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Original Research

Integrated weed management practices enhance maize (*Zea mays* L) productivity and weed control efficiency

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ABSTRACT

A field experiment was undertaken to determine optimum combination of weed management practices and inter-row spacing levels for effective weed control in maize at Bako agricultural research center, Western Oromia, Ethiopia during 2018 main cropping season. The treatments included pre-emergence s-metolachlor 290 g/L + atrazine 370 g/L (1.0, 2.0 and 3.0 L ha^{-1}), hand pulling and hoeing 25 and 45 days after sowing (DAS) and weedy check in combination with inter-row spacing levels (65, 70, 75, and 80 cm). The experiment was laid out in a randomized complete block design with a factorial arrangement in three replications. The experimental field was infested with 22 weed species belonging to 12 families, out of which 77.3 %, 18.2 % and 4.5 % were broad leaved, grass and sedges, respectively. Weed management practices (WMP), inter-row spacing (IRS) and their interaction significantly influenced the weed density, dry weight and weed control efficiency at 25 and 70 DAS. All parameters of the crop were significantly affected by WMP and IRS. However, their interaction was non-significant except for number of ear per plant and grain yield. The highest grain yield was recorded in inter-row spacing of 65 cm treated with hand pulling and hoeing 25 and 45 DAS (10492.0 kg ha^{-1}). Whereas, the lowest grain yield (2237.0 kg ha^{-1}) was obtained from weedy check plot at 80 cm inter-row spacing. On the other hand, maize planted at 65 cm IRS in combination with 2 L ha^{-1} s-metolachlor 290g/L + atrazine 370 g/L gave comparable grain yield which was statistically at par with that of hand pulling and hoeing 25 and 45 DAS and 3 L ha^{-1} s-metolachlor 290g/l. + atrazine 370 g/L involving the same IRS. Hence, putting the environmental concern and scarce labor force under consideration, the use of reduced rate (2 L ha^{-1}) of herbicide in combination with narrower IRS would be the best option for effective weed management in maize. Furthermore, integration of narrower IRS with other weed management treatments enhance maize grain yield there by improving weed control efficiency.

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Introduction

Maize (*Zea mays* L.) is the most important and widely grown among cereal crops in Africa; and a staple for around half the inhabitants in the continent (Macauley and Ramadjita, 2015). In Ethiopia, maize is one of the most important strategic crops and ranks second to teff in area coverage and first in terms of total production (CSA, 2017). The national average maize yield in the country in 2016 was 3.6t ha^{-1} which is far below the world average of 5.6 t ha^{-1} (FAO, 2017). Weeds, diseases and insect pests are the major biotic factors accountable for the low yield of maize in Ethiopia (CIMMYT, 2004). Weed infestation is the basic and major component of low yield in maize crop production system in the country (Fassil et al. 2006). Cultivated crops suffer from heavy competition of weed plants for nutrients, space and sunlight. Besides, weed harbor other pests which cause disease, interfere with the normal cultivation, and reduce the yields across the entire range of crops and add to the cost of cultivation (Farkas, 2006; Fanadzo, 2007). Maize, being a rainy season and widely spaced crop, gets infested with variety of weeds and subjected to heavy weed competition, which often inflicts huge losses ranging from 28 to 100 % elsewhere (Patel et al. 2006). In Ethiopia, yield losses in maize due to weeds range between 20 to 100 % (Tadious and Bogale, 1994; Megersa and Fufa, 2017). Therefore, weed management practices need to be developed to maintain or increase the sustainability of maize production.

Of weed management alternatives; mechanical methods, cultural methods and chemical methods are commonly practiced in maize field. However, none of the individual control measures can provide complete weed control. Although some methods are effective against weeds but they prove uneconomical for the farmers or pose environmental hazards (Pritam and Bhutada, 2015). As there are limitations of every weed control method therefore integrated weed management is a good option for sustainable agriculture. It involves the combination of all the possible methods to suppress the weeds below economic threshold level. Zhang et al. (2002) represented that integrating reduced doses of herbicides with other management methods such as cultural methods would efficiently suppress weeds. These methods include the mechanical ones such as cultivation, the cultural ones such as planting pattern and selection of highly competitive cultivars, and the ecological ones such as cover crops (Douglas, 2002). Likewise, Simić et al. (2017) suggested that, herbicide application needs to be combined with other measures, such as crop planting pattern and nitrogen fertilization that are able to create favorable conditions for maize development. Teasdale (1995) reported that maize cultivated with high density provided sustained weed management with lower need for herbicide application. Maize grown in narrow rows is able to suppress weed development and biomass production and increase the effectiveness of weed control with herbicides (Simić and Stefanović, 2007; Simić et al. 2012). Fanadzo et al. (2010) have been demonstrated that higher green biomass (11%) and grain yield (30%) of maize can be achieved by reducing inter-row space from 90 to 45 cm, i.e. by increasing plant population from 40000 to 60000 plants ha^{-1}, while reducing weed biomass by 58%.

In western parts of Ethiopia, small holder farmers and private investors rely on chemicals for weed control along with the wider (75 cm) inter-row spacing. However, this wide (75 cm) inter-row spacing promotes heavy weed growth and infestation in maize field. Furthermore, heavy usage of herbicides has causing environmental pollution, development of resistance in weed species and also availability and affordability is a challenge for small holders. S-metolachlor 290 g/L + Atrazine 370 g/l SC is one of the effective broad-spectrum pre-emergence herbicide which has been used to control weeds, and it is considered the best standard herbicide in maize including the country. On the other hand, mechanical methods like hand weeding and hoeing being practiced by some farmers is labor intensive even though it is environmentally safe. Thus, putting all this under consideration there is a need to evaluate different weed management options such an integration of methods that is ecologically and economically feasible. Hence, the present study was conducted to determine optimum combination of inter row spacing, and pre-emergence s- metolachlor 290 g/l + atrazine 370 g/l SC and hand weeding for weed management in maize.

