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Influence of Weed Management Practices on Weed Dynamics and Productivity of Maize (*Zea mays* L.) in Sierra Leone

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ABSTRACT

A two-year (2017 and 2018) field trials was conducted in the School of Agriculture, Njala University, Sierra Leone, to evaluate weed management practices on weed dynamics and productivity of maize. The experimental trials were laid out in a randomized complete block design (RCBD) with three replications. The treatment combinations comprised of weedy check (Control), two hoe weeding at 4 and 8 weeks after planting (WAP), Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP, *Gliricidia sepium* leaves mulch at 40 kg m^{-2} plus one hoe weeding at 8 WAP, weed-free check and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP. The results showed that growth and yield physiognomies differ significantly ($P<0.05$) among weed control practices across both years. The weed-free check treatment recorded the highest growth and yield physiognomies with respect to reduced weed density and increased weed control efficiency followed by herbicidal treatments, while weedy check had the lowest growth and yield attributes across both years. Nonetheless weed-free check required lot of labour force which was not economical to the farmer's point of judgment. Thus, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP proved to be better in controlling weeds, increasing crop yield and economical compared with other weed management practices. Hence Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP was recommended as a pre-emergence herbicide in maize production for effective and environmentally friendly weed control method.

Introduction

Maize (*Zea mays*) belongs to the family Poaceae and is one of the oldest human-cultivated crops and third most important cereal grain crop in the world, after wheat and rice (IITA, 2005; FAO, 2011; Shiferaw *et al.* 2011). It is the world's widely grown upland cereal and main staple food crop in many developing countries (Ram *et al*. 2017). Maize occupied more than 33 million hectares yearly in sub-Saharan Africa (FAOSTAT, 2015). Maize was introduced in Sierra Leone in the 16^{th}

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century and has been graded as the second most important cereal crop grown after rice which is the country's staple food (MAFFS/NARCCR, 2005; Cadoni and Angelucci, 2013). The area under maize cultivation in Sierra Leone was 20.828 ha with a yield of 0.77 metric tonnes ha^{-1} given a total production of 16.060 metric tonnes (FAO, 2012). Maize production in Sierra Leone is very essential among resource poor farmers, because it serves as a food for human, feed and fodder for livestock, source of employment and income for poor rural people, provides more than one-third of the calories and proteins to people (Chulze, 2010; Ajani and Onwubaya, 2012).

Despite the significance of maize, its yield obtained in Sierra Leone is below expectation due to weed infestation. Yield losses of about 89% have been ascribed to uncontrolled weed infestation in maize (Imoloame and Omolaiye, 2016). Similarly Quee *et al*. (2017) reported that weed infestation in maize is a limiting factor for efficient maize production in Sierra Leone, which led to yield reduction, increase in cost of production, quality and reduction in the returns of maize growers.

A wide range of weed control methods are being used in Sierra Leone without evaluating their effects on weeds, crop growth and yield. Manual weeding using hand pulling or hoeing is the commonest weed control method practiced in Sierra Leone, however it's not considered as the best options, because it is labour intensive, expensive, uncertain and energetic (Wszelaki et al. 2007; Thierfelder and Wall, 2009; Ulloa et al. 2011; Mandumbu et al. 2011). Hence, integrated weed management is a desirable alternative for sustainable maize production in Sierra Leone. But information on the influence of different weed management practices and their collaborative effects on productivity of maize are seldom available. Keeping these in view, the present study was planned to evaluate effective and efficient weed management practices on weed dynamics, yield and productivity of maize.

Materials and Methods

Description of experimental area

A two-year (2017 and 2018) field trials were conducted in the Global Agricultural and Food Security Programme (GAFSP) nursery site at School of Agriculture, Njala University Sierra Leone. The geographical location of the experimental site was 08.06^0 N and 12.06^0 W with an elevation of 63 m above mean sea level. The main flora of the study area was secondary scrub with a well drainage depressions, undulating grasslands and low upland. The climate of southern region is tropical, characterized by a wet season (May to September) and dry season (October to April). Data on weather conditions of the experimental area was collected using the WatchDog weather station (model: 2000 series) during 2017 and 2018 main cropping years (Table 1).

Table 1. Weather data from June - September 2017 and 2018 cropping years.

Month	Weather condition					
	2017			2018		
	Relative humidity (%)	Temperature (°C)	Rainfall (mm)	Relative humidity (%)	Temperature (°C)	Rainfall (mm)
June	85.79	26.15	400.60	86.53	25.95	379.00
July	88.20	25.40	340.70	90.85	25.18	528.50
August	91.00	25.20	552.20	90.24	25.18	272.10
September.	88.54	25.89	367.20	88.03	25.57	503.90

Experimental design and treatments

The experimental trial was laid out in a randomized complete block design (RCBD) with three replications. The treatment combinations comprised of weedy check (Control), two hoe weeding at 4 and 8 weeks after planting (WAP), Double force® at 4 L ha^{-1} (a.i 350g L^{-1} diuron +140 g L^{-1} paraquat dichloride + plus stench, dye and emetic SE) + one hoe weeding at 8 WAP, *Gliricidia sepium* leaves mulch at 40 kg m^{-2} + one hoe weeding at 8 WAP, weed-free check (Weeding every two weeks) and Atrazine 500 SC at 3 L ha^{-1} (a.i atrazine 50% SC) + one hoe weeding at 8 WAP.

Management Practices

The experimental plots were manually ploughed and leveled using hoe, demarcated to a plot size of 5 x 4 m, with 1 m between replications and 0.5 m within plots given an area of 450.5 m^2 (0.0455 ha). An improved maize variety 'Downy Mildew Resistance and Early Streak Resistance' yellow (DMR/ESR yellow) was sown at an inter and intra-row spacing of 75 x 50 cm respectively on the 5 x 4 m plots, given a plant population of 23,333 plants ha^{-1}. Two seeds were sown and thinned 14 days after sowing prior to the application of N-P-K (15:15:15) fertilizer at the rate of 200kg ha^{-1} using side placement method, while 60kg N ha^{-1} of urea (46% N) was top dressed at active growth and tassel stages (6 WAP) of the maize. Atrazine and Double force® were applied as pre-emergence herbicides one day after planting with manually operated 15 litre Knapsack sprayer using a spray volume of 200 litres of water ha^{-1}. The quantity of each herbicide was applied using these formulas:

$$Litres\ of\ water\ required/ha = \frac{Area\ to\ be\ sprayed\ (m^2)\ x\ output\ of\ the\ sprayer\ (L/ha)}{10{,}000\ m^2\ /ha}$$

$$Amount\ of\ herbicide/Area\ to\ be\ sprayed\ (m^2) = \frac{Amount\ of\ water\ required\ x\ Quantity\ of\ herbicide\ required\ (L/ha)}{Output\ of\ the\ sprayer\ (L/ha)}$$

Five plants were randomly selected from each plot and regular quantitative observations of the crop and weed parameters were recorded at 4, 8 and 12 WAP.

