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Non suitability of tembotrione and topramezone for weed management in sorghum [*Sorghum bicolor* (L.) Moench]

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ABSTRACT

A field experiment was conducted during rainy *(Kharif)* seasons of 2019 and 2020 at Hagari, Karnataka, India to assess the efficacy of post-emergence application (PoE) of two HPPD (p-hydroxy-phenyl-pyruvate dioxygenase) enzyme inhibitive herbicides, *viz*. tembotrione and topramezone in combination with pre-emergence application (PE) of atrazine. Among the 10 treatments tested, atrazine 1000 g/ha PE followed by (*fb*) atrazine 1000 g/ha PoE or 2,4-D Na salt 937.5 g/ha PoE or 2, 4-D Ethyl Ester 2368 g/ha PoE at 20 days after sowing (DAS) proved as effective as weed free treatment (hand weeding twice) in increasing the sorghum grain yield and net returns. The topramezone 37.5 and 56.3 g/ha PoE though provided effective weed control, caused phytotoxicity to sorghum resulting in 21 and 39% grain yield reduction and 32 and 74% net return reduction, respectively when compared to atrazine PE applied alone which recorded grain yield of 2.31 t/ha and net return of ₹ 45,007 but it was better than weedy check. The tembotrione 70.3 and 105.5 g/ha PoE also caused reduction of 2.1 and 3.3% in biological yield, 18.6 and 26.1 in grain yield and 19.2 and 63.9% in net returns, respectively and was significantly inferior to weedy check. The crop phytotoxicity of tembotrione resulted in negative herbicide efficiency index (-0.09 to -0.78) and high weed index values (37.32 to 51.7) indicating its non-suitability for use in sorghum. The uncontrolled weeds (weedy check) on an average have caused 32.1, 42.7 and 32.5% reduction in biological yield, grain yield and net returns, respectively when compared to weed free check.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the second most extensively grown millet crop of India after pearl millet under rainfed situations during both *Kharif* (rainy) and *Rabi* (winter) seasons. Of the estimated yield potential of 3.31 t/ha in *Kharif* season (Murty *et al.* 2007), farmers on an average (2013-14 to 2017-18) realized only 0.995 t/ha *i.e.* 30.1% of potential yields (Agricultural Statistics at a Glance, 2019). Karnataka, the second leading state of sorghum crop in terms of both area and production (1.09 Mha and 1.14 MT) after Maharashtra (Agricultural Statistics at a Glance 2019) too known for low productivity (1048 kg/ha during 2017-18). This low productivity realization of rain fed sorghum has been ascribed to various biotic and abiotic stresses and among the biotic stresses, weeds continue to be the most important one (Thompson *et al.* 2019, Mishra and Talwar 2020). This is more so during *Kharif* season owing to frequent rains that makes the crop prone to severe weed infestation and sometimes more than a flush of weeds are seen with untimely rains. Studies have indicated that uncontrolled weeds limit *Kharif* grain sorghum yield by 25.1% (Gharde *et al.* 2018) in India. This warrants for an effective weed management solution to achieve higher productivity and profitability. Traditional methods of weed management like animal drawn mechanical inter-row and manual hand weeding (Attalla 2002) though are quite effective, but are costly due to decline in draught animals and manpower availability leading to emergence of herbicides as effective weed management tool. Among herbicides, 2,4-D (Stahlman and Wicks 2000) and atrazine (Sharma *et al.* 2000) have become most commonly used herbicides for grain sorghum crop.

However, 2,4-D is selective to broad-leaved weeds and atrazine has low effectiveness against grasses and sedges (Dan *et al.* 2011) under moisture stress conditions. Further, repeated use of atrazine was found to bring in not only weed shift but also development of herbicide resistance in weeds (Heap 2020). Therefore, alternatives to atrazine are looked at for using in sorghum. The HPPD (p-hydroxy-phenyl-pyruvate dioxygenase) enzyme inhibitive post-emergent herbicides (topramezone and tembotrione) with broad-spectrum weed control, flexible application timing, tank-mix compatibilities, better crop safety (Singh *et al.* 2012) and ability to control triazine resistant weeds (Kohrt and Sprague 2017) have been made available to meet the above needs in maize. Thus, a study was undertaken at All India Coordinated Sorghum Improvement Project (AICSIP) to assess the suitability and efficacy of post-emergence application (PoE) of topramezone and tembotrione herbicides in sequence to the pre-emergence application (PE) of atrazine in grain sorghum grown in *Kharif* (rainy) season.

