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Atrazine use to control weeds and its residue determination in fodder crops of maize and sorghum

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ABSTRACT

Field experiments were conducted at the fodder farm of ICAR-IVRI, Izatnagar campus, Bareilly. Different doses of atrazine (0.50, 0.75, 1.00 and 2.00 kg/ha) as pre- and post-emergence were applied. The weedy check plots of fodder maize were largely infested by *Trianthema portulacastrum, T. monogyna* followed by other broad-leaved weeds during 1st year. However, during 2nd year, infestation of these weeds were considerably lower due to higher seed rate and use of ferti-seed-drill. In double-cut fodder sorghum, *Trianthema* sp. recorded the highest absolute density and absolute frequency followed by sedge (*Cyperus esculentus*), grasses (*Digitaria ciliaris, Setaria glauca*) and other broad-leaved weeds (*Coccinia grandis, Celosia argentea* and *Cleome viscosa*). The broad-leaved weeds *Ageratum conyzoides* and *Sonchus oleraceus* appeared after 1st cutting. In fodder maize, atrazine with all the doses as pre- and post-emergence showed effectiveness. Weeds in weedy check treatment caused a yield reduction of 22.6%, however, in 2nd year the value was 1.7% due to restricted weed growth. Most significant results were recorded in weedy check treatment in which 60.3% yield increment of green fodder maize was registered in 2nd year over 1st year and this resulted in the highest benefit: cost ratio of 3.15. ` 52,400/ha more profit was recorded over broadcasting method of sowing. Higher seed rate (63 kg/ha) along with the use of ferti-seed-drill was equally effective with atrazine treatments. In double-cut sorghum, pre-emergence treatments of atrazine 0.75 kg/ha and above recorded comparatively higher green fodder yield than post-emergence treatments. Weedy check treatment recorded the weed index value of 17.9%. Cumulative green fodder yield (1st and 2nd cut) was highest in weed-free treatment closely followed by atrazine 2.0 kg/ha as pre-emergence treatment. Additional investment of ` 2020/ha after 1st cutting registered the additional net returns of ` 43,100/ha. This indicated the benefits of growing double-cut sorghum and also shown the importance of growing multi-cut and perennial fodder crops. Both the green fodder crops contained atrazine residue at harvest.

INTRODUCTION

Due to competing land use, area under cultivated fodder is static to around 8.4 million hectares since last two decades. The fodder production in the country is not sufficient to meet the requirements of the growing livestock population and also the forages offered to animal are mostly of poor quality. At present, the country faces a net deficit of 33.10% green fodder, 11.41% dry crop residues and 64% feeds. 54% of the total fodder is met from crop residue, while 18% fodder is met from grasslands and only 28% fodder is met from cultivated fodder crops (Anonymous 2013). Like grain crops, weeds are also considered as a major constraint in fodder crops. Weeds possess several characters and that attribute advantages of weeds on fodder crops. Rapid emergence capacity, development of large weed population and aggressive growth of the weeds suppress the growth of fodder crops and, inflict greatest damage to the crop in terms of low green fodder yield and impairing quality of green fodder. Admixture of weeds with green fodder during harvest like *Coronopus didymus* with berseem, *Coccinia grandis* with fodder maize and sorghum, *Celosia argentea* with fodder sorghum, *Trianthema* with fodder maize and sorghum, reduces palatability of green fodder and thus affects milk production of milch animal. The loss in fodder yield due to weed

competition has been reported to the extent of 11.7% in lucerne and 8.3% in oat. In crops like sorghum, magnitude of yield loss was as high as 54%, while uptake of nitrogen, phosphorous and potassium by weeds was to the extent of 48.8, 22.0 and 55.0 kg/ha, respectively (Menhi Lal *et al.* 1994). In berseem, the infestation of weed flora reduced green fodder yield of 23 to 28% and seed yield of 38 to 44% (Wasnik *et al.* 2017). Therefore, the infestation of weed in forages needs to be checked starting from land preparation (Sunil *et al.* 2012). Yaduraju (2012) estimated a total economic loss in arable crops equivalent to approximately USD 13 billion/annum. In addition to direct effect on yield, weeds result in a considerable reduction in the efficiency of input used and quality (Yaduraju and Mishra 2018).

