Impact of Different Herbicidal Treatments on Hybrid Maize: A Review

Abstract

Maize (*Zea mays* L.) is an important cereal crop grown in the world. The living factors (insects, pests, weeds) and non-living factors (drought, salinity, heat stress) affects the yield of maize, among which weeds are considered as most destructive in decreasing the maize crop yield. Weeds negatively affects the grain yield of maize and increases the production cost of farmers. Various herbicides are used to control weeds in maize including atrazine, tembotrione etc. Atrazine is a pre-emergence herbicide used to control weeds. It is a selective herbicide used to control broad-leaved weeds ~~BLWs (broadleaf weeds)~~ and annual grasses. Tembotrione is a PoE (Post-emergence) broad spectrum herbicide used to control broad-leaved ~~BLWs~~ and grassy weeds in maize. This herbicide effectively reduces the density and dry weight of all the weeds present in maize crop. Tembotrione gives lower weed index and higher weed control efficiency, when applied at 150 g ha^{-1} + surfactant and at 125 g ha^{-1} + surfactant at 20 DAS.

Keywords: Atrazine, Dry weight, Maize, Weed Control and Weed Index

Introduction

Maize (*Zea mays* L.) is a very important cereal crop grown in the world. Maize is a C_4 type plant. It is a versatile crop ~~that means it grows on~~which can grow under different environmental conditions *i.e.*, it grows mainly in wet, hot weather but may also thrive~~s~~ in cold and dry conditions. Maize is a cross pollinated crop, and during harvest, maize grains consists of around 4% oil material along with 8-10 % protein (Kumar, 2020). ~~Maize~~ It ranks third in India after rice and wheat.

Comment [a1]: Ranks third in area or production?? Mention the data and source also.

In India maize is grown in both *kharif* and *rabi* season. Among cereal crops, maize has higher yield potential therefore known as the miracle crop or the "queen of cereals". Maize is known as a "wonder crop" as grains of maize ~~are~~is used for human usage, as animal food, and for starch and glucose industries. Maize is used for industrial raw material too. In India, nearly 28 % of maize is utilized for food purpose, 11 % , 48 % and 12 % ~~is~~ for livestock feed, poultry feed and in wet milling industries (for production of starch and oil), respectively. Maize is used as feed for piggery, chickens and other animals. This crop contains around 11.2 % protein, 70 % carbohydrate, 8 % oil, 10.4 % albumins, 2.3 % crude fiber, and 1.4 % ash. (Raut *et al.*, 2017) [38].

In India, maize is grown for various purposes such as for grain, green cobs, fodder, sweet corn, pop corn etc. The contribution of different states towards production of maize ~~are~~ is given as Andhra Pradesh (20.9 %), Rajasthan (9.9 %), Karnataka (16.5 %), Maharashtra (9.1 %), Madhya Pradesh (5.7 %), Bihar (8.9 %), Himachal Pradesh (4.4 %), Uttar Pradesh (6.1 %). Besides these states, the crop is also cultivated in North-~~-~~eastern states and Jammu & Kashmir. Himachal Pradesh is positioned 5th in area and has reported the highest production and productivity (Parihar *et al.*, 2011) [30]. In India during 2021-2022, maize crop is grown on an area of about 10.04 ~~M Ha~~mha with total production of 33.62 ~~Mt~~ mt and average productivity of 3349 kg ha^{-1} whereas in Himachal Pradesh, it is grown on an area of 270~~.0~~ thousand hectares, production 741.0 ~~Mt~~ mt and productivity is 2655.91 kg ha^{-1}. The districts Mandi, Kangra~~-~~, Hamirpur~~-~~, Chamba and Bilaspur in Himachal Pradesh ~~has~~ have the highest area and production of the maize crop. In district Sirmour, maize is cultivated over 24,000 hectares which yields 58750 Mt annually.