MATERIALS AND METHODS

A field experiment was conducted during two consecutive *Kharif* (rainy) seasons of 2019 and 2020 under All India Coordinated Sorghum Improvement Project at Agricultural Research Station Farm, Hagari, University of Agricultural Sciences, Raichur, Karnataka, India in grain sorghum. The experimental site was situated at 14° 70' N latitude, 76° 15' E longitude at an altitude of 458 m above mean sea level. The experimental non-saline (EC: 0.38 dS/m) alkaline (8.76 pH) clay soil was rated as medium for organic carbon (0.61%), available N and K (235.6 and 378.8 kg/ha) and high for available P (18.8 kg/ha). The experiment comprised of ten weed management treatments: atrazine 1000 g/ha PE followed by (*fb*) 2,4-D Na Salt 937.5 g/ha PoE at 20 days after seeding (DAS); atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS; atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS; atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS; atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS; atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS; weed free (hand weeding twice at 15 and 35 DAS) and weedy check. Experiment was laid out in Randomized complete block design (RCBD) with three replications. Sorghum cv. *CSH-25* seed (7.5 kg/ha) was dibbled in rows at 45 cm apart with an inter-plant spacing of 15 cm on 5th July, 2019 and 3rd July, 2020, respectively. Recommended dose of fertilizers and manures (100:33.3:37 kg/ha N: P: K + FYM 5 t/ha) were used in the experiment. FYM was applied 15 days prior to sowing. Entire dose of P and K along with 50% nitrogen in the form of di-ammonium phosphate, muriate of potash and urea, respectively were broadcast applied at the time of sowing. Remaining nitrogen was placed near the hill at 4 weeks after sowing. Recommended package of practices was adopted for crop production and crop was harvested on 21st November, 2019 and 12th November 2020 at physiological maturity. Application of herbicides was done as per treatment using 500 litres of spray volume/ha. The pre-emergence application of atrazine was done immediately after sowing. A rainfall of 517.8 and 528.8 mm was received in 30 and 27 rainy days during 2019 and 2020 crop cycle, respectively.

The species wise weed density (no./m^2) was recorded at 20, 40, 60 DAS and at harvest by placing three quadrats of 0.5 x 0.5 m per plot. The collected weeds were categorized as grasses, sedge and broad-leaved weeds and likewise weed dry weight (biomass) was recorded. Weed control efficiency (WCE) and herbicide efficiency index (HEI) were worked out taking weed biomass and grain yield into consideration, respectively. Weed index was worked out as ratio of grain yield from weed free plot – grain yield from treated plot / yield from weed free plot. The observations on phytotoxicity on sorghum plants were recorded on the basis of phytotoxicity rating scale (PRS) for the applied herbicides at 3, 6, 9 and 12 DAT (days after treatment). The parameters on phytotoxicity were taken as leaf epinasty and hyponasty, necrosis (leaf tips and margins) and wilting. The observation on the level of phytotoxicity through visual assessment of crop response was rated in the scale of 0-10 (0 = no adverse effect of herbicide on sorghum and 10= 100 % adverse effect of herbicide). Data on sorghum growth and gain yield attributes were recorded from 5 randomly selected plants, while yield data on net plot basis at harvest. For economics, prevailing market price of inputs and support price of outputs was used. As similar trend was observed in the results of 2019 and 2020 for all the characters, a pooled analysis was done for all the results of all the parameters studied and were subjected for statistical analysis and interpretation as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

The experiment field was infested by grassy and broad-leaved weeds during both the years. *Cynodon dactylon, Brachiaria reptans, Chloris inflata, Dactyloctenium aegeptium, Digitaria bicornis,*

Dinebra retroflexa and *Cynotis culcullata* (grassy weeds); *Euphorbia geniculata, Corchorus aestuans, Abutilon hirtum, Amaranthus viridis, Aristolachia bractiata, Digeria muricata* (synonym: *D. aravensis*) and *Euphorbia humifusa* (broad-leaved weeds) and *Cyperus rotundus* (sedge) were predominant during both the years of study.

