A Review on Management of Weeds in Maize (Zea mays L.)

Anwesh Rai1*, Debasis Mahata1, Everest Lepcha1, Kousik Nandi1 and Pijush Kanti Mukherjee2

1Department of Agronomy, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal-736165, India
2Farm Section, Indian Veterinary Research Institute (IVRI), Izatnagar, Bareilly, Uttar Pradesh-243122, India

*Corresponding author

Abstract

Weeds constitute one of the major economic important problem for maize growers and it can reduce yield up to 86 per cent. The magnitude of losses largely depends upon the composition of weed flora, period of crop-weed competition and its intensity. The highest weed control efficiency with lowest weed density and weed dry weight was noted in pre-emergence application of atrazine @ 1.0 kg a.i. ha\(^{-1}\) followed by (\(fb\)) one hand weeding (HW) at 30 DAS.

Keywords

Weed flora, Weed management practices, Weed density, Weed dry weight, Weed control efficiency

Introduction

Maize (Zea mays L.) is the third most important cereal crop of India. It is grown for fodder as well as for grain purpose. Among various other factors, weed is one the most important yield limiting factor. Their effects could be quite variable, but the most common is competition for available resources which leads to the drastic reduction in yield. Weed management strategies viz. mechanical, chemical and biological and integration of these three methods i.e. integrated weed management practices have been developed to limit the deleterious effects of weeds on crop plants.

Weed flora associated with maize crop

Dominant weed species present in the experimental site were Cynodon dactylon L., Cyperus rotundus L., Amaranthus viridis L., Anagalis arvensis L., Argemone maxicana L., Chenopodium album L., Melilotus indica L., Oxalis corniculata L., Convolvulus arvensis L., Rumex retroflex L. and Parthenium hysterophorus L. (Kumar et al., 2017). Among the different weed species that were observed in the field experiment, the major
weed species were: *Cynodon dactylon*, *Cyperus rotundus*, *Parthenium hysterophorus* L. and *Chenopodium album* L. (Abdullah et al., 2016). The important weeds noticed during winter (rabi) season were *Phalaris minor*, *Poa annua* among grass and *Medicago denticulata*, *Anagallis arvensis*, *Circium arvense*, and *Chenopodium album* among broad-leaf weed (Stanzen et al., 2016).

The major weed flora during kharif season in experimental field was composed of *Xanthium strumarium*, *Celosia argentea*, *Tridax procumbens*, *Phyllanthus niruri*, *Euphorbia geniculata*, *Euphorbia hirta*, *Alternanthera triandra*, *Parthenium hysterophorus*, *Digera arvensis*, *Cynodon dactylon*, *Cyperus rotundus*, *Amaranthus viridis*, *Dinebra arabica*, *Panicum spp*, *Commelina benghalensis* (Kakade et al., 2016).

Mukherjee and Rai (2015) observed that major weed flora were *Polygonum persicaria*, *P. pensylvanicum*, *P. orientale*, *Oldenlandia diffusa*, *Oldenlandia aquatic*, *Oxalis corniculata*, *Stellaria media*, *Stellaria aquatic*, *Physalis minima*, *Solanum nigrum*, *Hydrocotyl ranunculoides*, *Ageratum conyzoides* (appeared at latter part of crop growth), the sedge like *Cyperus rotundus* and the grasses like *Cynodon dactylon*, *Digitaria ciliaris*, *Setaria glauca*, *Echinocloa spp* and *Rottboellia exaltata* L. Among these weeds *Polygonum sp.*, *Cynodon dactylon*, *Digitaria ciliaris*, *Setaria glauca* were highly aggressive in maize. However, Singh et al., (2015), reported that the dominant weeds in the maize field were: *Medicago denticulata*, *Avena ludoviciana*, *Phalaris minor* and *Chenopodium album*.


Kannan and Chinnagounder (2014) reported that weed flora of the experimental field in maize predominantly consist of 12 species of broad leaved weeds, 5 species of grasses and a sedge weed. The dominant among broadleaved weeds were *Trianthema portulacastrum*, *Datura stramonium*, *Cleome gynandra*, *Digera arvensis*, *Physallis minima*, and *Corchorus olitorius*. The dominant grass weeds were *Setaria verticillata* and *Cynodon dactylon*, *C. rotundus* was the only sedge present in the experimental field. With respect to individual weed species during both the years, density of *T. portulacastrum* recorded about 162.80%.


Madhavi et al., (2013) reported that predominant weed flora in the experimental field comprised of *Cyperus rotundus*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Rottboellia exaltata*, *Parthenium hysterophorus*, *Celosia argentina*, *Euphorbea hirta*, *Digera arvensis* and *Trianthema portulacastrum*.
broad leaved weeds were dominating over grasses and sedge in the experimental field. Among the individual weed species, Trianthema portulacastrum, Cleome gynandra, Digera arvensis, Datura stramonium, Cynodon dactylon, Dactyloctenium aegyptium, Commelina bengalensis and Cyperus rotundus were predominant in maize field. Among broad leaved weeds, Trianthema portulacastrum was the dominant one during both the seasons. Similar studies reported that maize crop infested with major broad leaved weeds were Trianthema pórtulacastrum, Digera arvensis, Phyllanthus niniri, Amaranthus viridis. Among the grassy weeds Cynodon dactylon and Dactyloctenium aegyptium had dominated. Cyperus rotundus was the major sedge weed (Ramesh and Nadanassababady, 2005).

