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RESEARCH ARTICLE

Comparative evaluation of agronomical, mechanical and chemical management of weeds and their impact on sugarcane productivity

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ABSTRACT

Weeds are opportunistic plants causing serious yield reduction in sugarcane production, so management of unwanted vegetation is of paramount importance for sugarcane cultivation. With this objective, an experiment was planned at Navsari Agricultural University, Navsari (Gujarat) to assess the various weed management strategies including agronomical, mechanical/physical and herbicides on weeds and yield of sugarcane (*Saccharum officinarum*). The experiment comprised of 14 treatments (two control *i.e.* weedy check and weed free along with herbicides, *viz*. atrazine, pendimethalin, metribuzin. 2,4-D Na salt and 2,4-D amine salt and their combination in-between as well as with cultural practices) laid out in randomized complete block design replicated thrice. The weed flora of experimental site during *Kharif* season was alienated with 60% broad-leaf weeds and 40% grassy weeds. Among broad-leaf weeds, *Phyllanthus maderaspatensis, Alternanthera sessilis, Euphorbia hirta, Digera arvensis, Physalis minima, Convolvulus arvensis* and *Trianthema portulacastrum* were found as dominant. While, among grassy weeds *Eragrostis major, Brachiaria reptans, Echinochloa colonum, Cynodon dactylon, Digitaria sanguinalis* and *Commelina benghalensis,* were the major weeds, whereas there was only one dominating sedge *i.e. Cyperus rotundus*. The results showed all the weed management practices significantly produced higher sugarcane yield over weedy check and HW at 30, 60 and 90 DAP + IC at 45 and 90 DAP was found significantly superior, being at par with application of pre-emergence herbicides *i.e.* atrazine or metribuzin *fb* HW+IC at 60 DAP which recorded lowest weed density, weed dry matter, weed index and maximum weed control efficiency. The presence of weeds reduced cane yield about 49.8% in comparison to HW+IC (weed free). In addition to this, application of pre-emergence herbicides followed by post-emergence herbicides or smoother crop (sunnhemp) was also found remunerative.

Keywords*:* 2,4-D Amine salt, 2,4-D Na salt, Atrazine, Integrated Weed Management, Pendimethalin, Metribuzin, Sugarcane

INTRODUCTION

Sugarcane (*Saccharum* spp. hybrid complex), a key cash crop cultivated from 8°N to 30°N latitude covering diversity of climate and soil of India, having the second largest sugar making in the world (Patel *et al*. 2018). Sugar industry, located in rural areas of India is next to agro based industry after textiles (Lokhande *et al*. 2018). In India, s'cane is cultivated in an area of 4.85 million hectares with a cane production of 397.66 million tonnes and average productivity of 81.98 tonnes/ha. Gujarat is one of the prominent states in sugarcane and sugar production, where, sugarcane is cultivated in 1.83 lakh hectares with a production of 13.62 million tonnes. Highest cane yield produced by farmers for sugarcane was 261 t/ha, however, the average yield of state is about 74.53 t/ha. Thus, there is a wide gap amongst the usual yields and potential yield and production potential can be attained by adopting good agronomical practices of crop production (Anonymous 2021).

Many factors are responsible for the declining sugarcane yield. Weed infestation and poor agronomic practices proved fatal and caused heavy yield reductions. Sugarcane being a perennial crop having invasion of all sorts of weeds; seasonal, annual and perennials (Das 2009). The antagonism triggered through weeds is a main restrictive factor for sugarcane production. Heavy infestation of weeds comprising grasses, broad leaf weeds and sedges poses a big challenge for sugarcane production because its planted with a moderately wider row spacing, initial growth is very slow as it takes about 30 to 45 days for complete emergence and additional 60-75 days for developing full canopy cover, besides plentiful water and nutrient supply again provides ample opportunities for weeds to occupy the vacant space that is easily available between rows and thus, it

