria sanguinalis* closely followed by *Commelina benghalensis* (2.01 g m^{-2}) and *Dactylactenium aegyptium* (2.14 g m^{-2}) at first date of observation with the application of Atrazine 50% WP @ $4000 \text{ g a.i. ha}^{-1}$ (Table 2). Here also the *Cyperus* sp. was less affected by the application of tested herbicides without any significant difference with each other. The lower doses of Atrazine and Trifloxysulfuron exhibited considerably lower reduction in weed number and dry weight. Mishra et al. [20] also reported that post-emergent application of herbicides belonging from the triazine group significantly reduced the weed density in sugarcane. Similar findings were also reported by Singh et al. [21].

3.2 Different Weed Control Indices, Sugarcane Productivity and Harvest Index

The utmost dose of Atrazine exhibited maximum weed control efficiency accounting 63.10%, 58.80% and 54.50% efficiency at 15, 30 and 45

DAA (Table 3). The efficiencies of tested herbicides depicted lower values with lowering their application dose.

Weed persistence index (WPI) indicating relative dry matter accumulation of weeds per count in comparison to control. Data in Table 3 indicated that lower persistence index (0.87, 0.94 and 0.93 for all three dates of observations respectively) was found from the treatment spraying with Atrazine @ 1000 g a.i. ha⁻¹ closely followed by Trifloxysulfuron @ 30 g a.i ha⁻¹. Singh et al. [21] also observed that the application of a higher dose of Atrazine 50% WP proved itself as an efficient weed control measure, gave the lowest weed dry matter and stood at par with the application of Metribuzin at 1000 g ha⁻¹. The principal mode of the pesticidal action of Atrazine is to inhibit photosynthesis by preventing electron transfer at the reducing site of photosynthesis complex II in the chloroplasts.

The treatment efficiency index (TEI) indicates the weed-killing potential of treatment and its phytotoxicity on the crop. From Table 3, it was concluded that Atrazine 50% WP @ 4000 g a.i. ha⁻¹ had the highest TEI (0.71) followed by the lowering doses of tested herbicides. The crop resistance index (Table 3) indicating increased vigour of crop plant due to weed control measures indicated that the weedy check plot recorded lower resistance index (1.00) and higher value (3.18) was found from the utmost dose of Atrazine.

All the herbicide applications resulted in significantly (P=0.05) higher yield compared to non-treated control. Data in Table 3 depicted that the plot treated with Atrazine 50% WP @ 4000 g a.i. ha⁻¹ resulted in highest cane yield (85.41 t ha⁻¹) and stover yield (20.39 t ha⁻¹) closely followed by the treatment with similar herbicide at its lowering dose (3000 kg a.i. ha⁻¹). The lower yield of sugarcane may be due to higher weed density and lower weed control efficiency. A strong correlation (R² = 0.93) was found between total weed biomass and cane yield (Fig. 1). This result highlighted the poor competitive ability of crops with weeds and the need to control them effectively by suitable herbicides having good killing potential during the whole growing season. Chauhan and Opena [22] also found a similar correlation between yield and weed biomass at harvest. A similar trend was observed from the values of the harvest index depicted from the Table 3. The probable reasons behind such an incident may be due to the fact that in an environment free from weed flora, the crop could

not face any competition with weeds for water, essential nutrients, space and solar radiation resulting in improvement of yield-related traits and ultimately crop yield. Many reports support such a role of herbicide application in improving the yield related traits and yield of several crops through efficient weed management [23]. Devi et al. [24] also reported that the application of Metribuzine was effective in controlling weeds and had a favourable influence on growth and yield of sugarcane ratoon.

