Managing weeds using sequential herbicides in maize for improving crop growth and productivity under irrigated conditions in North-Western India

Ramanjit Kaur*, Rishi Raj, T K Das, Raj Singh, Manpreet Jaidka and Kapila Shekhawat

Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi-110 012

* Corresponding author: E-mail: ramaan180103@yahoo.com

Keywords: *Zea mays L., Grain yield, Growth, Herbicide, Weed control efficiency*

Abstract

Field experiments were conducted in *Kharif* 2015 and 2016 at the research farm, ICAR-Indian Agricultural Research Institute, New Delhi to determine the effect of different pre- and post-emergence herbicide applications on weed dynamics in maize (*Zea mays* L.). The investigation had a combination of eleven treatments using atrazine, pendimethalin, halosulfuron and tembotrione herbicides at different doses with different methods of application. One hand weeding (manual) treatment was kept as standard check and weedy check as control. Chemical weed control and weed free treatment recorded lower weed dry matter compared to weedy check. Highest leaf area was recorded in weed free treatment which was statistically at par with foliar application of halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha [30 days after sowing (DAS)] as tank mix] and pendimethalin @ 1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha but significantly higher than weedy check. Highest cob length (18.07 cm) was recorded in weed free which was significantly higher than other treatments except pendimethalin @ 1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha. A significant increase in 100-seed weight and bundle weight was recorded in weed free treatment and all the other chemical treatments relative to weedy check for both the years and significantly higher grain yield was recorded in weed free and chemical treatments {halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) or halosulfuron @ 90 g/ha fb tembotrione @ 120 g a.i./ha (post em)} relative to weedy check. During both the years, highest yield loss relative to weed free was recorded in weedy check (52.88 %). During both the years, weed free and chemical treatments like halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) recorded significantly lower weed density, weed dry matter and weed index than weedy check. Significantly higher weed control efficiency was recorded in weed free (manual) and with application of atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (PE) during both the years. Herbicide application treatments like halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) resulted in highest weed control index relative to weedy check.

Introduction

Weed infestation is one of the plant biotic stresses and also one of the major constraints of maize production in India. Being more aggressive, hardy and highly competitive, weeds grow better than the crop under identical set of growing conditions. Weeds, undesirable plants, due to wider adaptability and prolific growth rate, compete for growth factors like water, nutrients etc and reduce the crop yield by infesting different crop fields (Kaur et al, 2017). Worldwide up to 40% of production of maize is affected by weed menace. Heavy infestation of weeds alone has been reported to decrease the yield up to 35-80% because the weeds are the most important among other biotic stresses of this crop (Oerke and Dehne, 2004). On the whole, weeds cause the highest loss potential (37%) which is higher than loss potential of insect pests (18%), fungal and bacterial pathogens (16%) and viruses (2%) (Oerke, 2006). The loss in crop yield depends upon different factors: the kind of weed flora present in the crop field, weed seed bank and relative emergence, intensity and density of weeds, stage of crop growth relative to keen competition period and time for which weeds remains in the field. Weeds compete with the crops for resources resulted in serious yield losses, deterioration in the quality of the produce and also serve as a home/host for many associated disease causing organisms. The greatest yield loss in the maize grain is experienced when the weeds are not managed specifically during critical crop-weed competition period (i.e. the period during which weed control has to be carried out). Obviously, weather conditions and weed density have a great influence on the length of critical periods. Therefore, control of weeds or keeping the population level of weeds below economic threshold level is essential and mostly desirable for obtaining good crop-harvest.

Suitable weed management practices in maize resulted in increased grain yield (77 to 96.7%) than the unweeded control (Tesfay et al, 2014). Depending on the availability of the resources, there are various weed control methods used for managing the weeds under field conditions. Being economically cheaper, faster and better, chemical methods are most frequently used for the control of weeds (Chikoye et al, 2005) compared to manual weed control methods as they are getting expensive, laborious and time-consuming because of scarcity of manpower. Ali et al (2003) also reported that weed control with herbicides significantly increased maize yield and decreased the weed density. Weed control using pre-emergence and same herbicides year after year is not sufficient for effective weed management in maize as continuous use of currently registered herbicides caused changing weed flora, poor control, and evolution of some herbicide resistant weed biotypes, which necessitates the introduction of some new herbicide options with different modes of action or time of application. Studies involving pre and post-emergence herbicides in combination with other methods of weed control are also scant in the literature. Although there are well defined herbicides applied as pre-emergence for effective weed control in maize crop, but being *kharif* season crop receiving plenty of rainfall (specifically in NW India), weeds come out in different flushes throughout the crop growing season. Application of pre-emergence herbicides can control weeds for a month or so depending on the prevailing climatic conditions. For example, *Cyperus rotundus*, infests majority of *kharif* crops and it cannot be controlled by different herbicides used so far. From literature, it was found that halosulfuron herbicide was quite effective in controlling this particular weed. Therefore, this research was undertaken with the objective to find out the effect of application of pre and post-emergence herbicides in combination with residue retention on growth and productivity of maize and weed control efficiency.

Materials and Methods

Maize genotype and agronomic practices

Maize cv PMH-1 was sown on 15th June, 2015 and 14th June, 2016 following recommended package of practices for growing healthy crop during Kharif seasons of 2015 and 2016 on loamy sand soil at ICAR-Indian Agricultural Research Institute, New Delhi to study the performance of maize (*Zea mays* L.) to sequential application of herbicides. A seed rate of 20 kg ha^{-1} was used and the maize crop was planted at a spacing of 60 cm x 20 cm. Application of 50 kg of N and 62.5 P2O5 ha^{-1} before sowing through urea, single super phosphate, respectively was done. The recommended irrigation was provided through surface check basin method. Rabi wheat was sown in the experimental field during the previous winter seasons, 2014-15 and 2015-16. New Delhi is situated at 28°38′N latitude and 77°10′E longitude. The altitude is about 229 m above the mean sea level. The area comes under semi-arid and subtropical climate with very hot dry summers and cold winters. The experimental field had an even topography and a good drainage system. The soil of the experimental site was sandy loam, low in organic carbon (0.43%) and available N (177.7 kg ha^{-1}), medium in phosphorus (11.6 kg ha^{-1}) and potassium (178.5 kg ha^{-1}), having pH of 7.6 and EC of 0.33 dSm^{-1}.

