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Response of maize (*Zea mays*L) inbred lines to different herbicide combinations

Nyasha Sakadzo[1*], Kasirayi Makaza[1], Ignatius Chagonda[1], Jimmy Shanangura[2], and Tafadzwa T Haripo[2]

[1]Department of Agronomy, Faculty of Natural Resources Management and Agriculture, Midlands State University, P bag 9055, Gweru, Zimbabwe.
[2]Department of Soil and Plant Sciences. Faculty of Agricultural and Natural Sciences, Great Zimbabwe University, P.O. Box 1235 Masvingo, Zimbabwe.

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A field experiment was carried out at Agricultural Seed and Services Research Station in Zimbabwe to evaluate the response of maize inbred lines to different herbicide combinations. The trial was laid out in a 5×12 split plot design replicated three times. Herbicide combination was main plot factor with five levels; Hand-hoeing;metolachlor+ atrazine;metolachlor+ atrazine+ nicosulfuron; metolachlor+ atrazine+ halosulfuron and metolachlor +atrazine+ nicosulfuron+ halosulfuron. These combinations of herbicides have a broad spectrum activity and are able to control annual and perennial weeds with an inbred line as subplot factor with twelve levels; CML488, CML312, CML444, CML443, CML00001, CML395, CZL0610, CZL00003, CZL03014, L917 and N3.2.3.3. Data on germination, phytotoxicity, plant height, anthesis silking interval (ASI), ear height and grain yield were measured. There was a significant interaction (p<0.05) between herbicide combination and maize inbred line on germination, plant height (week 2 and 4), phytotoxicity, ASI, ear height and grain yield. There was no interaction (p>0.05) among herbicide combinations and maize inbred lines on plant height (week 12). That concluded metolachlor+ atrazine+ nicosulfuron and metolachlor +atrazine+nicosulfuron+ halosulfuron herbicides had a major effect on susceptible maize inbred lines. Inbred lines were grouped into three categories in relation to European Weed Research Council (EWRC) score, efficacy and survival rate into; tolerant (CML312, CML444, CML443 and CML00003), medium resistant (CML395, CZL0610, NAW5885 and CZL00003) and susceptible (CML488, CZL03014, L917 and N3.2.3.3). Therefore, the study recommends not using metolachlor+ atrazine+ nicosulfuron and metolachlor+ atrazine+ nicosulfuron+ halosulfuron herbicide combinations on susceptible maize inbred lines.

Key words: *Zea mays*, inbred lines, herbicide combinations, metolachlor, atrazine, nicosulfuron.

INTRODUCTION

Maize (*Zea mays L.*) is one of the most important staple food crop grown in Zimbabwe where it is ranked first in the number of producers, area grown and total cereal production (Mashingaidze, 2004). It is the mostly widely

*Corresponding author. E-mail: nsakadzo87@gmail.com. Tel:+263 775 985 724.

grown food crop in sub-Saharan Africa (SSA) and is produced on approximately 22 million hectares of land which is about 15.7% of the land area grown to maize globally (Pingali and Pandey, 2001).

Maize inbred lines are characterised by low vigour, slower growth and this makes them susceptible to various stress conditions (Stefanovic and Simici, 2007). These inbred lines can only compete successfully for light, water, nutrients and carbon dioxide if they are adequately protected against both annual and perennial (Johnson grass, wild sorghum and nutsedge) weeds. In order to keep the weed cover below the economic injury level, integrated weed management is often employed. However currently weed management is more centralised towards use of herbicides due to shortage of labour (Waddington and Karigwindi, 1996).

Sensitivity responses have been reported in maize inbred lines after treatment with Atrazine ® (triazine), an active agent considered being super-selective for maize (Shimabukiro et al., 1971). Rowe and Penner (1990) noted differences in tolerance of inbred lines when testing with Chloroacetamides. Similar tests conducted at Art farm (1999) using halosulfuron -75 % WG (sulfonylurea) on the maize inbred lines showed two genotypes to be sensitive. Herbicides tolerance tests done using 10 maize genotypes from CIMMYT at ART farm in 1999 showed three genotypes to be very sensitive, three very tolerant and four moderately sensitive to herbicides belonging to the sulfonylurea group and chloroacetamides (Eberlein et al., 1989; Stefanovic et al., 2010).

A continuous weed infestation has led to the adoption of Nicosulfuron-75%, Halosulfuron-75% and metolachlor-96% herbicides. These herbicides have proven to be very effective in reducing weed menace in certified seed maize production due to their broad spectrum activity. The response of maize inbred lines to various active agents depended on their genetic background (Stefanovic et al., 2000). Previous studies indicate that maize can metabolise nicosulfuron into harmless compounds by converting the parent herbicide to non phytotoxic-OH metabolite (Sun et al., 2017).

Certified seed production is greatly reduced by high weed pressure among other constraints. Weeds constantly interfere with the normal growth of crops (Patel, 2013). Maize production is inconceivable without herbicide being applied and this significantly depends on crop susceptibility. A shift in ear and tassel development phases caused by different herbicide combinations has directly resulted in reduced average yields and increased grain moisture. It is said some injuries could be induced by herbicides, which could result in yield losses (Tesfay et al., 2014). There is very little information which is known about the effect of herbicides especially 75% nicosulfuron WG, 75% halosulfuron WG and metolachlor-96 % on the current local maize inbred lines used to make commercial hybrid in Zimbabwe which are able to control annual and perennial weeds (Johnson grass, wild sorghum and nutsedge). Herbicide phytotoxicity symptoms are sometimes mistaken to fertiliser phytotoxicity and nutrient deficiency symptoms (Gaspar, 1998).