Data Collected

Crop sampling was carried out on five randomly selected plants from the two central rows of each plot to determine the following: Plant height, canopy width, stem diameter, number of leaves, leaf area, number of cobs plant^{-1}, number of grains cob^{-1}, number of grain rows cob^{-1}, Stover yield t ha^{-1}, 1000 grain weight g^{-1} and grain yield t ha^{-1}.

Plant height (m): Plant height was determined at 4, 8 and 12 WAP from 5 randomly selected plants (Tagged) at the two middle rows in each plot. Their heights were measured from the soil surface to the apex of the highest leaves using a meter rule and mean recorded plot^{-1}.

Number of leaves plant^{-1}: This was determined by visual count of the leaves of five randomly selected plants and mean also calculated plot^{-1}. Leaf Area (cm^2): Five maize plants were randomly selected, tagged and monitored at 4, 8 and 12 WAP. The broadest point of the longest leaf on the plant was calculated as the product of the total length and breadth. Leaf Area = lamina length x maximum width x k; where k (Constant) is 0.75 (Chanda and Singh, 2002). Stem diameter (cm): Stem diameter was similarly measured at 4, 8 and 12 WAP using the Vernier Caliper from 10 cm above the ground surface.

Canopy width (m): Canopy width was evaluated on five representative plants in each plot using canopy area cross-method; the longest length of canopy width from each edge across the plant was measured using a meter rule. The spread along that line is the horizontal distance between those two positions. Stover yield (t ha^{-1}): The dry Stover yield was determined by randomly harvesting the leaves and stems of 5 maize plants from the middle rows of each plot at maturity and oven dried at 80°C for 4 days and weighed.

Number of cobs (Plant^{-1}): The number of productive ears from 5 randomly selected tagged plants from the two central rows was used for counting.

1000- Grain weights (g): A number of 1000 of maize grains were determined by counting the bulk of grains from each plot harvested, adjusted to 12.5% moisture content and their weights recorded.

Grain yield (t ha^{-1}): The grain yield of maize was determined after harvesting the entire produce from the net plot area. Seeds harvested per plot were weighed after properly dried under the sun and grain yield converted to tonnes ha^{-1} using the formula reported by Ullah (2008).

$$Grain\ yield\ (kg/ha)\ = \frac{AGrain\ weight\ (kg)\ x\ 10{,}000\ (m^2)}{Area\ harvested\ (m^2)}$$

Weeds sampling (g m^{-2})

The populations of different types of weeds were assessed at 4, 8 and 12 weeks after planting. A quadrat with 0.5 m^2 dimension was randomly thrown two times in each plot and prevalent weed species from that area were identified, counted per specie and the harvested weed biomass plot^{-1} was oven- dried at 80^{0}C for 48 hours before reweighing. The weed density and weed biomass data were transformed using log base 10 (Log$_{10}$). Indices below were calculated according to Singh, *et al*. (2018).

$$Weed\ control\ efficiency\ (WCE)\ = \frac{Weed\ population\ in\ control\ plot-\ Weed\ population\ in\ treated\ plot}{Weed\ population\ in\ control\ plot} \times 100$$

$$Weed\ control\ index\ (WCI)\ = \frac{Weed\ dry\ weight\ in\ control\ plot\ -\ Weed\ dry\ weight\ in\ treated\ plot}{Weed\ dry\ weight\ in\ control} \times 100$$

$$Weed\ index\ (WI)\ = \frac{Yield\ in\ weed\ free\ plot\ -\ Yield\ in\ treated\ plot}{Yield\ in\ weed\ freeplot} \times 100$$

$$Relative\ density\ (RD)\ = \frac{Density\ of\ named\ species}{Total\ density\ of\ all\ species} \times 100$$

Economic analysis

The economic analysis was determined using partial budgeting (Okoruwa et al. 2005) to compare cost-effectiveness of the various weed control treatments in maize production systems. Thus, gross margin was computed as follows:

i. The unit price of 1 kg of maize was obtained from the open market to determine the total revenue (TR)
   Total revenue (TR) = Maize yield (t ha^{-1}) x Unit price of maize (SLL t ha^{-1}).
ii. Gross margin (SLL ha^{-1}) = Total revenue (SLL ha^{-1}) – Variable cost (SLL ha^{-1}) Variable costs (VC) are expenditures on Land preparation, planting material, cost of planting, cost of herbicide application, cost of herbicides, cost of *Gliricidia sepium* application, cost of *Gliricidia sepium*, weeding, feeding, harvesting and transportation.

Data analysis

Data collected were subjected to analysis of variance using the PROC GLM procedure of Statistical Analysis System (SAS) computer software programme, version 9.4. The Student Newman-Keuls (SNK) test was used to compare treatment means at 0.05 level of probability. Weed assessment data was analyzed after transformation using log base 10 (Log_{10}). Grain yields were determined and the means of variable cost (VC) and total revenue (TR) for the two years were combined to determine the gross margin (GM).

Results and Discussion

Plant height (m)

The analysis of variance revealed that plant height of maize was statistically significant affected by different weed management practices (Table 2). Plots treated with weed-free check recorded the tallest plant followed by Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP in all the stages of sampling for both years. This may be attributed to their ability to effectively control weeds which allowed the maize crop to utilize more nutrient, moisture and sunlight for better performance. In addition, the shortest plants were produced by the weedy check treatment due to greater intensity of weed competition with maize crop for growth resources which may have led to poor performance of the crop in both years. In the year 2017, plant heights in all the weed control treatments at 8 WAP were not statistically significant compared to the weedy check treatment. Similar trend was observed at 12 WAP among weed-free check, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP in 2018 cropping year. The findings for herbicide treatments in this study was similar to Hassan et al. (2010), reported that the herbicides are the most efficient and effective in controlling weeds in maize and also increase the plant height, crop growth and canopy development. Furthermore, Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP and *Gliricidia sepium* leaves mulch at 40 kg m^{-2} plus one hoe weeding at 8 WAP did not show significant difference at 8 and 12 WAP in 2017 cropping year. Similar trend was also observed between Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP and *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP treatments in 2018 at 8 weeks after planting. According to Khurshid et al. (2006); Shah, et al. (2009); Achieng et al. (2010) maize plant significantly increased in height under greater *Gliricidia sepium* leaf mulch levels. The differences in the heights of maize plant may be ascribed to capturing more sunlight and other growth factors and the intensities of weed competition with maize plants.