Comment [a2]: Add source of information

Various biotic (insects, pests, weeds) and abiotic factors (drought, salinity, heat stress) hampers the production of maize, and weed is considered as the leading factor for decreasing the maize crop yield (Sharma *et al.*, 2022) [40]. ~~Weeds are the one of the most important constituents that affects the maize production.~~ Weeds causes the yield losses of about 12.8 % with weed control methods and 29.2 % losses without weed control worldwide. Maize is a rainy season crop and being a wider spacing crop it gets infested with large number of weeds, which results in huge losses ~~ranges upto~~ranging from 28 to 100 % (Das *et al.*, 2012) [12]. If weed management is not done in maize, 100% yield loss occurs. Therefore, it is mandatory to control the weeds in suitable time period for obtaining higher yield and returns (Thukkaiyannan, 2021) [53]. The grassy weeds, BLWs (Broad-Leaf Weeds) and sedges infest the maize fields. Almost all kinds of weeds appears in maize field. The weeds causes yield losses in maize because of the multiple factors like weed density, emergence time of weeds and type of weeds (Pandey *et al.*, 2001) [29]. The crop-weed competition in maize occurs in between 15-45 DAS, therefore control weeds throughout this duration to obtain the greater yield of maize. Weeds grow faster due to wider spacing in maize which reduces the dry matter production and results in poor grain yield (Vaid *et al.*, 2010) [54] . The reduction in the grain yield of maize has appeared to be in the range of 33–50 % based on the type of weed species in ~~succeding~~succeeding reaping (Kumar and Singh 2020) [25]. Weed flora present in maize includes *Brachiaria reptans*, *Echinochloa colona*, *Digitaria cilliaris*, *Dactyloctenium aegyptium*, *Acrachne racemosa*, *Commelina benghalensis*, *Digera arvensis*, *Physallis minima*, *Phyllanthus niruri*, *Amaranthus viridis*, *Cucumis callosus* and *Cyperus rotundus* etc. (Punia *et al.*, 2007) [32].

In maize, different methods are used to control the weeds like cultural, biological, mechanical and chemical. Biological methods are not used frequently as it fails to control many weed species and controls only particular weed species. Cultural methods includesCultural methods include crop rotation, mulching, intercropping etc. These practices are unable to control the weeds alone at acceptable level but helps to reduce the weed count and population when used in combinations with other tactics. Mechanical method proves efficient for weed control in maize but this method is highly capital intensive so farmers are shifting to the other alternative cost-effecive methods (Duwadi, 2021). Chemical weed control methods by using Prepre- plant, pre-emergence (PE) and (PoE) post–emergence (PoE) herbicides. The chemical weed management is the best management practice to control the weeds in maize. This method control weeds in a better, faster and in a cost--effective manner (Ahmed *et al.*, 2008) [3].

Mechanical method requires high labour. So, to reduce the high labour cost, it is necessary to adopt the cost-effective method. SoTherefore, chemical method is preferred over mechanical method because it gives fast results, has low cost and also it is easy to apply. Herbicide also kills the perennial grasses. The herbicides persists in soil for longer time which helps to control the weeds for longer period. Sometimes, herbicides poses serious problems such as resulting in various environmental and health hazards of humans and animals if not used properly with cautions.

1.1. Losses due to weeds

According to Angiras and Singh (1989), weeds reduce grain output by 28–100%. Rao *et al.* (2009) [37] claim that weed growth that is out of control causes a 43% decrease in maize grain yield. According to Tagour *et al.* (2009) [51] the weed infestation reduced the grain production of maize by 56.8 to 57.2 percent.

Kumar and Angiras (2012) [25] observed that in silty clay loam soil of Palampur, weeds cause 50.3% reduction in grain yield of maize crop. Kumar *et al.* (2012) [26] reported that in silty clay loam soil of Palampur weeds causes about 50.3% reduction in grain yield of maize.

According to Yakadri *et al.* (2015) [58] observed that in maize field weeds cause yield losses of about 30-93%. Rana *et al.* (2017) [36] reported that on silty clay loam soil of Palampur, the weeds causes about 63.5% losses in the grain yield of maize.