3.3 Nutrient Removal by Weeds

Uptake of N, P and K by weeds followed the trend of weed biomass. Irrespective of all species total uptake of nitrogen, phosphorus and potassium by weeds at 45 DAA recorded significantly highest from unweeded control plot because of higher weed infestation (Table 4). Owing to an efficient controller of diversified weeds Atrazine 50% WP (4000 g a.i. ha⁻¹) treated plot removed least amount of nitrogen, phosphorus and potassium irrespective of all weed species. Among the grassy weeds *Dactylactenium aegyptium* removed maximum amount of major primary nutrients (NPK 4.96, 5.42 and 9.13 kg ha⁻¹ respectively) from unweeded check and it was least (NPK 0.58, 0.13 and 0.88 kg ha⁻¹ respectively) from the plot treated with Atrazine 50% WP (4000 g a.i. ha⁻¹). In case of sedges (*Cyperus* sp.) and broadleaf weeds viz. *Commelina benghalensis*, *Digera arevensis* and *Convolvulus arvensis* followed the same tendency of nutrient removal as followed by *Dactylactenium aegyptium* (Table 4). The findings of Dayaram [25] were similar with these results. Raj and Syriac [26] also observed that minimum removal of soil available nutrients by weeds was recorded from the higher dose post-emergent herbicidal application followed by its lower doses. Similarly, an increase in nutrient uptake by increasing the weed population was also reported by Babar and Velayutham [27].

3.4 Effect on Soil Micro-organism

Different weed management treatments significantly (P=0.05) influence the soil microbial populations at 30 DAA. Microbes were highly affected (68.50 CFU × 10⁴ g⁻¹ and 16.40 CFU × 10⁴ g⁻¹ bacteria and actinomycetes respectively) by higher dose of Atrazine compared with others (Fig. 2a and 2c) whereas fungi population was sharply hampered (23.20 CFU × 10⁴ g⁻¹) by the application of Trifloxysulfuron-Na (10% OD) @ 30 g a.i. ha⁻¹ which was closely followed by the

Table 1. Weed population m⁻² at 15, 30 and 45 days after application of herbicide in sugarcane (Mean data of two years)

Treatments	<i>Digitaria sanguinalis</i>			<i>Dactyloctenium aegyptium</i>			<i>Cyperus sp.</i>			<i>Digera arevensis</i>			<i>Commelina benghalensis</i>			<i>Convolvulus arvensis</i>		
	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45
Atrazine (1000 g a.i. ha ⁻¹)	3.84	8.42	9.53	6.15	9.11	10.83	10.08	18.49	21.83	5.28	8.06	11.35	3.31	5.13	6.49	3.48	6.64	9.14
Atrazine (2000 g a.i. ha ⁻¹)	2.31	6.23	7.13	4.53	7.02	8.14	8.72	16.49	20.48	4.03	5.84	9.29	1.90	3.33	4.92	2.26	3.71	6.64
Atrazine (3000 g a.i. ha ⁻¹)	2.15	5.75	6.57	3.81	6.83	7.71	8.87	15.81	19.41	3.72	5.87	8.97	1.91	3.08	5.04	2.13	3.61	6.24
Atrazine (4000 g a.i. ha ⁻¹)	1.77	4.92	5.37	3.48	5.94	6.29	7.44	15.23	18.96	3.43	5.14	8.06	1.72	2.85	4.27	1.87	3.19	5.29
Trifloxysulfuron (30 g a.i. ha ⁻¹)	3.33	7.11	7.81	5.32	8.57	9.84	9.04	17.83	21.25	4.89	7.85	10.37	3.21	4.86	6.11	3.37	6.06	8.81
Unweeded control (UWC)	7.84	12.97	14.29	10.20	15.57	18.62	10.71	19.91	24.37	10.31	12.69	15.06	9.67	11.55	12.94	8.41	12.05	14.41
LSD (P = 0.05)	0.57	1.07	1.38	0.77	1.15	1.43	NS	NS	NS	0.61	0.75	1.26	0.44	0.59	0.85	0.41	0.71	1.07

LSD - Least significant difference; NS - Non significant

Table 2. Weed biomass (g m⁻²) at 15, 30 and 45 days after application of herbicide in sugarcane (Mean data of two years)