Effect on weed density, weed biomass and weed control efficiency

Weed density and biomass at 20 DAS showed the effectiveness of atrazine (PE) in the management of entire associated weed flora (grasses, sedges, broad-leaved weeds) as it recorded significantly lower weed density and biomass than weedy check but was markedly higher than weed free, where hand weeding was carried out just 5 days prior to the observation (15 DAS) (**Table 1** and **2**). The PoE herbicide application was observed to be essential to manage increased weed density and biomass of grass and broad-leaved weeds at 40 DAS when compared to those observed at 20 DAS. The repeated application of atrazine as PoE provided effective control of grasses. But it was less effective against broad-leaved weeds. The use of 2,4-D Na salt or 2,4-D ethyl ester as PoE after the pre-emergence application of atrazine provided effective control of broad-leaved weeds but was less effective against grasses when compared to atrazine PoE. Tembotrione at both doses and topramezone 56.3 g/ha as PoE showed greater effectiveness against grasses than atrazine, 2,4-D Na salt and 2,4-D Ethyl Ester (PoE). The efficacy of tembotrione and topramezone on broad-leaved weeds control was intermediate to the efficacy between 2,4-D Na salt & 2,4-D Ethyl Ester and atrazine (PoE). The total weed density at 40 DAS was markedly lower with tembotrione and topramezone PoE than all other PoE herbicides tested and least total weed density was recorded with tembotrione 105.5 g/ha.

Weed control efficiency (an estimate based on weed biomass) at 20 DAS indicated that atrazine (PE) attained WCE values of 80.5-83.8% as against 100% in hand weeding while at 40 DAS, repeat application of atrazine (PoE at 20 DAS) enhanced its weed management efficacy further with 13.5% higher WCE than that at 20 DAS (70.2%) achieved with atrazine (PE) (**Table 2**). Use of 2,4-D Na salt or 2,4-D Ethyl Ester (PoE) following atrazine (PE) further enhanced WCE over atrazine (PE + PoE). Tembotrione at both doses and topramezone 56.3 g/ha (PoE) brought marked improvements in WCE values over 2,4-D Na salt and 2,4-D Ethyl Ester (PoE) and topramezone (37.5 g/ha).

Table 1. Effect of pre- and post-emergence herbicides on weed density at 20 and 40 days after seeding of *Kharif* grain sorghum (pooled data of 2019 and 2020)

Treatment	Weed density (no./m^2)							
	Grasses		Sedges		Broad-leaved		Total	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Atrazine 1000 g/ha PE	4.50 (2.18)	11.50 (3.43)	0.50 (0.86)	0.83 (1.04)	3.83 (2.02)	5.83 (2.47)	8.83 (3.01)	18.17 (4.29)
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	4.00 (2.06)	3.67 (1.97)	0.50 (0.86)	0.67 (0.96)	4.25 (2.12)	4.83 (2.25)	8.75 (3.00)	9.17 (3.07)
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	4.17 (2.10)	6.67 (2.63)	0.67 (0.96)	0.83 (1.04)	4.17 (2.10)	1.83 (1.44)	9.00 (3.04)	9.33 (3.10)
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	3.67 (1.98)	6.17 (2.53)	0.67 (0.96)	0.83 (1.04)	4.83 (2.25)	1.83 (1.44)	9.17 (3.07)	8.83 (3.01)
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	4.33 (2.14)	3.17 (1.85)	0.67 (0.96)	0.67 (0.96)	4.92 (2.27)	3.50 (1.94)	9.92 (3.19)	7.33 (2.75)
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	4.00 (2.06)	2.50 (1.66)	0.67 (0.96)	0.67 (0.96)	4.67 (2.22)	2.67 (1.71)	9.33 (3.10)	5.83 (2.47)
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	4.00 (2.06)	2.33 (1.61)	0.50 (0.86)	0.67 (0.96)	4.58 (2.20)	2.75 (1.73)	9.08 (3.06)	5.75 (2.45)
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	4.00 (2.06)	2.00 (1.50)	0.83 (1.04)	0.67 (0.96)	4.17 (2.10)	2.50 (1.65)	9.00 (3.04)	5.17 (2.33)
Weed free hand weeding twice at 15 and 35 DAS	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)
Weedy check	23.33 (4.86)	31.50 (5.63)	3.22 (1.86)	3.67 (1.98)	16.33 (4.07)	24.00 (4.92)	42.89 (6.57)	59.17 (7.71)
LSD (p=0.05)	0.08	0.15	0.09	0.11	0.07	0.13	0.08	0.13