An essential component of certified maize production technology in Zimbabwe is weed control which is generally carried out using herbicides. A strong weed menace and labour shortages in certified seed maize production has led to an increase in the adoption of herbicides. Herbicides provide timely weed control thereby reducing competition for labour between weeding and other farming activities. It has served farmers of undue, repeated inter-cultivations and hoeing. This has helped farmers in obtaining satisfactory weed control where physical methods often fail. Herbicides can be employed to control weeds as they emerge from the soil to eliminate weed-crop interference even at early stage of growth. However, by physical methods weeds are removed after they have offered considerable competition to the crops, and rarely at the critical time.

To address the phytotoxicity currently associated with chloroacetamides and sulfonylurea herbicides on the current maize inbred lines, there is need to explore the sensitivity response of inbred lines used to make commercial hybrids against herbicides of these particular groups in Zimbabwe. The ever-widening choice of herbicides in maize necessitates regular herbicide tolerance tests. There is limited information on optimum herbicide combinations for effective weed control and phytotoxicity of herbicides in maize seed production. Therefore, the object of the study was to assess the response of maize (*Zea mays)* inbred lines to different herbicide combinations on yield parameters phytotoxicity.

MATERIALS AND METHODS

Study site

The experiment was conducted at Agricultural Seeds and Services (Agriseeds) Research Station, located 19 km North West of Harare town in Zimbabwe. It is located at latitude 17° and longitude 30° E and at an elevation of 1500 m above sea level. The site is in Natural Region IIa which receives an annual rainfall range of 750 to 1000 mm and average annual minimum and maximum temperatures of 15°C and 27°C respectively, summer temperatures range from 25°C to 27°C (Vincent and Thomasm, 1960; Mugandani et al., 2012).

Experimental layout and plot management

A 5×12 split plot design was used with three replications. The main plot factor was herbicide with five levels (Table 1) while sub-plot factor was variety with 12 levels which were CZL00001, CZL00003, CZL0610, CZL03014, CML395, CML312, CML443, CML444, CML488, NAW5885, N3.2.3.3 and L917.

Gross plot size measured 50 m × 30 m having 12 rows of maize inbred lines per each sub plot. Net plot size was 36m × 16m. Main plot size was 33×5(165m^2) and sub plot was 8.25×4 (33m^2) A

Table 1. Herbicide combinations and application rates of active ingredients (Synegenta, 2000).

Description	Application rate/ha
Control(hand hoeing)	-
96 % Metolachlor+Atrazine	1.5lt+4lt respectively
96 % Metolachlor+Atrazine+75% Nicosulfuron WG	1.5lt+4lt,60g respectively
96 % Metolachlor+Atrazine, 75 % Halosulfuron WG	1.5lt+4lt,50g respectively
96 % Metolachlor +Atrazine, 75 % Nicosulfuron WG, 75 % Halosulfuron WG	1.5lt+4lt,60g, 50g respectively

Table 2. European Weed Research Council (EWRC) rating scale for phytotoxicity (WSSA, 2002).

EWRC score	Crop tolerance	Efficacy (weed kill)	Weed control (%)
1	No effect	Complete kill	100
2	Very slight effects; some stunting and yellowing just visible.	Excellent	99.9-98
3	Slight effects, stunting and yellowing effects reversible.	Very good	97.9-95
4	Substantial chlorosis and or stunting; most effects probably reversible.	Good-acceptable	94.9-90
5	Strong chlorosis/stunting; thinning of stand.	Moderately but generally not acceptable	89.9-82
6	Increasing severity of damage.	Fair	81.9-70
7	Increasing severity of damage.	Poor	69.9-55
8	Increasing severity of damage.	Very poor	54.9-30
9	Total loss of plant yield	None	29.0-0

distance of four meters was left between each block (Mashingaidze, 2004).

Land was disc-ploughed and disc-harrowed to a fine tilth, before planting. Planting was achieved by sowing two maize seeds per planting station using an interow and inrowspacing of 0.75m and 0.25m respectively. The maize plants were later thinned two weeks after emergence (WAE) to one plant per station to give a plant population of 37,000 plants /ha (Mashingaidze, 2004).

Compound D (7% N, 14% P_2O_5, and 7% K_2) was dribbled as a basal fertiliser at a rate of 400 kg /ha into the planting furrows before planting. The maize inbred lines were top-dressed with 200 kg/ha ammonium nitrate (34.5% N) at five weeks after emergence (WAE) using hill placement method (Mashingaidze, 2004).

A knapsack sprayer with a flat fan nozzle (FS6503) was used in herbicide application. Herbicide application rates were determined by following the labelled recommended doses (LRDs) for each herbicide as presented on Table 1. These herbicides were applied immediately after irrigation whilst the soil was moist to allow good herbicide uptake by both the soil and plants. Metolachlor and Atrazine was applied as pre-emergence herbicide as tank mixture at the same time.

Post -emergence herbicideNicosulfuron-75% WG was applied three weeks after crop emergence when maize was at two to five leaf stages, whilst Halosulfuron-75% *WG* herbicide was applied three to five weeks after planting of the crop when weeds were actively growing at two to four leaf stages (Table 2).