Some studies showed presence of atrazine residues in the soil and crop product at harvest. It has been reported that more than 95% of atrazine dissipated from the field at the time of crop harvest. The half-life values were found to be 9.38 - 21.54 days in soil (Sondhia 2002, Nag and Das 2009, Janaki *et al.* 2012). In an another study, atrazine residues in young sorghum plants treated with atrazine at a rate similar to those used commercially, were between 0.02 and 2.66 mg/kg in 30 day forage samples and less than 0.1 mg/kg in silage stage forage and mature fodder (Larson 1993). Levels of chlorometabolites of atrazine were less than 0.05 mg/kg in the 30 day forage. In mature fodder, residues of these metabolites were less than 0.01 mg/kg. The 2-amino-4isopropyl-6-hydroxy-*s*-triazine was found 0.48, 0.14, 0.019, and 0.06 mg/kg in 30 day forage, consisting of mature fodder, mature grain, and silage stage forage, respectively (Larsan and Ash 1992).

As very limited information is available about weed management in fodder crops, the investigation was planned and executed with the objective to study bio-efficacy of atrazine in managing weeds in fodder maize and double-cut fodder sorghum, and to determine atrazine residues in green fodder of maize and sorghum.

MATERIALS AND METHODS

Field experiments were conducted during the *pre-Kharif* (summer) season of 2016 and 2017 at the fodder farm of ICAR-IVRI, Izatnagar campus, Bareilly. The soil of the experimental field was sandy loam with the pH 6.5, low in available N (144 kg/ha), medium in available P (19.2 kg/ha), high in available K (298 kg/ha) and medium in organic carbon (0.56%). The weed control treatments comprised of atrazine 0.50 kg/ha as pre-emergence (PE); atrazine 0.75 kg/ha as PE; atrazine 1.0 kg/ha as PE; atrazine 2.0 kg/ha as PE; atrazine 0.50 kg/ha as post-emergence (PoE); atrazine 0.75 kg/ha as PoE; atrazine 1.0 kg/ha as PoE; atrazine 2.0 kg/ha as PoE; weedy check and weed-free. The treatments were laid out in a randomised block design with three replications. The PE atrazine was sprayed after sowing on wet soil and PoE was applied at 10 days after sowing (DAS) with the help of knap-sack sprayer fitted with flood-jet nozzle with discharge rate of 600 L water/ha. Variety of fodder maize '*African tall*' was grown on 06 February 2016 and 13 February 2017 and the variety of double cut fodder sorghum '*SSG* 59-3' was grown on 03 April 2016 in the experiments. Fodder maize was harvested on 62 DAS and double-cut fodder sorghum was harvested on 45 DAS for 1st cut and 45 days after 1st cutting for 2nd cut. During second year of experimentation, high density sowing (seed rate of fodder maize 63 kg/ha) with the help of ferti-seed-drill of narrow spacing (15 cm row to row distance) and localised placement of complex fertilizer (NPK ratio of 12:32:16) was adopted against the broadcasting method of sowing (seed rate of 43 kg/ha) and fertilizer (urea, single super phosphate and muriate of potash) application during 1st year of experimentation in maize. Green maize plant samples for atrazine residue analysis were collected at 60 days after application of atrazine (62 DAS). In case of fodder sorghum, atrazine at different doses was applied on 7 days after 1st cutting and green plant samples for residue analysis were collected on 38 days after application of atrazine (45 days after 1st cut). The atrazine residues were analyzed at residue laboratory of ICAR-Directorate of Weed Research, Jabalpur using a Shimadzu UFLC connected with PDA Detector with a flow of 0.35 ml/min using a solvent system of ACN: water 0.01% phosphoric acid (70:30).