The predominant weeds under monocot were Echinochloa colona (15.4%), Digiteria sanguinalis (13.1%), Cyperus rotundus (16.2%) and Commelina communis (14.0%). Phyllanthus niruri (14.4%) and Eclipta alba (13.6%) were prominent among dicot weeds. Many other minor weeds in small intensity (13.3%) were also present in maize ecosystem at 60 DAS stage (Sanodiya et al., 2013).

The predominant weed flora of the experimental field was Rough leaf cocklebur (Xanthium brasilicum Vell), Jimson weed (Datura stramonium Mill), Asthma weed (Euphorbia hita L.), Purslane (Portulaca oleracea L.), Plodder Hibiscus (Hibiscus trionum L.), Tar vine (Boerhavia erecta L.), White pigweed (Amaranthus graecizans L.), Pigweed (Amaranthus viridis L), Grip weed (Phyllanthus niruri L), Black night shade (Solanum nigrum L.), Common cal traps (Tribulus terrestris L.), Water grass (Echinochloa colona (L.) Link), Tropical crab grass (Digitaria ciliaris Retz), Love grass (Eragrostis magastachya Koel) and (Dinebra retroflexa Vahi) (Babiker et al., 2013).

Singh et al., (2012) observed uniform infestation of the grassy weeds Echinochloa colona L., Digitaria sanguinalis L. and Bracharia ramose L., while the broad leaf weed included Phyllanthus niruri L., Cleome viscosa L and Trianthema monogyna L., Cyperus rotundus L., was the only sedge in sandy loam soil of Uttarakhand.

The predominant weed flora were Echinochloa crusgalli L. and Cynodon dactylon L. among monocots; Cyperus rotundus L. among sedges; and Amaranthus viridis L., Digera arvensis L., Portulaca oleracea L., Alternentha sessili L. and Trianthema spp. among dicots. (Arvadiya et al., 2012).

The important grassy weeds observed were Cynadon dactylon, Dinebra retroflexa, Echinocloa colanum, Elusine indica. Cyperus rotundus was alone in sedge category. Among the broad leaved weeds Parthenium hysterophorus, Commelina bengalensis, Portulaca oleracea, Cynotis cuculata, Phylantus niruri and Amaranthus viridis were the dominant weeds (Haj et al., 2012).

Kumar et al., (2012) observed that weed flora was composed of Commelina benghalensis (25.6 and 12.3% at 60 DAS and at harvest, respectively), Ageratum conyzoides (45.1 and 56.1%), Echinochloa colona (L.) Link (17.6% and 8.7%), Panicum dichotomiflorum (8.4 and 7.7%), Cyperus iria (2.8 and 7.2%), Digitaria sanguinalis (0.0 and 8.2%) and Polygonum alatum (0.5 and 8.0%).

Sunitha et al., (2010) reported that during both the years of study, 23 weed species including six grasses, two sedges and 15 broad-leaved weeds were identified in the experimental field. Among these, Panicum repens (21.4%), Digitaria sanguinalis...
(18.5%), *Celosia argenta* (16.4%), *Acanthospermum hispidum* (15.5%) and *Cleome viscosa* (14.0%) were found to be the dominant weeds.

**Yield reduction in maize due to weeds**

A number of weed species compete with corn plant and have been observed to reduce yield as much as 65% with delay in weed control. Weeding in maize after the critical period of weed removal can result in up to 83% losses in grain yield (Ehsas et al., 2016).

Maize weeds comprise diverse plant species from grasses to broadleaf weeds and sedges and cause substantial yield losses (18–85%) (Jagadish et al., 2016).

Yield loss occurs up to 33% to complete crop failure due to weed competition in maize (Kakade et al., 2016).

In India, the presence of weeds, in general reduces the maize yield by 27-60%, depending upon the growth and persistence of weed population in maize crop (Kumar et al., 2015 and Jat et al., 2012). However, Yakadri et al., (2015) opined that wider spacing and initial slow growth of maize during the first 3-4 weeks provides enough opportunity for weeds to invade and offer severe competition, resulting in 30-93% yield losses.

Mahadevi et al., (2014) reported that maize being a widely spaced crop gets infested with a variety of weeds and subjected to heavy weed infestation, which often inflicts huge losses ranging from 28 to 100%.

Kannan and Chinnagounder (2013) opined that weeds constituent one of the major economic important problem for maize growers because they can reduce yield up to 86 per cent.

Ramachandran et al., (2012) opined that weed causes drastic reduction in growth, development and yield of the maize and accounts for 40% yield loss and even >70% yield loss under uncontrolled weed growth condition in maize.

Sunitha and Kalyani (2012) reported reduction in grain yield of maize due to weed infestation ranged from 40 to 60 per cent depending upon the intensity and types of weed flora. However, Kumar et al., (2015) opined that reduction in maize grain yield by weeds is in tune of 50.3%.

The extent of reduction in grain yield of maize has been reported to be in range of 33 to 50 percent depending on the weed species in standing crop (Hawaldar and Agasimani, 2012).

**Weed management practices**

**Cultural control**

The maximum grain yield of (8.92 t ha⁻¹) and minimum weed density and dry weight of all major weed species were recorded in 2 hand weeding (HW) at 15 and 30 days after sowing (DAS) (Kumar et al., 2017).

