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Weed management in maize (*Zea mays*) in western Indo-Gangetic Plains through tank-mix herbicide application

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ABSTRACT

To evaluate the bio-efficacy of pre-emergence tank-mix and sequential application (pre-emergence followed by (fb) post-emergence) of herbicides on weeds particularly *Cyperus rotundus* L. in maize (*Zea mays* L.), a field experiment was conducted in 2010 and 2011 at the Indian Agricultural Research Institute, New Delhi. It was observed that the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha with or without KNO_3 (6%) and pendimethalin 0.75 kg/ha + chlorimuron-p-ethyl 0.006 kg/ha resulted in significant suppression of *Cyperus rotundus,* broad leaved and grassy weeds, and caused a significant reduction in total weed population and dry weight. These tank-mixes were superior to other weed control treatments and resulted in higher weed control efficiency and weed control index. However, the pre-emergence tank-mix application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha resulted in comparable maize yield with weed-free check in both years, but the yields in this treatment were higher than in other weed control treatments. This treatment, excluding weed-free check, resulted in the highest net returns and net benefit:cost. Atrazine 1.0 kg/ha + mustard residue mulch @ 5 tonnes/ha was the next best treatment, resulting in higher maize yield through concurrent reduction in weed competition.

Key words: *Cyperus rotundus*, Imazethapyr, Maize, Pendimethalin, Tank-mixes, Weed control efficiency and index

Weeds, comprising of grassy, broad-leaved and sedges, occurring in different flushes during the rainy-season (*kharif*) are one of the major constraints in maize production in India. Maize is cultivated, mainly as a *kharif* crop, widely spaced and grows at a slow rate initially, which allows weeds to emerge by flushes in large number and compete heavily with maize. Due to weed competition, maize yield losses may range from 15 to 85% (Sen *et al.* 2000; Pandey *et al.* 2001). Weed control, therefore, is essential for obtaining higher yield and better quality of maize. Maize yield can be increased up to 50% by adopting different weed control methods of which herbicide appears to be the most important one. Pre-emergence herbicides provide early season weed control by suppressing or killing weed seeds at germination phase. Using the pre-emergent herbicides continuously for several years leads to preponderance of perennial weeds (Das 2008) like *Cyperus rotundus* L. (Purple nutsedge), which has become rampant, occurring in huge population in maize production system, where herbicides are being used for a long time. The insurgence of this weed is also rapid in other production systems like soybean (Kumar *et al*. 2012), mainly, because of less or no natural competitor annual weeds, which are normally controlled due to applications of pre-emergent herbicides.

Herbicides, which can effectively control all categories of weeds (grassy, broad-leaved and sedges), including *Cyperus rotundus* in maize, are hardly available. Therefore, a fool-proof strategy for controlling an array of weeds, including annuals and perennials by adopting an integrated approach including herbicides is highly required. The aceto-lactate synthase (ALS) inhibitors like imazethapyr (Imidazolinones) and chlorimuron-p-ethyl (Sulfonylureas) are broad-spectrum herbicides and can selectively control broad-leaved, grassy and sedge weeds, including *Cyperus rotundus*. These herbicides can be a possible option for controlling weeds in maize. But, studies relating to their selectivity to maize, bio-efficacy against composite weeds, including *Cyperus rotundus* and safer dose for use in maize are less documented in the literature. The combination of these herbicides with other pre-emergence herbicides as tank-mixes or sequential applications for effective weed control has also not been studied in India or elsewhere.

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Brown manuring with *Sesbania aculeata* L. (*Dhaincha*) is an economically viable and widely adopted tool for weed control in direct-seeded rice. Its economic viability and usefulness for weed control in maize has not been studied earlier. This has been attempted for the first time in maize in this study. Therefore, this experiment, involving multifarious herbicide combinations was undertaken to achieve an effective broad-spectrum weed control with major emphasis on *Cyperus rotundus* control.