The absolute and relative values of density, frequency, importance value index and summed dominance ratio for each of the weed was measured by following standard procedure and calculation for weed survey as followed by AICRP on Weed Management (ICAR), by plotting one meter square quadrats in randomized manner (Raju 1997). The weeds were dried in oven till a constant weight and then transformed into g/m^2 using the appropriate formula.

RESULTS AND DISCUSSION

Weed flora in fodder maize

Among the dominant weed flora, *Trianthema portulacastrum* and *T. monogyna* recorded the

highest values of absolute density (no./m^2) and absolute frequency followed by *Cyperus esculentus, Digitaria ciliaris, Chinopodium album, Cleome viscosa* and *Coccinia grandis* during late *Rabi* season and early summer season. However, during second year, infestation of the weeds was considerably lower than the first year because of using higher seed rate and ferti-seed-drill (**Table 1**). In second year, *Celosia argentea* was found along with other broadleaved weeds.

Weed flora in double-cut fodder sorghum

Like fodder maize, the highest values of absolute density and absolute frequency of *Trianthema* sp. were recorded followed by the sedge *Cyperus esculentus*, the grasses *Digitaria ciliaris, Setaria glauca*, the broad-leaved weeds *Coccinia grandis, Celosia argentea* and *Cleome viscosa* (**Table 2**). The broad-leaved weeds, *Ageratum conyzoides* and *Sonchus oleraceus* appeared after 1st cutting mainly due to undisturbed soil conditions as both the weeds preferred to grow in undisturbed soil and non-crop situation.

Weed control efficiency of atrazine and weed index in fodder maize

Atrazine with all the doses as pre- and post-emergence treatments showed higher weed control efficiency resulted from efficient controlling of weeds especially *Trianthema* and other grasses during 1st year of experimentation. Weeds in weedy check treatment caused yield reduction to the tune of 22.6% (weed index value). However, during second year the weed index of weedy check treatment was 1.7% as weed growth was very much limited. The large differences in weed control efficiency and weed index values in two corresponding years of the experiment were mainly due to the use of high seed rate (63 kg/ha) and adoption of ferti-seed-drill for sowing of fodder maize against the broadcasting method of sowing with the seed rate of 43 kg/ha implemented in 1st year of experimentation. In addition to reduction in weed infestation, yield increments ranging from 26.8 to 32.6% were recorded during 2nd year compared to 1st year of experimentation to the corresponding herbicide treatments (**Table 3**). Most significant results were obtained in weedy check treatment in which 60.3%

Table 1. Absolute density, relative density, absolute frequency, relative frequency, importance value and summed dominance ratio of weed flora appeared in fodder maize at 45 DAS

Weed	Absolute density (no./m^2)		Relative density (%)		Absolute frequency (%)		Relative frequency (%)		Importance value		Summed dominance ratio	
	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year
Trianthema sp.	41.0	9.3	36.4	26.4	100.0	66.7	20.0	18.2	56.4	44.6	28.2	22.3
Chinopodium album	14.0	5.0	12.4	14.2	100.0	33.3	20.0	9.1	32.4	23.2	16.2	11.6
Cleome viscosa	12.0	3.3	10.7	9.4	66.7	66.7	13.3	18.2	24.0	27.6	11.9	13.8
Coccinia grandis	5.0	2.3	4.4	6.6	33.3	33.3	6.7	9.1	11.1	15.7	5.5	7.8
Digitaria ciliaris	18.0	7.3	16.0	20.8	100.0	66.7	20.0	18.2	36.0	38.9	17.9	19.5
Cyperus esculentus	22.7	6.3	20.1	17.9	100.0	66.7	20.0	18.2	40.1	36.1	20.1	18.1
Celosia argentea		1.7		4.7		33.3		9.1		13.8		6.9