According to Rai *et al.* (2018) [34] weeds can reduce maize crop yield by up to 86%.

According to Sharma *et al.* (2018) [41] weed infestation reduced maize output by 48%. According to Agrawal *et al.* (2019), weeds can reduce maize output by up to 25–90%. Shrestha *et al.* (2019) [43] found that weed infestation reduced maize production by 20–80%.

Chhokar *et al.* (2019) [9] found that an unchecked weed population reduced maize production by 38.7 to 54.0%. According to Kakade *et al.* (2020) [19] weeds resulted in yield losses ranging from 12.49 % to 54.17 %.

Shrestha *et al.* (2021) [44] found that weeds could account for up to 50.99% of yield losses in maize crops.

1.2. Critical period of crop weed competition

Critical period of crop weed competition is the period during which weeds are not allowed to grow inorder to control yield losses. The length of crop-weed competition and the stage of the crop at which it occurs determine the amount of crop loss. In order to use weed control techniques more cost-effectively and reduce crop production losses, it is critical to ascertain the crop weed competition period.

According to Tagour *et al.* (2009) [51] the essential phase for crop-weed competition occurred three to seven weeks following crop sowing.

Tehulie (2021) [52] states that the first four to six weeks following sowing in maize are the most crucial for crop weed competition.

According to Duwadi *et al.* (2021) two to eight weeks of sowing are the most crucial times for crop-weed competition in maize.

1.3. Weed flora associated with maize crop

Walia *et al.* (2007) [56] reported that *Acrachne racemose, Commelina spp., Digera arvensis, Trianthema portulacastrum, Eleusine spp., Amaranthus viridis, and Eragrostris spp.* were the most common weed flora infesting the maize field.

According to Idziak and Woznica (2010) [16] , the broad-leaved weeds in the maize field in Poland's sandy loam soil included *Chenopodium album, V. arvensis, and volunteer B. napus,* while the grassy weeds included *Echinochloa crus-galli, P. Beauv., Setaria viridus, P. Beauv.,* and *Elymus repens.*

According to Kumar *et al.* (2012) [26] , *Echinochloa colona, Panicum dichotomiflorum, Cyperus iria, Commelina benghalensis, Ageratum conyzoides, Digitaria sanguinalis,* and *Polygonum alatum* were the most common weed flora found in maize fields.

According to Singh *et al.* (2012a) [46], the different weed species that infested the maize field were *Cyperus rotundus among sedges, Phyllanthus niruri, Cleome viscosa among BLWs,* and *Echinochloa colona* among grassy weeds.

Ahmed and Susheela (2012) [2] reported that the predominant weed species present in kharif maize were *Cyperus rotundus, Cynodon dactylon, Digitaria sanguinalis, Dactyloctenium aegyptium* among monocot weeds and *Parthtenium hysterophorus, Commelina benghalensis, Amaranthus viridis, Euphorbia geniculata, Celosia argentia, Digeria arvensis, Trichodesma indicum, Legasca mollies. Cyperus rotundus and Cynodon dactylon* among dicot weeds.

According to Barla *et al*. (2016) [6] the weeds *Alternenthara sessils, Commelina benghalensis, Commelina nudifolia, Ageratum conyzoides, Phyllanthus niruri* ; *Echinochloa colona, Echinochloa crusgalli, Digitaria sanguinalis, Paspalam distichum, Dactyloctenium aegyptium* ; and *Cyperus rotundus, Cyperus iria , Fimbristylis milliaceae* were found to be the most common among broadleaved weeds ,grassy weeds and sedges.

Ramarao *et al.* (2016) [35] at Bapatla the predominant weed flora associated with maize crop were *Cyperus spp., Dactyloctenium aegyptium. Phyllanthus niruri, Panicum repens, Trianthema portulacastrum, Cleome viscosa, Cynodon dactylon, Euphorbia hirta.*

According to Singh *et al.* (2017a) [47] the most common weed species found in the maize experimental field were *Dactyloctenium aegyptium, Coronopus didymus, Ageratum conyzodies, Eclipta alba, Anagallis arvensis,* and *Cyperus rotandus*.