Treatments	<i>Digitaria sanguinalis</i>			<i>Dactyloctenium aegyptium</i>			<i>Cyperus sp.</i>			<i>Digera arevensis</i>			<i>Commelina benghalensis</i>			<i>Convolvulus arvensis</i>		
	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45
Atrazine (1000 g a.i. ha ⁻¹)	1.98	2.63	3.17	3.21	3.44	5.55	3.15	4.47	6.58	3.44	3.63	4.72	3.11	3.46	4.70	3.59	4.81	6.44
Atrazine (2000 g a.i. ha ⁻¹)	1.65	2.14	2.70	2.70	3.18	4.87	3.01	4.39	6.35	3.22	3.31	4.27	2.74	3.08	4.30	2.94	3.90	5.62
Atrazine (3000 g a.i. ha ⁻¹)	1.63	2.12	2.57	2.46	2.84	4.33	2.88	4.36	6.38	2.92	2.95	4.23	2.44	2.82	4.14	2.92	3.79	5.48
Atrazine (4000 g a.i. ha ⁻¹)	1.46	1.82	2.31	2.14	2.65	4.08	2.67	4.12	6.32	2.55	2.72	3.71	2.01	2.42	3.78	2.67	3.29	4.93
Trifloxysulfuron (30 g a.i. ha ⁻¹)	1.93	2.55	3.13	3.01	3.32	5.43	3.03	4.61	6.57	3.33	3.46	4.71	3.06	3.36	4.61	3.74	4.98	6.52
Unweeded control (UWC)	4.80	5.07	6.16	4.96	5.42	9.13	4.36	5.97	8.50	6.82	6.98	9.40	6.55	7.21	9.63	6.57	7.84	10.52
LSD (P = 0.05)	0.21	0.32	0.37	0.37	0.41	0.55	NS	NS	NS	0.33	0.40	0.47	0.30	0.35	0.45	0.49	0.63	0.83

LSD - Least significant difference; NS - Non significant

Table 3. Different weed indices, yield and harvest index of sugarcane under different weed management options (Mean data of two years)

Treatments	WCE			WPI			TEI	CRI	Yield (t ha ⁻¹)		Harvest index
	15	30	45	15	30	45			Cane yield	Stover yield	
Atrazine (1000 g a.i. ha ⁻¹)	50.46	45.02	42.02	0.87	0.94	0.93	0.36	2.15	73.05	17.73	80.47
Atrazine (2000 g a.i. ha ⁻¹)	55.87	51.59	48.35	1.05	1.07	1.04	0.55	2.65	80.70	19.21	80.77
Atrazine (3000 g a.i. ha ⁻¹)	58.44	54.04	50.21	1.06	1.06	1.05	0.58	2.78	81.55	19.48	80.72
Atrazine (4000 g a.i. ha ⁻¹)	63.10	58.80	54.50	1.10	1.07	1.07	0.71	3.18	85.41	20.39	80.73
Trifloxysulfuron (30 g a.i. ha ⁻¹)	51.64	45.57	42.62	0.92	0.99	0.97	0.38	2.20	74.13	18.12	80.36
Unweeded control (UWC)	0	0	0	1.00	1.00	1.00	0.00	1.00	57.93	15.04	79.39
LSD (P = 0.05)	-	-	-	-	-	-	-	-	7.31	1.79	-

WCE - Weed control efficiency; WPI - Weed persistence Index; TEI - Treatment efficiency index; CRI - Crop resistance index; LSD - Least significant difference

Table 4. NPK uptake (kg ha⁻¹) of weed species under different weed management practices in sugarcane (Mean data of two years)

