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Assessing bioefficacy of herbicides and their mixtures for weed management in *Rabi* maize (*Zea maize* L.)

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Abstract
A field experiment was conducted on medium black calcareous soil at Junagadh (Gujarat) during *Rabi* season of 2019-20 to study the bioefficacy of herbicides and their mixtures for weed management in *Rabi* maize (*Zea mays* L.). The experiment was laid out in randomized block design with three replications. The treatments comprised of: Atrazine 500 g/ha as PE *fb* 2,4-D (SS) 500 g/ha as PoE at 30 DAS, Atrazine 500 g/ha as PE *fb* halosulfuron-methyl 60 g/ha PoE at 30 DAS, Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS, Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS, Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + 2,4-D (SS) 250 g/ha at 30 DAS, Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + tembotrione 50 g/ha at 30 DAS, Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + topramezone 12.5 g/ha at 30 DAS, HW at 15 and 30 DAS, Weed free check and Unweeded check. The results of the experiment indicated that application of atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS, atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS and HW at 15 and 30 DAS improved growth and yield attributes, suppressed weed growth, and ultimately recorded higher grain and dry fodder yields of maize along with higher net returns.

Keywords: Maize, weed management, herbicide, pre-emergence, post-emergence, bioefficacy

Introduction

Maize (*Zea mays* L.) also known as corn, is a cereal grain that was first grown by people in Central America. It is now the third most important cereal crop in the world and is called the 'Queen of Cereals'. Maize is a leafy stalk whose kernels have seeds inside. The importance of maize is due to its wide diversity of uses. It is used both as food for humans and feed for animals. Corn is nearly directly consumed as feed. Maize is converted into a variety of foods such as popped snack food and staple alkali-cooked "Mexican" foods. It is also fractionated by either dry or wet milling into food and industrial ingredients. The starch, the major constituent of the maize kernel, is used in foods and industrial products. The starch is also converted into glucose/ fructose for use as food sweetness. Glucose can be fermented into ethanol for fuel or beverages. Maize has a nutritional value for both animals and humans (NCML, 2017) [9].

Globally, it is cultivated on more than 191.99 million hectares area with production of 1104.88 million tones and productivity of 5.75 t/ha across 166 countries having wider diversity of soil, climate, biodiversity and management practices (USDA, 2019) [17]. The United States produces more than 35% of the world's maize harvest. Other top producing countries are China, Brazil, Mexico, Argentina and India.

The overall yield loss in different crops due to weed infestation is estimated at around 36.5% in India. The use of herbicides is the only viable on-farm technology today to control weeds (Muchhadiya *et al.*, 2022) [7]. Weed control is a practice of great importance for obtaining high maize yields. Weed is a serious problem for the maize and its control is needed especially in infested sides. Therefore, weed management is an integral part of maize production. Recently, research has reported that the density and distribution of weed species in the maize fields are significant parameters on yield losses. This happens because the weed species competes with the sunlight, water and nutrients, and may, depending on the level of infestation and species, hamper harvesting operations and compromise the quality of grains. Other important biological factors in weed management decisions include weed and crop density, seed bank processes, demographic variation, weed-crop competition and reproductive biology.

There are some production problems and weed problem is one of them owing to wider spacing and non-tillering habit. Uncontrolled weed growth throughout the crop growing period caused 43% reduction in grain yield (Rao *et al*., 2009) [12]. Herbicides alone or in combination with other weed management techniques reduce weed-crop competition and the risk of weeds growing unchecked in the initial growing period (Angiras *et al*., 2010; Fakoor *et al*., 2010) [2, 5].

Purple nutsedge (*Cyperus rotundus* L.) is one of the most troublesome invasive weeds in tropical and subtropical climates and has been described as the world's worst perennial weed. It reproduces predominantly by basal bulbs, rhizomes and tubers, which allow it to flourish under a wide range of growing conditions. Purple nutsedge is difficult to control with herbicides too. To be effective, herbicide must be translocated throughout the rhizome and tuber network of the plant. Most herbicides may kill the plant's leaves and shoots, but have no effect on the root system and the tubers. Till now control of nutsedge in crop fields remains an unsolved problem for farmers.

Research studies indicated that halosulfuron-methyl (Rahnavard *et al.,* 2010; Rathika *et al.,* 2013) [10, 13] has been found very effective for control of purple nutsedge. Very encouraging results are also obtained in station trials under non-crop situations. But due to the residual activity up to 90 days after application, farmers have to sacrifice one season for control of purple nutsedge. The halosulfuron-methyl, tembotrione and topramezone are registered in the country for use in maize crop. Hence, it is worthwhile to test halosulfuron-methyl and other new herbicides for control of purple nutsedge in *Rabi* maize.