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offers serious competition to crop. The occurrence of weeds in the sugarcane fields and no control has also led to a decrease in sugar yield (Roshan *et al.* 2006, Kanchan 2009) in proportion of sucrose, purity and brix (Rathika 2023). Generally, the increase in weed growth by one kilogram corresponds to a reduction in one kilogram of crop dry matter. Sugarcane crop faces tough competition with weeds between 60 to 120 days of its planting which causes heavy reduction ranging from 40-67 per cent (Chauhan and Srivastava 2002). Weed competition can decrease millable stalks by 32%, stalk thickness by 15% and sugar yield by 31% compared to weed-free plots (El-Shafai, *et al.* 2010). The reduction in cane yields due to weeds ranged from 40 to 60% noted by Kadam *et al.* (2011), about 24 to 52% were also noted by Khan (2015) and Fontenot *et al.* (2016). In India, weeds which sprout at later stages and twine around clumps affect cane growth and cause yield losses range from 12 to 72 per cent, could go up to 17.5 t/ha. Further, the total cane yield loss in the country per annum is around 25 million tonnes (equivalent to 2.5 million tons of sugar) valued around rupees 1500 crores (Takim *et al.* 2014). Besides, weeds act as host of certain pests and disease caused incidental losses. Bermuda grass (*C. dactylon*) cogan grass (*I. cylindrica*) and other grassy weeds are identified as alternate hosts to Ratoon Stunting Disease (RSD) of sugarcane (Walia 2003). Besides, *Ipomoea* spp. is a serious weed is many sugarcanes cultivating areas, escalating cost of farming, too decreasing cane yields. Weeds drain sizable amount of moisture, nutrients, solar radiations, capture space and may produce allele-chemicals (Abbas *et al.* 2017) that damage the crops and decrease the yield (Christoffoleti *et al.* 2006, Huang *et al.* 2018). Weeds uptake 4 times of N and P and 2.5 times of K compared to sugarcane within first seven-week period (Anusha and Rana 2016). So, management of weeds is not only essential task for gainful sugarcane production but also imperative for reduction in exhaustion of nutrient and water resources from soil.

Different kinds of socioeconomic and environmental aspects influence on the choice of weed management methods. Manual, biological, mechanical, and chemical methods are the usual ways of treating weeds. Manual weed control is challenging because it takes longer, is weather-dependent, and can cause a bad smell when weeds are uprooted. Mechanical weed control carries the risk of crop plant injury, as well as the distribution of weed seeds in fields and potential soil erosion issues (McErlich and Boydston 2013). One has to avail the excellent quality herbicides that have a great promise in controlling all kinds of weeds in sugarcane. Herbicides are being extensively used for weed control in many sugarcane growing countries of the world for the following reasons 1) Labour is becoming scarce and overpriced 2) Conventional approaches are inefficient 3) Early weed growth cannot be controlled by conventional methods 4) Well-timed weeding is becoming tough, time taking and expensive. Pre-emergence application of triazine molecules (atrazine, simazine *etc.*) resulted high mortality of weeds in sugarcane fields (Bimbraw and Kaur, 2004; Smith, *et al.* 2011). A large number of trials across the nation have directed that for sole crop of sugarcane, atrazine is the most reliable herbicide at dosages ranging from 1.25 to 2.0 kg/ha. Besides, 2,4-D at 1.0 to 1.5 kg/ha (sprayed on weeds between 20 and 40 days) has been found highly effective in controlling most of the broad-leaved weeds. Atrazine, metribuzin and 2,4-D have become very popular herbicides throughout the country in sugarcane. They give a more or less complete weed free condition for about 50 to 60 days. Moreover, post-emergence application of Paraquat dichloride and Glyphosate applied between the rows as directed spray on weeds can control wide variety of weeds suggested by Hameed *et al.* (2017). Especially glyphosate being translocated herbicide has a great promise in controlling pernicious weeds like *Cynodon dactylon* and *Cyperus* spp., in widely spaced cane crop (Singh and Kaur 2004). A hood should be used especially when Paraquat and Glyphosate is applied to target/kill only weeds and to safeguard the crop, as such, a protection on the nozzle avoids spray drift reaching the crop. For controlling twining weeds such as *Ipomoea* spp. and *Convolvulus* spp., application of atrazine (1.0 kg/ha) or metribuzin (1 kg/ha) may be done between the cane rows after final earthing up. Weed control through chemicals is comparatively more resourceful and reasonable due to entrance of novel chemistry and herbicides (Kahramanoglu and Uygur 2010, Khan 2015). Thus, it is important to know and select a compound that is the most effective in controlling weeds in sugarcane in order to reduce the operational cost of weed management. Sometimes single approach does not give satisfactory results to combat weeds below threshold or the selectively of herbicides with weed flora can limit the control of weeds. Hence, integrated weed management concept found more appropriate especially combination of chemical, physical and cultural methods.

Overall, a weed free environment during the germination and tillering phase is important for attainment higher yield. This can be accomplished by the introduction of effective herbicides that has revolutionised the weed control in sugarcane. Selection of appropriate herbicides along with accurate dose and time of application is the key to success for controlling weeds. Consequently, keeping in view of these perspectives, the current study aims to: (1) conduct a survey on weed species that are present in sugarcane fields, (2) assess the efficacy of herbicides to control the weeds in sugarcane and (3) study the effect of weed management strategies on sugarcane yield.

MATERIALS AND METHODS

Description of the study area: A field experiment was conducted for three years *i.e.* 2014-15, 2015-16 and 2017-18 at Instructional Farm, N.M. College of Agriculture, Navsari Agricultural University, Navsari on *Vertisols*. The experimental site was located at the longitude of 20.9229° N, 72.8882° E latitude with 10 m altitude, from mean sea level.