Treatments	<i>Digitaria sanguinalis</i>			<i>Dactyloctenium aegyptium</i>			<i>Cyperus sp.</i>			<i>Digera arevensis</i>			<i>Commelina benghalensis</i>			<i>Convolvulus arvensis</i>		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Atrazine (1000 g a.i. ha ⁻¹)	0.55	0.07	0.87	0.79	0.17	1.19	1.24	0.22	1.61	0.91	0.17	1.10	1.15	0.20	1.04	1.54	0.16	1.29
Atrazine (2000 g a.i. ha ⁻¹)	0.47	0.06	0.74	0.70	0.15	1.05	1.20	0.21	1.55	0.82	0.15	1.00	1.04	0.18	0.94	1.34	0.14	1.12
Atrazine (3000 g a.i. ha ⁻¹)	0.45	0.06	0.70	0.62	0.13	0.93	1.21	0.21	1.56	0.81	0.15	0.99	1.01	0.18	0.91	1.31	0.14	1.10
Atrazine (4000 g a.i. ha ⁻¹)	0.40	0.05	0.63	0.58	0.13	0.88	1.19	0.21	1.54	0.71	0.13	0.87	0.92	0.16	0.83	1.18	0.12	0.99
Trifloxysulfuron (30 g a.i. ha ⁻¹)	0.55	0.07	0.86	0.78	0.17	1.17	1.24	0.22	1.60	0.90	0.17	1.10	1.12	0.20	1.01	1.56	0.16	1.30
Unweeded control (UWC)	1.08	0.14	1.69	4.96	5.42	9.13	4.36	5.97	8.50	6.82	6.98	9.40	6.55	7.21	9.63	6.57	7.84	10.52
LSD (P = 0.05)	0.36	0.14	0.34	0.19	0.13	0.21	0.25	0.12	0.25	0.28	0.14	0.17	0.24	0.07	0.12	0.84	0.42	0.73

LSD - Least significant difference

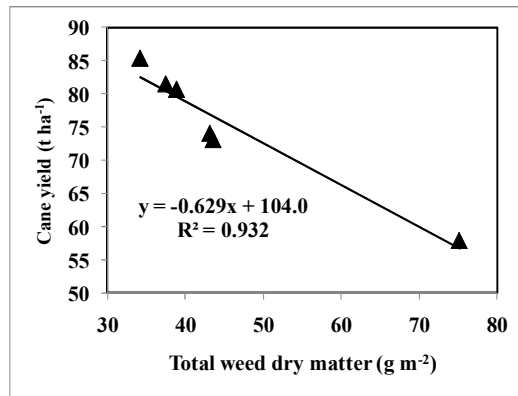


Fig. 1. Relationship between weed dry matter (45 DAA) and cane yield of sugarcane