Canopy width (m)

Weed management practices showed significant ($p<0.05$) differences on canopy width of maize among the various dates of observation (4, 8 and 12 weeks after planting) in both years (Table 3). The weed-free check recorded significantly ($p<0.05$) the widest canopy width at 4, 8 and 12 WAP in both study years. However, at 8 and 12 WAP, non-significant differences were observed between Double force® at 4L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP in 2017 cropping year. Similarly, at 8 WAP non-significant differences occurred between weed-free check and Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP in 2018 cropping year. The analysis of variance showed that the narrowest canopy width of maize was recorded in the weedy check treatment throughout the various sampling periods in both study years.

Table 2. Effect of weed management practices on plant height of maize in 2017 and 2018 cropping years.

Treatment	Plant height (m)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	0.96^{a}	1.96^{a}	2.94^{a}	0.18^{a}	1.33^{a}	2.95^{a}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	0.90^{ab}	1.93^{a}	2.59^{b}	0.16^{b}	1.27^{ab}	2.77^{a}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	0.83^{b}	1.88^{a}	2.48^{bc}	0.15^{b}	1.23^{bc}	2.64^{a}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	0.70^{c}	1.78^{a}	2.44^{bc}	0.10^{c}	1.21^{bc}	2.50^{ab}
Two hoe weeding at 4 and 8 WAP	0.65^{c}	1.72^{a}	2.31^{cd}	0.10^{cd}	1.19^{c}	2.39^{ab}
Weedy check	0.37^{d}	0.82^{b}	2.18^{d}	0.09^{d}	1.18^{c}	1.96^{b}
Pr > F	<.0001	<.0001	<.0001	<.0001	0.0018	0.0142
CV (%)	6.4	8.3	3.7	5.2	2.7	10.3

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Table 3. Effect of weed management practices on canopy width of maize during 2017 and 2018 cropping years.

Treatment	Canopy width (m)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	0.93^{a}	1.16^{a}	1.80^{a}	0.74^{a}	2.14^{a}	2.44^{a}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	0.89^{ab}	1.10^{ab}	1.73^{ab}	0.61^{b}	2.01^{a}	2.21^{ab}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	0.84^{bc}	1.09^{ab}	1.66^{ab}	0.54^{bc}	1.74^{b}	1.94^{bc}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	0.78^{cd}	1.04^{ab}	1.50^{bc}	0.48^{c}	1.50^{bc}	1.61^{cd}
Two hoe weeding at 4 and 8 WAP	0.73^{d}	0.97^{b}	1.34^{c}	0.38^{d}	1.28^{c}	1.36^{d}
Weedy check	0.57^{e}	0.86^{c}	0.88^{d}	0.23^{e}	0.78^{d}	0.89^{e}
Pr > F	<.0001	0.0007	<.0001	<.0001	<.0001	<.0001
CV (%)	4.7	5.2	6.7	9.4	8.4	11.5

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Stem diameter (cm)

Weed management practices revealed significant (p<0.05) effect on maize stem diameter during different sampling periods in both years (Table 4). The weed-free check management practice recorded significantly ($p<0.05$) the widest stem diameter in all sampling periods than other weed management practices in both years. The stem diameter values obtained in weed-free check and Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP did not statistically differ from each other at 8 and 12 WAP in 2017 cropping year. In the same 2017 cropping year at 8 WAP, stem diameter presented in Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP was wider than *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP and two hoe weeding at 4 and 8 WAP treatments, though they are not significantly different ($P>0.05$). In the subsequent year (2018), the stem diameter obtained in Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP treatments are not significantly different ($P>0.05$) at 4 and 8 WAP. Similar results were revealed between *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP and two hoe weeding at 4 and 8 WAP treatments in 2018 study year during 8 WAP observation. According to Xue et al. (2013) *G. sepium* leaves mulch significantly improved plant growth in terms of leaf area, number of leaves $plant^{-1}$ and stem diameter. Throughout the study years, weedy check treatment showed significantly the narrowest stem diameter of maize crop.

Table 4. Effect of weed control practices on stem diameter of maize during 2017 and 2018 cropping years.

Treatment	Stem diameter (cm)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	2.52^a	3.63^a	3.94^a	1.88^a	2.27^a	2.46^a
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	2.08^b	3.47^a	3.78^a	1.37^b	1.91^b	2.16^b
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	1.68^c	2.68^b	3.47^b	1.28^b	1.75^b	1.93^c
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	1.36^{cd}	2.48^b	3.34^{bc}	0.88^c	1.34^c	1.67^d
Two hoe weeding at 4 and 8 WAP	1.27^{cd}	2.14^b	3.23^{bc}	0.66^d	1.20^c	1.38^e
Weedy check	0.96^d	1.46^c	3.03^c	0.45^d	0.90^d	0.97^f
Pr > F	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001
CV (%)	11.3	11.0	4.3	10.8	5.9	4.8

Means with the same superscripts in column are not significantly different ($P>0.05$) as indicated by Student Newman-Keuls multiple range test.

Leaf number (Plant-1)

The lowest number of leaves $plant^{-1}$ was recorded in the weedy check treatment, which differs significantly ($p<0.05$) from other weed management practices in both years (Table 5). The consistent reduction in number of leaves in the weedy check plots might be due to competition for water, nutrient, light and space from weeds (Boydston, 2010). However, weed-free check and Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP treatments are not significantly different ($P>0.05$) at 4, 8 and 12 WAP in 2017 cropping year, though weed-free check showed greater leaf number. Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP, *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8

WAP and two hoe weeding at 4 and 8 WAP treatments were not significantly different at 8 WAP in 2017 study year. Also, in 2018 cropping year, weed-free check significantly ($p<0.05$) recorded the highest number of leaves compared with other weed management practices. Additionally, *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP and two hoe weeding at 4 and 8 WAP treatments are not statistically different at 12 WAP in 2018 cropping year. The significant increase of leaf number in the *Gliricidia sepium* leaves mulched plots over weedy check (Control) treatment could imply that the mulch plots constituted higher mineral nutrients from decomposed mulched materials. According to Namakha et al. (2008); Uwah et al. (2011) the optimum rates of *Gliricidia sepium* leaves mulch promote vigorous foliage.