Edaphic and climatic conditions: Before conducting the field trial, soil samples (0-30 cm depth) were collected randomly with the help of auger from the experimental area at the time of field lay out. All samples were mixed to form one composite sample to characterize its physical and chemical properties. The soil physical property of the study area was sand (14.30%), silt (19.56%) and clay (63.89%) means that soil of the experimental field was clay (deep black) in texture, organic carbon (0.53 %), pH (7.80) with EC of 0.419 dS/m shows the reaction of soil was slightly alkaline. The available N (248 kg/ha) and P (50.8 kg/ha) status of the soil was medium whereas available K (364 kg/ha) contents were in high range. The total rainfall received during the crop season was 1655, 1720 to 1585 mm in 49, 55 and 48 rainy days with annual average maximum and minimum temperatures of 39.85°C and 18.43°C, and mean temperature of 29.14°C. Out of total rainfall, most of the rainwater was received from the South-West monsoon period (June- September), however unexpected rain during off-season are very common. The mean relative humidity of the area was 77.5%, ranging from average maximum of 90% to minimum of 61%.

Treatments and experimental design: The experiment was laid out in randomised block design (RCBD), keeping with fourteen weed management strategies with three replications. The treatments included two control *i.e.* weedy check (allowed weed infestation throughout crop period) and weed free (kept weed free for season long) and the rest twelve treatments included herbicides (atrazine, pendimethalin, metribuzin. 2,4-D Na salt and 2,4-D Amine salt) and their integration in-between as well as with cultural practices. The details of the treatments are given in **Table 1**. Each plot was 7.2 m × 6.0 m (43.20 m^2) in size. There were eight-planting furrows of 6.0 m length spaced at 0.90 m distance. The distance between blocks, (replications) was 2.0 m and between plots was 1.5 m, so herbicides drifting could be avoided.

Crop husbandry: The field was prepared following the mechanical tillage (deep disc ploughing for removal of hardpan of the soil and harrowing for preparation of seedbed) practices to facilitate sugarcane setts plantation. Land was levelled and furrowed precisely. In accordance with the

Table 1. Weed management treatment details (trade name, active ingredient, formulation, herbicides doses and its time of application, other weed management strategies investigated)

Symbol	Treatment	Trade name	a.i. (%)	Formulation	Dose (kg/ha)	Application time
W_1	Weedy check	--	--	--	--	--
W_2	Three HW + two IC	--	--	--	--	at 30, 60 & 90 and 45 & 90 DAP
W_3	Atrazine	Atrataf	50	WP	2.0	Pre- emergence (PE)
W_4	Atrazine *fb* HW and IC	Atrataf	50	WP	2.0	PE and at 60 DAP
W_5	Pendimethalin *fb* HW and IC	Stomp	30	EC	1.0	PE and at 60 DAP
W_6	Metribuzin *fb* HW and IC	Sencor	70	DF	1.0	PE and at 60 DAP
W_7	Atrazine *fb* 2,4-D Na salt	Atrataf, Heera Super	50, 80	WP, WP	2.0 +1.0	PE and at 60 DAP
W_8	2,4-D Na salt *fb* Paraquat	Heera Super, Gramoxone	80, 24	WP, SL	1.0 + 0.5	At 30 *fb* 60 DAP
W_9	2,4-D Amine salt *fb* Paraquat	Zura, Gramoxone	58, 24	WSC, SL	1.0 + 0.5	At 30 *fb* 60 DAP
W_{10}	2,4-D Amine salt *fb* Metribuzin	Zura, Sencor	58, 70	WSC, WP	1.0 + 0.5	At 30 *fb* 60 DAP
W_{11}	2,4-D Amine salt *fb* Atrazine	Zura, Atrataf	58, 70	WSC, WP	1.0 + 1.0	At 30 *fb* 60 DAP
W_{12}	Pendimethalin + sunnhemp (smother crop)	Stomp	30	EC	1.0	PE *fb* at 60 DAS
W_{13}	Metribuzin + sunnhemp (smother crop)	Sencor	70	DF	1.0	PE *fb* at 60 DAS
W_{14}	Atrazine + sunnhemp (smother crop)	Atrataf	50	WP	1.0	PE *fb* at 60 DAS