MATERIALS AND METHODS

The field experiments were carried out with 12 treatments, which included weedy check (T_1); atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE) (T_2); atrazine 1.0 kg/ha + hand weeding at 30 DAS (T_3); atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha(T_4); pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_5); *KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_6); pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE) (T_7); pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand (T_8); pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand (T_9); brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS) (T_{10}); brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS) (T_{11}); and weed-free check (T_{12}). The treatments were laid out in a randomized complete block design with three replications. In the brown manuring with *Sesbania aculeata* L. treatments, *Sesbania* seed @ 5 and 10 kg/ha was sown by broadcasting over the entire plot at the time of sowing of maize and 2,4-D at 0.75 kg/ha was sprayed over the *Sesbania* plants at 25 DAS, which were then killed and dried up gradually to serve as much and supplier of nutrients, particularly N. For tank-mix pre-emergence application of herbicides, required quantities of respective doses of herbicides were tank-mixed in the field and sprayed. For sequential application of herbicides, imazethapyr 0.050 kg/ha and chlorimuron 0.006 kg/ha were mixed with sand @ 40 kg/ha and broadcast at 20 DAS on maize. KNO_3 (6%) was applied separately in the required amount with 400 l water/ha before the tank-mix application of pendimethalin and imazethapyr. All the pre- and post-emergence herbicides were applied with 350 l/ha of water using a knapsack sprayer fitted with a flat fan nozzle (Sukun Agencies India, Mumbai, Maharastra, India). Two sprays of endosulfan 35% EC @ 0.3% were given at 23 and 62 DAS to avoid the infestation of stem borer and other insect pests in maize. Weed-free check plots were maintained free from weeds throughout the cropping cycle by manual weeding. The gross and net plot sizes were 5.0 m × 4.9 m and 4.2 m × 4.1 m, respectively. Maize hybrid HQPM 1 was sown on 9 July in 2010 and 30 June in 2011 with a seed rate of 25 kg/ha in rows spaced at 60 cm. Half of the recommended dose of N was applied basally through broadcasting and mixed with soil before sowing of maize along with the full dose of P_2O_5 and K_2O. The remaining N was top-dressed as hill placement close to the maize plants at 35 days of growth. Thinning of excessive maize seedlings were done after 20 days of sowing to maintain a plant to plant distance of about 30 cm. Maize received three irrigations including a pre-sowing one. Nitrogen, P and K were given in the form of urea, single superphosphate and muriate of potash, respectively. Population and dry weight of weeds were recorded at 40 days after sowing (DAS) by placing a quadrat of 0.5 m × 0.5 m randomly from three places in each plot. Data on number and dry weight of weeds were subjected to square-root $\sqrt{(x+0.5)}$ transformation before analysis of variance. The prices of maize grain and stover per tonne were ₹ 8 800 and ₹ 1 000, respectively in 2010, and ₹ 9 800 and ₹ 1 000 in 2011. Some observations/results had similar error variance during 2010 and 2011, and, hence, such data were subjected to pooled analysis.

RESULTS AND DISCUSSION

Effect on weed growth

Seven major weed species comprising of three grassy weeds [*Achrachne racemosa* Heyne ex Roem & Ohwi, *Dactyloctenium aegyptium* (L.) P. Beauv., and *Setaria glauca* (L.) Beauv.], one sedge (*Cyperus rotundus* L.) and three broad-leaved weeds [*Trianthema portulacastrum* L., *Commelina benghalensis* L. and *Digera arvensis* (L) Forsk.] were present in maize field. The differential effects of herbicides, their dose and time of application led to a large variability in weed flora in maize across the treatments. Similar variation in the distribution of weeds has been reported across locations and crop growth stages (Gopinath and Kundu 2008, Angiras *et al*. 2010). Higher tolerance and persistent nature of perennial *Cyperus rotundus* was responsible for its consistent existence in many weed control treatments.