Table 5. Effect of weed management practices on leaf number of maize in 2017 and 2018 cropping years.

Treatment	Leaf number ($Plant^{-1}$)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	12.00^{a}	14.00^{a}	18.00^{a}	10.33^{a}	13.00^{a}	14.00^{a}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	11.33^{a}	14.00^{a}	18.00^{a}	9.00^{b}	12.00^{b}	13.00^{b}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	8.33^{b}	11.00^{b}	12.00^{b}	8.00^{c}	11.33^{bc}	12.00^{c}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	6.66^{bc}	11.00^{b}	11.33^{bc}	5.66^{d}	10.66^{cd}	11.33^{d}
Two hoe weeding at 4 and 8 WAP	6.66^{bc}	10.66^{b}	10.66^{c}	4.66^{e}	10.00^{d}	11.00^{d}
Weedy check	5.33^{c}	8.00^{c}	8.66^{d}	4.33^{e}	8.66^{e}	10.00^{e}
Pr > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	10.5	5.4	4.3	5.8	3.9	1.9

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Leaf area (cm)

The application of weed-free check treatment resulted significantly ($p<0.05$) to the largest area of leaves in both study years (Table 6). Statistically, at 12 WAP during 2017 main cropping year, not significant differences ($P>0.05$) among weed-free check, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP, Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP, *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP and two hoe weeding at 4 and 8 WAP treatments. Similarly, *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP and two hoe weeding at 4 and 8 WAP are not significantly different ($P>0.05$) at 12 WAP in 2018 main cropping year. These results showed that as competition from weeds was prolonged, the availability of essential growth resources to maize became limited and hence growth rate was reduced. According to Evans et al. (2003) the reduction in maize leaf area due to weed interference usually increasing with the stages of competition. Khan et al. (2002) stated that the maximum leaf area in those treatments where weeds were controlled.

Table 6. Effect of weed management practices on leaf area of maize during 2017 and 2018 cropping years.

Treatment	Leaf area (cm)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	123.33ᵃ	300.33ᵃ	610.33ᵃ	123.48ᵃ	300.83ᵃ	363.74ᵃ
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	109.00ᵇ	279.66ᵇ	598.00ᵃ	109.20ᵇ	280.17ᵇ	336.60ᵇ
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	94.66ᶜ	250.00ᶜ	565.00ᵃ	95.00ᶜ	250.59ᶜ	297.01ᶜ
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	82.33ᵈ	232.00ᵈ	528.33ᵃ	82.43ᵈ	232.34ᵈ	270.84ᵈ
Two hoe weeding at 4 and 8 WAP	64.33ᵉ	209.00ᵉ	521.67ᵃ	64.71ᵉ	209.32ᵉ	258.29ᵈ
Weedy check	44.33ᶠ	100.00ᶠ	247.00ᵇ	44.48ᶠ	100.18ᶠ	126.14ᵉ
Pr > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	5.9	2.7	7.7	5.7	2.7	4.5

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Number of cobs (plant^{-1})

With respect to yield attributes and yield of maize, all the weed management practices proved significantly (p<0.05) superior to weedy check treatment (Table 7). Weedy check treatment produced comparatively minimum number of cobs plant^{-1} in both study years compared to other weed management practices. It was evident from the analysis of variance that the number of maize cob plant^{-1} was highest in weed-free check treatment and was significantly higher than other treatments in for both years. The number of cobs plant^{-1} in the Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP, Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP and *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP treatments are not significantly different (P>0.05) in both years. According to Patel et al. (2006) all the weed control treatments proved significantly superior to weedy check with respect to yield attributes and yield of maize. Additionally, the effect of *Gliricidia sepium* leaves mulch on number of cobs plant^{-1} had been confirmed by Chapagain (2010); Egbe et al. (2012); Quee et al. (2017), *G. sepium* leaf titters could be as effective as commercial nitrogen fertilizer for growth and yield response of maize.

Number of grain rows (cob^{-1})

Number of grain rows cob^{-1} directly influenced cob weight and eventually grain yield of maize (Table 7). The results showed that maximum number of grain rows cob^{-1} in the weed-free check plots were significantly (p<0.05) different from other weed management practices in both years. Minimum number of grain rows cob^{-1} was recorded in the weedy check treatment which was statistically comparable to two hoe weeding at 4 and 8 WAP in both study years. In addition, number of grain rows cob^{-1} obtained in the Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP and *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding 8 WAP are not significantly different (P>0.05) in both years. The observations on number of grain rows cob^{-1} showed that good weed management practices are effective to obtain a greater number of grain rows cob^{-1} and consequently higher grain yield. According to Sulewska et al. (2006) weed controlled practices resulted in increased number of grain rows cob^{-1}.

Number of grains (cob^{-1})

The total number of grains cob^{-1} is a significant yield component parameter of maize (Table 7). Maximum number of grains cob^{-1} was significantly recorded in treatments where weed-free check was used to control weeds, which was however statistically at par with Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP treated plots in 2018 cropping year. The number of grains cob^{-1} under *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding 8 WAP and two hoe weeding at 4 and 8 WAP are not significantly different (P>0.05) in 2017 cropping year. Similarly, Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP, *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding 8 WAP and two hoe weeding at 4 and 8 WAP treatments were not significantly different (P>0.05) in 2018 cropping year. As anticipated, minimum number of grains cob^{-1} was observed in the weedy check plots for both years. The results indicated that with increasing weed control efficiency the number of grains and maize yield ultimately increased, which shows weed-maize crop competition for growth resources, thus decreases yield via reducing the yield related traits. Number of grains is an important yield related trait of maize and contributes to final yield and economics of farming enterprise. The highest number of grains cob^{-1} in weed-free check was due to lesser number of weeds and consequently more photosynthates were available for plant growth and development.

Table 7. Effect of weed management practices on number of cobs, grain rows and grains cob^{-1} during 2017 and 2018 cropping years.