Germination percentage of the 12 maize inbred varieties was taken eight days after crop emergence. This was done through physical counting of seedlings that has emerged then expressing it as a percent of total seed sown. The level of phytotoxicity (browning, stunting, tissue death) was determined by using the EWRC scale on Table 2. Crop tolerance, efficacy (weed kill), weed control (%) was also determined using the same scale. This was done first at second leaf stage after pre-emergence herbicide application to assess the level of phytotoxicity on herbicide sprayed plots and 10 days later after application of post emergence herbicides.

Plant height was recorded weekly from week one to week twelve. The number of days to mid pollen (DMP) was determined by counting the number of days as from planting up to when 50% of the plants have shed pollen. The number of days to mid silking was determined by using the same procedure as from planting up to when 50% of the plants per plot have silks 2-3cm long. Ear height was determined at 50% silking when ears of the plants had emerged. Anthesis Silking Interval (ASI) was determined by the difference between DMS and DMP. Grain moisture was recorded for each plot using a Dickey John moisture tester .Shelled grain weight was recorded by harvesting five plants per plot using an electric balance, adjusted to 12.5 % moisture content and converted to tonnes per hectare (Table 2).

Statistical analysis

Analysis of variance (ANOVA) was done using Genstart 2013. Fishers protected least significance test at 5 % was used to separate means where significance differences were noted (Steel et al., 1997).

RESULTS

Effects of herbicide combinations on germination of maize inbred lines

There was a significant interaction ($p < 0.05$) between

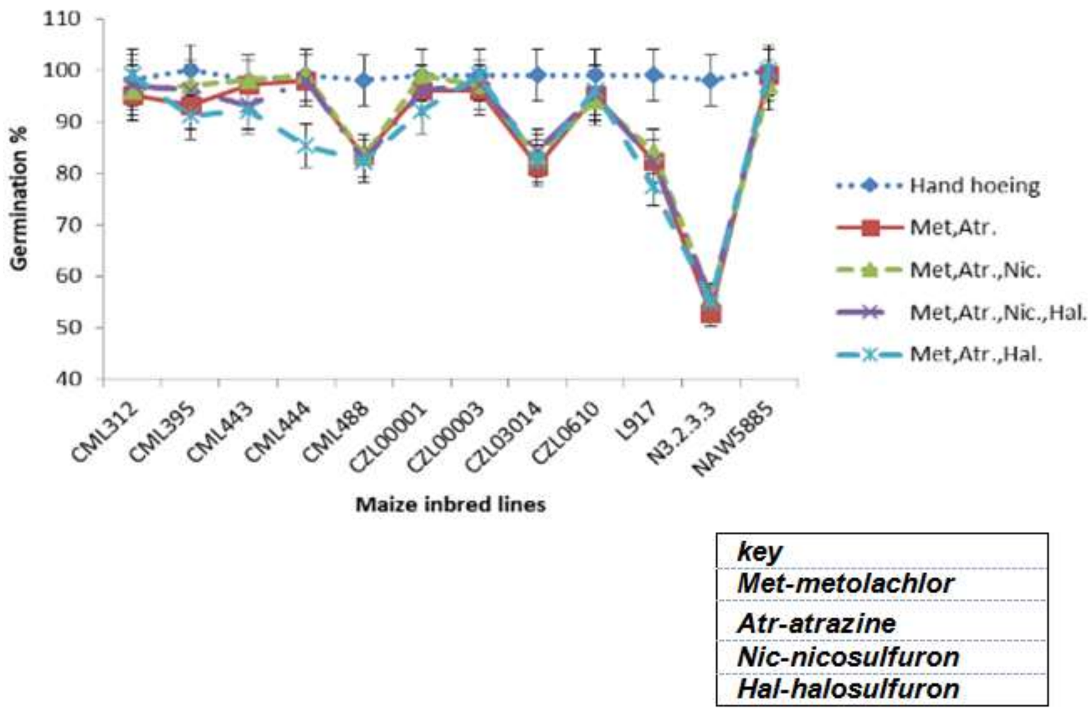

Figure1. Effect of herbicide combinations on germination of maize inbred lines.

herbicide combination and maize inbred line on germination. There was a significant difference (p<0.05) among weed control methods. The highest germination was observed in hand hoeing which recorded 100 % germination on inbred lines NAW5885 and CML312. However, there was a significant difference (p<0.05) among maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the highest germination percentage across all the herbicide combinations. CML488, CZL03014, L917 and N3.2.3.3 were susceptible they recorded the least germination percentage on metolachlor + atrazine herbicide combination (Figure 1).

Effects of herbicide combinations on plant height

Week 2

There was a significant interaction (p<0.05) between herbicide combination and inbred line on plant height. There was a significant difference (p<0.05) among weed control methods .The highest plant height was observed in hand hoeing on inbred line NAW5885 which recorded 29.1cm. There was also significant difference (p<0.05) among maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the highest plant height on metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination. CML488, CZL03014, L917 and N3.2.3.3 recorded the least plant height across different herbicide combinations (Figure 2).

Week 4

There was a significant interaction (p<0.05) between herbicide combination and inbred line on plant height. There was a significant difference (p<0.05) among weed control methods. The highest plant height was observed in hand hoeing on inbred lines CML443, CML444 andCZL0610 L917. However there was a significant difference (p<0.05) among maize inbred lines.CML312, CML444, CML443, CML00003 were tolerant, they recorded the highest plant height on metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination. Inbred lines CML488, CZL03014, L917 and N3.2.3.3 recorded the least plant height on metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination (Figure 3).