As a consequence of herbicide use, the presence of residues in field crop may cause damage to succeeding crop. Herbicide residues also remain in the soil surface due to the adsorption process which may potentially affect quality and yield of the next crop cultivated on the same field. Stable herbicides may be taken up by plants, which results in unwanted terminal residues (Battaglin *et al.* 2000) [3]. *Rabi* maize is commonly rotated with summer groundnut or sesame in Gujarat. Residue of herbicides can persist into the summer season. Since herbicides are necessary to manage prominent weeds, the presence of these residues in crop produce at harvest is of great concern.

Materials and Methods

A field experiment was conducted in Weed Control Research Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh during *Rabi* season of 2019-20. Geographically, Junagadh is situated at 21.5° N latitude and 70.5° E longitude with an altitude of 60 m above the mean sea level under South Saurashtra Agro-Climatic Zone of Gujarat state and enjoys a typically subtropical climate characterized by fairly cold and dry winter, hot and dry summer and warm and moderately humid monsoon. The rainy season commences in the first fortnight of June and ends by mid of September with an average rainfall of 1094 mm (average of last 10 years). The experimental soil was clayey in texture, medium in organic carbon (0.59) and slightly alkaline in reaction with pH 8.1 and EC 0.41 dS/m. The soil was low in available nitrogen (245.00 kg/ha) and available phosphorus (36.89 kg/ha) while medium in available potash (278.00 kg/ha). During the crop season, the minimum and maximum temperature ranged between 9.7 to 20.3 °C and 26.7 to 34.3 °C, respectively. While the average relative humidity was in the ranges of 32% to 66%. Wind speed ranges from 2.2 to 6.5 km/hr. Total rainfall received during crop growing season was 0.0 mm. The range of average sunshine and evaporation were 3.2-10.0 h and 3.1-7.5 mm, respectively.

The experiment comprising 10 treatments *viz.*, T_1: Atrazine 500 g/ha as PE *fb* 2,4-D (SS) 500 g/ha as PoE at 30 DAS, T_2: Atrazine 500 g/ha as PE *fb* halosulfuron-methyl 60 g/ha PoE at 30 DAS, T_3: Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS, T_4: Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS, T_5: Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + 2,4-D (SS) 250 g/ha at 30 DAS, T_6: Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + tembotrione 50 g/ha at 30 DAS, T_7: Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + topramezone 12.5 g/ha at 30 DAS, T_8: HW at 15 and 30 DAS, T_9: Weed free check and T_{10}: Unweeded check, was laid out in randomized block design with three replications.

The Gujarat Maize-6 (GM-6) was sown on November 27th, 2019 at row spacing of 60 cm x 20 cm using seed rate of 20 kg/ha. The gross and net plot size was 5.0 m x 3.6 m and 4.0 m x 2.4 m, respectively.

In aspect of weed studies the observation on various parameters species wise weed count, dry weight of weed, weed index and weed control efficiency (%) was recorded during experiment of research.

The crop was raised as per the recommended package of practices. The crop was harvested at physiological maturity on March 18th, 2020. The growth and yield attributes were recorded from the five tagged plants in each plot. Grain and fodder yield were recorded from the net plot area and converted into kilogram per hectare base.

The expenses to be incurred for all the cultivation operations from preparatory tillage to harvesting including the cost of inputs *viz.,* seeds, fertilizers, herbicides, *etc*. applied to each treatment will be calculated on the basis of prevailing local charges. The gross realization in terms of rupees per hectare will be worked out taking into consideration the maize grain and fodder yields from each treatment and local market prices. Net returns of each treatment will be calculated by deducting the total cost of cultivation from the gross returns. The benefit: cost ratio (B:C) was calculated by dividing gross return with cost of cultivation.

Results and Discussion

The results revealed that different treatments manifested significant influence on growth and yield of *Rabi* maize (Table 1). Among the different weed management treatments, the weed free check (T_9) registered significantly the highest plant height (172.33 cm) at harvest, which remained statistically at par with the treatments T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS), T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS), T_1 (Atrazine 500 g/ha as PE *fb* 2,4-D (SS) 500 g/ha as PoE at 30 DAS) and T_6 (Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + tembotrione 50 g/ha at 30 DAS).

The mean data from Table 1 revealed that the dry matter at harvest was significantly influenced with different treatments. Significantly the highest dry matter per plant (121.87 g) was given by the treatment T_9 (Weed free), but it was statistically comparable with the treatments T8 (HW at 15 and 30 DAS),

T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE fb topramezone 25 g/ha as PoE at 30 DAS) by registering dry matter of 118.28, 118.17 and 117.76 g, respectively.