Treatment	2017			2018		
	No. of cobs plant^{-1}	No. of grain rows cob^{-1}	No. of grains cob^{-1}	No. of cobs plant^{-1}	No. of grain rows cob^{-1}	No. of grains cob^{-1}
Weed-free check	6.66^{a}	18.33^{a}	176.66^{a}	6.66^{a}	17.00^{a}	166.66^{a}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	6.00^{ab}	16.66^{ab}	169.00^{ab}	6.00^{ab}	15.66^{ab}	159.00^{a}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	5.66^{ab}	15.66^{b}	152.00^{bc}	5.66^{ab}	14.66^{b}	142.00^{b}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	5.33^{ab}	15.00^{b}	146.33^{c}	5.33^{ab}	14.00^{b}	136.33^{b}
Two hoe weeding at 4 and 8 WAP	4.66^{b}	12.66^{c}	133.00^{c}	4.66^{b}	11.66^{c}	122.66^{b}
Weedy check	3.33^{c}	11.33^{c}	97.33^{d}	3.33^{c}	10.33^{c}	87.33^{c}
Pr > F	0.0003	<.0001	<.0001	0.0003	<.0001	<.0001
CV (%)	10.1	6.1	6.5	10.1	5.9	6.8

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Stover yield (t ha^{-1}) of maize

Stover yield (t ha^{-1}) attained the minimum value when weeds were not controlled (Weedy check) in maize throughout 2017 (10.82 t ha^{-1}) and 2018 (8.82 t ha^{-1}) cropping year. This resulted to severe competitive stress on maize crop for water, nutrient, light and space thus led to lower yield (Table 8). Among the weed management practices, weed-free check recorded significantly higher Stover yield in both years (18.32 t ha^{-1} and 16.32 t ha^{-1} respectively), due to enhanced control of weeds at critical stages hence providing suitable environment for better growth and development of maize. It may also be ascribed to the appropriate increase in maize plant height, attained wider canopy, which declined the weed species incidence that eventually produced vigorous crop plants. However, among the herbicidal weed control treatments, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP are not significantly different (P>0.05) in both study years. According to Chikoye et al. (2010); Gul et al. (2011); Khan et al. (2012) the higher biological yield was achieved due to effective weed control through different herbicides. Sale (2009) stated that under field conditions, the rate of mulch decomposition and mulch quality may produce the highest dry matter yield.

1000-Grain weight (g) of maize

Yield attributing traits like number of 1000-grain weight of maize was significantly affected by different weed management practices, being weightiest with weed-free check followed by Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP in both years (Table 8). These might be due to low level of weed competition at critical phases of maize growth which favoured maximum utilization of available resources and resulted to healthy crop stand and finally higher grain weight. The number of 1000-grain weights of maize were lighter in the weedy check treatment but are not significantly different (P>0.05) compared with two hoe weeding at 4 and 8 WAP in both years. According to Talebbeigi and Ghadiri, (2012), reduction in 1000-grain weights of maize due to weed competition. Shinggu et al. (2009) stated that early weed removal can increase maize grain weight cob^{-1} compared with weedy check. However, Ali et al. (2011) recorded that hand weeded and chemical weed control treatments gave the highest 1000-grain weight, grain and biological yields of maize. Earlier studies by Ramzan et al. (2012); Sale (2009) confirmed that mulching practices are useful for the enhancement of maize grain quality and affects thousand grain weights.

Grain yield (t ha^{-1})

The results of analysis of variance revealed that significant difference in grain yields of maize was observed in both study years (Table 8). Among the various weed management practices evaluated, weed-free check treatment revealed maximum grain yield (t ha^{-1}) followed by the application of Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP in both years. The increased growth and yield under weed-free check treatment may be attributed to the frequent removal of weeds as shown by low weed density, weed biomass and weed control efficiency compared to the other weed management practices. Thus, limited competition for growth factors from the weed-free check and Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP treatments helps to gain higher yields than the weedy check (Mathukia et al. 2014; Dobariya et al. 2015; Shankar et al. 2015; Barad et al. 2016). The grain yield was increased by weed-free check of 359.48%, 285.34% in Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP, 228.44% in Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP, 197.41% in *Gliricidia sepium* leaves mulch at 40 kg m^{-2} plus one hoe weeding at 8 WAP and 124.14% in two hoe weeding at 4 and 8 WAP was observed due to effective weed control over weedy check treatment in both study years. According to Larbi et al. (2013); Sepahvand et al. (2014); Abana and Godwin (2015) application of herbicides + hand hoeing once contributed to maximize grain yield and its attributes. The result further confirmed the reports of (Onasanya et al. 2009) and (Lelei et al. 2009) that increase in maize grain yield might be due to better growth, development and dry matter accumulation.

Table 8. Effect of weed management practices on Stover yield, 1000-grain weights and yield of maize during 2017 and 2018 cropping years.

Treatment	2017			2018		
	Stover yield (t ha^{-1})	1000 grain weight (g)	Yield (t ha^{-1})	Stover yield (t ha^{-1})	1000 grain weight (g)	Yield (t ha^{-1})
Weed-free check	18.32[a]	64.50[a]	5.33[a]	16.32[a]	59.50[a]	5.33[a]
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	17.07[ab]	61.60[ab]	4.30[ab]	15.07[ab]	56.60[ab]	4.63[ab]
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	16.54[ab]	55.60[bc]	3.76[b]	14.54[ab]	50.60[bc]	3.86[b]
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	15.73[bc]	52.20[c]	3.53[c]	13.73[bc]	47.16[c]	3.36[c]
Two hoe weeding at 4 and 8 WAP	14.10[c]	44.80[d]	2.60[d]	12.10[c]	39.80[d]	2.60[d]
Weedy check	10.82[d]	39.36[d]	1.16[e]	8.82[d]	34.35[d]	1.16[e]
Pr > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	6.4	6.7	4.5	7.4	7.4	8.1

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Weed flora composition

The documented weed flora along with their families, botanical names, growth habits, methods of propagation, life cycles and percent relative density are shown in both years (Tables 9 and 10). The experimental area in 2017 cropping year was infested with 24 different weed species belonging to 12 families when evaluated at 4, 8 and 12 WAP (Table 9). Similarly, 29 weed species belonging to 12 families were identified at 4, 8 and 12 WAP in 2018 cropping year (Table 10). Among the growth habits, the results revealed that broadleaved weeds (62.50%) followed by grasses (25.00%) and sedges (12.50%) during 2017 year of the research (Table 9), whereas broadleaved weeds (65.51%) followed by grasses (20.68%) and sedges (10.34%) in the 2018 cropping year (Table 10). According to Singh et al. (2007), Hussain et al. (2009); Hussain et al. (2009); Mehmeti et al. (2012) varying weed flora in crops was reported. In 2017 cropping year, 79.16% of weed species were reproduced by seeds, 12.50% by seeds/vegetative and 8.33% by vegetative parts (Table 9), while 82.75% were reproduced by seeds, 10.34% by seeds/vegetative and 6.89% by vegetative parts in 2018 cropping year (Table 10). Among the individual weed species, *Anadelphia sp, Calopogonium mucunoides, Croton hirtus, Euphorbia heterophylla* and *Spigelia anthelma* were prominent and infested with intensity of order in maize field during 2017 cropping year (Table 9). The significant and predominant weed flora observed in the maize field during 2018 cropping year were *Anadelphia sp, Andropogum tectorum, Euphorbia heterophylla, Euphorbia hirta* and *Spigelia anthelma* (Table 10). In Tables 9 and 10, weed species belonging to the families of Poaceae and Euphorbiceae were the most dominant during both study years, with Euphorbiaceae recording the highest.