At harvest, the significantly lower monocot and sedges were noted under weed control through sugarcane trash mulch @ 5 t ha⁻¹ (Ehsas et al., 2016).

Stanzen et al., (2016) observed that 2 HW recorded significantly higher number of grains cob⁻¹, 1,000-grain weight and grain yield which was statistically at par with atrazine 1 kg ha⁻¹.

Samanth et al., (2015) reported maximum grain yield in farmer’s practice (HW at 20 and 40 DAS) and was fb atrazine @ 1.0 kg a.i ha⁻¹ as PE fb HW at 30 DAS.

Pathak et al., (2015) reported that hoeing at
20 DAS fb atrazine 0.50 kg ha\(^{-1}\) being at par with 2 HW (20 and 40 DAS), registered significantly higher weed control efficiency (WCE) at all growth stages of maize.

Swetha (2015) reported that HW at 20 and 40 DAS recorded higher grain yield (6580 kg ha\(^{-1}\)) which was on par with topramezone + atrazine @ 25.2 + 250 g a.i ha\(^{-1}\) as PoE (6436 kg ha\(^{-1}\)).

Stover yield and harvest index was also higher in HW at 20 and 40 DAS.

Kumar et al., (2015) reported that brown manuring helps in suppressing the weeds up to 50% of total weed population on the account of the shade effect of killed green manure till 45 DAS up to which the critical period of crop weed competition continues in maize.

Madhavi et al., (2014) found that HW reported significantly higher grain yield on par with tank mix of topramezone + atrazine along with adjuvant MSO (@ 25.2 + 250 g a.i ha\(^{-1}\) and 21 + 250 g a.i ha\(^{-1}\) ) and topramezone @ 25.2 + 250 g a.i ha\(^{-1}\) without adjuvant.

Deshmukh et al., (2014) reported that the atrazine 1.0 kg ha\(^{-1}\) as PE fb mechanical /HW at 30 DAS proves better in controlling weed, dry matter accumulation, WCE, grain yield and net monetary returns.

Kumar et al., (2013) reported that highest grain yield was recorded in conventional-tillage maize where HW at 15 and 30 DAS on par with zero-tillage maize where glyphosate was applied as pre-plant incorporation followed by atrazine + halosulfuron @ 1.0 kg a.i ha\(^{-1}\) + 90 g a.i ha\(^{-1}\) as post-emergence (PoE).

Sanodiya et al., (2013) found that the highest grain yield and stover yields was noted in HW at 20 and 40 DAS fb atrazine 1.0 kg ha\(^{-1}\) + HW at 30 DAS.

Saini et al., (2013) from Palampur revealed that soybean intercropping + one mechanical weeding (20 DAS) recorded significantly lowest weed dry weight, higher yield attributes and maize equivalent yield which was at par with 2 mechanical weedicings (20 and 40 DAS) + mash intercropping in maize among all other treatments.

Madhavi et al., (2013) reported that highest grain yield recorded in HW treatment (7450 kg ha\(^{-1}\)) which was significantly superior to singular applications of pendimethalin (5350 kg ha\(^{-1}\)) or oxyfluorfen (6020 kg ha\(^{-1}\)) or atrazine (6570 kg ha\(^{-1}\)).

Malviya et al., (2012) noticed that highest grain yield was recorded in alachlor @ 2 kg a.i ha\(^{-1}\) fb one HW and was at par with weed free treatment.

Ahmed and Susheela (2012) opined that the farmer`s practice of eliminating weeds through intercultivation (IC) at 20 DAS fb HW 30 DAS reduced the weed density and weed dry matter production significantly and thereby increased the WCE (89.2%).

Sultana et al., (2012) found that two spading as intercultural operation along with HW at 10 and 20 days after emergence (DAE) + earthing-up at 30 DAE recorded the highest grain yield (7.74 t ha\(^{-1}\)) along with highest WCE (96.39%) and lowest weed dry weight.

Sarma et al., (2010) found two HW at 25 and 45 DAS to be best in producing higher yield of maize along with minimum weed density (4.0 %) and weed dry weight (3.3 %).

Prasad et al., (2008) reported that manual weeding at 15 and 30 DAS recorded the highest WCE (70.90 %) with grain yield of 32.30 q ha\(^{-1}\).
Gopinath and Kundu (2008) reported that PE application of atrazine at 1.25 kg ha\(^{-1}\) coupled with one HW resulted in significantly lower weed population and weed dry weight compared to the other treatments. Twice HW at 20 and 40 DAS and PE application of atrazine @ 0.50 kg a.i ha\(^{-1}\) in combination with pendimethalin @ 0.25 kg a.i ha\(^{-1}\) were found to be superior and recorded higher grain yield (3658 and 3652 kg ha\(^{-1}\), respectively) (Patel et al., 2006).

Hoeing at 15 DAS controlled the growth of all weed species and their population at 30 DAS was less than half (23-32 weeds m\(^{-2}\)) compared with no inter-culture (67-70 weeds m\(^{-2}\)). Earthing up at 30 DAS resulted in the virtual elimination of weeds throughout the crop growth period (Sharma et al., 2000).