Week 12

There was no interaction (p>0.05) between herbicide combination and inbred line on plant height. There was a significant difference (p<0.05) among different weed control methods. Hand hoeing significantly (p<0.05)

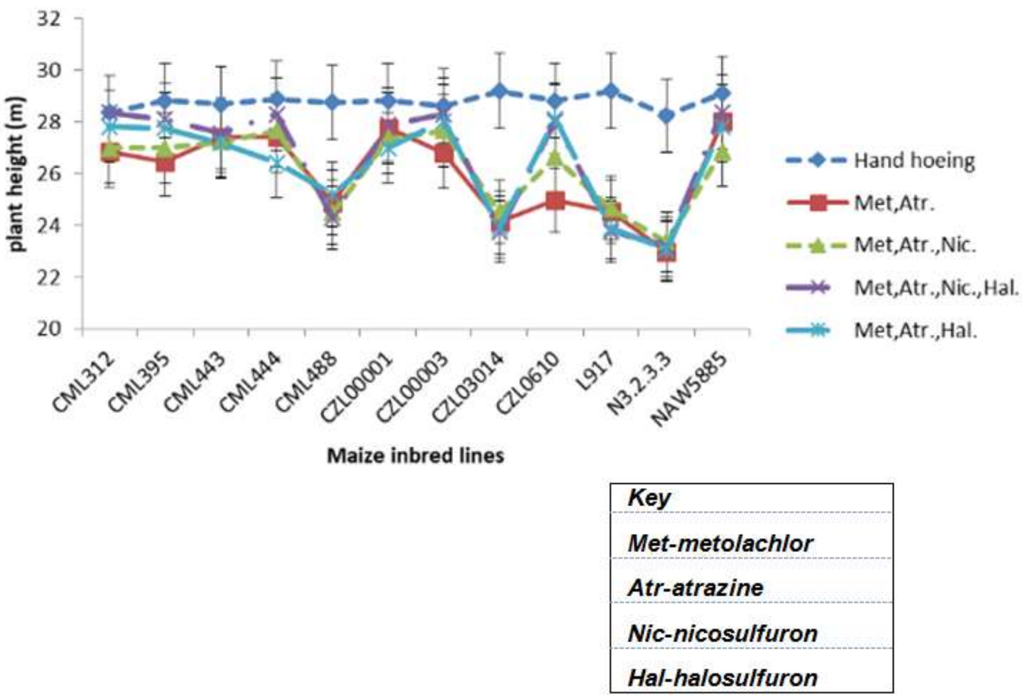

Figure 2. Effect of herbicides combinations on plant height of maize inbred lines, Week 2.

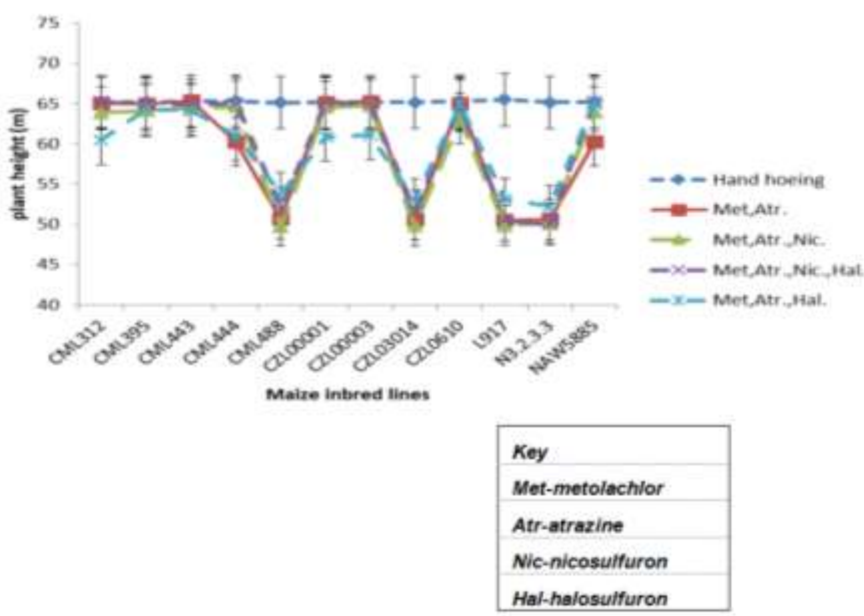

Figure 3. Effect of herbicide combinations on plant height of maize inbred lines, Week 4.

recorded the highest plant height of 187.65 cm as shown by the Table 3 below, metolachlor + atrazine + nic osulfuron herbicide combination recorded the lowest plant height but it was not significantly ($p<0.05$) different from metolachlor + atrazine + halosulfuron herbicide combination. Variety significantly ($p<0.05$) had an effect

Table 3. Effect of herbicide combination on plant height.

Herbicide	Plant height (cm)
Hand hoeing	187.65[c]
Met.Atr	177.21[b]
Met.Atr.,Nic	170.22[a]
Met,Atr.,Hal	171.61[a]
Met,Atr.,Nic.,Hal	177.53[b]
Grand mean	176.84
LSD	3.038
C.V %	3.7
$Fprob_{0.05}$	0.001

*Values followed by the same letter are not significantly different.

Table 4. Effect of maize variety on plant height.