Euphorbia heterophylla (39.43%) recorded the highest percentage of relative density (RD) and was the most common and predominant weed specie followed by *Croton hirtus* (11.76%) in 2017 cropping year (Table 9). Also, in 2018 cropping year, *Euphorbia hirta* was the most common and predominant weed specie (Table 10), thus recorded the highest percentage of relative density (20.84%) than all other weed species followed by *Euphorbia heterophylla* (10.52%). The consistent increase in relative density of the Euphorbiaceae family indicates its ability to adapt to wider range of climatic conditions and available resources, hence higher infestations on the crops. Kamble et al. (2005), Patel et al. (2006) and Sarma and Gautam (2010) observed that Euphorbiaceae was one of the major weed florae in maize cropping systems. Azmi and Baki (2002) similarly reported almost the same pattern of weed dominance ranking observed in the order of significance. In addition, the lowest values recorded for percent relative density in 2017 (Table 9) were observed in *Achyranthas sp.* (0.15%) *and Ipomoea involucrata* (0.15%) belonging to the Asteraceae and Convolvulaceae families respectively. *Diodia scandens* (0.32%) and *Commelina erecta* (0.32%) belonging to the Rubiaceae and Commelinaceae families respectively recorded the lowest per cent relative density than all other weed species and families during the 2018 cropping year (Table 10).

Table 9. Weed flora composition of the experimental site in 2017 maize cropping year.

Family	Species	Method of reproduction	Growth habit	Life cycle	Relative density (%)
Asteraceae	*Achyranthas sp.*	Seeds	Broadleaf	Annual	0.15
	Ageratum conyzoides	Seeds/ Vegetative	Broadleaf	Annual	0.46
	Aspilia Africana	Seeds	Broadleaf	Annual/ Perennial	0.46
Poaceae	*Anadelphia sp*	Seeds	Grass	Perennial	9.38
	Andropogum tectorum	Seeds	Grass	Perennial	4.00
	Brachiaria deflexa	Seeds	Grass	Annual	0.23
	Digitaria ciliaris	Seeds	Grass	Annual	2.92
	Imperata cylindrica	Seeds	Grass	Perennial	1.15
	Panicum maximum	Seeds	Grass	Annual	2.77
Fabaceae	*Calopogonium mucunoides*	Seeds	Broadleaf	perennial	9.30
	Centrocema pubecens	Seeds	Broadleaf	Perennial	1.38
	Mimosa pudica	Seeds/ Vegetative	Broadleaf	Annual/ Perennial	1.15
Euphorbiaceae	*Croton hirtus*	Seeds	Broadleaf	Annual	11.76
	Euphorbia heterophylla	Seeds	Broadleaf	Annual	39.43
	Euphorbia hirta	Seeds	Broadleaf	Annual	2.00
Cyperaceae	*Cyperus difformis*	Seeds	Sedge	Perennial	1.00
	Cyperus rotundus	Seeds	Sedge	Perennial	0.31
Commelinaceae	*Commelina erecta*	Seeds	Broadleaf	Annual/P erennial	0.38
Cleommaceae	*Cleome gynandra*	Seeds	Sedge	Annual	0.54
Rubiaceae	*Diodia scandens*	Vegetative	Broadleaf	perennial	0.77
Convolvulaceae	*Ipomoea involucrata*	Seeds/ Vegetative	Broadleaf	Annual/P erennial	0.15
Malvaceae	*Sida acuta*	Seeds	Broadleaf	Perennial	1.00
Loganiaceae	*Spigelia anthelma*	Seeds	Broadleaf	Annual	7.76
Amaranthaceae	*Altenanthera philoxeroides*	Vegetative	Broadleaf	Perennial	1.15

Table 10. Weed flora composition of the experimental site in 2018 maize cropping year

Family	Species	Method of reproduction	Growth habit	Life cycle	Relative density (%)
Asteraceae	*Achyranthas sp.*	Seeds	Broadleaf	Annual	1.49
	Acanthospernum hispidium	Seeds	Broadleaf	Annual	0.39
	Ageratum conyzoides	Seeds/ Vegetative	Broadleaf	Annual	2.14
	Aspilia Africana	Seeds	Broadleaf	Annual/ Perennial	0.39
	Bidens pilosa	Seeds	Broadleaf	Annual	0.65
	Tridax procumbens	Seeds	Broadleaf	Perennial	2.40
	Chromolaena odorata	Seeds			1.75
Poaceae	*Anadelphia sp*	Seeds	Grass	Perennial	8.25
	Andropogum tectorum	Seeds	Grass	Perennial	7.92
	Brachiaria deflexa	Seeds	Grass	Annual	2.60
	Digitaria ciliaris	Seeds	Grass	Annual	2.27
	Imperata cylindrica	Seeds	Grass	Perennial	0.97
	Panicum maximum	Seeds	Grass	Annual	3.05
Fabaceae	*Calopogonium mucunoides*	Seeds	Broadleaf	perennial	4.22
	Centrocema pubecens	Seeds	Broadleaf	Perennial	2.66
	Mimosa pudica	Seeds/ Vegetative	Broadleaf	Annual/ Perennial	0.97
Rubiaceae	*Diodia scandens*	Vegetative	Broadleaf	perennial	0.32
	Borreria latifolia	Seeds	Broadleaf	Annual/ Perennial	0.39
Euphorbiaceae	*Croton hirtus*	Seeds	Broadleaf	Annual	9.29
	Euphorbia heterophylla	Seeds	Broadleaf	Annual	10.52
	Euphorbia hirta	Seeds	Broadleaf	Annual	20.84
Cyperaceae	*Cyperus difformis*	Seeds	Sedge	Perennial	0.83
	Cyperus rotundus	Seeds	Sedge	Perennial	0.26
Commelinaceae	*Commelina erecta*	Seeds	Broadleaf	Annual/ Perennial	0.32
Cleommaceae	*Cleome gynandra*	Seeds	Sedge	Annual	0.45
Convolvulaceae	*Ipomoea involucrata*	Seeds/ Vegetative	Broadleaf	Annual/ Perennial	0.78
Malvaceae	*Sida acuta*	Seeds	Broadleaf	Perennial	0.84
Loganiaceae	*Spigelia anthelma*	Seeds	Broadleaf	Annual	9.42
Amaranthaceae	*Altenanthera philoxeroides*	Vegetative	Broadleaf	Perennial	2.66