A perusal of data presented in Table 1 indicated that different weed management treatments did not significantly influence days to 50% tasseling. So, data regarding days of silking showed that different weed management treatments did not impart their significant influence on days to 50% silking. This could be resulted in less weed-crop competition throughout the growth stage of the crop and created favorable environment for plant growth. Thus, enhanced availability of nutrients, moisture, light and space which might have accelerated the photosynthetic rate, thereby increasing the supply of carbohydrates, resulted in increase in growth characters. These findings are in agreement with those of Singh *et al.*, (2012) [12], Ahmed and Susheela (2012) [1], Hatti *et al.* (2015) [6], Rana *et al.* (2017) [11] and Sundari *et al.* (2019) [15].

The data presented in Table 1 revealed that the number of cobs per plant were significantly influenced by different weed management practices. Among the treatments, the weed free (T_9) recorded significantly the highest number of cobs per plant (2.37), but it was found statistically at par with the treatments T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS).

The data (Table 1) indicated that different treatments comprising herbicides and mechanical method did not influence the number of grain rows per cob. However, numerically the most number of grain rows (14.73) was found in the treatment T_9 (Weed free), whereas the treatment T_{10} (Unweeded check) recorded the least number of grain rows per cob (13.50).

The improved yield attributes under the treatments *viz*., weed free (T_9) and HW at 15 and 30 DAS (T_8) might be due to periodical removal of weeds by hand weeding as evidenced by less number of weeds and dry weight of weeds which might have maintained high soil fertility status and moisture content by means of less removal of plant nutrients and water by weeds. So, this might have increased nutrients and water uptake by the crop leading to increased rate of photosynthesis. Supply of photosynthates to various metabolic sinks might have favored yield attributes. Improved yield attributes under the treatments T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) might be attributed to better control of weeds from the initial stage by pre-emergence applied atrazine and post-emergence application of tembotrione or topramezone as evidenced by less count and dry weight of weeds, which might have resulted in the better utilization of nutrients and moisture available in the soil by the crop leading to production of more photosynthates. The superiority of these treatments could be explained on the basis that better growth under these practices might have produced more photosynthates and converted into numerous metabolites needed for such yield attributes. These findings are in close conformity with those reported by Ahmed and Susheela (2012) [1], Duary *et al.* (2015) [4] and Mukkund *et al.* (2017) [8].

A perusal of data (Table 1) revealed that different weed management treatments exhibited their significant influence on grain yield. Significantly the highest grain yield (4268 kg/ha) was recorded under the treatment T_9 (Weed free), but it remained statistically equivalent to the treatments T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) with grain yield of 4057, 3956 and 3827 kg/ha, respectively. On the contrary, the treatment T_{10} (Weedy check) recorded significantly the lowest grain yield (2512 kg/ha). So the extent of increase in grain yield with the treatments T_9 (Weed free), T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) was 69.92, 61.52, 57.47 and 52.36 per cent, respectively over the unweeded control (T_{10}).

Scrutiny of data (Table 1) showed that different weed management treatments caused their significant influence on dry fodder yield. Significantly the highest dry fodder yield (6308 kg/ha) was registered under the treatment T_9 (Weed free), which was found statistically equivalent to the treatments T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) with corresponding dry fodder yield of 5987, 5758 and 5381 kg/ha. However, significantly the lowest fodder yield (3573 kg/ha) was produced under the treatment T_{10} (Weedy check). So the magnitude of increase in fodder yield with the treatments T_9 (Weed free), T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) was 76.53, 67.57, 61.15 and 50.59 per cent, respectively over the unweeded control (T_{10}). It might be due to enhanced photosynthetic activity and partitioning of assimilates, resulting in improved yield attributes *viz*., cob length, cob girth, number of cobs per plant, number of grains per cob, grain weight per cob, 100-grain weight, 100-grain volume and shelling percentage, which were positively correlated with grain yield, evidently resulted in higher grain yield under the above mentioned treatments. So significantly the lowest grain and dry fodder yields were recorded under the unweeded control (T_{10}). Deprived growth and development of the crop under the unweeded control owing to severe crop-weed competition for resources might have been responsible for poor yields.

The data on total weeds at 30 DAS (Table 2) subsequently to the treatment T_9 (Weed free), significantly the lowest number of total weeds (6.00/m^2) was recorded under the treatment of HW at 15 and 30 DAS (T_8). Remaining treatments except the unweeded control have almost equal performance in this respect having total weed count of 43.33 to 55.00/m^2. Whereas, significantly the highest density of total weeds (81.00/m^2) was observed under the unweeded control (T_{10}).