All weed control treatments adopted in the study resulted in significant reductions in populations of broad-leaved, *Cyperus rotundus,* grassy weeds as well as total weeds at 40 DAS compared to weedy check (Table 1). However, the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha with or without KNO_3 (6%) and pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha caused a better suppression of *Cyperus rotundus* and other grassy and broad-leaved weeds in both years. Probably, the sedge killing ability of imazethapyr was responsible (Grichar and Sestak 2000). The effect of KNO_3 in combination with the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha was not much pronounced on *Cyperus rotundus*, probably, due to its vegetative propagations (Susha *et al*. 2014). The KNO_3 at the dose tested (from previous experience) might have fallen short to break dormancy of the underground tubers for killing by pre-emergence tank-mix herbicide applications. With respect to weed control, atrazine 1.0 kg/ha + hand weeding at 30 DAS closely followed these treatments. Atrazine is more effective against broad-leaved weeds than pendimethalin, while pendimethalin is more effective than atrazine

Table 1 Species-wise and total weed population and weed control efficiency (WCE) and index (WCI) at 40 DAS of maize (mean of two years)

Treatment	Broad leaved weed (No./m2)**	*Cyperus rotundus* (No./m2)	Grassy weed (No./m2)**	Total weed population (No./m2)	WCE (%)	WCI (%)
Weedy check	8.3 (68.0)	9.5 (90.7)	8.6 (72.7)	15.2 (231.3)	0.0	0.0
Atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE)	5.5 30.0)	5.5 (32.0)	3.0 (8.3)	8.4 (70.3)	69.6	74.4
Atrazine 1.0 kg/ha + hand weeding at 30 DAS	4.6 (20.7)	3.7 (13.3)	4.0 (16.0)	7.1 (50.0)	78.4	87.0
Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha	6.1 (37.3)	4.3 (17.7)	4.8 (22.7)	8.8 (77.7)	66.4	74.8
Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	3.6 (12.3)	3.1 (9.3)	0.7 (0.0)	4.7 (21.7)	90.6	90.9
*KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	3.7 (13.0)	3.3 (10.7)	1.2 (1.3)	5.0 (25.0)	89.2	87.3
Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE)	4.5 (19.7)	3.5 (12.0)	1.3 (1.7)	5.8 (33.3)	85.6	85.3
Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand	5.2 (26.7)	4.9 (24.0)	0.7 (0.0)	7.1 (50.7)	78.1	76.8
Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand	5.3 (28.0)	5.3 (28.7)	0.7 (0.0)	7.0 (56.7)	75.5	74.0
Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	4.2 (17.3)	4.0 (15.7)	7.7 (60.0)	9.4 (93.0)	59.8	60.3
Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	3.8 (14.7)	3.8 (14.0)	7.3 (53.3)	8.8 (82.0)	64.6	67.7
Weed-free check	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	100.0	100.0
SEm ±	0.25	0.41	0.13	0.35		
LSD (P=0.05)	0.73	1.20	0.39	1.02		

* KNO_3 was applied separately; PE –pre-emergence; POE – post emergence; ** Broad leaved species included *Commelina benghalensis*, *Trianthema portulacastrum* and *Digera arvensis*. Grasses include *Aerachne racemosa* and *Dactyloctenium aegyptium*; Data were subjected to square-root $\sqrt{(x+0.5)}$ transformation; Figures in the parentheses are original values.

against grassy weeds (Singh *et al*. 2007, Das 2008, Das *et al*. 2010). Therefore, the tank-mix pre-emergence application of atrazine + pendimethalin (0.75 + 0.75 kg/ha) has been recommended as the practice for weed control in maize. It, however, was found highly inferior to the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha and pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha in controlling *Cyperus rotundus*. It resulted in better control of annual grassy and broad-leaved weeds, which could not pose enough natural competition with *Cyperus rotundus*. As a result, *Cyperus rotundus*, for want of natural competition, and not being controlled by the usual pre-emergence treatments came up in large number.

Broad-leaved weeds were less contolled by the sequential application of pendimethalin 0.75 kg/ha - imazethapyr 0.050 kg/ha as well as pendimethalin 0.75 kg/ha - chlorimuron 0.006 kg/ha in both years. In the sequential applications, pendimethalin was applied as pre-emergence, which was less effective against broad-leaved weeds like *Commelina benghalensis* and *Digera arvensis* (Das 2008). These broad-leaved weeds not being controlled by pre-emergence pendimethalin, had enough growth when post-emergence imazethapyr or chlorimuron was applied, which provided increased tolerance to these weeds against imazethapyr or chlorimuron and were not controlled. The results indicated that pre-emergence tank-mix applications of pendimethalin with imazethapyr or chlorimuron was superior to that of sequential applications of these herbicides in terms of weed control as well as selectivity to maize crop. Chlorimuron inflicted phytotoxicity to maize plants both as pre- and post-emergence applications and was least selective to maize.