Herbicide treatments

The experiment was laid out in a randomised block design (RBD) replicated three times with eleven treatment combinations *i.e.*, atrazine @ 0.75kg ai/ha + pendimethalin @0.75kg ai/ha (PE), atrazine @1.0kg ai/ha (PE)+residue @2.5t/ha, pendimethalin @1.0kg ai/ha (PE) + residue @2.5/ha, atrazine @0.75kg ai/ha (PE) fb halosulfuron @90g/ha (POE), atrazine @0.75kg ai/ha (PE) fb tembotrione @ 120g a.i./ha (POE), pendimethalin @0.75kg ai/ha (PE)+ halosulfuron @90g/ha (POE), pendimethalin @ 0.75kg ai/ha (PE)+ tembotrione @ 120 g a.i./ha (POE), halosulfuron @90g/ha + tembotrione @ 120g a.i./ha (Tank mix, POE), halosulfuron @90g/ha fb tembotrione @ 120g a.i./ha (POE), unweeded control and weed free. Pre-emergence herbicides were applied within 2 DAS and post-emergence application was done at 30 DAS. The detail of the treatments imposed was as given below (Table1):

In this study, two new post emergence herbicides were used and a brief picture of these two molecules is given as:

1 Tembotrione (Laudis OD) is a new herbicide for the selective control of broadleaved weeds and annual grasses in maize (*brit.* maize) and it is a member of the triketone class of herbicides. There are a variety of impressive herbicides acting by different molecular modes of action used in maize for effective management of weeds. Long time proven molecules such as atrazine, dicamba, or metolachlor have been more recently supplemented with products such as nicosulfuron, rimsulfuron and foramsulfuron. Rapid bleaching and

Table 1 - Details of treatments

	Treatments	Time of application (DAS) Days After Sowing
T1	Atrazine @ 0.75 kg a.i./ha + Pendimethalin @ 0.75 kg a.i./ha (pre-em)	Herbicide was applied 2 DAS as Pre-emergence
T2	Atrazine @1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha	Herbicide was applied 2-3 DAS as Pre-emergence and wheat residue was used @2.5t/ha as mulch within 6-7 DAS
T3	Pendimethalin @ 1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha	Herbicide was applied 2-3 DAS as Pre-emergence and wheat residue was used @2.5t/ha as mulch within 6-7 DAS DAS
T4	Atrazine @ 0.75 kg a.i./ha (pre-em) fb Halosulfuron @ 90 g/ha (post em)	Herbicide was applied 2-3 DAS as Pre-emergence followed by halosufuron after 30 DAS as post emergence.
T5	Atrazine @ 1.0 kg a.i./ha (pre-em) fb Tembotrione @ 120 g a.i./ha (post em)	Herbicide was applied 2-3 DAS as Pre-emergence followed by Tembotrione after 30 DAS as post emergence.
T6	Pendimethalin @ 0.75 kg a.i./ha (pre-em)+ Halosulfuron @ 90 g/ha (post em)	Pendimethalin was applied 2-3 DAS as Pre-emergence and Halosulfuron was applied after 30 DAS as post emergence.
T7	Pendimethalin @ 0.75 kg a.i./ha (pre-em)+ Tembotrione @ 120 g a.i./ha (post em)	Pendimethalin was applied 2-3 DAS as Pre-emergence and Tembotrione was applied after 30 DAS as post emergence.
T8	Halosulfuron @ 90 g/ha + Tembotrione @ 120 g a.i./ha (Tank mix, post em)	Halosulfuron and Tembotrione was applied 25 DAS as tank mix post emergence.
T9	Halosulfuron @ 90 g/ha fb Tembotrione @ 120 g a.i./ha (post em)	Halosulfuron was applied at 15 DAS followed by post emergence application of tembotrione at 30 DAS
T10	Unweeded control/Weedy check	Without any weed control option
T11	Weed-free control	Kept totally free from weeds throughout the crop season

quick elimination of susceptible weeds were the symptoms observed after application of a triketone herbicide. In the structure, introduction of the innovative OCH 2-CF substituent into the triketone ring system results in a herbicide with solubility properties that permit easy entry of hydrophilic (aqueous) and lipophilic (waxy, fatty) barriers on the way from the spray deposit on the weed surface to the sites of molecular action inside the plant cells. As a result the spectrum of susceptible weeds has been significantly improved compared with existing products in this class. The addition of isoxadifen-ethyl, a proprietary safener protects maize from herbicide stress and ensures crop tolerance even under very challenging growing conditions.

Tembotrione, like all other triketone herbicides, inhibits the enzyme 4-hydroxy phenylpyruvate dioxygenase (HPPD), disrupted the formation of carotenoids which resulted in depletion of chlorophyll, the sites of photo synthesis. The mode of action of tembotrione has shown a minimal risk of resistance development. No weeds resistant against HPPD inhibitors have been detected to date under realistic agronomic use conditions.

2 The second new herbicide used in this study was Halosulfuron-methyl is a new sulfonylurea compound for the selective control of the perennial sedge species, nutgrass (*Cyperus rotundus*). Efficacy trials carried out in eastern Australia indicated good control of Nut grass and there was no evidence of phytotoxicity in the turf species tested. Advantages of halosulfuron-methyl include less phytotoxicity to grass species and better control than the limited chemical treatments currently available. Soil degradation occurs by hydrolysis at a rate which increases with increasing pH. Halosulfuron-methyl is likely to have low persistence in the soil or water.

Sampling techniques and observations

Weed control effects

A quadrat (0.5 m × 0.5 m) was randomly placed in each plot at 60 DAS and individual weed species were counted, collected, sun dried for 2 days and kept in an oven at 65 ± 5°C for 48 h for recording dry weight. At 15 days after herbicide application, per cent weed control efficacy and per cent damage to maize plants were visually evaluated and rating was made on a scale from 0 to 100% (control/phytotoxicity) scale.