* **a.i.** : Active ingredient**, WP :** Wettable powder**, EC**: Emulsifiable concentrate, **DF**: Dry Flowables, **SL**: Soluble Liquide, **WSC**: Water-Soluble Concentrates, **HW:** Hand Weeding, **IC**: Inter-cultivation, **PE**: pre-emergence and **DAP**: Days after planting

specifications of the design, a field layout was prepared. After furrow adaptation, disease-free, well-fertilized seed canes were chopped. Healthy three budded sugarcane cultivar (Co. 99004) setts were collected and used for planting. Carbendazim (1 g /1 litre of water) was used to prevent the disease transmission at the time of cutting and chopping. Sugarcane chopping knife was also sterilized with Dettol before chopping. The dry method of sugarcane planting was used and done by manual labour in flat bed method, eventually irrigation was applied. Setts were planted by overlapping three budded setts in the furrows and covered them with soils. Planting was done on first half of December and harvested after fourteen months during all the three seasons of experiments. All plots were uniformly received 250-125-125 kg NPK/ha + FYM 10 t/ha on area based. Before application of FYM, it was blended with bio-fertilizer (*Acetobacter* + PSB 12.5 lit/ha) and Trichoderma as prophylactic measure. Half dose of phosphorus, full dose of potash and ¼ dose of nitrogen were used during crop sowing while remaining dose of nitrogen was used in to 3 equal portions; ¼ at germination completion, ¼ at tillering and remaining ¼ nitrogen and ½ phosphorus at final earthing up. Total 13-irrigations were given according to crop requirement by tube well. All other cultural practices except weed management followed the sugarcane production guidelines.

Herbicides treatments: Five herbicides were tested *i.e.* atrazine, pendimethalin, metribuzin. 2,4-D Na salt and 2,4-D Amine salt. These herbicides were applied at different rates using the hand operated knapsack sprayer (15 litter capacity) fitted with flat fan nozzle covered by a spray hood to avoid unnecessary drifting towards neighbour plots. A spray volume of 495 lit. of water was used per hectare. The hand weeding operations were carried out with the help of "*Khurpi*" and intercutting was carryout with bled harrow as per the treatments, while, control plots were treated by water only.

Weed species survey: Weed species survey was conducted randomly from one-meter square from each plot of experimental field. Green weed plants were pulled out from the soil. The weed species that were easy to identify were recorded in the field, those species which could not be identified in the field were brought to the laboratory and were identified using the weed identification guide (Naidu 2012). Weeds were then identified and classified into three groups *i.e.* monocot, dicot and sedges.

Observation on weeds: Weeds from one-meter square were taken from the quadrate from each plot by hand pulling of weeds. Weeds were separated and air-dried followed by oven dried at 65^{0}C ±2 for 48 hrs. and weighed. The effect of tested herbicide on density (no./m^2) and dry weight of grass weeds (g/m^2) was recorded at 60 DAP and at final earthing up of the crop and the data were subjected to log transformation by adding 0.5 to original value prior to statistical analysis. Same data were used to know the reduction percentage in the dry weight and calculate the weed control efficacy (WCE) by using formula given by Mani *et al.* (1973) as followed.

$$\text{WCE (\%)} = \frac{\text{WDc - WDt}}{\text{WDc}} \text{ X } 100$$

Where, WDc = Dry weight of weed in control, and

WDt = Dry weight of weed in treatment

Further, weed index is defined as the extent of yield reduction due to incidence of weeds in comparison with weed free condition. In other sense, it expresses the competition offered by weeds that measured as per cent reduction in yield owing to their occurrence in the field. To know the losses caused by weeds in sugarcane, weed index was computed as procedure given by Gill and Kumar (1969) using the following formula:

$$\text{WI (\%)} = \frac{\text{X-Y}}{\text{X}} \text{ X } 100$$

Whereas, X = Yield from weed free plot (hand weeding)

Y= Yield of plot for which WI is calculated

Observation on crop: Data on millable canes yield was taken at the time of harvest per plot, finally converted in to tonnes per hectare. The primary data generated through observations and laboratory analysis during the investigation was statistically analysed and the differences among the treatment means were tested for their significance (P=0.05) as described by Gomez and Gomez (1984).

RESULT AND DISCUSSION

Weed composition

Since, sugarcane is long duration crop, a diverse weed flora was observed from the investigational plots and the major were *Cyperus rotundus* from sedge; *Echinochloa colonum, Cynodon dactylon Commelina benghalensis* and *Digitaria sanguinalis* were dominated weeds belongs to monocot; whereas *Phyllanthus maderaspatensis, Alternanthera sessilis, Digera arvensis*, *Trianthema portulacastrum* and *Convolvulus arvensis* were major weeds from dicot. In addition to the aforementioned species, other weeds were also observed in relatively low densities. Overall, seven of these weeds were classified as monocots (44%), eleven as dicots (46%), and two as sedges (10%). Results are in conformity with Suwanarak (1994) and Singh *et al.* (2012).

Weed density

The impact of weed management techniques on weed density, categorized by species, was observed at 60 days after planting (DAP) and at the final earthing up stage. The results, as presented in **Table 2**, indicate that the treatments applied to sugarcane field had a significant influence on the weed density. The weedy check treatment recorded a higher count of monocot, dicot, and sedge weeds, which was significantly greater than the other weed management strategies that were successful in weed knockdown.