The data on total weeds at 60 DAS (Table 2) revealed that in addition to the weed free (T_9), the treatment of HW at 15 and 30 DAS (T_8) recorded significantly the lowest density of total weeds (12.00/m^2) at 60 DAS, followed by atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS (T_3) and atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS (T_4) with corresponding total weed density of 28.67 and 35.67/m^2. Whereas, significantly the highest number of total weeds (113.33/m^2) at 60 DAS was detected under the unweeded control (T_{10}).

Table 1: Growth and yield of *Rabi* maize under various weed management practices

Treatments	Plant height (cm)	Dry matter/ plant (g)	Days to 50% tasseling	Days to 50% silking)	Number of cobs per plant	Number of grain rows per cob	Grain yield (kg/ha)	Fodder yield (kg/ha)
T_1 : Atrazine 500 g/ha as PE *fb* 2,4-D (SS) 500 g/ha as PoE at 30 DAS	160.07	110.50	55.33	58.33	1.87	13.87	3409	4974
T_2 : Atrazine 500 g/ha as PE *fb* halosulfuron-methyl 60 g/ha PoE at 30 DAS	134.43	107.33	53.67	56.67	1.83	13.53	3212	4656
T_3 : Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS	166.33	118.17	57.33	60.33	2.07	14.50	3956	5758
T_4 : Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS	165.27	117.76	56.33	59.33	2.03	14.20	3827	5381
T_5 : Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + 2,4-D (SS) 250 g/ha at 30 DAS	139.67	108.67	54.00	57.00	1.83	13.60	3267	4689
T_6 : Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + tembotrione 50 g/ha at 30 DAS	157.97	110.31	54.33	57.33	1.87	13.83	3395	4926
T_7 : Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + topramezone 12.5 g/ha at 30 DAS	146.47	110.33	55.00	58.00	1.87	13.73	3377	4845
T_8 : HW at 15 and 30 DAS	167.73	118.88	57.67	60.33	2.27	14.67	4057	5987
T_9 : Weed free check	172.33	121.87	59.00	61.67	2.37	14.73	4268	6308
T_{10} : Unweeded check	127.13	91.00	52.33	56.00	1.43	13.50	2512	3573
S.Em.±	5.38	3.52	1.93	1.95	0.16	0.45	220	330
CD (P=0.05)	15.97	10.45	NS	NS	0.48	NS	653	981
C.V.%	6.06	5.47	6.04	5.78	14.27	5.60	10.79	11.19

Table 2: Total number of weeds, dry weight of weeds, weed control efficiency, weed index and economics under various weed management practices in *Rabi* maize

Treatments	Total weeds (No./m^2) at 30 DAS	Total weeds (No./m^2) at 60 DAS	Total weeds (No./m^2) at harvest	Dry weight of weeds (kg/ha)	WCE (%)	WI (%)	Net return (₹/ha)	B:C ratio
T_1 : Atrazine 500 g/ha as PE *fb* 2,4-D (SS) 500 g/ha as PoE at 30 DAS	6.66 (44.33)	7.26 (52.67)	7.67 (60.00)	600	57.14	20.13	38044	2.34
T_2 : Atrazine 500 g/ha as PE *fb* halosulfuron-methyl 60 g/ha PoE at 30 DAS	7.27 (53.00)	7.66 (58.67)	8.61 (74.33)	743	46.90	24.76	29316	1.88
T_3 : Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS	6.58 (43.33)	5.34 (28.67)	6.00 (37.00)	185	86.79	7.33	45253	2.43
T_4 : Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS	6.75 (45.67)	5.97 (35.67)	6.67 (44.67)	223	84.05	10.33	42224	2.32
T_5 : Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + 2,4-D (SS) 250 g/ha at 30 DAS	7.39 (54.67)	7.63 (58.33)	8.36 (70.67)	707	49.52	23.46	32774	2.07
T_6 : Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + tembotrione 50 g/ha at 30 DAS	6.97 (48.67)	6.30 (39.67)	7.89 (62.33)	630	55.00	20.45	33529	2.03
T_7 : Atrazine 500 g/ha as PE *fb* tank-mix halosulfuron 30 g/ha + topramezone 12.5 g/ha at 30 DAS	7.41 (55.00)	6.88 (47.33)	8.24 (68.00)	680	51.43	20.87	34005	2.08
T_8 : HW at 15 and 30 DAS	2.44 (6.00)	3.46 (12.00)	3.87 (15.00)	75	94.64	4.94	38785	1.96
T_9 : Weed free check	1.63 (2.67)	1.63 (2.67)	1.58 (2.67)	13	99.05	-	38633	1.87
T_{10} : Unweeded check	8.96 (81.00)	10.60 (113.33)	11.82 (140.00)	1400	-	41.15	22216	1.84
S.Em.±	0.26	0.27	0.41	52	-	-		
CD (P=0.05)	0.77	0.79	1.23	154	-	-		
C.V.%	7.24	7.36	10.13	17.10	-	-		