Weed Population - The weed population count was taken with the help of 0.5 m×0.5 m quadrat thrown randomly at two places in each plot and was converted into per square meter.

Weed Dry weight – For recording weed dry weight, the weed plants were harvested from each quadrat (0.5m x 0.5m) and then the harvested plants were categorized specie wise and kept in paper bags and dried in oven at a temperature of 65°C for 24 hours till constant weight is achieved and subsequently the dry weight was taken and converted in to g m^{-2}.

Agronomic observations

The various growth and yield parameters of maize were recorded as per standard procedures and statistically analyzed. For plant height, five plants were randomly selected from each plot and their height was recorded in cm. Leaf area of five plants from each plot was measured and leaf are index was calculated and averaged for presentation. After taking leaf area of five plants, the whole plant was kept in oven at 65°C for drying till they attained a constant weight. Then dry weight was recorded and presented in g/plant. Similarly, for yield attributing characters, five plants were randomly selected from each treatment and data on number of cobs, length of cob, girth of cob, number of ranks/cob, 100- grain weight were recorded. Yield data was recorded and finally presented on t/ha basis. Sometimes the magnitude of loss due to weeds is not depicted clearly from weed count or dry matter of weeds. So, following studies are very useful.

Weed control efficiency

Weed control efficiency (WCE), which reflects per cent reduction in weed density by a treatment and was determined using eq.1 (Nath et al, 2016).

$$WCE(\%) = [\{(WPc - WPt)\ x100\} / WPc] \quad (1)$$

Where, WPc and WPt are weed density (No. m^{-2}) in UWC (weedy check) and treated plots, respectively.

Weed control index (WCI), which reflects per cent reduction in weed dry weight by a treatment and was determined using eq. 2 (Nath et al, 2016).

$$WCI(\%) = [\{(WDc - WDt)\ x100\} / WDc] \quad (2)$$

Where, WDc and WDt are weed dry weights (g m^{-2}) in UWC (weedy check) and treated plots, respectively.

Weed index (WI) is a measure of the efficacy of particular treatment in terms of yield output when compared with weed-free treatment. It reflects per cent yield loss due to a treatment and was calculated using eq. 3 (Asres and Das, 2011).

$$W\ (\%) = [\{(Ywf - Yt)*100\}/Ywf] \quad (3)$$

Where, Ywf and Yt are Maize yields in weed-free control and treatment, respectively.

Relative yield loss: Crop yield loss was calculated based on the maximum yield obtained from a treatment /treatment combination i.e. interaction as follows:

$$\text{Relative yield loss } (\%) = [\{(MY\text{-}YT)*100\}/MY]$$

Where, MY = yield from weed free treatment, YT = yield from a particular treatment.

Statistical analysis

All data on weed and maize crop were subjected to analysis of variance (ANOVA) using the PROC GLM procedure of SAS. The two-year data were subject to pool analysis to visualize the variations of particular crop/weed parameters between the years, treatments, and the year × treatment interactions, which were mostly non-significant at P = 0.05. The significance was tested by variance ratio (i.e., F value) at P = 0.05 (Gomez and Gomez, 1984). Standard error (SE) and least significant difference (LSD) were calculated for each parameter of weeds studied for comparing the treatment means

Results and discussion

Maize growth parameters

During 2015 the highest maize plant height (Fig. 1) was observed in weed free treatment (T_{10}) which was significantly higher (21.3%) than T_4, T_6, T_7, T_9 and T_{11} (weedy check) but statistically at par with T_1, T_2, T_3, T_5 and T_8. Weedy check (T_{11}) registered the lowest plant height as compared to other weed control treatments. All the herbicide treatments were found statistically at par with each other as well as with weed free treatment in terms of plant height. During the second year of study (2016), weed free (T_{10}) treatment recorded the highest plant height which was statistically at par with chemical weed control treatments but significantly higher than weedy check (T_{11}) with per cent increase of 19.3%. Furthermore, all the chemical treatments tested, were found statically at par with each other but significantly different from weedy check (T_{11}). Evaluation of data showed suppressing effect of atrazine on maize plant height when applied @ 0.75 kg a.i./ha as pre-emergence fb halosulfuron @ 90 g/ha (post-em). During 2016, although T_6 and T_7 did not vary significantly from each other but T_6 had lower plant height than T_7. Thus, it can be concluded that application of halosulfuron @ 90 g/ha at 30 DAS had more suppressing effect on maize plant height as compared to tembotrione applied @ 120 g a.i./ha at 30 DAS.

Furthermore, analysis of data depicted highest dry matter (Fig. 1) accumulation in T_{10} treatment (weed free) (106.90 g/plant) which reached the level of significance as compared to all other weed control treatments. Among herbicide treatments, highest maize dry matter was registered by application of atrazine @ 1.0 kg a.i./ha as pre-emergence fb halosulfuron @ 90 g/ha (post em) (T_4) which was statistically similar to other treatments except T_6 and T_9. At the same time, T_6 and T_9 treatments were found to be statistically at par with weedy check (T_{11}). Almost similar results were recorded for dry matter accumulation in both the years under study, where T_{10} treatment (weed free) registered highest and significantly higher dry matter accumulation as compared to other weed control treatments. Chemical weed control treatments showed significantly higher dry matter accumulation than weedy check (T_{11}). Among herbicide treatments, T_9 treatment (halosulfuron @ 90 g/ha (15 DAS) fb tembotrione @ 120 g a.i./ha (30 DAS) registered lower dry matter accumulation than T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) which indicates better efficacy of halosulfuron and tembotrione herbicides when applied as tank mix than their sequential application. During both years under study, lower dry matter accu-