According to Rana *et al.* (2017) [36] *Brachiaria ramose, Commelina benghalensis, Polygonum alatum, Ageratum conyzoides, Cynodon dactylon, Panicum dichotomiflorum, Gallinsoga parviflora, and Phasalis minimum* were the main weed species found in kharif maize.

According to Akhtar *et al*. (2017) [4] the major weeds *Phyllanthus niruri, Solanum nigrum*; *Cynodon dactylon, Digitaria sangunalis, Sorghum common* ; *Cyperus rotundus* were found to be the most common among broad leaved weeds ,grassy weeds and sedges in the field of maize.

According to Singh *et al.* (2017b) [48] *Cyperus rotundus, Anagallis arvensis, Eclipta alba, Ageratum conyzodies, Coronopus didymus, Brachiaria reptans,* and *Dactyloctenium aegyptium* were the main weed flora found in the maize field.

Nazreen and Subramanyam (2017) [28] reported that the major weed flora observed in experimental plot of maize were *Cyperus rotundus, Phyllanthus niruri, Boerhavia erecta, Digera arvensis, Digitaria sanguinalis, Trichodesma indicum* and *Borreria hispida.*

Swetha *et al.* (2018) [50] observed the weed flora associated with maize crop were *Cynodon dactylon L., Digitaria sanguinalis L., Dactyloctenium aegyptium L., Echinocloa spp and Rottboellia exaltata L; Parthenium hysterophorus L., Commelina benghalensis L., Amaranthus viridis L., Euphorbia geniculata L., Digera arvensis L and Trianthema portulacastrum L;* and *Cyperus rotundus L.* among grasses, broadleaf weeds and sedge.

According to Sharma *et al.* (2018) [41], the maize field was infested with three types of weeds: *Cynodon dactylon* and *Echinochloa colona among the grasses; Cyperus iria* and *Fimbristylis miliacea among the sedges;* and *Ludwigia parviflora, Commelina nudiflora, Cyanotis axillaris, Phyllanthus niruri, Melochia corchorifolia* among the broadleaved weeds.

Yadav *et al.* (2018) [57] reported that the weeds *Dactyloctenium aegyptium, Brachiaria reptans, Digitaria sanguinalis, Leptochloa chinensis, Echinochloa colona; Euphorbia hirta, Amaranthus viridis* ;*Cyperus rotundus* were common among broad-leaf weeds , sedges and grasses.

According to Verma *et al.* (2018) [55] the most common weed species found in maize were *Cynodon dactylon, Echinochloa crusgalli, Dactyloctenium aegyptium, Digitaria sanguinalis, Brachiaria ramose, Commelina benghalensis, Digera arvensis, Amaranthus viridis, Trianthema portulacastrum, Phyllanthus niruri, Cyperus rotundus* and *Cyperus esculantus.*

Chhokar *et al.* (2019) [9] Major weed flora observed in maize were *Dactyloctenium aegyptium E. crus-galli, Digitaria sanguinalis, Trianthema portulacastrum, Digera arvensis, Phyllanthus niruri.* The dominant weed species were *E. crus-galli, D. arvensis, D. aegyptium T. portulacastrum.*

The most common weeds found in the maize field were *Commelina spp*., *Ageratum conyzoides, Digitaria sanguinalis, Echinochloa colona, Panicum dichotomiflorum, Cyperus spp., Cleome spp., Polygonum alatum, Phyllanthus niruri, Dactyloctenium aegyptiacum, Acrachne racemosa, Eragrostis tenella, Fimbristylis miliacea, Trianthema portulacastrum , Euphorbia hirta, Digera arvensis, Cynodon dactylon, Amaranthus viridis, Panicum repens, Trianthema portulacastrum, Datura stramonium, Corchorus olitorius, Digera arvensis, Physallis minima, Brachiaria spp*., *Asphodelus tenuifolius L. Cav., Portulaca oleracea* etc. (Kumar and Singh, 2020) [25].