Note: Figures in the parentheses are transformed $\sqrt{x+0.25}$ values and ante parentheses are original values. Transformed values were statistically analysed; PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding

Effect on sorghum growth and yield attributes

The higher sorghum plant height and yield attributes of sorghum was observed with all the weed management treatments when compared to weedy check, except topramezone 56.3 g/ha combination (**Table 3)**. Topramezone 56.3 g/ha (PoE) had significantly lower plant height and yield attributes than weedy check due to its phytotoxicity as evidenced from negative HEI values (**Table 3**). Atrazine PE followed by atrazine or 2,4-D Na or 2,4-D Ethyl Ester PoE registered panicles/m^2 and test weight values at par to that of weed free treatment. However, weed free treatment recorded markedly taller plants and higher number of grains/panicle than all other treatments. Topramezone and tembotrione (PoE) were found to be phytotoxic to sorghum crop and the phytotoxicity increased with their higher doses. Tembotrione at both doses and topramezone at 56.3 g/ha significantly reduced the plant height, panicles/m^2 and grains/panicle and test weight when compared to atrazine PE. Tembotrione showed its negative impacts on test weight also when applied at 105.5 g/ha. Phytotoxicity scale indicated a dose dependence increase in both topramezone and tembotrione (2.00-3.83) and topramezone showed greater phytotoxicity ratings than tembotrione. The observed phytotoxicity in this study is in accordance with the findings of Dan *et al.* (2010).

Effect on sorghum grain yield and harvest index

The weed free treatment recorded the highest sorghum biological yield, grain yield and harvest index due to taller plants, higher yield attributes, while the lowest values were recorded in weedy check (**Table 4**). The uncontrolled weeds in sorghum caused 31.2 and 29.9% reduction in biological and grain yields as compared to weed free. Gharde *et al.* (2018) reported 25.1% sorghum grain yield loss due to uncontrolled weeds. Atrazine PE has bridged the grain yield gap by 51.4% and when atrazine PE was followed by PoE herbicide use (atrazine / 2,4-D Na Salt / 2,4-D Ethyl Ester), almost 94.8-97.7% yield gap was bridged resulting in grain yield that was at par with weedy free check. Atrazine PE *fb* tembotrione 70.3 g/ha PoE though proved as effective as above PE + PoE herbicide combinations

Table 2. Effect of pre- and post-emergence herbicides on weed biomass and weed control efficiency in grain sorghum (pooled data of 2019 and 2020)

Treatment	Weed biomass (g/m^2)								Weed control efficiency (%)	
	Grasses		Sedges		Broad-leaved		Total			
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Atrazine 1000 g/ha PE	1.41 (1.29)	8.18 (2.90)	0.11 (0.60)	0.46 (0.84)	1.37 (1.27)	4.85 (2.26)	2.88 (1.77)	13.48 (3.71)	80.53	70.23
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	1.08 (1.15)	2.94 (1.78)	0.11 (0.60)	0.34 (0.77)	1.25 (1.22)	4.07 (2.08)	2.45 (1.64)	7.35 (2.75)	83.61	83.78
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	1.22 (1.21)	4.68 (2.22)	0.15 (0.63)	0.42 (0.81)	1.18 (1.19)	1.48 (1.32)	2.54 (1.67)	6.58 (2.61)	82.86	85.48
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	1.09 (1.16)	4.19 (2.11)	0.15 (0.63)	0.41 (0.81)	1.54 (1.34)	1.38 (1.27)	2.78 (1.74)	5.97 (2.49)	81.27	86.81
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	1.27 (1.23)	2.11 (1.54)	0.16 (0.64)	0.33 (0.76)	1.40 (1.28)	2.46 (1.65)	2.83 (1.76)	4.90 (2.27)	80.90	89.19
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	0.98 (1.11)	1.57 (1.35)	0.14 (0.62)	0.32 (0.75)	1.28 (1.23)	1.92 (1.47)	2.40 (1.63)	3.81 (2.02)	83.82	91.58
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	1.04 (1.13)	1.15 (1.18)	0.11 (0.60)	0.31 (0.75)	1.35 (1.26)	2.00 (1.50)	2.49 (1.65)	3.45 (1.92)	83.29	92.37
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	1.15 (1.18)	1.25 (1.22)	0.18 (0.65)	0.31 (0.75)	1.16 (1.18)	1.81 (1.43)	2.48 (1.65)	3.37 (1.90)	83.26	92.56
Weed free hand weeding twice at 15 and 35 DAS	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	100.00	100.00
Weedy check	7.28 (2.74)	24.47 (4.97)	0.78 (1.01)	1.95 (1.48)	6.81 (2.66)	18.88 (4.37)	14.87 (3.89)	45.30 (6.75)	0.00	0.00
LSD (p=0.05)	0.09	0.08	0.03	0.05	0.06	0.14	0.09	0.13	1.11	1.29