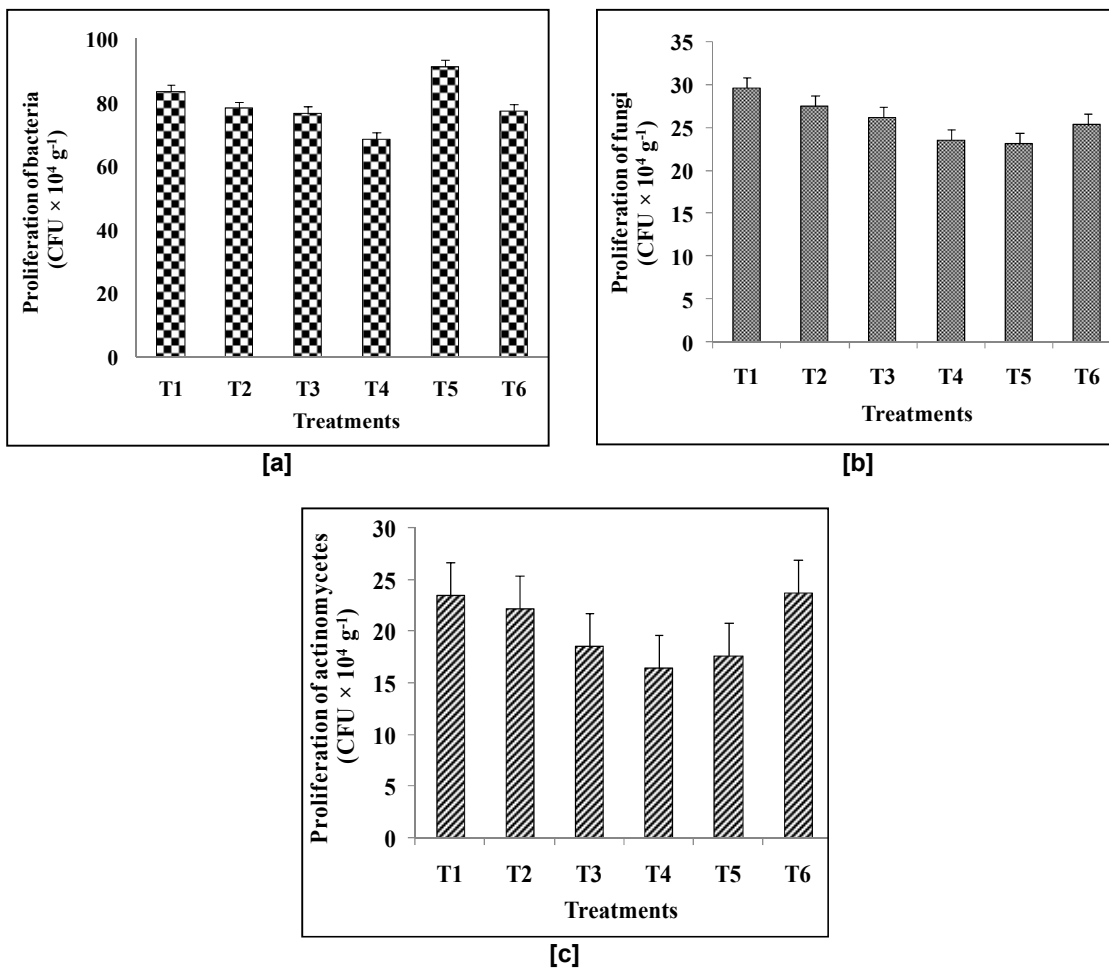


Fig. 2. Microbial populations in soil as affected by weed control treatments at 30 DAA

[a, b and c]

T₁, Atrazine 50% WP (1000 g a.i. ha⁻¹); T₂, Atrazine 50% WP (2000 g a.i. ha⁻¹); T₃, Atrazine 50% WP (3000 g a.i. ha⁻¹); T₄, Atrazine 50% WP (4000 g a.i. ha⁻¹); T₅, Trifloxysulfuron 10% OD (30 g a.i. ha⁻¹); DAA, days after application. Error bars represent LSD (P = 0.05)

application of the former one (Fig. 2b). The population of rhizospheric micro floras was least affected by lowering doses of tested herbicides. These results were in tune with the findings of

Das et al. [16] who reported that the chemical natures, formulations, and doses of herbicides resulted in variable impacts on micro-organisms. The persistence of herbicides in the rhizosphere also played roles. The herbicides were applied at 15 DAP and observations were recorded at 30 DAA. By that time, herbicides might have undergone degradation by micro-organisms and their effects got mitigated. The degraded organic herbicides provide carbon-rich substrates which in turn maximize the microbial population in the rhizosphere in the future Jarvan et al. [28] and also influence the transformations and availability of plant nutrients in the soil [10]. The highest dose showed slightly more non-target effects, but suppressed more weeds and gave higher sugarcane yields.

3.5 Phytotoxicity of Herbicides on Sugarcane

The sugarcane plants were critically examined for phytotoxic symptoms at 1, 3, 5, 7 and 10 days after herbicide application. The level of phytotoxicity was estimated by visual assessment based on Phytotoxicity Rating Scale (PRS) 0 to 10, where 0 = No crop injury while 10 = Heavy injury or complete destruction of test crop. As per our observation there was no phytotoxicity like epinasty, hyponasty, necrosis, vein clearing, wilting and leaf injury on tip/surface in the plants.

4. CONCLUSION

In Eastern India, sugarcane monoculture with high labour-requiring hand weeding is practiced (farmers' practice). The present experiment had an intention to discern the effectiveness of herbicides on various weed floras in sugarcane cultivation, their residuality on non-target organisms and soil properties. From this experiment, it can be concluded that the herbicide Atrazine 50% WP 4000 g a.i. ha⁻¹ had the supreme potential to control diversified weed flora in sugarcane within a critical crop-weed infestation period that resulted in about 47% cane yield increment of sugarcane over control without showing any phytotoxicity on plants. There was no long-term adverse effect of the applied herbicides on the microbial population in soil rhizosphere. As a part of a resistance management strategy, long-term changes in weed flora, herbicide efficacy, crop resistance and productivity should be monitored regularly for effective weed management practices. Further research is needed to develop timing

strategies with minimum effective dosages which could be the most economical and ecologically desirable weed management approach for sustainable sugarcane cultivation practices in the eastern part of India.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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