Singh (2020) discovered that the major weed flora in maize was *Portulaca oleracea, Cyperus rotundus, Amaranthus viridis, Dactyloctenium aegyptium, Phyllanthus niruri, Digera arvensis* and *Brachiaria reptans.*

According to Ghrasiram *et al.* (2020) [13] the dominant weed species in the maize field were *Digitaria sanguinalis, Sorghum helepense, Brachiaria reptans, Dactyloctenium aegyptium, Digera arvensis, Commelina benghalensis, Cleome viscose L., Euphorbia hirta, Boerhavia erecta, Celosia argentea, Ipomea pestigr* and *Cyperus rotundus.*

The weed flora associated with maize crop were *Mimosa pudica, Xanthium strumarium, Celosia argentea, Calotropis gigantea, Tridax procumbens, Phyllanthus niruri, Portulaca oleracae, Lagasca mollis, Dinebra arabica, Abutilon indicum, Abelmoschus moschatus, Ischaemum pilosum, Amaranthis viridis, Bidens pilosa, Boerhavia diffusa, Cyanotis axillaris, Ageratum conyzoides, Alternanthera triandra, Parthenium hysterophorus, Euphorbia geniculate, Digera arvensis, Cynodon dactylon, Cyperus rotundus, Panicum spp., Commelina benghalensis, Digitaria sanguinalis, Dinebra retroflexa, Poa annua, Euphorbia hirta* etc. (Kakade *et al.* 2020) [19]

Paul *et al.* (2020) [31] reported that the weeds *Dactyloctenium aegyptium, Echinochloa colonumin* among grasses, *Cyperus esculentus, Cyperus rotundus* among sedges and *Acalypha indica, Boerhavia erecta, Cleome viscosa, Commelina benghalensis, Croton sparsiflorus, Eclipta* *alba, Phyllanthus maderaspatensis, Phyllanthus niruri, Trianthema portulacastrum* among broad leaved weeds were present in the experimental field of maize.

According to Shrestha *et al.* (2021) [44] the most common weeds in experimental field of maize were *Digitaria spp., Chenopodium album, Fimbristylis spp, Stellaria media, Oryza sativa, Cynodon dactylon, Ageratum conyzoides, Cyperus rotundus*.

Acharya *et al*. (2022) [1] found that the most common weeds in maize field were *Anagallis arvensis*, *Commelina diffusa*, *Polygonum convolvulus*, *Alternanthera sessilis*, *Oxalis corniculata Trifolium repens*, *Cynodon dactylon*,*Ageratum conizoides*, *Elusine indica*, *Amaranthus viridis* ,*Cyperus rotundus*.

Khose *et al.* (2022) [24] reported that the dominant weed flora present in maize field were *Cynodon dactylon*, *Digitria chalaris* sedges are *cyperus iria*, *Cyperus rotondus* among grasses and *Polygon pensyivanicum, Polygon persicaria, Chenopodium album, Physils minima* among broad leaf weeds.

According to Chaudhari *et al.* (2023) [8] the weed flora observed in the experimental field of maize were *Eleusine indica, Eragrostis major, Setaria glauca, Dactyloctenium aegyptium, Asphodelus tenuifoliu*, *Commelina benghalensis*, *Digitaria sanguinalis* among monocot weeds and *Chenopodium album, Chenopodium murale, Digera arvensis, Phyllanthus niruri, Melilotus alba, Boerhavia erecta* and *Oldenlandia umbellate* among dicot weeds.