Variety	Plant height (cm)
CML312	181.38[b]
CML395	181.27[b]
CML443	180.28[b]
CML444	180.21[b]
CML488	171.09[a]
CZL00001	182.04[b]
CZL00003	180.76[b]
CZL03014	168.44[a]
CZL0610	179.13[b]
L917	168.67[a]
N3.2.3.3	168.12[a]
NAW5885	180.73[b]
Grand mean	176.84
LSD	4.706
C.V %	3.7
$Fprop_{0.05}$	0.001

*Values followed by the same later are not significantly different.

on plant height. Inbred line CZL0610 recorded the highest plant height but was not significantly different from CML444, CML443, NAW5885, CZL00003, CML395 and CML312. N3.2.3.3 inbred line recorded the lowest plant height of 168.12 cm but it was not significantly ($p<0.05$) different from CZL03014, L917 and CML488 inbred lines as shown on Table 4.

Effect of herbicide combinations on phytotoxicity of maize inbred lines:

There was a significant interaction ($p<0.05$) between herbicide combination and maize inbred line on phytotoxicity. There was a significant difference ($p<0.05$) among herbicide control methods. No changes in plant form due to phytotoxicity were observed in hand hoeing. However, there was a significant difference ($p<0.05$) among maize inbred lines. CML312, CML444, CML443 and CML00003 were tolerant they recorded the lowest EWRC % score of phytotoxicity in metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. Inbred lines CML488, CZL03014, L917 and N3.2.3.3 were susceptible; they had the highest phytotoxicity score in metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron +halosulfuron herbicide combinations (Figure 4).

Effect of herbicide combination on anthesis silking interval (ASI)

There was a significant interaction ($p<0.05$) between herbicide combination and maize inbred line on ASI. There was a significant difference ($p<0.05$) among the weed control methods. The shortest ASI was observed on hand hoeing. There was also a significant difference ($p<0.05$) among maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the shortest ASI number of days on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. CML488, CZL03014, L917 and N3.2.3.3 inbred lines were susceptible; they recorded the highest ASI number of days on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron (Figure 5).

Effect of herbicide combinations on ear height of maize inbred lines

There was a significant interaction ($p<0.05$) between herbicide combination and maize inbred line on ear height. There was a significant difference ($p<0.05$) among different weed control methods. The highest ear height was observed in hand hoeing on inbred line CZL0610 which recorded 135.23 cm. However, there was a significant difference ($p<0.05$) among the maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the least ear height on metolachlor + atrazine and metolachlor + atrazine + halosulfuron herbicide combinations. CML488, CZL03014, L917 and N3.2.3.3 were susceptible; they recorded the least ear height on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations (Figure 6).

Effect of herbicide combination on grain yield of maize inbred lines

There was a significant interaction ($p<0.05$) between

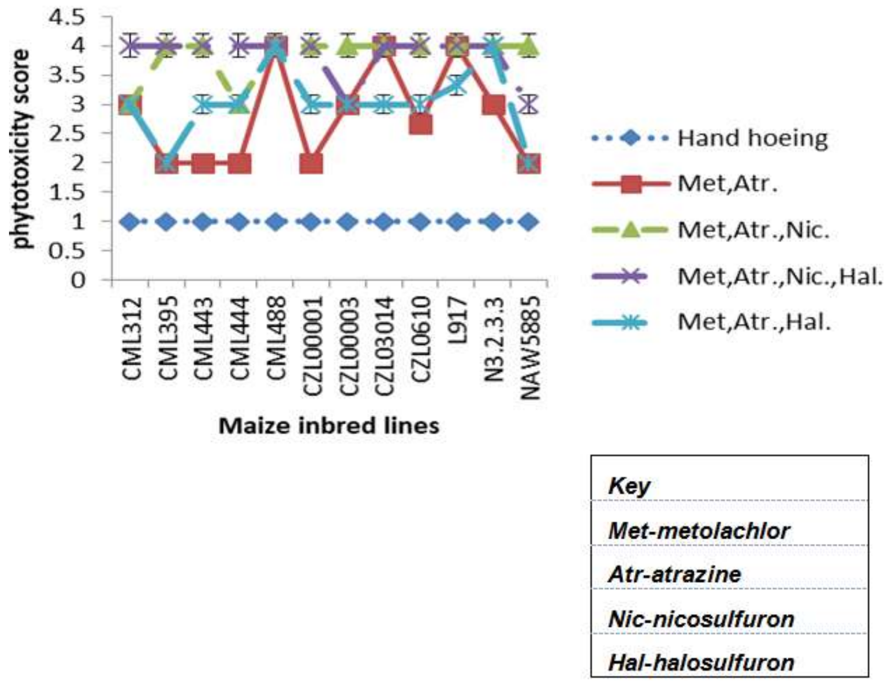

Figure 4. Effect of herbicide combinations on phytotoxicity of maize inbred lines.