Materials and Methods

The experimental site

The field experiment was conducted at research site of Bako agricultural research center during the main rainy season from May to December 2018. The research center is found in the East Wollega Zone of the Oromia Regional State with about 133 km from Ambo town, West Shoa zone and 260 km west of Addis Ababa, the capital city of Ethiopia. The experimental site is located at 9° 05' 518'' N latitude and 37° 02' 739 E'' longitude and altitude of 1634 masl. During the cropping season, 1161.7 mm total annual rain fall was received with a monthly mean minimum and maximum temperatures varying between 13-14.7 °C and 26.3-34.2 °C, respectively, and relative humidity ranged from 44 to 55% in the year of 2018.

Experimental design and treatments

The treatments were consisted of five weed management practices (three application rates of s-metolachlor 290 g/L + atrazine 370 g/L i.e., 1.0, 2.0 and 3.0 L ha^{-1}, hand pulling and hoeing at 25 and 45 days after planting (DAP), weedy check) and four levels of inter-row spacing (65 cm, 70 cm, 75 cm and 80 cm) having the corresponding plant population of 51, 282; 47, 619; 44, 444 and 41,667 plant ha^{-1}, respectively. The 20 treatments were arranged in a randomized complete block design (RCBD) with factorial combinations in three replications. The treatment set up that contain 75 x 30 cm spacing (44,444 plants ha^{-1} with three litres of s-metolachlor 290 g/L + atrazine 370 g/L ha^{-1}) was used as a standard check for comparisons; whereas hand pulling and hoeing at 25 and 45 days after planting (DAP) and weedy check were used as farmer practice and negative control, respectively. S-metolachlor 290g/L + atrazine 370 g/L was calibrated and applied as pre-emergence onto the soil as per the treatment immediately i.e., two days after planting. The spray volume of water was 200 L ha^{-1}. The herbicide s-metolachlor 290g/L + atrazine 370 g/L (common name) which is also known as Primagram Gold 660 SC (Trade name) was registered for control of annual broadleaf and grassy weeds in maize in Ethiopia.

The experimental materials and management practices

Planting was done in June 2018 by placing the seeds in furrows at the intra row spacing of 30 and at the inter row spacing of 65, 70, 75 or 80 cm depending on treatment. The hybrid maize variety, BH-546 was planted on the plot size of 4.7 m x 4.5 m (21.15 m^2) by placing two seeds per hole. The seedling was thinned out to one (1) plant per hill at knee height stage (35 days after sowing). *S*-metolachlor 290g/L. + Atrazine 370 g/L was calibrated and applied as pre-emergence onto the soil as per the treatment immediately i.e., two days after planting. The spray volume of water was 200 litres ha^{-1}. The herbicide S-metolachlor 290g/L. + Atrazine 370 g/L. (common name) which is also known as Primagram Gold 660 SC (Trade name) was registered for control of annual broadleaf and grassy weeds in maize in Ethiopia. Except the treatments, all other recommended crop husbandry practices were applied uniformly throughout the cropping seasons.

Data Collection

Weed infestation was assessed and scored in number and species by throwing quadrant of 50 cm × 50 cm area two times per plot at 25 DAP and harvesting (14 days before the expected harvest time). The counted weeds were categorized as broad leaved, grass and sedge. The weed species found within the sample quadrate were identified, counted and expressed as total weed density m^{-2}. The dry weight of weeds samples were recorded after air drying for seven (7) days and oven drying at 65° C for 48 hours. The dry weight of weed was taken by an electrical balance and expressed in gm^{-2}. Weed control efficiency was calculated using the following formula developed by (Cruz et al., 1986)

$$\text{Weed control efficiency (WCE)} = \left(\frac{\text{WDC}-\text{WDT}}{\text{WDC}}\right) \times 100 \qquad \text{(Equation. 1)}$$

Where, WDC and WDT are weed dry weight (gm^{-2}) in weedy check and any particular treatment, respectively. Data on maize leaf area index, number of ears per plant, ear length (cm), thousand kernel weight (gm) and number of kernel rows per ear were recorded from ten plants selected randomly and tagged from the central rows in each plot. The leaf area, at the stage of tasseling, was determined first from ten randomly taken plants from the net plot by multiplying leaf length and maximum leaf width, adjusted by a correction factor of 0.75 (i.e. 0.75 x leaf length x maximum leaf width) as suggested by (Francis et al., 1969). Then leaf area index was determined by dividing total leaf area of a plant to the ground area cover by single plant (Radford, 1969). Maize grain yield was obtained from central rows excluding one row in each side of the plot. The total number of plants in the net plot was harvested and the field weight was measured using electronic balance. After that, grains were shelled from center of some ears of each plot and were immediately measured their moisture content using moisture tester. The measured values were adjusted to the standard moisture content of 12.5 (Biru, 1976) and finally, maize grain yield (ton) per hectare and yield advantage was calculated by the formula suggested below.

$$\text{Grain yield ton ha}^{-1} = \left(\frac{(\text{CW}*0.81)*(100-\text{AM})}{(100-12.5)}\right) \qquad \text{(Equation 2)}$$

Where, CW is Cob weight and AM is actual moisture at harvest.