Sachan *et al.* (2023) reported that the major weed flora associated with maize field were *Echinochloa colonum, Brachiaria ramosa, Digitaria sanguinalis, Dactyloctenium aegyptium, Eleusine indica, Setaria glauca, Sorghum halepense, Panicum spp., Cynodon dactylon, Digitaria setigera, Leptochloa chinensis, Digitaria ciliaris,* among grasses*; CommeIina benghalensis, Ageratum conyzoides, Galinsoga parviflora, Euphorbia geniculata, Undernia cilata, Oxalis latifolia, Celosia argentea, Portulaca oleracea, Aschynomene indica, Phyllanthus niruri, Amaranthus viridis, Parthenium hysterophorus, Tridax procumbens, Acalypha indica,* and *Euphorbia hirta* among non-grassy weeds and *Cyperus iria, Cyperus rotundus* among sedges.

Sharma *et al.* (2023) [42] reported that the dominant weed flora observed in maize were *Cynodon dactylon, Echinochloa colona* among the grasses*; Cyperus iria, Fimbristylis miliacea* among the sedges and *Ludwigia parviflora Raven, Commelina nudiflora, Cyanotis axillaris, Phyllanthus niruri, Melochia corchorifolia, Ludwigia parviflora, C. dactylon , F. miliacea* among broadleaf weeds.

Raghuwanshi *et al.* (2023) [33] reported that the predominant weed flora present in kharif maize were *Echinochloa colona, Commelina communis, Digitaria sanguinalis* among monocots, *Phyllanthus niruri, Eclipta alba* among dicots.

1.4. Weed management in maize

1.4.1. Tembotrione

Singh *et al.* (2012a) [46] observed that the maize crop resulted in higher grain yield when tembotrione was applied at 120 g ha^{-1} along with surfactant as compared to other herbicidal treatements.

Singh *et al.* (2012b) [45] found that the higher grain yield was recorded with the post emergence application of tembotrione 120 g ha^{-1} along with surfactant and this treatment was at par with a lower dose of tembotrione at 110 g ha^{-1} along with surfactant.

Rana *et al.* (2017) [36] observed that significantly higher weed control efficiency, higher crop resistance index, efficiency index was observed when tembotrione was applied at 150 g ha^{-1} + surfactant which was *fb* tembotrione at 125 g ha^{-1} + surfactant treatment.

Singh *et al.* (2017a) [47] observed that tembotrione effectively controls different weeds and lowers the weed density and dry matter when tembotrione was applied at 120 g ha^{-1} + surfactant.

According to Singh *et al.* (2017b) [48] found that highest yield attributes i.e. cob length , number of seed rows per cob, number of grain per cob, 100 grain weight, grain weight per cob and cob yield with or without husk, grain yield and stover yield was recorded with the application of Alachlor 2000 g ha^{-1} which was *fb* tembotrione 120 g ha^{-1} + S.

Akhtar *et al.*(2017) [4] reported that the tembotrione applied as PoE at 120 g ha^{-1} has reduced the total weed population, weeds dry weight and weed index at 15 DAS. Also it resulted in higher weed control efficiency and yield of maize.

Verma *et al.* (2018) [55] observed that lower density, dry weight, higher weed control efficiency and grain yield in maize was recorded when tembotrione was applied as (PoE) at 120 g ha^{-1}.

Sharma *et al.* (2018) [41] noted that the combined application of tembotrione and atrazine was found to be superior to its sole application .Lower weed index, dry weight, weed density and higher values of weed control efficiency, growth , yield & yield attributes of maize was recorded when tembotrione was applied at 100 g ha^{-1} + stefes mero surfactant at 733 g ha^{-1} + atrazine 500 g ha^{-1} and this treatement was at par with tembotrione at 80 g ha^{-1} + stefes mero surfactant at 733 g ha^{-1} + atrazine 500 g ha^{-1} .

Jayabhaye *et al.* (2020) [18] observed that higher weed control efficiency along with higher growth and yield attributes of maize with the application of Atrazine 0.50 kg ha^{-1} *fb* tembotrione 0.120 kg ha^{-1}.

Ghrasiram *et al.* (2020) [13] found that higher grain yield and weed control efficiency (WCE) were obtained with the application of atrazine at 1.0 kg ha^{-1} *fb* tembotrione at 0.120 kg ha^{-1}.