Note: Figures in the parentheses are transformed $\sqrt{x+0.25}$ values and ante parentheses are original values. Transformed values were statistically analysed; PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding

for grain yields, but was markedly inferior to weed free check. Better grain yield performance of these herbicide treatments could be ascribed to higher number of panicles/m^2, grains/panicle and test weight (**Table 3**) due to enhanced resource supplies (light, space, water, nutrients) to crop under effective management of complex weed flora. The atrazine (PE) + tembotrione 70.3 g/ha PoE has recorded sorghum grain yield markedly lower than that in sole application of atrazine PE. Topramezone PoE at both doses (37.5 and 56.3 g/ha) following atrazine (PE) proved counterproductive as evident from significantly reduced grain yields (21 and 39%) than PE atrazine (2.31 t/ha). There was a significant reduction in harvest index values with topramezone (56.3 g/ha) and tembotrione (105.5 g/ha) over their lower rates, all other herbicides and even in treatments without herbicides.

Herbicide efficiency index (HEI), weed index (WI) and phytotoxicity

Weed index data (**Table 3**) indicated that atrazine PE *fb* 2,4-D Na salt PoE / 2,4-D ethyl ester PoE being at par with atrazine PE *fb* atrazine (PoE) provided efficient weed control in grain sorghum. Topramezone 37.5 g/ha PoE proved ineffective as evident from its at par weed index values as weedy check (34.6) and less effective than weedy check when applied at higher dose (51.7 g/ha PoE). These low weed index values of topramezone are reflected in negative herbicide efficiency index values *i.e.* -0.09 and -0.78 with 37.5 and 56.3 g/ha rates of application, respectively. Significantly higher weed index values with tembotrione 105.5 g/ha PoE (24.3) over atrazine PE (15.9) reveals its ineffectiveness and its phytotoxicity when HEI of its lower and higher dose (2.41 and 1.92) are compared. Topramezone and tembotrione phytotoxicity (0-10 scale) increased from 2.83 to 3.83 and 2.00 to 2.83, respectively as dose increased from low to high level. Similar phytotoxicity effects of tembotrione (Dan *et al*. 2010) and topramezone (Grossmann and Ehrhardt 2007) have been already reported in sorghum, elsewhere. Tembotrione and topramezone phytotoxicity persisted for 20-25 days and later the sorghum crop gradually recovered at later stages as reported by Shidenura (2019) and Rajesh Patil (2020).

Economics

The weed free (hand weeding twice) treatment costed ₹ 8,955/ha and thus cost of production over weedy check (₹ 33,007/ha) was enhanced by 27.1% (**Table 4**). However, atrazine PE *fb* 2,4-D ethyl ester PoE, atrazine PE *fb* PoE and atrazine PE *fb* 2,4-D Na salt PoE incurred only 35.1, 37.2 and 40.5% of the cost of weed free treatment. The lower cost of weeding with PE *fb* PoE herbicides treatments coupled with statistically similar stover and grain yields has resulted in statistically at par net incomes as weed free treatment (₹ 51,834/ha). Atrazine PE *fb* 2,4-D Na salt PoE and atrazine PE *fb* PoE on account of lower cost of cultivation despite of slightly lower yields attained significantly higher B:C ratio (2.52 & 2.46) than weed free treatment (2.22). Similar economic superiority of PE *fb* PoE herbicides treatments over weed-free treatment was reported by Shidenura (2019) and Rajesh Patil (2020).