**Chemical control**

Sahoo et al., (2017) found that highest grain yield of 81.38 q ha\(^{-1}\) was obtained with the application of atrazine @ 1 kg ha\(^{-1}\) in maize.

Ehsas et al., (2016) reported that among herbicide treatment, PE application of atrazine @ 0.75 kg ha\(^{-1}\) + pendimethalin @ 0.75 kg ha\(^{-1}\) recorded significantly higher grain yield of 6267 kg ha\(^{-1}\) fb PE application of alachlor @ 1.5 kg ha\(^{-1}\) + atrazine @ 0.5 kg ha\(^{-1}\) (5918 kg ha\(^{-1}\)).

These findings corroborate the results of Patel et al., (2006), Sanodiya et al., (2013) and Mathukia et al., (2014) in maize.

Sraw et al., (2016) observed the highest average grain yield of maize (4.9 t ha\(^{-1}\)) was recorded in maize intercropped with cowpea (used as mulch) fb maize intercropped with cowpea (used as fodder) at 30 DAS which was 27.9 and 22.2 % respectively, higher as compared to control.

Kakade et al., (2016) reported that sequential application of PE and PoE herbicides i.e., atrazine 0.50 kg ha\(^{-1}\) fb 2,4-D sodium salt 0.5 Kg PoE at 30 DAS proves better in controlling weeds and found economical compare to conventional weed management practice in maize.

Kumar et al., (2012) opined that atrazine 1.0 kg ha\(^{-1}\) + pendimethalin 0.5 kg ha\(^{-1}\) (PE) fb 2,4-D 0.75 kg ha\(^{-1}\) (PoE), fb atrazine 1.5 kg ha\(^{-1}\) (PE) fb atrazine 0.75 kg ha\(^{-1}\) (PoE) could be the better alternatives to HW in managing different flushes of weeds in maize.

Application of atrazine 1.5 kg ha\(^{-1}\) recorded grain yield of 44.48 q ha\(^{-1}\) which was on par with atrazine 0.75 kg ha\(^{-1}\) and pendimethalin 1.0 kg ha\(^{-1}\) and 9.94 per cent higher yield than pendimethalin 1.5 kg ha\(^{-1}\) because of the herbicides prevented the germination of weed and reduced the growth of weed (Samant et al., 2015).

Kannan and Chinnagounder (2014) reported that among the weed control treatments, PoE application of glyphosate at 1800 g a.i. ha\(^{-1}\) in transgenic corn hybrid recorded higher grain yield of 12.21 t ha\(^{-1}\).

Hatti et al., (2014) observed that significantly higher grain yield was recorded in oxyflurofen @ 200 g a.i ha\(^{-1}\) + 2, 4-D Na @ 500 g a.i ha\(^{-1}\) as PoE which was on par with HW at 20 and 40 DAS.

Chhetri et al., (2014) found that atrazine at the dose of 1.1 kg ha\(^{-1}\) can be applied in maize safely as PoE application treatment for effective controlling weeds. Higher grain yield (5,173 kg ha\(^{-1}\)) was achieved in atrazine 1.0 kg ha\(^{-1}\) fb atrazine 1.0 kg ha\(^{-1}\) treated plot (Ahmed and Susheela, 2012).

Nadiger et al., (2013) observed higher grain yield (10,436 kg ha\(^{-1}\)) with application of atrazine 1.25 kg ha\(^{-1}\) due to effective control.
of weeds and minimum dry weight \(1.80 (2.73) \text{ g m}^{-2}\) of weeds.

Kannan and Chinnagounder (2013) reported that PoE application of potassium salt of glyphosate at 1800 g ha\(^{-1}\) in transgenic and conventional maize hybrid of 30V92 enhanced the complete control of broad spectrum weeds and hence significantly lowered weed density, weed dry weight and higher WCE ranging from 96-99%.

Singh, et al., (2012) reported that PoE application of tembotrione 120 g ha\(^{-1}\) along with surfactant (100 ml ha\(^{-1}\)) was found most effective to control the grassy as well as non-grassy weeds as compared to other herbicidal treatments either applied as pre- or post-emergence with maximum WCE (90%).

Reddy et al., (2012) reported the highest grain yield 170% higher than that of unweeded control along with lowest density (no. m\(^{-2}\)) and dry weight (g m\(^{-2}\)) of grasses, and broad-leaved weeds at 30 DAS with tank mix application of atrazine + glyphosate (0.75 + 0.8 kg ha\(^{-1}\)).

Glyphosate (1.6 kg ha\(^{-1}\)) was found superior to atrazine (1.5 kg ha\(^{-1}\)) and paraquat (1.5 kg ha\(^{-1}\)) for density, dry weight of weeds and WCE.

Singh et al., (2012) observed that tembotrione @ 120 g a.i ha\(^{-1}\) as PoE along with surfactant recorded significantly highest grain yield and was on par with reduced dose of 110 g a.i ha\(^{-1}\) + surfactant and HW at 20 and 40 DAS.

Ramachandran et al., (2012) observed the highest grain (7.23 t ha\(^{-1}\)) and stover yield (11.56 t ha\(^{-1}\)) with PE alachlor 1.0 kg ha\(^{-1}\) + brown-manuring. It was closely followed by PE alachlor 1.0 kg ha\(^{-1}\) + daincha as intercrop with in-situ incorporation on 35 DAS (6.38 and 10.20 t ha\(^{-1}\)). Significantly higher seed yield (5302 kg ha\(^{-1}\)) was obtained in atrazine 1.25 kg ha\(^{-1}\) fb glyphosate 2.5 kg ha\(^{-1}\) when compared to weedy check (Haji et al., 2012).