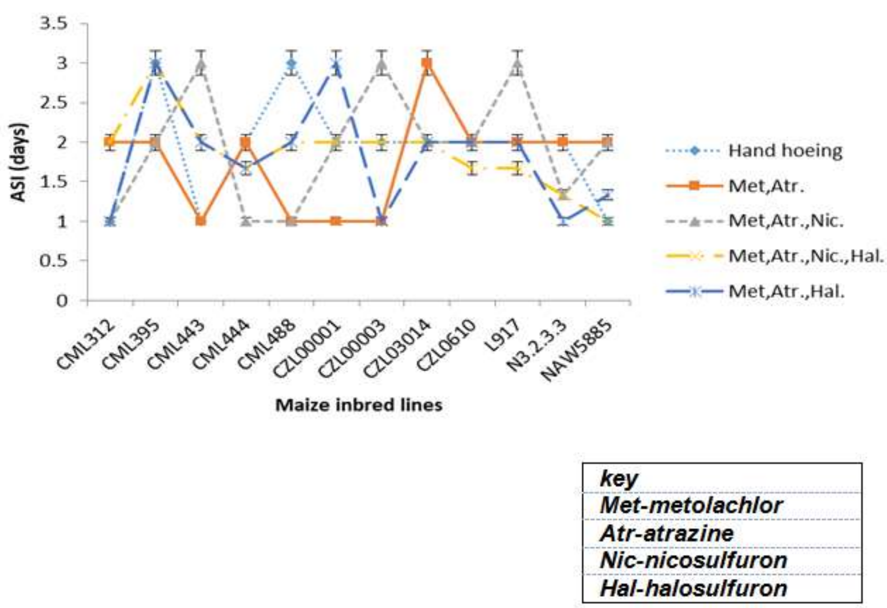

Figure 5. Effect of herbicide combinations on Anthesis Silking Interval of maize inbred lines.

herbicide combination and maize inbred line on grain yield. There was significant differences ($p<0.05$) among the weed control methods. The highest grain yield was observed in hand hoeing on inbred line CZL0610 which recorded 5.34t/ha. However, there was a significant difference ($p<0.05$) among maize inbred lines. CML312, CML444, CML443 and CML00003 were tolerant, they recorded the highest grain yield on metolachlor + atrazine and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. Inbred lines CML488, CZL03014,

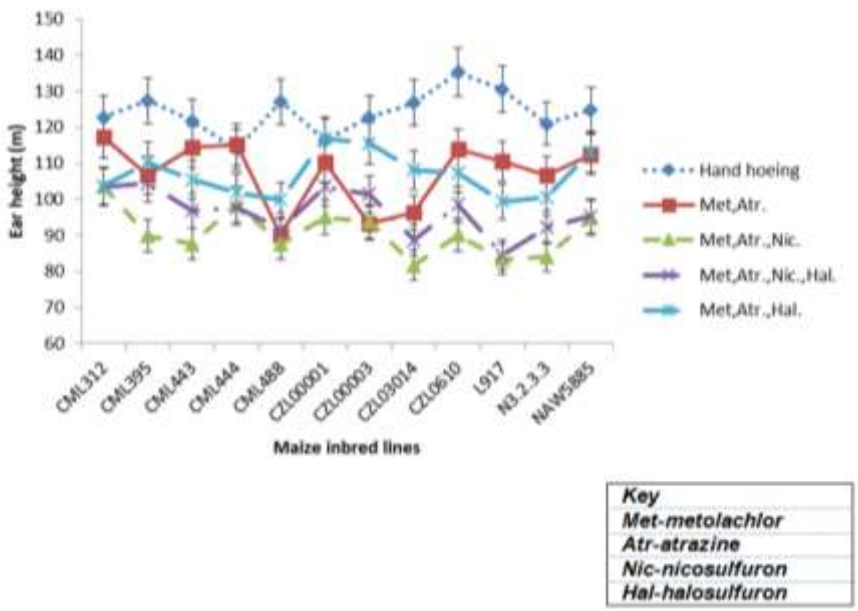

Figure 6. Effect of herbicide combinations on ear height of maize inbred lines.

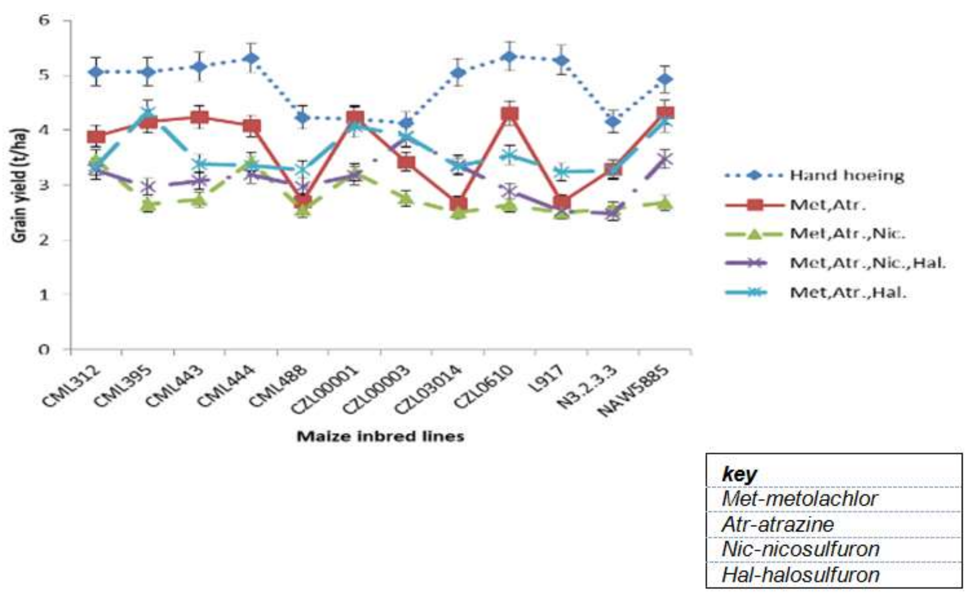

Figure 7. Effect of herbicide combinations on grain yield of maize inbred lines.

L917 and N3.2.3.3 were susceptible; they recorded the least grain yield on metolachlor +atrazine+ nicosulfuron herbicide combination (Figure 7).