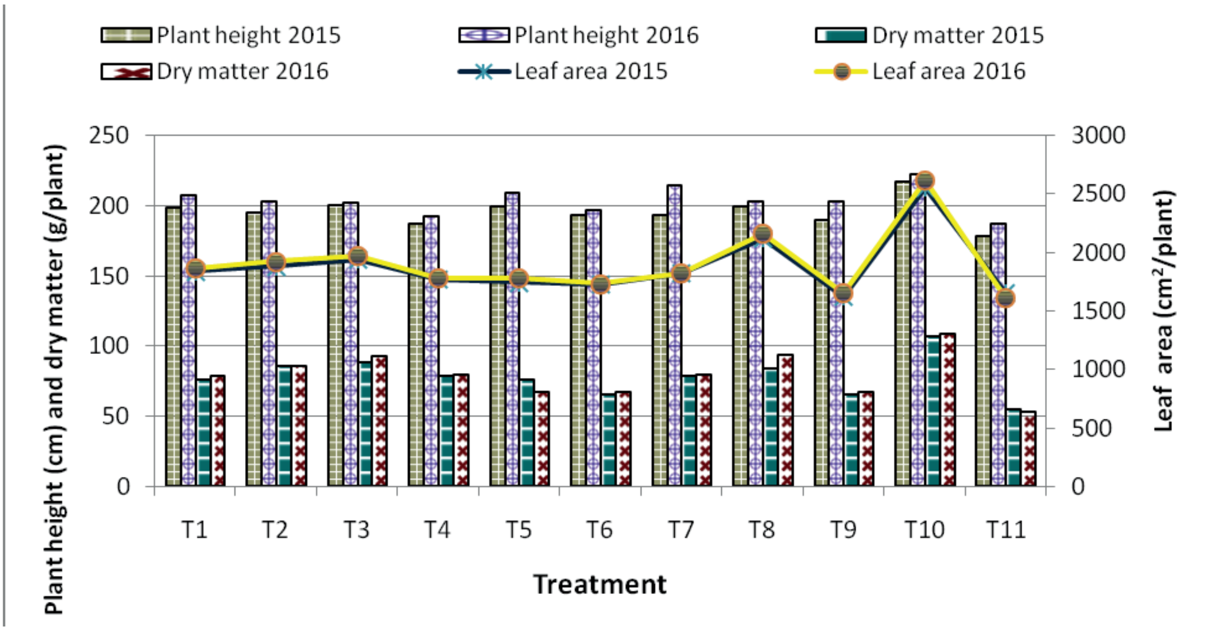

Fig. 1 - Growth Parameters of maize crop at 75 DAS during 2015 and 2016

mulation in T_6 as compared to T_7 clearly demonstrates relatively more suppressing effect of halosulfuron than tembotrione. In 2015, highest leaf area (Fig. 1) was recorded in T_{10} treatment (weed free) which was significantly different from rest of the treatments. In context of chemical treatments, highest leaf area was registered by T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) which was statistically at par with T_3 (pendimethalin @ 1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha) but significantly higher than other treatments including weedy check (T_{11}). Lowest value of leaf area was recorded in weedy check which was statistically equal with T_1, T_2, T_4, T_5, T_6, T_7 and T_9. Sequential application of halosulfuron and tembotrione had suppressing effect on leaf area as compared to tank mix application which is apparent from lower leaf area in T_9 than T_8 treatment. Furthermore, relative to tembotrione, halosulfuron showed more suppressing effect in terms of maize leaf area which is evident from leaf area difference between T_6 and T_7 treatments. Similarly, in 2016, weed free treatment (T_{10}) registered significantly higher leaf area in comparison to other treatments. Minimum leaf area per plant was recorded in weedy check (T_{11}) which was statistically at par with T_4, T_5, T_6, T_7 and T_9. Among chemical control treatments, lowest leaf area was registered by T_9 treatment (halosulfuron @ 90 g/ha (15 DAS) fb tembotrione @ 120 g a.i./ha (30 DAS). In the year, 2016, sequential application of halosulfuron and tembotrione showed suppressing effect on leaf area of maize plant as compared to their tank mix application. It is also apparent from the comparison of T_6 and T_7 treatments which showed that post-emergence application of halosulfuron suppresses the maize crop more compared to tembotrione. Increase in growth parameters viz. plant height, dry matter and leaf area in weed free treatment can be attributed to lowest possible weed infestation, decrease in duration of weed interference and lack of crop-weed competition during the life cycle of crop which in turn led to better availability of inputs to crop. On the contrary, weedy check (T) registered minimum level of growth parameters owing to critical crop weed competition during crop life cycle.

Yield attributes of maize

In the first year of investigation (2015), highest cob length (18.07 cm) was recorded (Fig. 2) in T_{10} (weed free) which was significantly higher than other treatments except T_3 (pendimethalin @ 1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha). Lowest cob length was recorded in weedy check (T_{11}) which was significantly lower than rest of the treatments. Among chemical treatments, highest cob length was observed in T_3 (pendimethalin @ 1.0 kg a.i./ha (pre-em) + residue @ 2.5 t/ha) which was statistically equal with all other chemical treatments. Like 2015, highest cob length was registered by weed free treatment (T_{10}) which was significantly different from other weed control treatments during the year 2016. Significantly lower cob length was recorded in weedy check (T_{11}) in comparison to other treatments. Among chemical control treatments, highest cob length (16.40 cm) was recorded in T_1 (atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (both pre-emergence) and lowest was recorded in