Weed density (weeds m^{-2})

The type of weed species, incidence and severity of infestation in the maize experimental fields are considered the pioneers of yield loss in the crop. Thus, timely weed control is very necessary for realizing optimum yield of any crop. In the present study, the results pertaining to weed density revealed significant ($p<0.05$) reduction in the quantity of weeds, except in the weedy check treatments for both years (Table 11). The lowest weed density was recorded in the weed-free check treatments followed by Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP in both years. The reduced crop-weed competition in the weed-free check treatment was due to consistent removal of weeds in the early and later phases of crop growth

(Subbulakshmi *et al*. 2009; Hawaldar and Agasimani, 2012). The weedy check treatment significantly ($p<0.05$) recorded the highest weed density followed by two hoe weeding at 4 and 8 WAP compared to other weed management practices in both years. Similar discovery was affirmed by Kumar *et al*. (2017) who found significantly the highest weed density and biomass in weedy check treatments. Hence the findings from this study suggests that weeds continually need a long-term management practices to tackle its problem. Mahadi *et al*. (2007) reported that a weedy check treatment produced the highest weed cover score and weed dry weight at harvest. Also, increase in weed density up till ripeness of crop evidently shows that weed seeds germinated throughout the growth period of maize. Similar results were also reported by Khan et al. (2012), who concluded that weed density per unit area increases with increased crop growth. Weed-free check, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC @ 3 L ha^{-1} plus one hoe weeding at 8 WAP are statistically not significant at 4 WAP in both years. In addition, the herbicidal treatments are not significantly different ($P>0.05$) at 4, 8 and 12 WAP in both years. Though herbicides are effective and efficient weed control method, yet they posed negative effects on the environment if not properly used. But Muoni *et al*. (2013) reported that their usage ensures a decrease in weed density over time. However, at 12 WAP similar trend was observed among Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP, Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP and *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP in both years. According to Makumba *et al*. (2007), the application of *Gliricidia. sepium* leaves mulch widely used for mulching purposes has allelopathic effects on weed seed germination and resulted to positive yield response of maize.

Table 11. Effect of weed management practices on weed density of maize in 2017 and 2018 cropping years.

Treatment	Weed density (m^{-2})					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	1.33^{c}	1.33^{d}	3.33^{c}	3.67^{c}	2.66^{d}	3.33^{c}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	3.33^{c}	6.66^{cd}	8.33^{bc}	10.67^{c}	6.33^{cd}	8.33^{bc}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	5.66^{c}	9.33^{cd}	20.00^{bc}	17.67^{c}	6.66^{cd}	19.66^{bc}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	14.66^{bc}	22.33^{bc}	28.00^{bc}	30.67^{bc}	20.66^{bc}	26.00^{bc}
Two hoe weeding at 4 and 8 WAP	30.00^{b}	33.66^{b}	32.33^{b}	54.67^{b}	27.66^{b}	31.66^{b}
Weedy check	66.66^{a}	69.33^{a}	77.33^{a}	91.67^{a}	64.33^{a}	78.66^{a}
Pr > F	0.0001	<.0001	<.0001	0.0001	<.0001	<.0001
CV (%)	50.9	32.7	35.1	39.7	32.9	36.1

Means with the same superscripts in column are not significantly different ($P>0.05$) as indicated by Student Newman-Keuls multiple range test.

Weed dry weight (g m^{-2})

The use of numerous weed management practices followed by one supplementary hoe weeding gave season long weed control and better yields of maize in both years (Table 12). This shows that dry matter accumulation reflects on the growth behavior of weeds and gives better indication of weed-crop competition. From the weed dry matter results, it was apparent that weed-free check treatment gave adequate weed control followed by Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP respectively in both years. While the weedy check treatment consistently produced significantly ($p<0.05$) higher weed dry matter than all other treatments in both years. This indicates that superior weed dry weight reflects more utilization of soil and environmental resources by weeds at the expense of crop growth. In the 2017 cropping year, nearly all the weed management practices incorporated with one hoe weeding resulted to lower weed dry matter at 4, 8 and 12 weeks after planting, but not significantly different ($P>0.05$) at 4 and 12 WAP. Additionally, in 2018 cropping year, weed-free check treatment however gave comparable weed dry matter at 4, 8 and 12 WAP with Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP (Table 12). However, among the pre-emergence herbicide treatments, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP provided weed growth reduction and consequently resulted to better weed control in both study years. Our findings are in agreement with those reported by Waheedullah *et al.* (2008) and Hassan et al. (2010) that reduced weed biomass was attained due to use of selective pre-emergence herbicides for controlling different weed species in maize crop. Furthermore, in 2017 and 2018 maize cropping years, application of *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP significantly ($p<0.05$) showed lower weed dry matter comparable to two hoe weeding at 4 and 8 WAP. This is probably as a result of *Gliricidia sepium* leaves mulch having an allelopathic impact and suppresses light demanding weeds, thus resulted to positive yield response of maize (Sileshi et al. 2007; Essien et al. 2009).

Table 12. Effect of weed management practices on weed dry weight of maize during 2017 and 2018 cropping years.

Treatment	Weed dry weight (g m^{-2})					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	0.03^{b}	0.33^{d}	1.00^{b}	0.30^{d}	1.43^{c}	1.60^{e}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	0.70^{b}	1.66^{d}	2.66^{b}	0.43^{d}	2.53^{c}	3.60^{e}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	2.00^{b}	3.00^{d}	4.66^{b}	0.83^{cd}	3.46^{c}	7.23^{d}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	2.33^{b}	6.66^{c}	7.33^{b}	1.43^{c}	4.33^{c}	9.76^{c}
Two hoe weeding at 4 and 8 WAP	5.66^{b}	10.33^{b}	10.33^{b}	2.23^{b}	10.80^{b}	20.26^{b}
Weedy check	14.66^{a}	17.33^{a}	30.33^{a}	3.23^{a}	17.40^{a}	25.20^{a}
Pr > F	<.0001	<.0001	0.0288	<.0001	<.0001	<.0001
CV (%)	52.2	19.6	98.9	29.5	24.1	10.8

Means with the same superscripts in column are not significantly different ($P>0.05$) as indicated by Student Newman-Keuls multiple range test.