DISCUSSION

Effect of herbicide combination on germination of maize inbred lines

The results indicated that there was an interaction between herbicide combination and maize inbred line on germination. Herbicides specifically metolachlor-96% might have inhibited growth in the germination phase. It was believed that this led to a reduction in the rate of shoot elongation, and so increased the time taken for the seedling to emerge from the soil. The different categories of these maize inbreds in response to different herbicide combination may be proof that tolerance to metolachlor in maize is genetically controlled. This may be attributed to the failure of the susceptible inbred lines (CML488, CZL03014, L917 and N3.2.3.3) enzymes to degrade the herbicides into less toxic form. Tolerant inbred lines CML312, CML444, CML443 and CML00003 metabolised (conjugation or degradation) the herbicide into less toxic form leading to poor uptake and translocation of the herbicide. Hand hoeing provided a true reflection that under free herbicide environment inbred lines had a maximum genetic performance due to absence of stress from herbicides. Results observed are in agreement with the findings by Bernards et al. (2006) that the variable response of hybrids to metolachlor was probably due to genetic inheritance. These results may be a true reflection of what may happen under field conditions, a result that was noted by Kanyomeka (2002) on his research on sensitivity of inbreds and hybrids to selected herbicides. Kanyomeka (2002) concluded that the susceptible inbreds may lose their germination capacity when they are exposed to different herbicide combinations.

Effect of herbicide combinations on plant height of maize inbred lines

Plant height was drastically reduced a week after pre-emergence herbicide application. These results are in line with those of Stefanovic et al (2010) who found that herbicides affect plant height of inbred lines. Mode of action of the herbicide and the genetic makeup might have contributed significantly to different inbred responses. Hand hoeing recorded significantly the highest plant height throughout the experiment. This might have been due to the ability of the inbred lines to perform and fully express their genetic potential in the absence of stress induced by herbicides. Previous studies indicated that sulfonylurea herbicides could seriously affect maize growth leading to yield loss (Stefanovic et al., 2010; Brankov et al., 2015).

At week two, metolachlor-96% might have inhibited growth on susceptible inbred lines since it is a shoot inhibitor of grass coleoptiles. It is believed that leaf curling and growth reduction experienced might have led to realisation of low plant height. A reduction in photosynthesis tissue at early stages is also believed to have contributed to these results. At week four significant differences in height were noted, this might have been a contribution of the mode of action of the herbicides; Nicosulfuron-75 % WG and Halosulfuron-75 % WG are protein amino acids inhibitors. They might have affected the biochemical pathway of the enzyme acetolactate synthase which triggers the manufacture of amino acids within the plant; this will have resulted in protein starvation and growth inhibition. The least plant height was observed on susceptible inbred lines CML488, CZL03014, L917 and N3.2.3.3 in metolachlor + atrazine + nicosulfuron and metolachlor + atrazine+ nicosulfuron + halosulfuron herbicide combinations.

Presence of the recessive gene which fails to degrade the herbicides into less toxic form might have contributed to herbicide susceptibility. These results were in accordance to those found by Green and Ulrich (1993) that, sensitivity of these inbred lines has been reported as being conditioned by single recessive genes which may affect inbred plant height. Different metabolic reactions and enzymes might have contributed so much in determining the rate of decomposition of the herbicide within the plant. An interaction of the environment, variety and herbicide might have speeded up the rate of absorption of the herbicide by susceptible inbred lines since higher temperatures and high humidity were experienced at the early stages of the season. Significant differences were observed among inbred lines and different herbicide conditions. At week 12, there was no interaction between herbicide combination and maize inbred line. These changes in height were noticeable at the beginning of the growing season and later on decrease significantly (Stefanovic et al., 2000) as exhibited on Table 4.

Effect of herbicide combinations on phytotoxicity of maize inbred lines:

At the beginning of the growing season higher temperatures and higher humidity were experienced, these conditions might have triggered a greater absorption and faster symptom development on susceptible inbred lines. No phytotoxicity symptoms were observed in hand hoeing since inbred lines expressed fully their genetic potential in the absence of herbicide. Tolerant inbred lines CML312, CML444, CZL00001 had the lowest phytotoxicity score; this might have been a contribution of good genetic makeup and the ability to degrade these herbicides into less toxic form (Sun et al., 2017).

Susceptible inbred lines CML488, CZL03014, L917 and N3.2.3.3 developed injury symptoms in response to metolachlor injury; they exhibited stunted shoots and leaf crinkling. It was believed that the genetic makeup has a major contribution on plant's response to herbicides. Herbicide combinations metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron scored the highest EWRC% score mostly on the susceptible inbred lines. Phytotoxicity symptoms of sulfonylurea herbicides were observed on the susceptible lines, roots exhibited bottle brush growth (unbranched, stubby), resulting in purple stems and leaves, along with overall plant stunting. Leaf tissue became light yellow from the outer edge of the leaf toward the veins, while veins turn light to dark purple.

In some cases, it is said that herbicides could decrease phytic and inorganic phosphorous content in maize leaves as in case of sulfonylurea herbicides (Brankov et al., 2015). These changes were noticeable at the beginning of the growing season, and later on decrease significantly (Stefanovic et al., 2000; 2007). It was believed that the active growing plant stage and thin stems absorbed herbicides at a faster rate. Obtained results were in line with those found by Zaric et al. (1998), Stefanovic et al. (1997, 2000) that under such conditions, very susceptible and moderately susceptible inbreds mainly were affected by unfavourable climatic conditions. Results are a supporting statement that environmental factors, such as high temperature and high humidity directly or indirectly affect absorption of herbicides and their effect on plants (Stefanovic et al., 2010).