Monocots: At sixty (60) days after planting, pre-emergence application of Atrazine, and hand weeding + inter-cultivation significantly reduced the monocot density followed by pre- emergence spraying of metribuzin and pendimethalin. Further, application of Paraquat significantly minimized the monocot count, which was statistically followed by three hand weeding+ two inter-cultivations, and postemergence application of herbicides *i.e.* Atrazine and Metribuzin as well as smoother cropping with sunnhemp at final earthing-up.

Dicots: Hand weeding thrice in combination with inter-cultivation twice recoded significantly lower dicot weeds density at 60 DAP and at earthing-up, application of herbicides *viz*. Atrazine, metribuzin and 2,4-D (Na salt or amine salt) were found equally effect at 60 DAP.

Sedges: Application of 2,4-D (Na salt or amine salt) and HW+IC found superior by reducing the sedges weed density at 60 DAP. Further, at earthing-up, adaptation of HW thrice + IC twice significantly curtailed the sedges count and recorded significantly the lower sedges, being at par with 2,4-D (Na salt or amine salt) *fb* Paraquat application.

Total weeds density: Removed the weeds through three hand weeding + two inter-cultivation recorded significantly the lowest density of weeds at both 60 DAP and at earthing-up. Moreover, other weed management combinations also significantly minimized the total weed density compared to weedy check, however failed to compete with HW+IC method of weed removal.

The data on weed count (**Table 2**) respond by weed management option including herbicide sprayed either pre or post-emergence shows significant reduction in density of monocot, dicot, sedge weeds ultimately reflected in total weed density at all crop growth stages compared to weedy condition. However, none of the herbicides as well as integrated weed management treatments were found as effective as hand weeding + inter-cultivation observed for weed density reduction. Rana and Singh, (2004), Tomar *et al.* (2005) also concluded that the density of the weeds likely to increase with progress in crop age up to ninety days and decline thereby irrespective of the treatments, because at start the needs of weeds remains low that permits the new weeds to establish, while at a later stage intra-weed competition resulted in exclusion of later germinated weed plants and also due to slow initial growth of cane that gives more chance to weeds for

Table 2. Monocot, dicot and sedge count at 60 days after planting and at erthing-up in sugarcane as influenced by various weed management strategies (pooled over 3 years)

Treatment	Monocot (no./m^2)		Dicot (no./m^2)		Sedge (no./m^2)		Total weed (no./m^2)	
	60 DAP	At earthing up	60 DAP	At earthing up	60 DAP	At earthing up	60 DAP	At earthing up
Weedy check	8.19(67.1)	10.87(118.3)	7.64(58.9)	6.57(43.2)	2.78(7.8)	3.19(10.2)	11.5(133.8)	13.1(171.8)
Three HW + two IC	4.10(17.2)	5.14(26.9)	3.73(14.2)	3.76(14.4)	1.55(2.6)	1.47(2.2)	5.82(34.0)	6.53(43.2)
Atrazine	4.55(20.8)	7.34(54.2)	5.51(30.7)	5.75(33.6)	2.32(5.4)	2.73(7.6)	7.52(56.9)	9.74(95.3)
Atrazine *fb* HW and IC	4.14(18.3)	7.14(51.1)	4.94(24.7)	4.98(25.0)	2.35(5.6)	2.44(6.0)	6.94(48.6)	9.05(82.1)
Pendimethalin *fb* HW and IC	4.82(23.6)	7.04(49.7)	5.29(28.2)	4.87(24.2)	2.37(5.7)	2.64(7.0)	7.57(57.4)	8.98(80.9)
Metribuzin *fb* HW & IC	4.41(19.8)	6.94(48.9)	4.89(24.3)	4.85(23.7)	2.42(5.9)	2.68(7.3)	7.06(50.0)	8.90(79.9)
Atrazine *fb* 2,4-D Na salt	4.00(16.8)	5.66(32.3)	4.95(24.7)	4.33(18.9)	2.39(5.8)	1.94(3.9)	6.83(47.2)	7.42(55.1)
2,4-D Na salt *fb* paraquat	7.81(61.1)	5.04(25.6)	3.95(15.9)	4.62(21.6)	1.63(2.8)	1.62(2.7)	8.92(79.8)	7.05(49.8)
2,4-D Amine salt *fb* paraquat	7.72(59.7)	5.09(26.1)	3.93(15.8)	4.62(21.4)	1.71(3.0)	1.57(2.7)	8.85(78.4)	7.08(50.2)
2,4-D Amine salt *fb* metribuzin	7.64(58.9)	5.05(25.8)	3.90(15.7)	4.63(21.7)	1.65(2.9)	2.10(4.6)	8.76(77.4)	7.20(52.0)
2,4-D Amine salt *fb* atrazine	7.42(55.3)	5.08(25.9)	4.10(17.1)	4.60(21.3)	1.52(2.4)	2.14(4.8)	8.64(74.9)	7.21(52.0)
Pendimethalin + sunnhemp	4.62(21.9)	5.06(25.7)	4.53(20.6)	5.31(28.3)	2.11(4.6)	2.37(5.7)	6.84(47.0)	7.72(59.7)
Metribuzin + sunnhemp	4.62(21.7)	5.58(31.3)	5.17(26.9)	5.37(29.0)	2.20(5.0)	1.99(4.1)	7.30(53.6)	8.01(64.4)
Atrazine + sunnhemp	4.82(23.4)	5.61(31.6)	5.09(26.4)	5.40(29.2)	2.18(4.8)	2.07(4.3)	7.38(54.7)	8.06(65.1)
LSD (p=0.05)	0.56	0.48	0.55	0.44	0.26	0.30	0.50	0.48