The application of 2,4-D for killing *Sesbania* in brown manuring treatments caused a signifcant reduction in broad-leaved weed population, but increased the population of grassy weeds. Using 10 kg seed/ha of *Sesbania* for brown manuring proved superior to 5 kg. This indicates that *Sesbania* seed rate may be increased to some extent to get desired level of weed control. Considering maize, a non-tillering crop and higher seed rate of *Sesbania* would be more suppressive to maize at the initial stage seed rate higher than 10 kg was not used. Atrazine 1.0 kg/ha + mustard residue mulch brought about sigificant suppression of *Cyperus rotundus* and grassy weeds like *Achrachne racemosa* and *Dactyloctenium aegyptium.* This might be due to the suppresive as well as allelopathic effects of mustard residue that inhibited germination and growth of

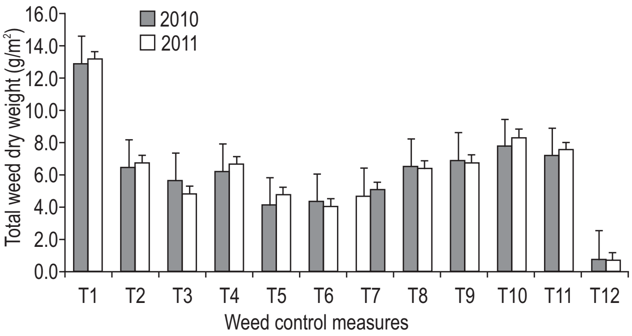

Fig 1 Total weed dry weight in maize (transformed values) at 40 DAS

*T1 to T12 are treatments mentioned in table 1

weeds (Gopinath and Kundu 2008).

The highest weed control efficiency (WCE) and weed control index (WCI) at 40 DAS was achieved by the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 g/ha (Table 1). With respect to WCE and WCI, all the weed control treatments including brown manuring showed superiority over weedy check. Among the weed control treatments, tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha with or without KNO_3 (6%), and pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha caused a significant reduction in total weed dry weight at 40 DAS (Figure 1) in both the years compared with weedy check.

Effect on nutrient uptake

There were no perceptible changes in the content of N, P and K in weeds at harvest in different weed control treatments. The mean N, P and K content was 1.36, 0.125 and 1.75%, respectively. The uptake of K by weeds was highest followed by that of N and P (Fig 2, 3 & 4). Weedy check resulted in the highest N, P and K uptake by weeds. This was followed by brown manuring (*Sesbania* @ 5 kg/ha+ 2, 4-D 0.75 kg/ha at 25 DAS) treatment. The NPK uptake was proportional to the dry matter yield of weeds as the content was not affected. However, the lowest N, P and K uptake by weeds was under atrazine 1.0 kg/ha + hand weeding followed by tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha. They were found to be comparable in both years. Contrarily, N, P and K uptake by maize were found

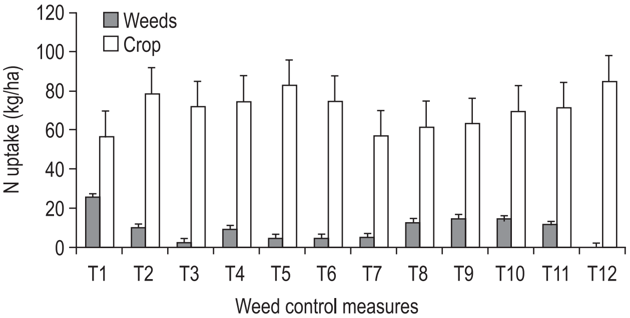

Fig 2 N uptake by maize and weeds at harvest (pooled data of two years)