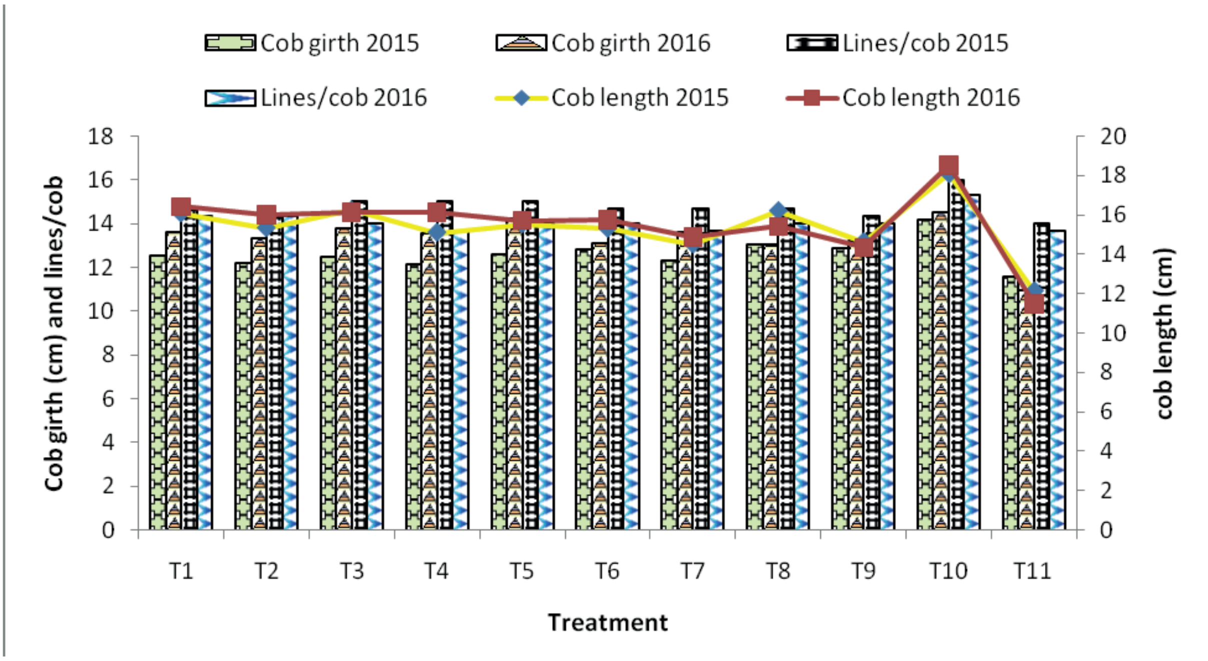

Fig. 2 - Yield attributes of maize as affected by weed management practices during 2015 and 2016

T_9 (halosulfuron @ 90 g/ha (15 DAS) fb tembotrione @ 120 g a.i./ha (30 DAS). Highest cob length in T_1 was attributed to effective weed control, lesser weed density (Fig. 2) and lower crop weed competition for available resources. Analysis of data on cob girth (Fig. 2) depicted a significant increase of 22.2% in T_{10} (weed free) as compared to weedy check (T_{11}) during 2015. Cob girth of weedy check (T_{11}) was statistically equal with all chemical weed control treatments except T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix). All the chemical weed control treatments were found statistically at par with each other. Similarly, highest cob girth (14.50 cm) was registered by T_{10} (weed free) which was significantly different from weedy check (T_{11}) during 2016. Lowest cob girth (10.93 cm) was recorded in weedy check which was significantly lower from other weed control treatments. Among chemical treatments, highest cob girth was reported in T_5 [(atrazine @ 1.0 kg a.i./ha (pre-em) fb tembotrione @ 120 g a.i./ha (post em)] treatment which was statistically at par with other chemical weed control treatments except T_6, T_8 and T_9.

Data pertaining to number of lines per cob during 2015 (Fig. 2) showed significant increase in weed free treatment relative to other treatments. Minimum number of lines per cob was recorded in weedy check (T_{11}) which was statistically at par with T_1, T_2, T_6, T_7, T_8 and T_9 treatments. All the chemical treatments were found statistically at par with each other. Likewise, weed free (T_{10}) treatment registered highest number of lines per cob in both the years of investigation, which was significantly different from rest of the treatments. During 2015, highest number of cobs per plot (82) (Table 2) were recorded in weed free (T_{10}) treatment and it was significantly better than other weed control treatments. Minimum number of cobs per plot (29) was recorded in weedy check (T_{11}) which was significantly lower from all the chemical weed control treatments. Treatment T_1 (atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (both pre-emergence) surpassed all the chemical control measures and it was statistically at par with T_4 and T_6 treatments. On the contrary, T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) recorded minimum number of cobs per plot. Minimum number of cobs per plot in weedy check can be attributed to more crop-weed competition, increased period of weed interference and the weeds rob the crop of growth factors which would have otherwise be available for proper crop growth and development. Highest row number in Treatment T_1 is clearly witnessed by minimum weed density (Table 4) due to effective weed control in this particular treatment compared to other chemical weed control treatments. In 2016, highest cob number (85.67) per plot was recorded in T_7 (pendimethalin @0.75 kg a.i./ha (pre-emergence) + tembotrione @ 120 g a.i./ha (30 DAS) which was statistically at par with weed free (T_{10}), T_3, T_6 and T_8 treatments but significantly different from other treatments including weedy check (T_{11}). Data pertaining to 100-seed weight (Table 2) showed significant increase in weed free (T_{10}) treatment which was statistically at par with T_8 and T_9 but significantly different from rest of the treatments. The treatments using herbicides for controlling weeds also achieved level of significance relative to weedy check which is evident from lowest value of 100-seed weight in weedy check. Among herbicide treatments, highest 100-seed weight (32.87 g) was recorded by T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) while lowest 100-seed weight was observed in T_4 (atrazine @ 0.75 kg a.i./ha (pre-em) fb halosulfuron @ 90 g/ha (post-em). Similarly, in 2016, weed free (T_{10}) treatment registered highest 100-seed weight (30.73 g) of maize which was significantly different from T_4, T_7 and weedy check (T_{11}) but statistically at par with rest of the treatments. Lowest 100-seed weight was recorded in weedy check (T_{11}) which was statistically at par with T_4 and T_7 but significantly less from all other treatments. All chemical weed control treatments except T_4 and T_7 reached level of significance when compared with weedy check. During both the years, lower value of 100-seed weight in T_9 compared to T_8 clearly demonstrates the more effectiveness of tank mixing of halosulfuron and tembotrione compared with their sequential application.

Analysis of data showed that weed free (T_{10}) treatment registered highest bundle weight (11.5 t/ha) which was significantly different from weedy check (T_{11}). Lowest bundle weight (6.5 t/ha) was recorded in weedy check. All the treatments including chemical treatments were found statistically at par with each other and reached the level of significance in comparison to weedy check. Similar results were recorded during 2016 where weed free registered highest bundle weight (11.67 t/ha) which was significantly different from T_3, T_4, T_5, T_6, T_7 and weedy check (T_{11}). All herbicide treatments were found statistically at par with each other but significantly better to weedy check.