Table 2. Absolute density, relative density, absolute frequency, relative frequency, importance value and summed dominance ratio of weed flora appeared in double-cut fodder sorghum at 45 DAS in 1st cutting and 45 DAS after 1st cutting in 2nd cutting

Weed	Absolute density (no./m^2)		Relative density (%)		Absolute frequency (%)		Relative frequency (%)		Importance value		Summed dominance ratio	
	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting
Trianthema sp.	49.0	65.3	28.0	37.9	100.0	100.0	13.6	13.0	41.6	51.0	20.8	25.5
Chinopodium album	6.0	0.0	3.4	0.0	66.7	0.0	9.1	0.0	12.5	0.0	6.3	0.0
Cleome viscosa	15.7	25.0	9.0	14.5	66.7	66.7	9.1	8.7	18.0	23.2	9.0	11.6
Coccinia grandis	17.3	4.7	9.9	2.7	100.0	33.3	13.6	4.3	23.5	7.1	11.8	3.5
Digitaria ciliaris	24.7	20.7	14.1	12.0	100.0	100.0	13.6	13.0	27.7	25.0	13.9	12.5
Cyperus esculentus	28.3	6.3	16.2	3.7	100.0	100.0	13.6	13.0	29.8	16.7	14.9	8.4
Celosia argentea	16.3	5.7	9.3	3.3	100.0	100.0	13.6	13.0	23.0	16.3	11.5	8.2
Setaria glauca	17.7	23.0	10.1	13.3	100.0	100.0	13.6	13.0	23.7	26.4	11.9	13.2
Ageratum conyzoides	0.0	12.3	0.0	7.2	0.0	100.0	0.0	13.0	0.0	20.2	0.0	10.1
Sonchus oleraceus	0.0	9.3	0.0	5.4	0.0	66.7	0.0	8.7	0.0	14.1	0.0	7.1

Table 3. Weed control efficiency, weed index and yield increment in second year over first year of experimentation in green fodder maize

Treatment	Weed control efficiency (%) at 45 DAS		Weed index (%)		Yield increment (%) in second year over first year
	1st Year	2nd Year	1st Year	2nd Year	
Atrazine 0.50 kg/ha as PE	79.8	9.8	6.5	1.7	32.7
Atrazine 0.75 kg/ha as PE	81.8	23.0	3.2	1.4	28.6
Atrazine 1.00 kg/ha as PE	85.3	36.1	3.2	1.5	28.4
Atrazine 2.00 kg/ha as PE	95.8	54.1	1.1	0.9	24.5
Atrazine 0.50 kg/ha as PoE	78.8	3.3	7.4	2.7	32.6
Atrazine 0.75 kg/ha as PoE	81.0	14.8	6.6	2.3	32.1
Atrazine 1.00 kg/ha as PoE	84.0	26.2	6.3	1.8	32.2
Atrazine 2.00 kg/ha as PoE	95.2	39.3	1.2	0.8	26.8
Weedy check	-	-	22.6	1.7	60.3

yield increment was found in 2nd year over weedy check treatment of 1st year. Lower weed control efficiency during 2nd year of experimentation was mainly because of lower level of weed infestation due to competitive advantages of fodder maize resulted from the use of ferti-seed-drill and higher seed rate. Weed index of weedy check treatment was almost equal with the atrazine treatments and the values indicated that the use of higher seed rate and ferti-seed-drill was equally effective with herbicide treatments for controlling weeds.