Kumar et al., (2012) reported that pendimethalin 1.50 kg ha\(^{-1}\), atrazine fb atrazine 0.75 kg ha\(^{-1}\), atrazine 0.75/1.0 + pendimethalin 0.75/0.50 fb metsulfuron methyl 4 g ha\(^{-1}\) effectively controlled Echinochloa colona. Atrazine fb atrazine brought about significant reduction in the count of Panicum dichotomiflorum up to 60 DAS. Pendimethalin fb atrazine, atrazine 1.0 + pendimethalin 0.50 fb 2, 4-D 0.75 kg ha\(^{-1}\) and HW twice effectively reduced the population of Commelina up to 60 DAS. Pendimethalin/atrazine fb atrazine and atrazine + pendimethalin fb 2,4-D/ metsulfuron-methyl controlled Ageratum conyzoides up to 60 DAS.

Rani, et al., (2011) reported that application of sulfosulfuron 15 g ha\(^{-1}\) + imazethapyr 25 g ha\(^{-1}\) as PE with HW at 40 DAS was found to be effective and economic weed management practice for irrigated sweet corn. Sunitha et al., (2010) reported that PE application of atrazine @ 1 kg ha\(^{-1}\) fb HW at 30 DAS provided significant weed control during the critical crop-weed competition period in sweet corn upto 45 DAS. Nadeem et al., (2010) reported that metolachlor + atrazine @ 1110 + 740 g a.i ha\(^{-1}\) as PE recorded highest grain yield on par with manual hoeing + earthing-up.

**Integrated weed management**

Abdullah et al., (2016) found that the most effective treatment in controlling weed population and increasing the grain yield of maize were atrazine @ 1.00 kg ha\(^{-1}\) + HW, 2 HW and paddy straw mulching, producing grain yield of (203.48 g, 188.34 g and 186.82 g) respectively, as compared to un-weeded plot (68.30 g).

Rasool and Khan (2016) found that PE
application of atrazine @ 1.0 kg a.i. ha\(^{-1}\) + HW at 20 DAS recorded maximum grain yield \(fb\) atrazine @ 1.0 kg a.i. ha\(^{-1}\) PE + isoproturon @ 1.0 kg a.i. ha\(^{-1}\) PoE. Maize + dhaincha (1:1) and (1:2) as green manure and maize alone with 2 HW during 1st year where as maize + cowpea as seed crop (1:1) and maize alone with 2 HW during 2\(^{nd}\) year produced significantly higher yield and lower weed dry weight (Kumar et al., 2015).

Kumar et al., (2013) reported that in zero tillage maize pre-plant incorporation of glyphosate \(fb\) atrazine + halosulfuron @ (1.0 + 90 g a.i ha\(^{-1}\)) as PoE resulted in highest grain yield.

Malviya et al., (2012) reported higher grain yield of maize with HW at 20 and 40 DAS and pendimethalin @ 1.0 kg a.i ha\(^{-1}\) as PE \(fb\) HW at 30 DAS and were at par with weed free treatment.

Sanodiya et al., (2013) stated that lowest weed biomass was recorded in weed free treatment (HW at 20 and 40 DAS) \(fb\) application of atrazine @ 1.0 kg a.i ha\(^{-1}\) as PE \(fb\) hand weeding at 30 DAS.

Verma et al., (2009) revealed that in maize-green gram system, manual weeding at 20 DAS \(fb\) earthing up at 30 DAS in maize recorded significantly higher plant height, culm girth and dry weight of plant. Deshmukh et al., (2009) reported significantly higher grain yield and fodder yield with atrazine @ 0.75 kg a.i ha\(^{-1}\) as PE \(fb\) one HW at 45 DAS.

Influence of weed management practices on weed characteristics and weed control efficiency

Weed density

Abdullah et al., (2016) found that maximum reduction in density of the weeds (m\(^{-2}\)) was observed with the treatment Paddy straw mulching (61.00) and Black polythene mulching (61.0) \(fb\) pre-emergence atrazine @ 1.0 kg ha\(^{-1}\) + one HW @ 45 DAS (75.0).

Application of atrazine + pendimethalin 0.50 + 0.50 kg ha\(^{-1}\) as PE similar to HW at 20 and 40 DAS recorded reduced weed density of narrow-leaf, broad-leaf and sedges at 30 and 60 DAS. The extent of reduction was to the tune of 69.8, 96.9 and 85.1% at 30 days and 73.7, 85.7 and 88.2% at 60 DAS, respectively (Barla et al., 2016).

Stanzen et al., (2016) reported the minimum density of weeds and biomass was observed under 2 HW which was at par with atrazine 1 kg ha\(^{-1}\).

Shankar et al., (2015) found that lower density and dry weight of weeds m\(^{-2}\) was recorded with atrazine (50%) @ 1.25 kg lit\(^{-1}\) or pendimethalin (50%) @ 2.5 lit ha\(^{-1}\) as compared to other chemical weed management treatments.