Effect of herbicide treatments on maize yield

Data pertaining to grain yield (Table 2) depicted highest grain yield of maize in weed free (T_{10}) treatment which was statistically at par with rest of the treatments except T_5, T_7 and weedy check (T_{11}). Lowest maize yield was registered by weedy check with per cent decrease of 52.88 compared to weed free. Amongst herbicide treatments, highest grain yield was recorded in T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) which was statistically at par with T_1, T_2, T_3, T_4, T_6 and T_9 but significantly better from T_5 and T_7. Post emergence application of halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha at 30 DAS as tank mix resulted in 107.4 % higher grain yield when compared with weedy check (T_{11}). Similar results were recorded during 2016 where weed free treatment (T_{10}) recorded the highest (6.70 t/ha) grain yield and it was statistically at par with rest of the treatments except T_5, T_7 and weedy check (T_{11}).

Minimum grain yield was recorded in weedy check with per cent decrease of 49.70 relative to weed free. All the chemical weed control treatments except T_7 reached level of significance relative to weedy check (T_{11}). Among chemical weed control treatments, highest grain yield was recorded in T_9 (halosulfuron @ 90 g/ha (15 DAS) fb tembotrione @ 120 g a.i./ha (30 DAS) which was statistically at par with T_1,T_2, T_3, T_4, T_6 and T_8 but significantly different from T_5 and T_7. From the results of both the years pertaining to grain yield, it can be concluded that depending on availability, farmer can

Table 2 - Grain yield and yield attributes of maize under the influence of weed management practices during 2015 and 2016

Treatments	Cobs/plot no.		100-seed weight (g)		Bundle Weight (t/ha)		Grain Yield (t/ha)		Yield loss relative to weed free (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T1	70	72.00	30.33	30.07	10.13	10.33	6.30	6.53	4.55	2.54
T2	59	60.33	30.80	30.07	10.25	9.95	5.92	5.99	10.30	10.60
T3	63	70.00	29.53	29.13	9.25	9.15	5.50	5.48	16.67	18.21
T4	63	64.67	26.53	26.13	9.13	9.33	5.51	5.82	16.52	13.13
T5	60	63.00	30.93	28.73	9.38	9.45	5.10	5.30	22.73	20.90
T6	69	67.67	29.60	28.53	9.63	9.68	5.73	5.95	13.18	11.19
T7	61	65.67	29.60	27.63	8.75	8.81	4.40	4.47	33.33	33.28
T8	63	71.67	32.87	29.73	10.50	10.65	6.45	6.60	2.27	1.49
T9	64	68.67	31.73	29.67	10.47	10.65	6.41	6.69	2.88	0.15
T10	82	81.33	34.73	30.73	11.5	11.67	6.60	6.70	0.00	0.00
T11	29	31.00	24.87	20.87	6.5	6.37	3.11	3.37	52.88	49.70
CV (%)	**12.00**	**12.00**	**6.48**	**7.48**	**9.47**	**8.27**	**16.51**	**8.70**	--	--
LSD (p=0.05)	**8.0**	**10.44**	**3.27**	**2.85**	**1.78**	**1.98**	**1.30**	**1.31**	--	--

Table 3 - Weed floral composition of experimental area

S. No.	Botanical Name	Family
1	*Amaranthus viridus L.*	*Amaranthaceae*
2	*Commelina benghalensis L.*	*Commelineae*
3	*Trianthema portulacastrum*	*Aizoaceae*
4	*Cynodon dactylon L.*	*Poaceae*
5	*Cyperus esculentus L.*	*Cyperaceae*
6	*Cyperus rotundus L.*	*Cyperaceae*
7	*Erucastrum arabicum Fisch and May*	*Brassicaceae*
8	*Digitaria sanguinalis*	*Poaceae*
9	*Polygonum nepalense Meisn*	*Polygonaceae*

go for application of pendimethalin and it can be done either by mixing it with atrazine as pre-emergence or using halosulfuron as sequential application. Furthermore, either tank mixing (T_8) or sequential application (T_9) of halosulfuron and tembotrione can be done for obtaining better grain yield. Results pertaining to grain yield are in line with William et al (2014) who reported significant decrease in maize yield in weedy check relative to herbicide treatments. During 2015, highest yield loss relative to weed free (Table 2) was recorded in weedy check (52.88 %). Among chemical treatments, application of pendimethalin @ 0.75 kg a.i./ha (pre-em) + tembotrione @ 120 g a.i./ha (post-em) (T_7) registered highest yield loss while T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) treatment had minimum yield loss (2.27 %) followed by T_9 (halosulfuron @ 90 g/ha (15 DAS) fb tembotrione @ 120 g a.i./ha (30 DAS) (2.88%) and T_1 (atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (pre-em) (4.55%). In 2016 also, weedy check showed highest yield loss (49.70%) relative to weed free. Among chemical treatments, highest yield loss was recorded in T_7 (pendimethalin @ 0.75 kg a.i./ha (pre-em)+ tembotrione @ 120 g a.i./ha (post-em) (33.28 %) but minimum yield was observed in T_9 (halosulfuron @ 90 g/ha (15 DAS) fb tembotrione @ 120 g a.i./ha (30 DAS) (0.15%) followed by T_8 (halosulfuron @ 90 g/ha + tembotrione @ 120 g a.i./ha (30 DAS as tank mix) (1.49 %) and T_1 (atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (pre-em) (2.54%). The results reported by Kaur et al (2014) indicated a decreasing trend in effective tillers, number of grains/ear, 1000-grain weight and grain yield of wheat with increasing population densities of *Malva neglecta* from 3 to 12 plants/m2. These results are also supported by Kaur et al (2020).