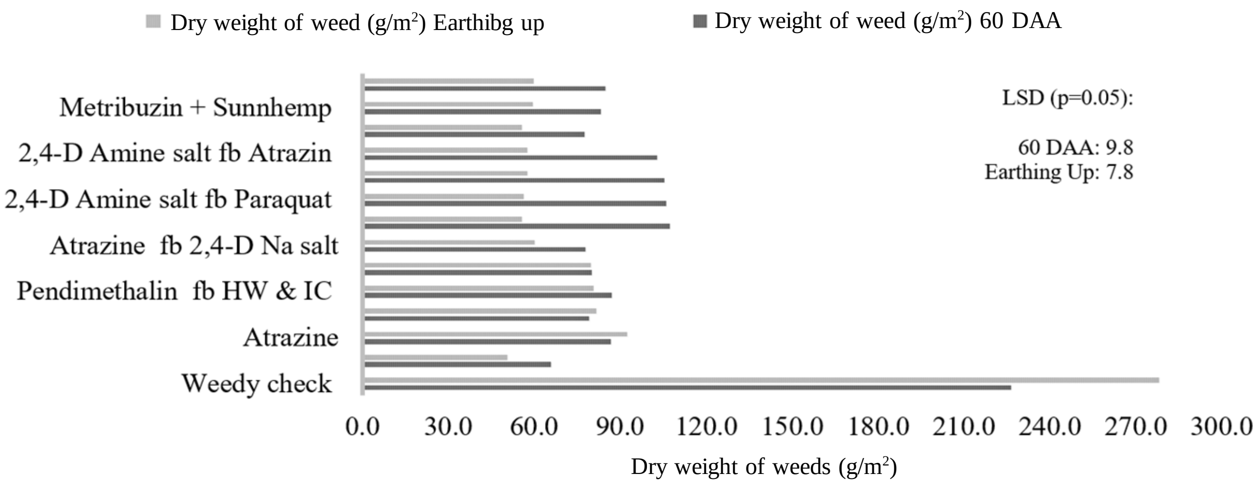


Figure 1. Weeds dry weight influenced by weed management (pooled of 3 years)

emergence, while it deceased afterword due to smothering effects of sugarcane. Srivastava *et al.* (2005), Tomar *et al.* (2005), Lal *et al.* (2006) and Singh *et al.* (2013) also concluded that inter-culturing at 30-45 days' interval is most effective in reducing weed density. Further application of herbicides (pre and post) caused highest reduction in density of all types of weeds, might be due to fact that most of the weeds at initial stage were actively growing and herbicide was effectively absorbed by roots and moved with transpiration stream and caused toxicity at the site of action of different weed. The more density of monocots was observed in plots treated with 2, 4-D because its a selective herbicide that eliminates dicots without harming monocots (Song 2014). Whereas, application of atrazine and metribuzin significantly reduced the weed density in sugarcane reported by Mishra *et. al* (2012) and Singh *et.al* (2012).

Overall response of different treatments was also justified with the results reported by Singh *et al.* (2013) as they all documented clearly that the treated plots significant minimized the density of weeds compared to weedy plot due to phytotoxicity or mortality of weed by various management techniques. The response was found more superior in HW+IC, because periodical removal of weeds physically and mechanically destroyed the three flushes of weeds from the sugarcane filed.

Dry weight of weeds

The data on dry weight of total weeds (**Figure 1**) varied in different weed management treatments, might be due to variable density of weeds. Perusing of the data also revealed that, the biomass buildup of weeds increased with progression of crop stage up to 90 days and dropped subsequently regardless of the treatments. The maximum decrease in total weed dry weight was noted under hand weeding (30, 60 and 90 120 DAP) + inter cultivation (45 and 90 DAP). The next better treatments were application of 2,4-D Na salt *fb* Paraquat, 2,4-D amine salt *fb* Paraquat, 2,4-D amine salt *fb* metribuzin, 2,4-D amine salt *fb* atrazine and pendimethalin + sunnhemp as smoother crop, that also reduced the dry matter accumulation significantly compared to weedy check. The minimum decline in dry weight of weeds was recorded with the application of atrazine because single application of herbicide only killed initial germinating weeds and failed to cause phytotoxicity on later emerged weeds. Decrease in weed dry matter, attributed to physical and mechanical weed management, has also been noticed by Singh *et al.* (2012) and Kumar *et al.* (2014).