Kakar *et al.* (2021) [20] reported that the pre-emergence application of atrazine at 1.5 kg ha^{-1} *fb* post-emergence application of tembotrione 120 g ha^{-1} at 25 DAS reported higher grain row^{-1}, number of grain cob^{-1} and Grain weight cob^{-1}.

Kaur *et al.* (2022) [21] reported that the application of tembotrione at 125 g ha^{-1} along with surfactant on 20 DAS were proved effective in controlling weeds.

1.4.2. Atrazine

Sivamurugan *et al.* (2017) [49] reported that the higher grain yield, stover yield and seed index were obtained in treatment T_2 *i.e.*, weed free which was *fb* treatment T_{10} *i.e.*, Atrazine at 1.5 kg a.i. ha^{-1} *fb* tembotrione at 120 g a.i.ha^{-1} as post-emergence at 25 DAS.

Gupta *et al.* (2018) [14] reported that when atrazine + pendimethalin at 750 g ha^{-1} was applied as post-emergence, it results in higher growth of crop ,yield attributes, grain and stover yield of hybrid maize.

Rai *et al.* (2018) [34] reported that higher weed control efficiency (WCE), weed density and dry weight was observed with pre-emergence application of atrazine at 1.0 kg a.i.ha^{-1} *fb* 1 HW at 30 DAS.

Mali *et al.* (2019) [27] found that higher grain and stover yield were recorded with the application of atrazine at 0.5 kg ha^{-1} + tembotrione 0.125 kg ha^{-1} at 15 DAS.

Kumar *et al.* (2019) showed that the pre-emergence application of atrazine (50 % WP) at 500 g ha^{-1} *fb* (PoE) tembotrione (34.4 % SC) at 125 g ha^{-1} increased the weed control efficiency and grain yield of maize.

Kaur and Kaur (2019) [22] observed that lowest weed density was found in the weed free treatment *fb* tembotrione at 0.110 kg ha^{-1}.

Paul *et al.* (2020) reported that higher grain yield were obtained with the PE application of atrazine 0.25 kg ha^{-1} *fb* PoE application of tembotrione at 120 g ha^{-1}.

Kakar *et al.* (2021) [20] found that the higher grain yield were recorded with the pre-emergence application of atrazine at 1.5 kg ha^{-1} which was *fb* the post- emergence application of tembotrione at 120 g ha^{-1} at 25 DAS.

Fayaz *et al.* (2022) reported that the highest growth parameters as well as yield parameters were obtained with the pre-emergence application of Atrazine at 0.5 kg ha^{-1} *fb* tembotrione at 120 g ha^{-1} at 35 DAS.

Acharya *et al.* (2022) [1] showed that the higher yield of maize was obtained with the pre-emergence application of atrazine at 1 kg a.i. ha^{-1} *fb* post–emergence application of tembotrione at 120 g ha^{-1} which was followed by 2 HW at 30 and 40 DAS treatment.

Jadhav *et al.*(2022) [17] observed that lower weed index, weed dry matter and higher weed control efficieny were recorded with the application of topramezone + atrazine at 250 g a.i. ha^{-1} which was *fb* tembotrione at 105 g ha^{-1} + atrazine at 250 g a.i. ha^{-1}

Sachan *et al.* (2023) [39] found that the higher weed control efficiency were obtained when atrazine (PE) at 1.0 kg a.i. ha^{-1} at 20 DAS and atrazine at 0.5 kg a.i. ha^{-1} were applied.

Raghuwanshi *et al.* (2023) [33] reported that highest weed control efficiency was recorded with the application of topramezone at 35 g ha^{-1} + atrazine at 250 g ha^{-1} and tembotrione 120 g ha^{-1} + atrazine 250 g ha^{-1} .