The data (Table 2) revealed that all the weed management treatments significantly curbed the number of total weeds at harvest over the unweeded control (T_{10}), which noted the highest total weed density (140.00/m^2). Next to the weed free (T_9), HW at 15 and 30 DAS (T_8) recorded significantly the lowest count of total weeds (15.00/m^2), followed by atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS (T_3) and atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS (T_4) with total weed count of 37.00 and 44.67/m^2, respectively.

The data on dry weight of weeds (Table 2) revealed that there were conspicuous differences in dry weight of weeds at harvest among different weed management treatments. Next to the treatment T_9 (Weed free), significantly the lowest dry weight of weeds (75 kg/ha) was recorded under the treatment T_8 (HW at 15 and 30 DAS), followed by the treatments T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) with weed dry weight of 185 and 223 kg/ha, respectively. Conversely, significantly the highest dry weight of weeds (1400 kg/ha) was recorded under the treatment T_{10} (Unweeded control).

The computed data on weed control efficiency (WCE) are presented in Table 2. The 99.05% WCE was observed under the treatment T_9 (Weed free). Among the rest of the weed management treatments, the highest WCE (94.64%) was registered under the treatment T_8 (HW at 15 and 30 DAS), followed by the treatments T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) having WCE of 86.79 and 84.05%, respectively. The lowest WCE (46.90%) was observed under the treatment T_2 (Atrazine 500 g/ha as PE *fb* halosulfuron-methyl 60 g/ha PoE at 30 DAS).

The calculated data on weed index (WI) are furnished in Table 2. The highest WI (41.15%) was recorded under the unweeded control (T_{10}), which indicates the unrestricted weed growth reduced the grain yield of maize by 41.15%. Among the rest of treatments, the lowest WI of 4.94% was recorded under the treatment comprising HW at 15 and 30 DAS (T_8), closely followed by atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS (T_3) and atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS (T_4) with WI of 7.33 and 10.33%, respectively. So, this might be attributed to the effective control of weeds under these treatments, which is reflected in less number of weeds and ultimately lower weed biomass. In addition to this, dense crop canopy might have suppressed weed growth and ultimately less biomass. The unweeded control (T_{10}) recorded significantly the highest dry weight of weeds owing to uncontrolled conditions that favored luxurious weed growth leading to increased dry matter. On the other hand this might be due to elimination of weeds by manual weeding or by herbicides under the treatments T_8 (HW at 15 and 30 DAS), T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS). The combined effect on lower dry weight of weeds and higher grain yield under these treatments might have been responsible for the excellent weed indices.

The data on economics (Table 2) indicated that maximum net return of ₹ 45253/ha was realized with the treatment T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS), followed by the treatments T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS), T_8 (HW at 15 and 30 DAS) and T_9 (Weed free check) by recording net return of ₹ 42224, and 38785 and 38633/ha, respectively. The lowest net return of ₹ 22216/ha was achieved under the treatment T_{10} (Weedy check).

An appraisal of data (Table 2) showed that maximum B:C of 2.43 was obtained with the treatment T_3 (Atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS), followed by the treatments T_1 (Atrazine 500 g/ha as PE *fb* 2,4-D (SS) 500 g/ha as PoE at 30 DAS) and T_4 (Atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS) by securing B:C of 2.34 and 2.32, respectively. The lowest B:C of 1.84 was accrued under the treatment T_{10} (Unweeded check). The highest net return and B:C ratio gained in the treatment T_3. This might be due to effective and efficient control of weeds by hand weeding and pre-emergence herbicide atrazine and post-emergence herbicides tembotrione and topramezone. The highest B:C ratio under these treatments might have been due to less cost of herbicides and higher production of grain as well as fodder. These findings are in close vicinity with those reported by Duary *et al.* (2015) [4], Rana *et al.* (2017) [11] and Swetha *et al.* (2015) [16].

Conclusion

On the basis of the results obtained from the present one year field experimentation, it could be concluded that effective and economical control of weeds with higher grain yield of *Rabi* maize can be obtained by pre-emergence application of atrazine 500 g/ha and post emergence application of either tembotrione 100 g/ha or topramezone 25 g/ha at 30 days after sowing under South Saurashtra Agro-Climatic Zone.

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