Statistical Analysis

Analyses of variances (ANOVA) for all data recorded were conducted using the SAS version 9.3. Least significant difference (LSD) test at 5% probability was used for mean separation if the analysis of variance indicated the presence of significant treatment differences.

Results and Discussion

Weed community

Weed flora which comprised of broadleaved, grass and sedges were observed in experimental site. The broad leaved contributed to higher percentage (77.3%) of totally noticed weeds while grass weeds and sedge shared lower percentage (18.2 % and 4.5 %, respectively). A total of twenty two (22) weed species belonging to twelve (12) families were appeared to infest the experimental maize crop. Of these families, Asteraceae, Gramineae and Amaranthaceae contains the maximum number of species five (5), four (4) and three (3), and contributed to the highest percentage (22.7 %, 18.2 %, and 13.6 %, respectively). *Commelina benghalensis*, *Guizotia scarba, Galinsoga parviflora, Stellaria media* were among most dominant broadleaved species; whereas *Eleusine indica* was dominant grass leaf weed species having higher degree of infestation. This is in analogy with the findings of Megersa et al. (2018), who reported that twelve weed species belonging to six families are appeared to infest the experimental maize crop field.

Effect of treatments on weed density (m^{-2}) at 25 days after planting (25 DAP)

The analysis of variance showed that the main effects of weed management practices, inter-row spacing and their interaction was highly significant ($P<0.01$) on weed density at 25 days after planting of maize (Table 1). The minimum weed density (1.6 m^{-2}) was obtained with the application of s- metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} along with 65 cm which was statistically at par with the interaction of both s- metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} and 2 L ha^{-1} at all the levels of inter-row spacing (Table 1). It was also observed that application of s-metolachlor 290 g/L. + atrazine 370 g/L. at lowest rate (1 L ha^{-1}) significantly reduced the weed density compared to un-weeded plots. In this experiment the weeds grew uninterrupted in handweeding and hoeing treatment as this operation was resorted after taking this observation. Generally, weed density shown reduction with increments in herbicide rate and decrement in inter row spacing. This showed that weeds failed to keep pace with metabolism of the applied herbicide at higher doses, and also reduced row spacing can also provide the crop with a competitive advantage over weeds. The results are in line with Mahadi (2014); Frehiwot et al. (2013) who recorded significantly lower weed density in plots treated with Atrazine + Metolachlor at 2.6 kg a.i/ha^{-1} and 1.9 kg a.i/ha^{-1} in comparisons to the weedy check. Similarly, Maqbool et al. (2006) reported that, the row spacing of 55 cm in maize was effective in suppressing weeds and the maximum weed density and biomass at 30 days after emergence indicate the need of early weeding in maize.

Table 1. Total weed density (m^{-2}) at 25 DAP as influenced by interaction effect of weed management practices and inter-row spacing in maize during cropping season of 2018 at Bako.

Weed management practices	Inter row spacing (cm)			
	65	70	75	80
Weedy check	73.5e	81.2bcd	81.8bcd	85.8ab
S+A at 1 L ha^{-1}	10.3f	10.8f	11.5f	12.6f
S+A at 2 L ha^{-1}	3.7g	4.1g	2.8g	4.4g
S+A at 3 L ha^{-1}	1.6g	2.0g	2.4g	2.5g
Hand weeding	78.7d	80.8cd	83.5abc	87.1a
LSD (5%) WMP * IRS = 4.3		CV (%) = 7.2		

Means followed by the same letter within column are not significantly different at P at 5%. Note: S+ A= s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding= Hand pulling and hoeing at 25 and 45 DAP, LSD (5%)= Least significant difference and CV(%) = Cofficient of variation.

Effect of treatments on weed density (m^{-2}) at 70 days after planting (70 DAP)

The main effect of weed management practices (P<0.01), inter-row spacing (P<0.05) and their interaction (P<0.05) were significantly affected the weed density at 70 DAP (Table 2). Accordingly, weed management treatments significantly reduced weed density as compared to the weedy check at all inter-row spacing levels. The lowest (0.94 m^{-2}) density was obtained from hand pulling and hoeing at 25 and 45 DAP in combination with narrowest row spacing (65 cm) which was statistically the same with result achieved at all row spacing levels involving the same treatment, as well as plots treated with s-metolachlor 290g/L + atrazine 370 g/L at 3 L ha^{-1} and 2 L ha^{-1}. In general, weed density decreased with increasing in herbicide rates and decreasing inter-row spacing. This decline in weed density in weed management treatments could be attributed to successful weed control provided by those treatments that might inhibit the weed germination and/or growth in the field. This result is in agreement to the findings of Mahadi (2014), who recorded significantly lower weed density in plots treated with Atrazine + Metolachlor at 2.6 kg a.i/ha^{-1} and 1.9 kg a.i/ha^{-1}, as well as those weeded twice in comparisons to the weedy check.

Table 2. Total weed density (m^{-2}) at 70 DAP as affected by interaction of weed management practices and inter-row spacing during cropping season of 2018 at Bako.

Weed management practices	Inter row spacing (cm)			
	65	70	75	80
Weedy check	111.9c	127.5bc	135.9b	160.4a
S+A at 1 L ha^{-1}	13.0de	16.4de	24.9d	24.9d
S+A at 2 L ha^{-1}	8.2de	8.1de	12.4de	13.3de
S+A at 3 L ha^{-1}	3.3e	6.9de	6.0de	11.6de
Hand weeding	0.9e	3.6e	5.7de	4.4e
LSD (5%) WMP * IRS = 20.38		CV (%) = 21.1		

Means followed by the same letter within column are not significantly different at P at 5%. Note: S+ A = s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding = Hand pulling and hoeing at 25 and 45 DAP, LSD (5%) = Least significant difference and CV (%) = Cofficient of variation.