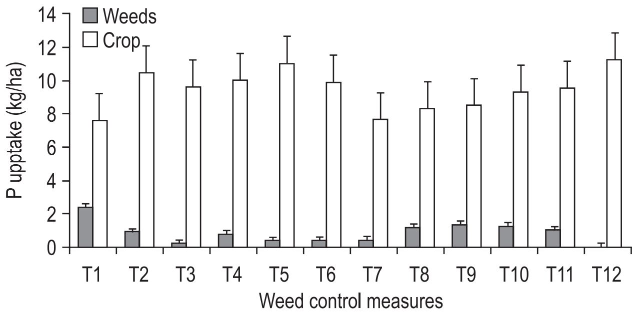

Fig 3 P uptake by maize and weeds at harvest (pooled data of two years)

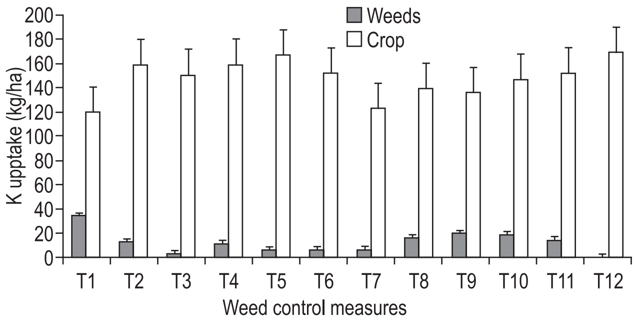

Fig 4 K uptake by maize and weeds at harvest (pooled data of two years)

to be higher in pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix pre-emergence) followed by atrazine 1.0 kg/ha + mustard residue mulch @ 5 tonnes/ha in both years. The results are in conformity with Gopinath and Kundu (2008).

Effect on maize growth and yield

Tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha, and atrazine 1.0 kg/ha +mustard residue mulch @ 5 tonnes/ha showed higher leaf area index (LAI) and dry matter accumulation next to weed free check in both the years (Table 2). Observed phytotoxicity to maize plants led to lower LAI, dry matter accumulation and plant population of maize in pendimathalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE) treatment, although this treatment had considerably lower weed growth. Chlorimuron appeared to be non-selective to maize even at lower doses. Its both pre- as well as post-emergence application was phytotoxic. It inhibits the activity of ALS/AHAS enzyme and prevents the bio-synthesis of three branched-chain amino acids, which, consequently leads to drop in protein synthesis and significant decrease in protein content of maize shoot (Alla *et al*. 2008).

Intense crop-weed competition in the unweeded control did not allow maize plants to accumulate sufficient dry matter to produce cobs on some of the plants and proper grain filling of the cobs (Table 2). Pooled grain yield and stover yield varied significantly across the weed control treatments. Higher grain yield and stover yield in tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha, atrazine 1.0 kg/ha + mustard

Table 2 Leaf area index (LAI) and dry weight at 40 DAS and yield attributes and yield of maize (mean of two years)

Treatment	LAI	Dry matter weight (g/m^2)	Cobs/ plant	Grain weight/ cob(g)	Test weight (g)	Grain yield (t/ha)	Stover yield (t/ha)
Weedy check	1.84	218.9	0.96	61.4	209.3	2.53	6.44
Atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (tank-mix PE)	2.66	295.0	1.01	80.5	226.7	3.65	8.55
Atrazine 1.0 kg/ha + hand weeding at 30 DAS (T_3)	2.95	337.1	1.02	84.8	220.0	3.53	8.23
Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha (T_4)	3.07	320.8	1.03	80.4	246.7	3.76	8.48
Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_5)	3.19	347.9	1.05	80.3	250.7	3.95	8.85
*KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)(T_6)	2.96	311.1	1.01	84.4	223.3	3.63	8.20
Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE) (T_7)	1.49	143.5	0.98	73.8	200.7	2.75	6.59
Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand (T_8)	2.47	284.2	1.00	69.2	231.3	2.91	7.62
Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand (T_9)	2.44	278.4	1.02	81.0	238.1	2.78	7.35
Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS) (T_{10})	2.66	294.8	1.11	73.2	242.6	3.13	7.85
Brown manuring (*Sesbania* @ 10 kg/ha + 2,4-D 0.75 kg/ha at 25 DAS) (T_{11})	2.57	291.1	0.97	71.7	224.0	3.29	8.20
Weed-free check (T_{12})	3.48	350.6	1.04	86.6	252.3	4.12	8.96
SEm ±	0.30	2.94	0.06	4.96	8.16	0.34	0.40
LSD (P=0.05)	0.87	8.63	NS	14.56	23.95	0.68	0.80