Weed parameters

Analysis of data (Table 4) on weeds revealed that the lowest weed density (4.00/m^2) was recorded in weed free (T_{10}) treatment which was significantly better from other treatments. At the same time, highest weed density i.e., 137.32/m^2, was recorded in weedy check (T_{11}) which was statistically at par with T_5 (atrazine @ 1.0 kg a.i./ha (pre-em) fb tembotrione @ 120 g a.i./ha (post em). Amongst the chemical weed control treatments, T1 (atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (both pre-emergence) reported the lowest weed density while, highest weed density (126.68/m^2) was recorded in T_5 (atrazine @ 1.0 kg a.i./ha (pre-em) fb tembotrione @ 120 g a.i./ha (post em). Likewise, weed

Table 4 - Effect of weed management applications on weed density and weed dry matter during 2015 and 2016

Treatments	Weed Density 75 DAS (/m^2)		Weed Dry matter 75 DAS (g/m^2)		Weed Index (%)		Weed Control Efficiency (%		Weed Control Index (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T1	60.00	62.68	36.40	40.40	29.33	32.59	56.31	58.76	63.85	62.21
T2	101.32	96.00	67.48	59.60	28.00	41.73	26.22	36.84	32.98	44.26
T3	108.00	109.32	70.00	72.80	40.00	36.96	21.35	28.08	30.47	31.91
T4	96.00	98.68	33.08	31.72	40.00	33.66	30.09	35.08	67.14	70.33
T5	126.68	126.68	97.88	84.00	33.33	28.99	7.75	16.66	2.78	21.44
T6	105.32	110.68	87.48	84.80	24.00	32.39	23.30	27.18	13.11	20.69
T7	108.00	110.68	90.40	94.68	28.00	40.95	21.35	27.18	10.21	11.45
T8	80.00	81.32	50.52	56.00	14.00	31.42	41.74	46.50	49.82	47.62
T9	88.00	88.00	34.12	31.48	14.53	28.02	35.92	42.11	66.11	70.56
T10	4.00	4.00	4.00	4.00	0.00	0.00	97.09	97.37	96.03	96.26
T11	137.32	152.00	100.68	106.92	58.53	67.22	0.00	0.00	0.00	0.00
CV (%)	15.70	11.83	17.02	12.37						
LSD (p=0.05)	27.96	20.16	18.12	12.76						

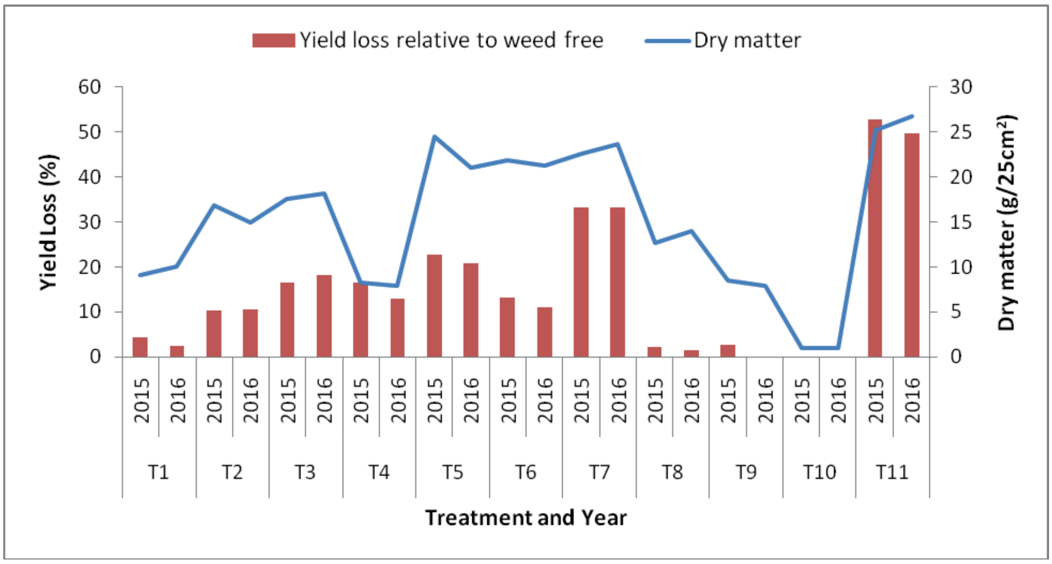

Fig. 3 - Relation between weed dry matter and loss of grain yield of maize during 2015 and 2016

free treatment recorded the lowest weed density (4.00/m^2) during 2016, which was significantly lower than other weed control treatments. Highest weed density (152.00/m^2) was recorded in weedy check (T_{11}) which was found significantly higher from rest of the treatments. Shankar et al (2015) also reported significant decrease in weed population in weed free and herbicide treatments in comparison with weedy check. The analysis of data on weed dry matter (Table 4) showed significantly lower dry matter accumulation (4.00 g/m^2) in T_{10} (weed free) treatment as compared to all other treatments. At the same time, highest weed dry matter of weeds was recorded in weedy check (T_{11}) which was found statistically at par with T_5, T_6 and T_7. Amongst chemical weed control treatments, lowest weed dry matter was recorded in T_1 (atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (both pre-emergence) which was statistically at par with T_4, T_8 and T_9. In the year 2016, weed free treatment had lowest weed dry matter (4.00 g/m^2) which was significantly lower from rest of the treatments. Highest weed dry matter was recorded in weedy check (T_{11}) which was found to be statistically at par with T_7 (pendimethalin @ 0.75 kg a.i./ha (pre-emergence) + tembotrione @ 120 g a.i./ha (30 DAS) but significantly higher from other herbicide treatments. Among chemical treatments, lowest weed dry matter was recorded in T_1 which was statistically at par with T_4 and T_9 treatments. On the basis of weed dry matter during 2015 and 2016, it can be concluded that treatments T_1, T_4 and T_9 proved equally effective in reaching the level of significance when compared with weedy check (T_{11}) which witnesses the availability of three possible options with the farmers to maintain the weed dry matter below the economic threshold. Results pertaining to weed dry matter are in accordance with Kandasamy (2017).