Samant et al., (2015) reported that farmers practice produced the minimum weed density (20.16 m\(^{-2}\)). PE application of atrazine 50% WP @1.0 kg ha\(^{-1}\) \(fb\) one HW at 30 DAS produced lower weed density (47.52 m\(^{-2}\)) which found superior over rest of herbicidal treatments in controlling weed density.

Singh et al., (2015.) reported that lowest weed density (49.5 m\(^{-2}\)) was recorded with pendimethalin (1000 g) + 1 HW which was statistically similar to pendimethalin (500g) + atrazine (500 g) and both were significantly superior to weedy check.

Kannan and Chinnagounder, (2014) reported that lower weed density was achieved under non transgenic maize hybrid BIO 9681 and 30B11 with PE application of atrazine at 0.5 kg ha\(^{-1}\) \(fb\) HW at 20 DAS.

Shingrup et al., (2014) reported that the
application of atrazine 0.75 kg ha\(^{-1}\) PE fb 2,4-D PoE significantly reduced the weed population in maize.

Madhavi et al., (2014) observed that tank mix application of PoE herbicide topramezone + atrazine @ 25.2 + 250 g a.i ha\(^{-1}\) recorded significantly lowest density of weeds compared to other treatments.

Lowest weed dry matter and highest WCE readings were recorded with HW (89.8%) fb atrazine fb intercultivation (87.5%), oxyfluorfen fb intercultivation (84.2%) and pendimethalin fb intercultivation (81.3%) (Madhavi et al., 2013).

Nadiger et al., (2013) reported that in maize HW fb IC at 20 and 30 DAS recorded significantly lowest weed density on par with atrazine @ 1.25 kg a.i ha\(^{-1}\) as PE fb IC at 30 DAS.

Ramachandran et al., (2012) reported that PE alachlor 1.0 kg ha\(^{-1}\) + brown manuring proved to be effective in registering the lowest weed density of grasses, sedges, broad-leaved weeds and total weeds.

Arvadiya et al., (2012) observed the marked reduction in weed density with PE application of atrazine 0.5 kg ha\(^{-1}\) coupled with pendimethalin 0.25 kg ha\(^{-1}\) fb application of PE atrazine 1.0 kg ha\(^{-1}\).

Sunitha and Kalyani (2012) found that the PE application of atrazine 0.5 to 1.0 kg ha\(^{-1}\) in combination with HW at 30 DAS recorded lowest weed density.

Singh et al., (2012) reported that tembotrione @ 120 g a.i ha\(^{-1}\) as PoE along with surfactant effectively reduced the growth and density of grasses *Echinochloa colona* L. and *Digitaria sanguinalis* L. sedge *Cyperus rotundus* L.

Srividya et al., (2011) found that application of either atrazine 1.25 kg ha\(^{-1}\) or pendimethalin 1.5 kg ha\(^{-1}\) in combination with paraquat 0.6 kg ha\(^{-1}\) at 3 weeks after sowing (WAS) recorded lower weed density (16.67 m\(^{-2}\)).

Dubey, (2008) found that application of pendimethalin 1.0 kg ha\(^{-1}\) along with one HW at 30 DAS significantly reduced the density of weeds than weedy check.

Among weed control methods, atrazine 1.5 kg ha\(^{-1}\) being statistically at par with acetachlor 1.25 kg ha\(^{-1}\) produced significantly lower density and dry matter of weeds and resulted in significant increase in all the yield attributes of maize crop and thereby its grain yield by 75.18 and 71.66%, respectively, over unweeded check (Chopra and Angiras, 2008).

**Weed dry weight**

Barad et al., (2016) reported that the lowest dry weight of weed was observed under HW and IC at 15 and 30 DAS (208 kg ha\(^{-1}\)), though it was found statistically at par with atrazine 0.5 kg ha\(^{-1}\) as PE fb HW and IC at 30 DAS (295 kg ha\(^{-1}\)).

Ehsas et al.,(2016) reported that minimum dry weight of weeds (60.96 kg ha\(^{-1}\)) at harvest was recorded under treatment of PE application of atrazine @ 0.75 kg ha\(^{-1}\) + pendimethalin @ 0.75 kg ha\(^{-1}\), which remained at par with PE application of alachlor @ 1.5 kg ha\(^{-1}\)+ atrazine @ 0.5 kg ha\(^{-1}\) (68.53 kg ha\(^{-1}\)). Samanth et al., (2015) reported that the minimum weed dry biomass (27.05 g m\(^{-2}\)) was obtained in farmers practice of two HW at 20 & 40 DAS and among the herbicidal treatments PE application of atrazine 50% WP@1.0 kg ha\(^{-1}\) fb one HW at 30 DAS recorded the minimum weed dry biomass (40.57 g m\(^{-2}\)).

Singh et al., (2015), reported that application
of pendimethalin (1000 g) + 1 HW recorded the lowest weed dry matter (44.8 g m⁻²) which was statistically similar to pendimethalin (500g) + atrazine (500 g) and both were significantly superior to weedy check.

Kumari et al., (2014) concluded that acetachlor @ 2250 g a.i ha⁻¹ as PE fb 2,4-D Na salt @ 500 g a.i ha⁻¹ as PoE recorded lowest weed dry matter on par with application of topramezone + atrazine (25.2+250 g ha⁻¹) and tembotrione + isoxadifen- ethyl @ (105+52 g ha⁻¹) + adjuvant as PoE.