Dry biomass weight of weeds (g m^{-2}) as influenced by treatments at 25 days after planting

Inter row spacing, weed management practices and their interactive effect were highly significantly (p<0.01) affected dry weight of weeds per unit area (Table 3). Significantly maximum dry weight of weeds (37.8 g m^{-2}) was recorded from weedy check plots in combination with 80 cm inter-row spacing (41, 667 plants ha^{-1}). In contrary, the minimum (1.1 g m^{-2}) weed dry weight was recorded from plots treated with s- metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} in combination with 65 cm inter-row spacing (51, 282 plants ha^{-1}) which was statistically at par with all inter-row spacing levels involving application rate (3 L ha^{-1}) as well as s- metolachlor 290 g/L + atrazine 370 g/L at 2 L ha^{-1} with the interaction of 70 cm spacing (Table 3). These results are in agreement with the findings of Teymoori *et al*. (2013) who noticed the significant effect of planting density, management and their interaction on weed dry weight.

Weeds dry matter weight of (g m^{-2}) as influenced by treatments at 70 days after planting (DAP)

Significant effect (P<0.01) of inter-row spacing, weed management practices and their interaction were observed on weed dry weight (Table 3). All weed management practices significantly reduced weed dry weight over the weedy check at all inter-row spacing levels. Accordingly, the lowest (3.1) weed dry biomass was obtained from hand pulling and hoeing at 25 and 45 DAP in combination with narrowest row spacing (65 cm) which was statistically the same with result achieved at all row spacing levels involving the same treatment, as well as plots treated with s-metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} except for widest spacing (80 cm) (Table 3). In general, decrease in weed dry weight in weed control treatments could be attributed to effective weed control provided that might reduce weed density. The current result is in conformity of the findings of Hussein et al. (2008) who reported that, application of the weed control treatments resulted in less weed biomass and greater maize yield in narrow compared to wide-spacing maize. Weed biomass was reduced 28% by reducing row spacing to 56 cm and by 16 to 29% in 38 cm rows, and decrease in dry weight of weeds with decreased spacing was due to decrease in weed number and fresh weight (Begna et al. 2001).

Table 3. Interaction effect of weed management practices and inter row spacing on total weed dry biomass weight (g m^{-2}) at 25 and 70 DAP in maize field at Bako, 2018.

Weed management practices	Inter row spacing (cm)							
	At 25 DAP				At 70 DAP			
	65	70	75	80	65	70	75	80
Weedy check	27.0e	33.6c	34.3c	37.8a	120.9c	139.5b	139.6b	160.6a
S+A at 1 L ha-1	4.1fgi	4.9f	5.2f	5.3f	19.03ef	20.79e	28.79d	30.7d
S+A at 2 L ha-1	2.8hijk	2.1jkl	2.8ijk	3.3ghij	12.54g	13.53g	14.30fg	22.6e
S+A at 3 L ha-1	1.1l	1.3l	1.2l	1.5kl	5.55hi	4.73hi	6.21hi	9.6gh
Hand weeding	27.3e	31.0d	33.6c	36.5b	3.14i	2.54i	3.23i	5.8hi
LSD (5%) WMP * IRS		1.2				4.8		
CV (%)		4.9				7.5		

Means followed by the same letter within column are not significantly different at P at 5%. Note: S+ A = s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding = Hand pulling and hoeing at 25 and 45 DAP, LSD (5%) = Least significant difference and CV (%) = Cofficient of variation.

Weed control efficacy (WCE %) as influenced by treatments at 70 days after planting

There was a significant effect (P<0.01) of inter-row spacing, weed control methods and their interaction on weed control efficiency (Figure 1). The interactive effect of various treatments improved weed control efficiency over the weedy check. The highest weed control efficiency was recorded for twice hand and hoe weeded plot followed by s-metolachlor 290 g/L + atrazine 370 g/L 3 L ha^{-1}; while the lowest weed control efficiency recorded at weedy check at all level of row spacing. Twice hand pulling and hoeing at 25 and 45 DAP, and the highest dose (3 L ha^{-1}) of primagram were more effective in reducing the density and dry weights of weeds for all levels of row spacing as compared to weedy check (Table 2 and 3). The higher weed control efficiency could be attributed to the lower weed density and weed dry weight. On the other hand, the weed control efficacy shown decreasing trend with decreased herbicide rate. In general, the lower weed control efficiency could be due to the poor weed control by the treatment to reduce infestation of weeds. Hussein *et al*. (2008) demonstrated that, maize weeds control by the hoeing or herbicides treatments was enhanced in narrow compared to wide-spacing maize at eight weeks after sowing (8 WAS).