Paraquat is classified as a contact herbicide and is not translocated extensively throughout the plant. It acts quickly with no selectively, and is lethal to all plant cells it comes in contact with. Atrazine is a pre- and post-emergence, slowly acting herbicide, that moves within the plant's structure (Heri *et al.* 2008). The effectiveness of both herbicides in controlling weed density and weed biomass showed gradual declines and disappeared within 30 to 60 days after application. Increases in weed biomass at 60 DAA were attributed to the successful growth of some weed species up to the reproductive stage, which completes the life cycle, particularly within a single herbicide application. As expected, the sequential applications of herbicides resulted in better check on re-growth of weeds (**Table 2 and Figure 1**). Shade-tolerance was another characteristic characterized by the most common weed species in sugarcane fields observed due to smothering effect. The methods used to control the dominant weed species are, therefore, dependent on species, environment, and soil type; as well as the dissipation of toxicity at 30 to 60 DAA. While, maximum weed biomass was noticed under weedy check because weed species were free to germinate, reach maturity, and successfully completed its entire lifespan without facing any hurdles and management aspect.

Weed control efficiency (%): Data pertaining to the effect of various weed management treatments on weed control efficiency (%) calculated in terms of percentage at final earthing-up are furnished in **Figure 2**. Highest weed control efficiency of 81.8 per cent was found under the treatment three HW (30, 60 and 90 DAP) + two IC (45 and 90 DAP), whereas lowest weed control efficiency *i.e.* 66.83 per cent observed in single application of Atrazine at earthing-up. The weed control obtained under various treatments was in the order of $W_2 > W_{12} > W_8 > W_9 > W_{10}$e”$W_{11} > W_{13} > W_{14}$e”$W_7 > W_6 > W_5 > W_4 > W_3$.

The maximum control efficiency was noticed with three HW+ two IC, might be due periodical removal of weeds that curtailed the unwanted vegetation frequently leads maximum weed control efficiency. Moreover, application of pre- emergence herbicides killed the weeds at the times of germination or just after germination that provided sufficient time and space to emergence and establishment of crops seedlings for next thirty to thirty-five days, whereas, later emerged weeds destroyed with application of post emergence herbicides lead to comparable weed control efficacy. Similarly, integration of different weed management *i.e.* chemicals, physical, cultural methods appreciably control the weeds compared to weedy check and alone application of atrazine because either weeds was freely established or only one flush was removed in single application of herbicide.

Sugarcane yield: The data furnished in **Figure 3** indicated that all the weed management practices significantly improved the sugarcane production compared to weedy check. Significantly higher cane yield of 129.64 t/ha was recorded with three HW (at 30, 60 and 90 DAP) + two IC (at 45 and 90 DAP), being at par with metribuzin (PE) *fb* HW and IC (at 60 DAP) and atrazine (PE) *fb* HW and IC (at 60 DAP) that produced 99.1, 91.6 and 85.9 per cent higher than weedy check. Presence of weeds in weedy check compete badly for inputs and resources with the sugarcane plants throughout the year, in due course reduced the cane yield by 49.8%. Overall, mechanical weeding or integration of pre-emergence with mechanical weeding found significantly superior. Moreover, sequential application of pre and/ or post emergence herbicides was not significantly comparable with superior treatment combinations, however produced significantly higher cane yield (62.6%, on an average) than weedy check. Additionally, pre-emergence application of herbicides with agronomical practices *i.e.* smoother cropping also produced significantly higher yield (47.3%, on an average) than control and proved it efficacy.