Madhavi et al., (2014) noticed that lowest weed dry matter of weeds was recorded in tank mix application of topramezone + atrazine @ 25.2 + 250 g a.i ha⁻¹ as PoE and was on par with application of topramezone + atrazine @ 21 + 250 g a.i ha⁻¹.

Kannan and Chinnagounder (2014) found that considerable reduction in weed dry weight was recorded with the application of glyphosate at 1800 g a.e ha⁻¹ in transgenic 30V92 and POE controlled application of glyphosate at 1800 g a.e ha⁻¹ in conventional maize hybrid of 30V92 (1.58 and 1.82 g m⁻²) at 40 DAS.

Shingrup et al., (2014) observed the lowest weed dry matter accumulation due to application of atrazine 0.75 kg ha⁻¹ PE fb 2,4-D PoE. However, Nadiger et al., (2013) observed the minimum dry weight [1.80 (2.73) g m⁻²] of weeds with application of atrazine 1.25 kg ha⁻¹.

In maize, significantly lowest weed dry weight was recorded with pre-plant incorporation of glyphosate fb atrazine + halosulfuron @ 1.0 kg + 90 g a.i ha⁻¹ as PoE at 30 and 60 DAS, which was on par with pre-plant incorporation of glyphosate fb topramezone + atrazine @ 40 ml + 500 g ha⁻¹ as PoE (Kumar et al., 2013).

Sanodiya et al., (2013) observed that tank mix application of atrazine + pendimethalin @ 0.75 + 0.75 kg a.i ha⁻¹ recorded significantly lowest dry weight of Echinochloa colona L., Digitaria sanguinalis L., Cyperus rotundus L., Commelina benghalensis L. and Phyllanthus niruri L., at 60 DAS compared to application of herbicides alone. Singh et al., (2012) reported that tembotrione + surfactant @ 120 g a.i ha⁻¹ as PoE recorded significantly lowest weed dry matter at 30 and 45 DAS.

Kumar et al., (2012) reported that pendimethalin 1.5 kg ha⁻¹ PE fb atrazine 0.75 kg ha⁻¹ PoE, atrazine 1.5 kg ha⁻¹ PE fb atrazine 0.75 kg ha⁻¹ PoE were all effective in reducing total weed dry weight as compared to untreated check up to harvest.

Sunitha and Kalyani (2012) reported that the PE application of atrazine 0.5 to 1.0 kg ha⁻¹ in combination with HW at 30 DAS recorded lowest weed dry weight. Sequential application of atrazine 0.75 kg ha⁻¹ fb 2,4-D 1.0 kg ha⁻¹ recorded significantly lower dry weight of weeds which was on par with mechanical weeding (Hawaldar and Agasimani, 2012).

Haji et al., (2012) reported that lower total weed dry weight was noticed in atrazine 1.25 kg ha⁻¹ fb glyphosate 2.5 kg ha⁻¹. Significant weed control was also reported by Sarma and Gautam (2010). At 45 DAS the lowest weed dry weight was recorded with tembotrione 120 g ha⁻¹ + surfactant fb its lower dose (110 g ha⁻¹ + surfactant) (Singh et al., 2012).

Srividya et al., (2011) found that application of either atrazine 1.25 kg ha⁻¹ or pendimethalin 1.5 kg ha⁻¹ in combination with paraquat 0.6 kg ha⁻¹ at 3 weeks after sowing (WAS) recorded lower weed dry matter comparable with that of two HW and IC with.
power weeder at 4 WAS.

Application of atrazine 0.5-1.25 kg ha\(^{-1}\) had significantly reduced the populations and dry weight of weeds (Anon., 2010). Chopra and Angiras (2008) opined that application of atrazine 1.5 kg ha\(^{-1}\) at 60 DAS was proved to be significantly superior in reducing the dry matter of weeds.

Rout and Satapathy (1996) and Sharma et al., (2000) also proved the superiority of atrazine to control weeds.

Significantly lower dry weight of weeds (28.8 kg ha\(^{-1}\)) was achieved under treatment of atrazine + pendimethalin but was at par with weed free (Patel et al., 2006).

**Weed control efficiency**

Application of PE herbicides atrazine @ 1 kg ha\(^{-1}\) fb glyphosate @ 2.5 kg ha\(^{-1}\) was recorded with weed control efficiency (WCE) of 92.12% next to weed free check (Sahoo et al., 2017).

Ehsas et al., (2016) observed that highest WCE was recorded under the treatment of PE application of atrazine @ 0.75 kg ha\(^{-1}\) + pendimethalin @ 0.75 kg ha\(^{-1}\) (88.97%) fb PE application of alachlor @ 1.5 kg ha\(^{-1}\) + atrazine @ 0.5 kg ha\(^{-1}\) (80.75%) and PE application of atrazine @ 0.75 kg ha\(^{-1}\) + 2,4-D @ 0.5 kg ha\(^{-1}\) (80.25%).

Sraw et al., (2016) reported that highest WCE (91.6%) was observed in maize: cowpea (mulch 30 DAS) fb maize: cowpea (fodder at 30 DAS). Atrazine @ 1.0 kg ha\(^{-1}\) fb HW at 30 DAS gave least WCE due to higher weed dry weight (70.45 g m\(^{-2}\) and 45.6 g m\(^{-2}\) respectively). Dimitrios et al., (2010) also found that maize intercropped with legumes considerably reduced the weed density compared with the mono-cropping maize.