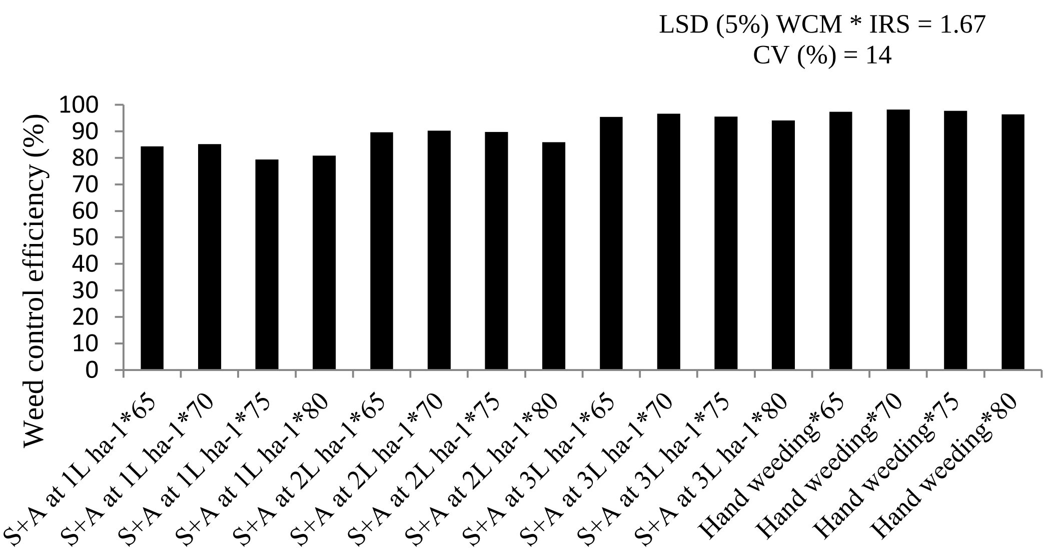

Figure 1. Weed control efficiency (%) as influenced by the weed management treatments at 70 days after planting at Bako. Note: S+ A = s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding = Hand pulling and hoeing at 25 and 45 DAP, LSD (5%) = Least significant difference and CV (%) = Cofficient of variation.

Effect of treatments on leaf area index (LAI) of maize

Result shown that, main effects of weed management practices significantly ($P < 0.05$) and inter-row spacing highly significantly ($P<0.01$) affected leaf area index. However, weed management practices and inter-row spacing did not significantly interact to influence this parameter (Table 4). The maximum LAI (4.73) was recorded in plots hand and hoe weeded at 25 and 45 DAS. Whereas, the minimum LAI (4.16) was recorded from weedy check plots (Table 4).This increase in leaf area index at less weed infested plots implies that improving weed control efficiency increases leaf area index on account of more area occupied by green canopy of plants per unit area. El-Naim and Ahmed (2010) indicated that the reduced competition and increased availability of resources like nutrients, soil moisture and light paved way for higher leaf area index of maize. The highest LAI (4.95) was recorded at 65 cm inter row spacing (51, 282 plant ha^{-1}) while the lowest LAI (4.15) was observed from the widest inter row spacing of (80 cm) or at lowest plant population density of 41, 667 plant ha^{-1} (Table 4). Generally, consistent increments in LAI were observed with decreased row spacing. This dramatic increase in LAI with reduced inter row spacing or with increase in the plant population density indicates occupation of more unit area by green canopy of the plants. Increasing maize planting density significantly increased the leaf area index, relative growth rate and crop growth rate (Teymoori et al. 2013).

Ear length (ER) of maize as influenced by treatments

Result shown that the main effect of weed management practices highly significantly ($P<0.01$) and inter-row spacing ($P<0.05$) significantly influenced the length of ear. However, the interaction effect of weed management practices and inter-row spacing was not significant (Table 4). Ear length increased with the increase in effectiveness of weed management practices against weed plants. The highest ear length (20.30 cm) was recorded on twice hand and hoe weeded plots which was statistically at par with the result obtained from plots sprayed with s-metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} and at 2 L ha^{-1}. Significantly the shortest ear length (17.38 cm) was recorded for the weedy check (Table 4). This increment in ear length with increasing weed control efficiency might be due to the increase in maize growth as a result of decrease in inter-specific competition between maize and growing weeds in utilizing necessary resources. This result is in conformity with the works of Uremis et al. (2009) who observed that, ear length significantly decreased with increasing weed-maize competition. The maximum (18.62 cm) length of cob was recorded in the plots of s-metolachlor at 600 mL ac^{-1}, and it was statistically similar to that of hoeing where length of cob was 17.35 cm. While, significantly the minimum length of cob was 14.58 cm in the weedy check plots (Amir et al. 2013). On the other hand, the highest ear length (19.81 cm) produced at wider inter-row spacing of 80 cm (41, 667 plants ha^{-1}), followed by 19.73 cm which produced at 75 cm inter-row spacing. The lowest ear length (18.75 cm) was obtained at the narrowest (65 cm) inter-row spacing (51, 282 plants ha^{-1}) (Table 4). Generally, ear length tended to increase with the decrease inter-row spacing or plant density. This implies the narrowest spacing had a negative impact on ear length. Getahun (2017) reported that highest ear length (20 cm) was obtained at a plant density of 31,250 plants ha^{-1}; while the lowest ear length (17 cm) produced at a plant density of 62,500 plants ha^{-1}. The reduction of ear length in the narrow plant spacing might be due to crowded stress and series competition among plants and among different organs within a plant. In analogy to this result, Zamir et al. (2011) was indicated the existence of positive relationship between plant spacing and cob length of maize, probably due to variable plant competition.

Number of kernel rows per ear (NKRPE)

Result showed that the main effect of weed management practices ($P<0.01$) and inter-row spacing ($P<0.05$) significantly affected the number of kernel rows per ear. However, their interactions were not significant on this parameter (Table 4). The maximum NKRPE (15.72) was recorded from hand and hoe weeded plots at 25 and 45 DAS which was statistically at par to 15.49 which obtained from application of s-metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1}. The lowest NKRPE (14.60) was recorded from the weedy check (Table 4). The NKRPE was increased with increasing in efficiency and effectiveness of weed control treatments over the weedy check. In case of inter-row spacing, the maximum NKRPE (15.47) was obtained when maize hybrid was sown at 80 cm row spacing, but it was statistically at par with 15.14 which achieved under 75 cm inter-row spacing. The lowest NKRPE (14.96) was recorded when maize plant sown at 65 cm inter-row spacing (Table 4).There was an increasing trend in NKRPE with the increase in inter-row spacing. This increase could be attributed to low stress and low competition for growth resources under wider row spacing while reduction of NKRPE under narrow row spacing might be due to crowded stress and intense competition. Abuzar et al. (2011) stated that number of grain rows per ear decreased as the plant population increased.