Bahrami *et al.* (2023) [5] found that higher grain yield of maize were obtained with the pre-emergence application of atrazine at 500 g ha^{-1} *fb* post-emergence application of tembotrione at 100 g ha^{-1} at 30 DAS, pre-emergence application of atrazine at 500 g ha^{-1} *fb* post-emergence application of topramezone at 25 g ha^{-1} at 30 DAS.

1.5. Phyto-toxicity and residual effect

Hatti *et al.* (2014) [15] reported that due to the selective nature of the tembotrione there was no phytotoxic effect on maize like epinasty, necrotic symptoms, hyponasty, stunted growth and wilting after spraying.

Singh *et al.* (2012a) [46] observed that there was no phytotoxicity of tembotrione at 100-120g ha^{-1} (with or without surfactant) and tembotrione at 120 and 240 g ha^{-1} (with surfactant) on maize and also tembotrione has no residual phyto-toxic effect on the upcoming wheat crop.

1.6. Economics

Ramarao *et al.* (2016) [35] found that the highest returns were obtained with the pre-emergence application of atrazine at 1.0 kg a.i ha^{-1} *fb* topramezone spray at 25 g a.i ha^{-1} at 20 DAS (2.00).

Sivamurugan *et al.* (2017) [49] noted that the highest net returns were found in T_2 (weed free) treatment *fb* T_9 treatment i.e.,pre -emergence application of pendimethalin at 1 kg a.i. ha^{-1} *fb* atrazine 0.75 kg a.i. ha^{-1} + 2,4-D Amine at 0.4 kg a.i. ha^{-1} and higher Benefit Cost Ratio was noted in this treatment which was followed by treatment T_5 i.e.,pre -emergence application of atrazine 1.5 kg a.i. ha^{-1} + 2,4-D Amine at 0.4 kg a.i. ha^{-1}.

Akhtar *et al.* (2017) [4] reported that the higher cost of cultivation were obtained in the weed free treatment which was *fb* 2 HW at 15 and 30 DAS whereas higher net returns and B:C ratio was recorded with the PoE application of tembotrione at 120 g ha^{-1} at 15 DAS .

Yadav *et al.* (2018) highlighted that during both the years higher BC ratio was recorded with the PoE application of tembotrione at 120 g ha^{-1} with surfactant at 1000 ml ha^{-1}.

Barua *et al.* (2019) [7] reported that highest B: C ratio and net returns was observed in T_{11} treatment (pre-emergence application of Atrazine at 1.5 kg ha^{-1} *fb* post emergence application of Tembotrione at 120 g ha^{-1} at 25 DAS) and this treatment was *fb* T10 treatment (pre-emergence application of Pendimethalin at 1000 ml ha^{-1} *fb* Atrazine at 750 g ha^{-1} + post emergence application of 2,4-D Amine at 0.4 kg ha^{-1} at 25 DAS.

Bahrami *et al.* (2023) [5] found that with the pre-emergence application of atrazine at 500 g ha^{-1} *fb* Post-emergence application of tembotrione at 100 g ha^{-1} at 30 DAS, highest net returns and BC ratio were recorded and this treatment was followed by the pre-emergence application of atrazine at 500 g ha^{-1} *fb* Post-emergence application of topramezone 25 g ha^{-1} at 30 DAS.

Chaudhari *et al.* (2023) [8] reported with the pre-emergence application of atrazine + pendimethalin 500 + 250 g ha^{-1} or Early Post-emergence (EPoE) application of at 10-15 DAS of topramezone 336 + atrazine 25.2 + 500 g ha^{-1}, tembotrione + atrazine at 120 + 500 g ha^{-1}.

Kaur and kaur, (2023) [23] noted that the higher gross returns, net returns and B:C ratio was recorded with integration of pre-emergene application of atrazine at 1.25 kg ha^{-1} or Pendimethalin at 1.5 kg ha^{-1} *fb* paraquat at 0.6 kg ha^{-1} at 3 weeks after sowing (WAS) or pre-emergence application of atrazine at 1.0 kg ha^{-1} *fb* topramezone at 0.030 kg ha^{-1} at 30 DAS.

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