It was concluded that application of atrazine 1000 g/ha PE followed by 2, 4-D Na salt 937.5 g/ha PoE at 20 DAS could be the best herbicide weed-management option for grain sorghum grown in *Kharif* season, from productivity and profitability

Table 3. Effect of pre- and post-emergence herbicides on sorghum growth and yield attributes, weed index (WI), herbicide efficiency index (HEI) and phytotoxicity to sorghum (pooled data of 2019 and 2020)

Treatment	Sorghum plant height (cm) at harvest	Panicles no./m^2	Grains/ panicle (no.)	Test weight (g)	WI (%)	HEI	Phyto-toxicity (0-10 scale)
Atrazine 1000 g/ha PE	147.2	13.63	2475	29.2	15.93	0.94	0.00
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	148.6	14.25	2621	29.8	3.58	2.26	0.00
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	149.6	14.22	2723	30.5	2.46	2.36	0.00
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	148.6	14.24	2575	29.8	6.17	2.14	0.00
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	144.5	12.62	2260	28.7	37.32	-0.09	2.83
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	148.8	13.62	2583	29.5	9.66	2.41	2.00
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	140.1	12.00	2106	28.2	51.70	-0.78	3.83
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	147.8	13.28	2337	29.2	24.33	1.92	2.83
Weed free hand weeding twice at 15 and 35 DAS	152.9	14.36	2955	30.5	0.00	-	0.00
Weedy check	144.9	12.99	2301	29.0	34.61	0.00	0.00
LSD (p=0.05)	2.19	0.72	213	0.70	13.44	-	0.14

PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding

Table 4. Economics of *Kharif* grain sorghum cultivation as influenced by pre- and post-emergence herbicides (pooled data of 2019 and 2020)

Treatment	Biological yield (t/ha)			Grain yield (t/ha)			Harvest Index	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C
	2019	2020	Pooled	2019	2020	Pooled				
Atrazine 1000 g/ha PE	8.23	15.16	11.69	1.43	3.19	2.31	19.39	34730	45006	2.28
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	9.82	16.33	13.08	1.76	3.46	2.61	19.68	36340	53459	2.46
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	9.92	17.20	13.56	1.77	3.51	2.64	19.24	36154	55404	2.52
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	9.34	16.42	12.88	1.65	3.48	2.56	19.56	36632	51618	2.40
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	4.48	14.31	9.39	0.76	2.90	1.83	18.92	37271	26190	1.69
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	9.41	15.73	12.57	1.64	3.25	2.44	19.18	36794	48007	2.29
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	4.02	11.59	7.81	0.62	2.18	1.40	17.37	38067	11697	1.30
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	7.81	15.06	11.43	1.16	3.09	2.12	17.99	36993	37699	2.01
Weed free hand weeding twice at 15 and 35 DAS	10.10	17.77	13.94	1.83	3.57	2.70	19.21	41962	51834	2.22
Weedy check	4.68	14.51	9.59	0.84	2.95	1.89	19.33	33007	32401	1.96
LSD (p=0.05)	1.46	0.77	1.06	0.26	0.34	0.17	0.87	-	5900	0.21

Note: Labour: ₹ 396.5, Bullock pair: ₹ 1250/day, Tractor hiring: ₹ 800/hour, FYM: ₹ 1250/t, Urea: ₹ 5.80/kg, DAP: ₹ 26.0/kg, MOP: ₹ 18.60/kg, Seeds: ₹ 115/kg, atrazine 50% WP ₹ 586/kg, 2,4-D Na Salt 80 WP/2,4-D Ethyl Ester 38EC: ₹ 360/l, Topramezone 33.6 SC: ₹ 3950 /75 ml, Tembotrione 34.4 SC: ₹ 1063/75 ml, Chloropyrifos: ₹ 600/l, Chlorantraniliprole 18.5% SC (Coragen) ₹ 15167/l, Sorghum grain (stover): 26.4 (2)/kg, Marketing charges 3% of the produce and Interest on outlay: 7% per annum.

point of view, in lieu of manual weeding (weed free with hand weeding twice) treatment. New herbicide, topramezone was found counter productive while tembotrione was also not an economically viable alternative.

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