Thousand Kernel weight (TKW)

There was significant main effect of weed management practices ($P<0.01$) and inter-row spacing ($P<0.05$) on thousand kernel weight. However, the interaction effect of the two factors was not significant (Table 4). Weed management practices shown increment in TKW over the weedy check. Accordingly, the highest TKW (393.01g) was recorded from hand pulling and hoeing at 25 and 45 DAS. Significantly the lowest TKW (314.09 g) was obtained from the weedy check (Table 4). This increase in TKW in treated plots might be due to the effective control of weeds and reduced competition from weeds thus increase in uptake of nutrients and thereby healthy growth and developments of crop which resulted in higher grain weight. In agreement with this result, Soliman and Gharib (2011) found that hand hoeing twice at 18 and 30 days after planting was significantly produced the greatest 100-grain weight compared with other weed control. Likewise, Nadeem et al. (2006) stated that 1000- grain weight of maize was increased with the use of herbicides. In case inter-row spacing, the widest inter-row (80 cm) or (41, 667 plants ha^{-1}) produced the highest kernel weight of 379.93 g which was statistically at par to 371.75 g that obtained from inter-row spacing of 75 cm. Whereas, the lowest kernel weight (350.99g) was recorded from the narrowest spacing (65 cm) or (51, 282 plants ha^{-1}) (Table 4). In general, decreasing inter-row spacing decreased TKW. The higher kernels weight at the widest inter-row spacing could be due to availability of more resources (light, nutrient, and water) for comparatively less number of plants which they utilized efficiently. This result is in conformity to the findings of Zamir et al. (2011) who pointed out that, low kernels weight at narrower row spacing (high plant density) was probably due to availability of less photosynthates for kernel development on account of high intra-specific competition.

Table 4. Effect of weed management practices and inter row spacing on growth and yield components of maize at Bako, 2018.

Treatments	Leaf area index	Ear length (cm)	No. Rows per ear	TKW (gm)
		Weed management practices		
Hand weeding	4.73a	20.30a	15.72a	393.01a
S+A at 3 L ha^{-1}	4.72a	20.26a	15.49a	384.11ab
S+A at 2 L ha^{-1}	4.63a	19.73ab	14.98b	365.95ab
S+A at 1 L ha^{-1}	4.53ab	19.13b	14.93bc	362.09b
Weedy check	4.16b	17.38c	14.6c	314.09c
LSD (5%)	0.37	0.97	0.38	27.1
		Inter row spacing (cm)		
80	4.15c	19.81a	15.47a	379.93a
75	4.48b	19.73a	15.14ab	371.75ab
70	4.63ab	19.14ab	15.00b	352.73b
65	4.95a	18.75b	14.96b	350.99b
LSD (5%)	0.33	0.86	0.34	24.24
CV (%)	9.8	6.0	3.0	9.0

Means within the same factor and column followed by the same letter are not significantly different at P at 5%. Note: S+ A = s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding = Hand pulling and hoeing at 25 and 45 DAS, LSD (5%) = Least significant difference and CV (%) = Cofficient of variation.

Number of ear per plant (NEPP)

The analysis of variance depicted that there was highly significant effect of weed management practices ($P < 0.01$), and significant ($P < 0.05$) effect due to inter rows spacing and factors interaction on this parameter (Table 5). The highest number of ears per plant was achieved at the widest (80 cm) inter row spacing in combination with hand pulling and hoeing at 25 and 45 DAS, s-metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} and at 2 L ha^{-1}. On the other hand, the lowest number of ears per plant was obtained from weedy check regardless of the inter row spacing levels (Table 5). At all row spacing, number of ears per plant tended to increase with the increase in weed control efficiency. Generally, decreasing in row spacing resulted significant reduction in number of ears per plant. This could be due to the fact that the use of narrow inter row spacing (high plant densities) can be attributed to more competition for growth limiting factors such as nutrients, water, light and aeration that might inhibit the growing ear. In analogy with the current result, Maqbool et al. (2006) also demonstrated significant interaction effect of weed control and plant density on number of ears per plant in maize. High stand establishment creates competition for light, aeration, nutrients and consequently compelling the plants to undergo less reproductive growth (Getahun, 2017; Zamir et al. 2011).

Table 5. Interaction effect of weed management practices and inter row spacing on number of ear per plant during 2018 cropping season at Bako.

Weed management practices	Inter row spacing (cm)			
	65	70	75	80
Weedy check	0.81i	0.92hi	1.0efgh	1.03fgh
S+A at 1 L ha^{-1}	0.96ghi	1.11cdefg	0.98ghi	1.23abcde
S+A at 2 L ha^{-1}	1.15cdefg	1.19bcdef	1.07defgh	1.29abc
S+A at 3 L ha^{-1}	1.24abcde	1.21bcdef	1.25abcd	1.27abcd
Hand weeding	1.26abc	1.27ab	1.38abcd	1.43a
LSD (5%) WMP * IRS = 0.17		CV (%) = 9.1		

Means followed by the same letter within column are not significantly different at P at 5%. Note: S+ A = s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding = Hand pulling and hoeing at 25 and 45 DAS, LSD (5%) = Least significant difference and CV (%) = Cofficient of variation.