Weed control efficiency of atrazine and weed index in double-cut green fodder sorghum

Pre-emergence treatments of atrazine recorded comparatively higher green fodder yield than that of its post-emergence treatments in 1st cutting due to better weed control obtained from the application of atrazine. The lower dose of atrazine (0.50 kg/ha) was not effective in controlling weeds as it recorded low weed control efficiency (65 to 68% and 55 to 58%) and higher weed index (10.8 to 15.7%) based on cumulative yield in corresponding pre-emergence and post-emergence treatments of atrazine 0.50 kg/ha, respectively (**Table 4**). Weedy check treatment recorded the weed index value of 17.9%, which indicated yield reduction due to weeds. Cumulative green fodder yield from 1st and 2nd cutting was highest to the tune of 74.2 t/ha in weed-free treatment and was closely followed by 73.6 t/ha recorded by atrazine 2.0 kg/ha as pre-emergence treatment applied just after sowing and atrazine 2.0 kg/ha applied at 7 days after 1st cutting. Double-cut fodder sorghum gave more green fodder yield than single-cut fodder sorghum in which double cut fodder sorghum was harvested at 45 DAS as 1st cutting and 45 days after 1st cutting as 2nd cutting. This indicated the benefits of growing double-cut sorghum without turnaround time, several tillage operations and, sowing operations and this has shown the importance of growing multi-cut and perennial fodder crops instead of growing single-cut fodder crops.

Green fodder yield and economics of fodder maize cultivation

Data pertaining to economics of green fodder maize production are given in **Table 5.** Use of ferti-seed-drill with higher seed rate resulted in highest benefit: cost ratio of 3.15 in weedy check treatment. Yield increment due to adoption of higher seed rate and use of ferti-seed-drill recorded ` 52,400/ha more profit over broadcasting method of sowing with traditional seed rate in weedy check treatment. Higher seed rate (63 kg/ha) and use of ferti-seed-drill was equally effective with weed management by atrazine in terms of green fodder yield and net returns.

Green fodder yield and economics of double-cut green fodder sorghum production

Data on economics of double-cut green fodder sorghum production presented in **Table 6** revealed that weed control with the use of atrazine 2.0 kg/ha as pre-emergence treatment followed by application of atrazine with the same dose at 7 days after 1st cutting recorded highest net returns of ` 94,200/ha in two cumulative cuttings, which was closely followed by

Table 4. Weed control efficiency and weed index of double-cut fodder sorghum

Treatment	Weed control efficiency (%)		Weed index (%) based on cumulative yield
	1st Cutting (at 45 DAS)	45 days after 1st cutting	
Atrazine 0.50 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	67.6	64.7	10.8
Atrazine 0.75 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	77.7	72.7	4.9
Atrazine 1.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	83.4	76.2	4.5
Atrazine 2.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	90.4	87.7	0.2
Atrazine 0.50 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	58.3	54.9	15.7
Atrazine 0.75 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	74.4	71.4	6.7
Atrazine 1.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	76.6	73.5	6.1
Atrazine 2.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	88.4	86.0	1.1
Weedy check	-	-	17.9

PE: Pre-emergence; PoE: Post-emergence

Table 5. Green fodder yield and economics of fodder maize cultivation

Treatment	Cost of cultivation (× 10^3 `/ha)		Green fodder yield (t/ha)		Transportation and chap cutting cost (x10^3 `)		Net returns (x10^3 `/ha)		Benefit: cost ratio	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Atrazine 0.50 kg/ha as PE	16.3	18.4	49.3	65.4	9.9	13.2	59.7	98.7	2.2	3.1
Atrazine 0.75 kg/ha as PE	16.3	18.4	51.0	65.6	10.2	13.1	62.2	99.1	2.3	3.1
Atrazine 1.00 kg/ha as PE	16.3	18.4	51.0	65.5	10.2	13.1	62	98.7	2.3	3.1
Atrazine 2.00 kg/ha as PE	16.3	18.4	52.1	65.9	10.4	13.2	63.1	98.7	2.2	2.9
Atrazine 0.50 kg/ha as PoE	16.3	18.4	48.8	64.7	9.8	12.9	58.9	97.6	2.2	3.1
Atrazine 0.75 kg/ha as PoE	16.3	18.4	49.2	65.0	9.8	13.0	59.4	97.9	2.2	3.1
Atrazine 1.00 kg/ha as PoE	16.3	18.4	49.4	65.3	9.9	13.1	59.5	98.3	2.2	3.0
Atrazine 2.00 kg/ha as PoE	16.3	18.4	52.1	66.0	10.4	13.2	63	98.9	2.2	2.9
Weedy check	16.3	18.4	40.8	65.4	8.2	13.1	46.9	99.3	1.9	3.1