* KNO_3 was applied separately; PE –pre-emergence; POE - post emergence

residue mulch @ 5 tonnes/ha, atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE), pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha with KNO_3 (6%) (tank-mix PE) and atrazine 1.0 kg/ha + hand weeding at 30 DAS indicated the superiority of these treatments on weed control and crop growth. Thus, tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha gave the lowest weed index (WI) in both years followed by atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ ha (tank-mix PE) in 2010 and atrazine 1.0 kg/ha +mustard residue mulch @ 5 tonnes/ha in 2011 (Figure 5). Efficacy of atrazine in controlling weeds in maize is well established

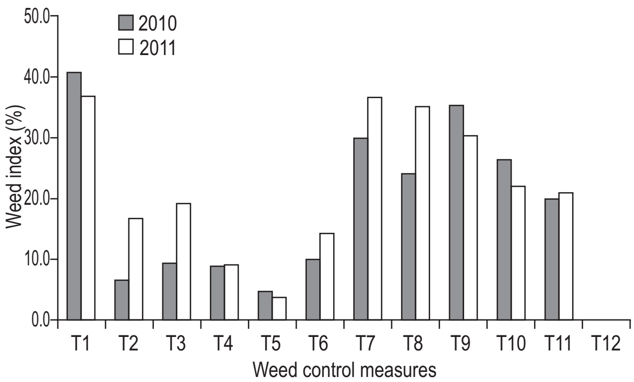

Fig 5 Weed index (%) as affected by weed control measures

(Singh *et al*. 2007; Pandey *et al*. 2001). The yield performance of sequential application of herbicides as well as brown manuring was poor compared with those in other weed control treatments, might be due to increased crop-weed competition.

Economics

In terms of net returns and net B:C, the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha was superior to other treatments including weed-free check, mainly because of higher maize yield and lower cost of cultivation (Table 3). This treatment with KNO_3 application and weed-free check although fetched higher gross returns, were inferior to this treatment because they incurred higher cost of cultivation owing to higher cost incurred for KNO_3 as well as for manual weeding. Generally, the cost of the herbicides was much lower than the cost of manual weeding provided for maintaining weed-free situation for the whole season. Singh *et al*. (2007) reported similar variation in net returns and net B:C among treatments due to variation in yield and expenditure incurred by the treatments.

On the basis of two years experimentation, it can be concluded that the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha is more effective in controlling weeds including *Cyperus rotundus,* and, thus, increased weed control efficiency and

Table 3 Effect of weed control measures on economics of maize

Treatment	Cost of cultivation (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Net B:C
Weedy check	16.7	15.2	0.91
Atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (tank-mix PE)	18.7	23.3	1.24
Atrazine 1.0 kg/ha + hand weeding at 30 DAS	20.8	19.8	0.95
Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha	20.8	24.3	1.17
Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	19.0	28.6	1.50
*KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	28.0	14.7	0.53
Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE)	18.2	13.9	0.76
Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand	19.5	14.3	0.73
Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand	18.7	16.8	0.90
Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	18.0	21.3	1.18
Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	18.0	22.0	1.22
Weed-free check	25.7	23.4	0.91

* KNO_3 was applied separately

index in maize. It caused a significant reduction in the uptake of N, P and K by weeds and increased yield performance of maize considerably. Therefore, this may be recommended for better weed control in maize. Atrazine 1.0 kg/ha + mustard residue mulch @ 5 tonnes/ha was more or less comparable with it on weed control as well as growth and yield attributes of maize. Therefore, this can be the next best option for weed management in maize. However, where *Cyperus rotundus* is not prevalent in maize, tank-mix pre-emergence application of atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha is worth recommending.

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