Grain Yield (GY)

The main effects of weed management practices and inter-row spacing on grain yield were significant (P<0.01) and their interaction was also significant (P<0.01) (Table 6). The highest grain yield was recorded in inter-row spacing of 65 cm treated with hand pulling and hoeing at 25 and 45 DAS (10492 kg ha^{-1}), followed by application of s-metolachlor 290g/L + atrazine 370 g/L at 3 L ha^{-1} involving the same row spacing (65 cm). In contrary, the lowest grain yield (2237.0 kg ha^{-1}) was obtained from weedy check plot at 80 cm inter-row spacing (Table 6). In general, the grain yield ha^{-1} was increased with the increase in weed control efficiency of weed management practices and with decreasing in inter-row spacing. On the other hand, the severe reduction in grain yield in the weedy check plots could be attributed to severe weed competition with the crop for light, water, nutrients and space which negatively affected the vegetative growth and dry matter accumulation. This result is in conformity with the findings of Frehiwot et al. (2013) who noticed significant decrement in maize grain yield in weedy check that might be due to significantly higher weed infestation i.e., weed density and dry weight that resulted in severe competition. Moreover, increase in maize grain yield under reduced spacing might be due to efficient utilization of available resources (nutrient water and light) as well as improved maize suppressive ability against weeds. Hussein et al. (2008) reported maize weeds control by the hoeing or herbicides treatments was enhanced in narrow compared to wide-spacing maize and the highest biological and grain yields of maize resulted at spacing of 60 x 25 cm (28000 plant population/fed).

Table 6. Interaction effect of weed management practices and inter row spacing on grain yield (kg ha^{-1}) of maize during 2018 cropping season at Bako.

Weed management practices	Inter row spacing (cm)			
	65	70	75	80
Weedy check	3014i	2771ij	2597ij	2237j
S+A at 1 L ha^{-1}	7517fg	7024g	6347h	6191h
S+A at 2 L ha^{-1}	9634bc	8687de	7707f	7393fg
S+A at 3 L ha^{-1}	9945ab	9237cd	8452e	7521fg
Hand weeding	10492a	9922ab	8790de	7705f
LSD (5%) WMP * IRS = 565.0		CV (%) = 4.8		

Means followed by the same letter within column are not significantly different at P at 5%. Note: S+ A = s-metolachlor 290 g/L + atrazine 370 g/L, Hand weeding = Hand pulling and hoeing at 25 and 45 DAS, LSD (5%) = Least significant difference and CV (%) = Cofficient of variation.

Conclusion

Weed is one of the major biotic factors that are responsible for low yield of maize, and effective weed management is substantive for increasing the crop productivity. The results of present study revealed that combination of weed management practices with narrower inter row spacing improved weed control efficiency there by decreasing weed density (m^{-2}) and weed dry biomass weight (gm^{-2}). The uses of narrow inter row spacing leading to a greater crop suppressive ability against weeds while improving the grain yield. The maximum grain yield was recorded in inter-row spacing of 65 cm in combination with hand pulling and hoeing at 25 and 45 DAS (10492.0 kg ha^{-1}); while the minimum grain yield (2237.0 kg ha^{-1}) was obtained from weedy check plot at 80 cm inter-row spacing. Furthermore, maize planted at 65 IRS in combination with s-metolachlor 290g/L + atrazine 370 g/L 2 L ha^{-1} gave 9634 kg ha^{-1}, which was statistically equal with 9945 kg ha^{-1} which obtained under application of s-metolachlor 290 g/L + atrazine 370 g/L at 3 L ha^{-1} involving the same row spacing (65 cm). Hence, farmers in the area might be advised to use the optimum weed management practice to increase the productivity of maize crop.

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Conflicts of Interest

The authors declare that there is no conflict of interests concerning the publication of this paper.

References

Abuzar M.R, Sadozai G.U, Baloch M.S, Baloch A.A, Shah I.H, Javaid T, Hussain N. 2011. Effect of Plant Population Densities on Yield of Maize. J. Anim. Plant Sci. 21(4): 692-695.

Amir K, Muhammad Z, Khalid N, Ishaq M, Wiqar A. 2013. Effect of various herbicides and manual control on yield, yield components and weeds of maize. Pak. J. Weed Sci. Res. 19(2): 209-216.

Begna H, Hamilton R, Dywer M, Stewart W, Cloutier D, Assemat L, Foroutan-Pour K, Smith D. 2001. Weed biomass production response to plant spacing and corn (*Zea mays*) hybrids differing in canopy architecture. Weed Technology. 15: 647-653.

Biru A. 1976. Agronomy research manual. Part II-Information for special trial for particular crops.

CIMMYT. 2004. Second semiannual progress report for the quality protein maize development project for the Horn and East Africa (XP 31519).

Cruz E.D, Moody K, Ramos M.B. 1986. Reducing variability in sampling weeds in transplant aman rice (*Oryza sativa* L.). Philippines J. Weed Sci. 13: 56-59

CSA (Central Statistical Agency). 2017. Agricultural Sample Survey Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Addis Ababa, Ethiopia, pp. 1–112.

Douglas D.B. 2002. Challenges and opportunities for integrated weed management. Weed Sci. 50: 273-80.

El-Naim A.M, Ahmed S.E. 2010. Effect of weeding frequencies on growth and yield of two roselle (*Hibiscus sabdariffa L*) Varieties under rain fed. AJBAS. 4(9): 4250-4255.