Computation of weed index (Table 4) recorded the lowest value (0%) in weed free (T_{10}) treatment while the highest was recorded in weedy check during the year 2015. Among chemical weed control treatments, tank mix application of halosulfuron @ 90 g/ha and tembotrione @ 120 g a.i./ha at 30 DAS (T_8) resulted in lowest weed index while T_3 and T_4 treatments recorded highest value of weed index. During 2016 also, weed free treatment (T_{10}) reported lowest weed index and weedy check recorded the highest weed index. Among herbicide treatments, minimum weed index was obtained with sequential application of halosulfuron @ 90 g/ha (15 DAS) and tembotrione @ 120 g a.i./ha at 30 DAS (T_9) followed by pre-emergence application of atrazine @ 1.0 kg a.i./ha fb tembotrione @ 120 g a.i./ha (post em) (T_5). As weed index is inversely related to effective weed management so lower value of weed index in weed free and herbicide treatments indicates the effectiveness of herbicides for managing weeds in maize as compared to weedy check. Results of weed free and herbicidal treatments are in line with Samant et al (2015). The results reported by Kaur et al (2014) indicated a decreasing trend in various yield parameters and grain yield of wheat with increasing population densities of *Malva neglecta* from 3 to 12 plants/m^2. Furthermore, during 2015, highest weed control efficiency (WCE) of 97.09 % was recorded in weed free treatment (T_{10}) while weedy check treatment registered minimum weed control efficiency. Among herbicide treatments, highest weed control efficiency (56.31%) was obtained with pre-emergence application of atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (T_1) while minimum (7.7%) was recorded with pre-emergence application of atrazine @ 1.0 kg a.i./ha fb tembotrione @ 120 g a.i./ha (post-em) (T_5). Similar results were obtained in the second year (2016) of study where maximum weed control efficiency (97.37%) was reported in weed free treatment while minimum in weedy check. Pre-emergence application of atrazine @ 0.75 kg a.i./ha + pendimethalin @ 0.75 kg a.i./ha (T_1) registered highest weed control efficiency while minimum (7.7%) was recorded with pre-emergence application of atrazine @ 1.0 kg a.i./ha fb tembotrione @ 120 g a.i./ha (post-em) (T_5). Shankar et al (2015) also reported higher WCE in weed free (T_{10}) and herbicide treatments. In 2015, weed free treatment (T_{10}) recorded maximum weed control index (WCI) (96.03%), while weedy check had minimum WCI (0.0%) compared to rest of the treatments. Among herbicide treatments, pre-emergence application of atrazine @ 0.75 kg a.i./ha registered highest WCI (67.14%) followed by sequential application of halosulfuron @ 90 g/ha (15 DAS) and tembotrione @ 120 g a.i./ha (30 DAS) (T_9). In 2016 also, weed free (T_{10}) reported maximum WCI (96.26%) and weedy check (T_{11}) registered minimum WCI (0.00%) compared with rest of the treatments. Furthermore, post-emergence application of halosulfuron @ 90 g/ha (15 DAS) and tembotrione @ 120 g a.i./ha (30 DAS) (T_9) had highest WCI (70.56%) followed by pre-emergence application of atrazine @ 0.75 kg a.i./ha (pre-em) fb halosulfuron @ 90 g/ha (post-em) (70.33%) (T_4). Results of WCI are in conformity with Kandasamy (2017).

Conclusions

The various weed control treatments which implied post-emergence herbicides resulted in better control of weeds and ultimately resulted in better crop growth and productivity; this output might be due to continuous longer persistence effect of pre and post emergence herbicides which keeps the crop free from weeds for a longer period and by that time the crop grows to a sufficient height to have a smothering effect on the weeds. Whereas the observations under weed free treatment could be attributed to the reduced crop weed competition at the initial stages and to the removal of late emerged weeds.

Acknowledgements

The authors are thankful to the Director, ICAR-Indian Agricultural Research Institute, New Delhi, India, for providing facilities to carry out this piece of research.

References

Chikoye D, Udensi UE, Fontem A Lum, 2005. Evaluation of a new formulation of atrazine and metolachlor mixture for weed control in maize in Nigeria. Crop Prot 24: 1016-1020

Ali R, Khalil SK, Raza SM, Khan H, 2003. Effects of herbicides and row spacing on maize (Zea mays L.). Pak J Weed Sci Res 9: 171-178

Gomez AK, Gomez AA, 1984. Statistical Procedures for Agricultural Research, second ed. Wiley Interscience, New York, USA.

Nath CP, Das TK, Rana KS, 2016. Effects of herbicides and tillage practices on weeds and summer mungbean (Vigna radiata) in wheat (Triticum aestivum)-mungbean cropping sequence. Indian J Agril Sci 86: 860-864

Kandasamy S, 2017. Effect of weed management practices on weed control index, yield and yield components of sweet maize. J Agril Res 2: 1-4

Kaur R, Jaidka M, Kingra PK, 2017.Correlation analysis of growth, yield and yield components of wheat (Triticum aestivum) under varying weed densities. Indian J Agril Sci 87: 746-753

Kaur R, Jaidka M, 2014. Spectral reflectance characteristics to distinguish Malva neglecta in wheat (Triticum aestivum). Indian J Agril Sci 84: 1243-1249

Kaur R, Das T K, Benerjee T, Raj Rishi, Singh R and Sen S, 2020. Impacts of sequential herbicides and residue mulching on weeds and productivity and profitability of vegetable pea in North-western Indo-Gangetic Plains. Scientia Horti. DOI: 10.1016/j.scienta.2020.109456

Oerke EC, 2006. Crop losses to pests. J Agril Sci 144: 31-43

Oerke EC, Dehne HW, 2004. Safeguarding production-losses in major crops and the role of crop protection. Crop Prot 23: 275-285

Tesfay A, Amin M and Mulugeta N. 2014. Management of Weeds in Maize (Zea mays L.) through Various Pre and Post Emergency Herbicides. Adv Crop Sci Tech 2(5): 151. DOI: 10.4172/2329-8863.1000151.

Samant TK, Dhir BC, Mohanty B, 2015. Weed growth, yield components, productivity, economics and nutrient uptake of maize (Zea mays L.) as influenced by various herbicide applications under rainfed condition. Scholars J Agri Vet Sci 2: 79-83

Shankar KA, Yogesh LN, Prashanth SM, Channabasavanna AS, Channagoudar RF, 2015. Effect of weed management practices on weed growth and yield of maize. Int J Sci Environ 4: 1540-1545

Williams MK, Heiniger RW, Everman WJ, Jordan DL, 2014. Weed control and maize (Zea mays L.) response to planting pattern and herbicide program with high seeding rates in North Carolina. Advances in Agriculture: 1-8