Maize inbred lines were ranked by their response towards different herbicide combinations by the EWRC % scale into three categories, Tolerant; CML312, CML444, CML444 and CZL00001, Medium resistant; CML395, CZL0610, NAW5885 and CZL00003, Susceptible; CML488, CZL03014, L917 and N3.2.3.3. This was determined by looking at the EWRC scale (WSSA, 2002).

Effect of herbicide combination on ASI

The shortest ASI was observed in hand hoeing weed control method. This might have been a contribution of the maximum genetic potential of the inbred lines to perform well in the absence of herbicide stress. Tolerant inbred lines CML312, CML444, CML443 and CML00003 recorded the shortest ASI number of days on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. A combination of genetic inheritance, herbicide stress and moisture stress towards the reproductive phase might have affected the ASI. These results also point out that herbicides might have affected phases in the tassel and ear development. It is believed that a contribution of high temperatures experienced during the season promoted stunting and premature reproductive phase on susceptible inbred lines. This can be explained in such a way that if susceptible inbred lines are exposed to stress environments such as the presence of herbicides, there is a delay in DMS and a speeding up of DMP. This might have led to prolonged ASI thereby affecting pollen-silk synchronisation. These results were in line with those found by Stefanovic et al. (2010) and Zaric et al. (1998) who observed that these phases were shifted and normal ear fertilisation was not possible in three out of 15 inbred lines.

Effect of herbicide combination on ear height of maize inbred lines

Ear height is one of the most important yield attribute in seed production. It contributes significantly to the successes of good pollen-silk synchronisation. It determines the most effective position of the silk to receive maximum pollen for fertilisation. The highest ear height was observed in hand hoeing on inbred line CZL0610. Hand hoeing might have resulted in the eradication of potential weed competitors thereby allowing the inbred line to exhibit its genetic potential fully. The inbred line exhibited its maximum genetic potential in the absence of herbicides because it fully utilised its resources like nutrients, water and sunlight in the absence of stress. The least ear height was observed in metolachlor + atrazine + nicosulfuron herbicide combination on inbred line CZL03014. It is believed that an interaction of variety, herbicide and environment might have contributed significantly to the realisation of these results. This was observed on susceptible inbred lines CML488, L917 and N3.2.3.3. It is believed that any factor that affected plant height is believed to have affected ear height. Reduction in inbred plant height might have directly affected ear height. Most of the factors that were shortlisted to have affected plant height are believed to be the one that affected ear height. CML312, CML444, CML443 and CZL00001 recorded the highest ear height since they are late mature varieties with good genetic makeup and good seed quality standards. These findings were in accordance with those found by Stefanovic et al. (2010) that herbicides had an effect on ear height of maize inbred lines.

Effect of herbicide combination on grain yield of maize inbred lines

The highest grain yield was observed in inbred line CZL0610 in hand hoeing weed control method. The inbred line could fully utilise its resources in the absence of growth inhibitors such as herbicides. The least grain yield was observed in metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination on inbred line N3.2.3.3. This might have been an attribute of poor genetic potential in response to herbicides. Brankov (2016) observed that white and popcorn maize genotypes are more sensitive than standard maize genotypes. Yield is an attribute of many growth parameters which is believed to have an effect on the final grain yield. All the parameters measured in this experiment which were affected by herbicides might have contributed significantly to the final grain yield. Previous studies indicated that sulfonylurea herbicides could seriously affect maize growth leading to yield loss (Stefanovic et al., 2010; Brankov et al., 2015). These parameters are determined by the genetic potential of inbred lines to withstand stresses. A lag in development stages on inbred lines might have posed an effect on the final grain yield. Susceptible inbred lines CML488, CZL03014, L917 and N3.2.3.3 had the lowest final yield whilst CML395, CZL0610, CZL00003 and NAW5885 had the medium; CML312, CML444, CML443 and CZL00001 had the highest final grain yield. Herbicides had an effect on growth parameters which later affected the final yield (Stefanovic et al., 2010).

Conclusion and Recommendations

Metolachlor +atrazine +nicosulfuron and metolachlor +atrazine +nicosulfuron +halosulfuron herbicide combinations significantly affected germination, phytotoxicity, plant height, ASI, ear height and grain yield of maize inbred lines. Metolachlor + Atrazine and Metolachlor + Atrazine + Halosulfuron were the best effective weed control combinations to use across all maize inbred lines used in this experiment.

Variety significantly affected response of maize inbred lines to different herbicide combination. It was observed that parental components of hybrids of early maturity group (CML488, CZL03014, L917 and N3.2.3.3) expressed greater susceptibility to herbicides. Inbred lines were grouped into three categories in relation to EWRC score, efficacy and survival rate into; Tolerant (CML312, CML444, CML443 and CML00003), Medium resistant (CML395, CZL0610, NAW5885 and CZL00003; Susceptible (CML488, CZL03014, L917 and N3.2.3.3).

Based on findings of this study, farmers are advised not to use metolachlor +atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + Halosulfuron herbicide combinations on susceptible inbred lines (CML488, CZL03014, L917 and N3.2.3.3) because these herbicide combinations had an effect on germination, phytotoxicity, plant height, ASI, ear height and grain yield of these inbred lines. Therefore, it is recommended to use hand hoeing, metolachlor + Atrazine and Metolachlor + Atrazine + Halosulfuron as weed control methods on maize inbred lines used in the experiment.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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