Fanadzo M, Chiduza C, Mnkeni P.S. 2010. Effect of inter-row spacing and plant population on weed dynamics and maize (*Zea mays* L.) yield at Zanyokwe irrigation scheme, Easter Cape, South Africa. Afr J Agric Res. 5(7): 518-523.

Fanadzo M. 2007. Weed management by small-scale irrigation farmers: The story of Zanyokwe. SA Irrigation. 29 (6): 20-24.

FAO (Food and Agriculture Organization). 2017. Statistical databases and data-sets of the Food and Agriculture Organization of the United Nations. http://faostat.fao.org/default.aspx. Accessed 18 Dec 2017.

Farkas A. 2006. Soil management and tillage possibilities in weed control. Herbologia. 7(1): 9-23.

Fassil R, Matias M, Rezene F, Tamado T. 2006. Weed research in sorghum and maize. In: proceeding of the 14th annual conference of the plant protection society of Ethiopia (PPSE); Abraham Tadesse (eds.). Addis Ababa, Ethiopia. Pp. 303-323.

Francis C.A, Rutger J.N, palmer A.F. 1969. Rapid method for plant leaf area estimation in maize. Crop sci. 9:537-539.

Frehiwot S, Sharma J.J, Mashilla D. 2013. Effect of Herbicides and their Application Rates on Weeds and Yield of Maize (*Zea mays* L.). Eth. J.Weed Mgt. 6: 73-84.

Getahun D. 2017. Determination of plant density and weeding frequency effect on weed control and productivity of maize at Assosa district, Benishangul Gumuz Regional State, Ethiopia. M.Sc. thesis, Ambo University, Ethiopia.

Hussein F.A, El-Metwally I.M, El-Desoki E.R. 2008. Effect of Plant Spacing and Weed Control Treatments on Maize Yield and Associated Weeds in Sandy Soils. J. Agric. & Environ. Sci. 4 (1): 09-17

Macauley H, Ramadjita T. 2015. Cereal crops: rice, maize, millet, sorghum and wheat: background paper. Conference on 'Feeding Africa' Dakar, Senegal. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/DakAgri2015/Cereal_Crops

Maqbool M.M, Tanveer A, Ata Z, Ahmad R. 2006. Growth and yield of maize (*Zea mays* L.) as affected by row spacing and weed competition durations. Pak. J. bot. 38 (4): 1227-1236.

Mahadi M.A. 2014. Growth, Nutrient Uptake and Yield of Maize (*Zea Mays* L.) as Influenced by Weed Control and Poultry Manure. Int. J. Sci Nat. 5(1): 94-10.

Megersa K, Gudeta B, Fufa A. 2018. Integration of Glyphosates and Hand Weeding for Weeds Management in Maize (*Zea mays*. L). Agri Res & Tech. 18(5): 1-6.

Megersa K, Fufa A. 2017. Efficacy of Pre-emergence Herbicides for the Control of Major Weeds in Maize (*Zea mays L.*) at Bako, Western Oromia, Ethiopia. AJAR. 5(5): 173-180.

Nadeem M.A, Tufail M.S, Tahir, M. 2006. Effect of different herbicides on growth and yield of spring maize (*Zea mays* L.). In: International Symposium on Sustainable Crop Improvement and Integrated Management, Faisalabad. Faisalabad: University of Agriculture.

Pritam O, Bhutada. 2015. Present senior of weed management in maize. Int J Adv Res. 3(3): 266-268

Patel V.J, Upadhyay P.N, Patel J.B, Meisuriya M.I. 2006. Effect of Herbicide mixtures on weeds in kharif maize (*Zea Mays* L.) under Middle Gujarat conditions. Indian J. Weed Sci. 38(1/2): 54-57.

Radford P.J. 1967. Growth analyses formula - their use and abuse. *Crop Sci*. 7:171-175.

Simić M, Dragičević V, Brankov M. 2017. Influence of growing measures on weed interference and water status in maize. Pestic. Phytomed. 32(2): 113–120

Simić M, Dolijanović Ž, Maletić R, Stefanović L, Filipović M. 2012. Weed suppression and crop productivity by different arrangement patterns of maize. Plant, Soil Environ. 58(3): 148-153.

Simić M, Stefanović L. 2007. Effects of maize density and sowing pattern on weed suppression and maize grain yield. Pesticides & Phytomedicine. 22(2): 93-103.

Soliman I.E, Gharib H.S. 2011. Response of weeds and maize (*Zea mays* L.) to some weed control treatments under different nitrogen fertilizer rates. Zagazig J. Agric. Res. 38(2): 249-271.

Tadious T, Bogale T. 1994. Effect of different weed management methods on grain yield of maize in western Ethiopia. CIMMYT, Mexico. pp. 223-228.

Teasdale J.R.1995. "Influence of narrow row/high population corn (*Zea mays*) on weed control and light transmittance. Weed Technol. 9(1): 113-118.

Teymoori M, Mohammad A, Eskandar Z, Hamid M, Saeed M. 2013. Weed management in maize field by chemical, mechanical and cultural methods. Res Crops. 14(3): 729-735.

Uremis I, Uludag A, Ulger A.C, Cakir B. 2009. Determination of critical period for weed control in the second crop corn under Mediterranean conditions. AJB. 8(18): 4475-4480.

Zamir M.S, Ahmad A.H, Javeed H.M, Latif T. 2011. Growth and yield behavior of two maize hybrids towards different plant spacing. Cercetări Agronomice. 14(2): 33-40.

Zhang J, Weaver S.E, Hamil A.S. 2002. Risks and reliability of using herbicides at below-labeled rates. Weed Technol. 14: 106-15.

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