Common cost of cultivation in 1st year: ` 16260/ha

(Field preparation {tillage, cost of hiring tractor, field layout, cost of diesel, skilled labourer}: ` 4173/ha, Cost of seed {43 kg/ha} and sowing operation: ` 1909/ha, Cost of fertilizer {NPK ratio12:32:16 and Urea, Dose 80:40:20} and fertilizer application: ` 3373/ha, Cost of irrigation {3 irrigations}: ` 4333/ha, Cost of harvesting operation: ` 2472/ha)

Common cost of cultivation in 2nd year: ` 18439/ha

(Field preparation (tillage, cost of hiring tractor, field layout, cost of diesel, skilled labourer}: ` 4181/ha, Cost of seed {63 kg/ha} and sowing operation through seed drill: ` 3681/ha, Cost of fertilizer {NPK ratio 12:32:16 and Urea, Dose 80:40:20} and fertilizer application: ` 3595/ha, Cost of irrigation {3 irrigations}: ` 4390/ha, Cost of harvesting operation: ` 2592/ha)

Transportation and cost of chap cutting: ` 200/t; Selling price of green fodder: 2000/t)

Table 6. Green fodder yield and economics of double-cut fodder sorghum cultivation

Treatment	Common cost of cultivation (x10^3 `/ha)		Green fodder yield (t/ha)		Transportation and chap cutting cost (x10^3 `)		Net returns (x10^3 `/ha)		Benefit: cost ratio	
	A	B	A	B	A	B	A	B	A	B
Atrazine 0.50 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	39.8	66.6	7.9	13.3	44.9	84.3	1.8	2.6
Atrazine 0.75 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	42.2	70.1	8.4	14.0	48.4	89.6	1.9	2.7
Atrazine 1.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	42.6	71.0	8.5	14.2	48.9	90.8	1.9	2.7
Atrazine 2.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	44.5	73.6	8.9	14.7	51.1	94.2	1.9	2.7
Atrazine 0.50 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	37.6	62.9	7.5	12.6	41.4	78.6	1.7	2.5
Atrazine 0.75 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	41.6	68.1	8.3	13.6	47.5	86.5	1.9	2.6
Atrazine 1.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	41.9	69.8	8.4	13.9	47.7	89.0	1.9	2.7
Atrazine 2.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	44.1	73.1	8.8	14.6	50.5	93.5	1.9	2.7
Weedy check	16.4	18.4	36.6	61.6	7.3	12.3	40.3	77.0	1.7	2.5

A-1st cutting, B-Cumulative of two cuttings

Common cost of cultivation per hectare for 1st cutting: ` 16426/ha,

(Field preparation {tillage, cost of hiring tractor, field layout, cost of diesel, skilled labourer}: ` 4101/ha, Cost of seed {30 kg/ha} and sowing operation: ` 1968/ha, Cost of fertilizer {NPK ratio12:32:16 and Urea, Dose 60:40:20} and fertilizer application: ` 3395/ha, Cost of irrigation {3 irrigations}: ` 4370/ha, Cost of harvesting operation: ` 2592/ha)

Additional common cost of cultivation for 2nd cutting: ` 2020/ha

(Cost of irrigation {one}: ` 1457/ha, Cost of fertilizer {Urea} and fertilizer application: ` 563/ha)