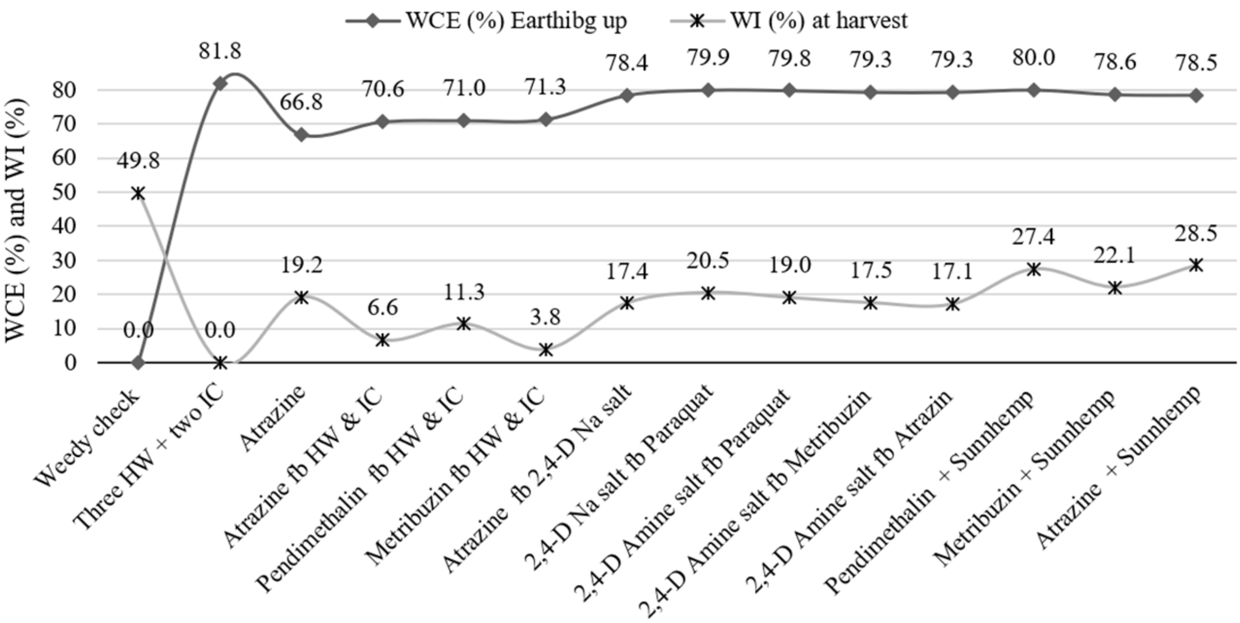
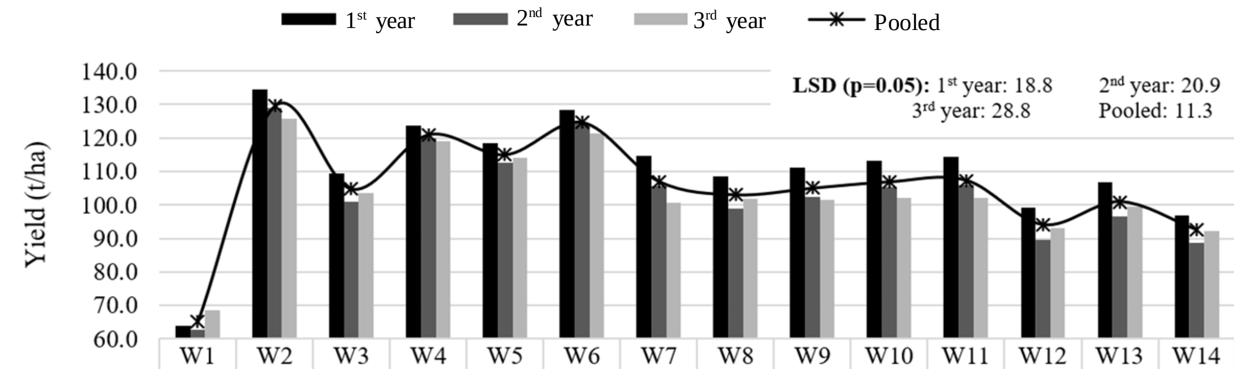


Figure 2. Weed control efficiency (WCE, %) and weed index (WI, %) influenced by different weed management (pooled of 3 years)



	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1st year	63.8	134.4	109.3	123.8	118.4	128.4	114.7	108.5	111.1	113.1	114.3	99.2	106.8	96.8
2nd year	62.8	128.9	101.1	120.0	112.5	124.2	105.5	98.9	102.5	105.3	106.0	89.7	96.7	88.6
3rd year	68.6	125.7	103.7	119.1	114.1	121.5	100.7	101.7	101.5	102.2	102.0	93.2	99.6	92.2
Pooled	65.1	129.6	104.7	121.0	115.0	124.7	107.0	103.0	105.0	106.9	107.4	94.1	101.0	92.6

Figure 3. Yield of sugarcane as influenced by weed management (individual years and in pooled)

Removal of weeds by any means, definitely minimized the weed infestation considerably that ensued higher sugarcane yield, however the yield increments was directly correlated with weed management methods, its timing and selectivity of herbicides employed for weed removal.

Residue analysis

The reports on soil and plant samples analysis for herbicides residue reflected that the residues of different herbicides were in below detectable levels *i.e.* 0.05 μg/ml, it revealed that herbicides can be applicable for sugarcane crop.

Conclusion

Weeds become a serious threat for sugarcane crop production that caused 49.8 per cent yield reduction. Cane yield can be increase significantly with any of the weed management practices. Thus, HW (30, 60 and 90 DAP) + IC (40 and 90 DAP) found to be effective weed management strategy as it produced higher cane yield with maximum weed control efficiency. Pre-emergence application of atrazine or metribuzin effectively reduced the weed menace during early slow growth period of sugarcane while the HW+IC at 60 DAP eradicated later emerged weed flora from the field, hence integrated approach of chemical followed by mechanical weed control proved effective.

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