Kakade et al., (2016) reported that the highest WCE (80.09%) and less weed index (13.50%) was achieved with atrazine 0.50 kg ha\(^{-1}\) fb 2, 4-D sodium salt 0.5 kg ha\(^{-1}\) PoE 30 DAS.

Samant et al., (2015) found that the WCE varied from the maximum of 80.87% with farmers’ practice to the minimum of 54.12% with application of pendimethalin 1.5 kg ha\(^{-1}\) fb one HW at 30 DAS. Application with atrazine 1.0 kg ha\(^{-1}\) as PE fb one HW at 30 DAS recorded higher WCE (71.31%) than rest of herbicide treatments.

Mukherjee and Rai (2015) observed that highest WCE and lowest weed index values were registered with atrazine (1.0 kg ha\(^{-1}\)) as PE + atrazine (1.1 kg ha\(^{-1}\)) as PoE. Shankar et al., (2015) reported that highest WCE was found with application of atrazine (50%) @ 1.25 kg or lit + pendimethalin (50%) @ 2.5 lit ha\(^{-1}\).

Madhavi et al., (2014) found that tank mix application of topramezone + atrazine @ 25.2 + 250 g a.i ha\(^{-1}\) as PoE along with adjuvant methylated seed oil recorded highest WCE of grasses, sedges and broad leaved weeds compared to application of herbicide without adjuvant.

Kamaiah et al., (2014) also found that tank mixture application of atrazine @ 0.625 kg ha\(^{-1}\) + pendimethalin @ 0.5 kg ha\(^{-1}\) fb 2,4-D @ 0.5 kg ha\(^{-1}\) recorded higher WCE.

Shingrup et al., (2014) reported that the highest WCE was achieved with the application of atrazine 0.75 kg ha\(^{-1}\) PE fb 2,4-D PoE.

Madhavi et al., (2013) observed that lowest weed dry matter and highest WCE readings were recorded with HW (89.8%), fb atrazine fb IC (87.5%), oxyfluorfen fb IC (84.2%) and pendimethalin fb IC (81.3%).

Sanodiya et al., (2013) reported that WCE
was maximum with 2 HW closely fb alachlor 2.5 kg ha\(^{-1}\) + HW at 30 DAS, atrazine 1.0 kg ha\(^{-1}\) + HW at 30 DAS, combined application of atrazine 0.75 kg/ha + pendimethalin 0.75 kg ha\(^{-1}\) and atrazine 0.75 kg ha\(^{-1}\) + alachlor 2.25 kg ha\(^{-1}\) but lowest WCE found with PE application of atrazine 1.0 kg ha\(^{-1}\), pendimethalin 1.0 kg ha\(^{-1}\) and alachlor 2.5 kg ha\(^{-1}\) alone. These results are in agreement with findings of Walia et al., (2007).

Babiker et al., (2013) reported that maximum WCE was observed under treatment of Stomp in combination with Gearprim @ (1.5 L a.i +1.6 kg a.i) 97.9% in the first season and 96.6% in the second season. This finding was in conformity with the result of Patel et al., (2006) who stated that the WCE of >98% was achieved with PE application of atrazine in combination with pendimethalin.

With regard to WCE, it was higher (84.41, 92.15 and 89.65% at 20, 40 and 60 DAS, respectively) in PE alachlor 1.0 kg ha\(^{-1}\) + brown manuring. This was closely fb PE alachlor 1.0 kg ha\(^{-1}\) + daincha as intercrop with in-situ incorporation on 35 DAS (86.04%) (Ramachandran et al., 2012).

Hawaldar and Agasimani (2012) also reported that the highest WCE at all the stages of crop growth was recorded with sequential application of atrazine 0.75 kg ha\(^{-1}\) fb 2,4-D (1.0 kg ha\(^{-1}\)).

Sunitha and Kalyani (2012) reported that PE application of atrazine 0.5 to 1.0 kg ha\(^{-1}\) in combination with HW at 30 DAS recorded highest WCE. Sunitha et al., (2010) also observed the highest WCE with PE application of atrazine 1 kg ha\(^{-1}\) fb HW at 30 DAS,

Kumar et al., (2012) concluded that sequential application of atrazine @ (1.5 fb 0.75 kg a.i ha\(^{-1}\)) recorded highest WCE 80.3% which was closely fb pendimethalin @ 1.5 kg a.i ha\(^{-1}\) as PE fb atrazine @ 0.75 kg a.i ha\(^{-1}\) as PoE.

Malviya et al., (2012) reported higher WCE with HW at 20 and 40 DAS fb application of pendimethalin @ 1.0 kg a.i ha\(^{-1}\) as PE and HW at 30 DAS.

Srividy et al., (2011) reported that higher WCE with lower weed index (21.3%) was noticed with application of atrazine 1.25 kg ha\(^{-1}\)+ paraquat 0.6 kg ha\(^{-1}\) application fb pendimethalin 1.5 kg ha\(^{-1}\)+ paraquat 0.6 kg ha\(^{-1}\) and these were at par with that of weed free check and IC with power weeder.

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