Total common cost of cultivation for two cuttings: ` 18446/ha; Transportation and cost of chap cutting: ` 200/t; Selling price of green fodder ` 1750/t)

other doses of atrazine from 0.75 kg/ha as pre-emergence treatment in 1st cutting followed by atrazine 0.75 kg/ha applied at 7 days after 1st cutting. Pre-emergence treatment of atrazine in 1st cut recorded comparative higher net returns than that of its post-emergence treatment applied at 10 DAS in 1st cut. Cultivation of double cut sorghum showed the benefits in terms of net returns as additional investment of ` 2020/ha after 1st cutting registered the additional net returns of ` 43,100/ha in the treatment comprised by atrazine 2.0 kg/ha applied as pre-emergence followed by application of same dose of atrazine at 7 days after 1st cutting. This result was closely followed by other doses of atrazine from 0.75 kg/ha applied as pre-emergence in 1st cutting followed by atrazine 0.75 kg/ha applied at 7 days after 1st cutting.

Atrazine residue in green fodder of maize and sorghum

Atrazine residues were detected in the green fodder of maize at 60 days after its application *i.e.* at harvesting stage (**Table 7**) and 38 days after application *i.e.* on 2nd cutting in double-cut fodder

Table 7. Residue content of atrazine in maize and sorghum fodder

Pre-emergence treatment	Atrazine residue in maize fodder at 62 DAS (µg/g)	Atrazine residue in sorghum fodder at 45 DAS (µg/g)
Atrazine 0.50 kg/ha	0.008	0.129
Atrazine 0.75 kg/ha	0.014	0.212
Atrazine 1.0 kg/ha	0.181	0.544
Atrazine 2.0 kg/ha	0.531	0.811

Table 8. Maximum residue limit (MRL) of atrazine and simazine in crops and water

Authority	Herbicide (atrazine/ simazine)	MRL in ppm	Crops and water
Food Safety and Standards Authority of India (FSSAI)	Simazine	0.25	Sugarcane
World Health Organization (WHO)	Atrazine	0.002	Water
United States Environment Protection Agency (USEPA)	Atrazine	0.003	Water
The Agricultural and Processed Food Products Export Development Authority (APEDA)	Atrazine	0.10	Fruits
Japan Food Chemical Research Foundation	Atrazine	0.02	Mango

sorghum (**Table 7**) at all the doses of atrazine. Atrazine residues were found from 0.008 to 0.531 µg/g in the green fodder maize at 60 days after application while 0.129 to 0.811 µg/g residues were detected in the green fodder sorghum at 38 days after application.

These results are in agreement with other studies. In a study, in a young corn plants treated with atrazine at a rate similar to those used commercially, atrazine residues were reported to be between 0.003 and 1.23 mg/kg in 30 days forage samples and less than 0.02 mg/kg in silage stage forage and mature fodder (Larson 1993). Residues of chlorometabolites of atrazine were less than 0.02 mg/kg in the 30 day forage. In mature fodder, residues of these metabolites were less than 0.01 mg/kg. The major metabolite of atrazine identified was 2-amino-4-isopropyl-6hydroxy-s-triazine, present in amounts of up to 0.27, 0.33, 0.005, and 0.14 mg/kg in 30 days forage, mature fodder, mature grain, and silage stage forage, respectively (Larson 1993). Similarly, in plant foliage collected at harvest traces of atrazine residues were detected in few samples in first year but in the second year residues were not detected (Nag and Das 2009).

It is concluded that atrazine showed selectivity and effectiveness in controlling weeds both in fodder maize and sorghum at the dose of 0.75 kg/ha and above as pre-emergence, however, green fodder contained atrazine residues at harvest in both the fodder crops. Higher seed rate of maize along with the use of ferti-seed-drill was equally effective with weed management by atrazine, providing higher green fodder yield and net returns. Double-cut sorghum recorded more green fodder yield and profit in comparison to single-cut and this indicated the importance of growing multi-cut and perennial fodder crops instead of growing single-cut fodder crops.

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