Weed control index (%)

Weed control index was the highest with weed-free check treatments in 2017 cropping year, but was not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test to Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP during 4, 8 and 12 WAP evaluations. Similarly, in 2018 cropping year, weed-free check recorded the highest weed control index at 4, 8 and 12 WAP. But was not significantly different (P>0.05) to Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP, Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP and *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP during 8 WAP assessment (Table 13). Weedy check treatment recorded significantly the lowest percentage of weed control index than all other weed management practices in the experimental years. This result was in accordance with Mukherjee *et al*. (2012) and Priya and Kubsad (2013) who similarly reported higher weed control efficiency and lower weed index in herbicide treatments compared to the weedy check treatment owing to lower weed dry weight, higher weed control efficiency and lower weed index as a result of effective control of obnoxious weed flora.

Table 13. Effect of weed management practices on weed control index of maize during 2017 and 2018 cropping years.

Treatment	Weed control index (%)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	99.83[a]	98.24[a]	95.51[a]	90.54[a]	91.527[a]	93.61[a]
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	95.61[a]	90.48[a]	88.76[a]	86.40[a]	85.01[a]	85.59[b]
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	85.23[a]	82.93[a]	79.80[a]	73.71[ab]	79.21[a]	71.49[c]
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	81.83[a]	62.27[b]	69.72[ab]	52.53[b]	73.70[a]	60.72[d]
Two hoe weeding at 4 and 8 WAP	56.42[b]	40.83[c]	54.08[b]	28.54[c]	35.94[b]	18.99[e]
Weedy check	0.00[c]	0.00[d]	0.00[c]	0.00[d]	0.00[c]	0.00[f]
Pr > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	14.0	11.4	17.4	22.9	11.8	6.6

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Weed control efficiency (%)

Table 14 showed weed control efficiencies of the various weed management practices in maize during 2017 and 2018 cropping years. The best weed suppression and higher weed control efficiency was observed in the weed-free check treatment compared to other weed management practices, thus resulted to decreased weed population in both years. However, at 4 WAP in 2017 cropping year, plots treated with weed-free check treatment are not significantly different (P>0.05) to Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP and Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP. The results further showed that both herbicidal treatments had statistically similar weed control efficiency at 8 WAP during both years. These herbicidal treatments are more effective in reducing density and dry weights of weeds as compared to *Gliricidia sepium* leaves mulch at 40kg m^{-2} plus one hoe weeding at 8 WAP, two hoe weeding at 4 and 8 WAP and weedy check (Control) treatments. This result indicated that herbicides reduced weed infestation and control weeds better compared to the weedy check treatment. The minimum weed control efficiency was recorded under weedy check treatment (0.00%) in both years, which attributed to the continuous competition of maize crop with obnoxious weed species for growth factors such as nutrient and moisture.

Table 14. Effect of weed management practices on weed control efficiencies of maize in 2017 and 2018 cropping years.

Treatment	Weed control efficiency (%)					
	2017			2018		
	4WAP	8WAP	12WAP	4WAP	8WAP	12WAP
Weed-free check	97.99^{a}	98.08^{a}	95.43^{a}	95.18^{a}	95.63^{a}	95.47^{a}
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	95.08^{a}	90.33^{b}	88.66^{a}	86.03^{ab}	89.76^{b}	88.90^{a}
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	90.61^{a}	86.09^{b}	73.04^{b}	81.52^{ab}	87.36^{b}	73.79^{b}
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	76.90^{b}	68.39^{c}	62.36^{b}	67.58^{b}	67.40^{c}	66.32^{bc}
Two hoe weeding at 4 and 8 WAP	55.18^{c}	50.58^{d}	55.71^{b}	39.22^{c}	57.67^{d}	58.15^{c}
Weedy check	0.00^{d}	0.00^{e}	0.00^{c}	0.00^{d}	0.000^{e}	0.00^{d}
Pr > F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	5.1	5.2	13.1	17.5	4.4	9.7

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Student Newman-Keuls multiple range test.

Weed index

As described in Figure 1, weed management practices exhibited a significant influence on weed index in 2017 and 2018 years of study. The percentage of weed index was found to be significantly (p<0.05) higher in the weedy check treated plots followed by two hoe weeding at 4 and 8 WAP compared to all other weed management practices in both years. In addition, the weed-free check treated plots resulted to significantly (p<0.05) lower percentage of weed index in both years. Whereas Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP was at par with Atrazine 500 SC at 3 L ha^{-1} plus one hoe weeding at 8 WAP in the years of study.

Economic assessment of weed management

Weed-free check treatment recorded the highest yield (5.33 t ha^{-1}), total revenue (37,310,000.00 SLL ha^{-1}) and gross margin (29,760,000.00 SLL ha^{-1}) followed by Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP in both study years (Table 15). Though the highest weed reduction was obtained by weed-free check treatment, the involvement of intense labour with its associated tediousness may render it uneconomical and unfeasible (Alhassan et al. 2015). The weedy check (Control) treatment recorded the lowest yield (1.16 t ha^{-1}), variable cost of production (SLL 350,000.00 ha^{-1}), total revenue (SLL 8,120,000.00 ha^{-1}) and gross margin (SLL 7,770,000.00 ha^{-1}) compared to the other weed control methods evaluated in both years. This result agrees with the report of Khan et al. (2005) and Imoloame et al. (2010) that the use of herbicides was more profitable than hoe weeding in the production of various crops. The highest variable cost of production was observed in the weed-free check (SLL 7,550,000.00 ha^{-1}) followed by two hoe weeding at 4 and 8 WAP (SLL 6,150,000.00 ha^{-1}), whereas less variable cost of production was obtained in the herbicidal as well as in weedy check treatments. The high variable cost of production could be ascribed to very high cost of labour ha^{-1} than the cost of purchasing herbicides and obtaining *Gliricidia sepium* leaves. The gross margin was higher where the yield was high, though weed-free check treatment recorded the highest gross margin (29,760,000.00 SLL ha^{-1}), it could not be recommended to maize growers due to its higher variable cost of production (SLL 7,550,000.00 ha^{-1}). Thus, Double force® at 4 L ha^{-1} plus one hoe weeding at 8 WAP proved to be more beneficial and economical compared with other weed management practices because of its low variable cost of production, high total revenue and gross margin. These results proposed that the use of herbicide is more financially rewarding for maize production compared with other weed control treatments in both study years. Similar results of cost-effectiveness in maize production due to herbicide application have been testified by Koprivlenski et al. (2015).

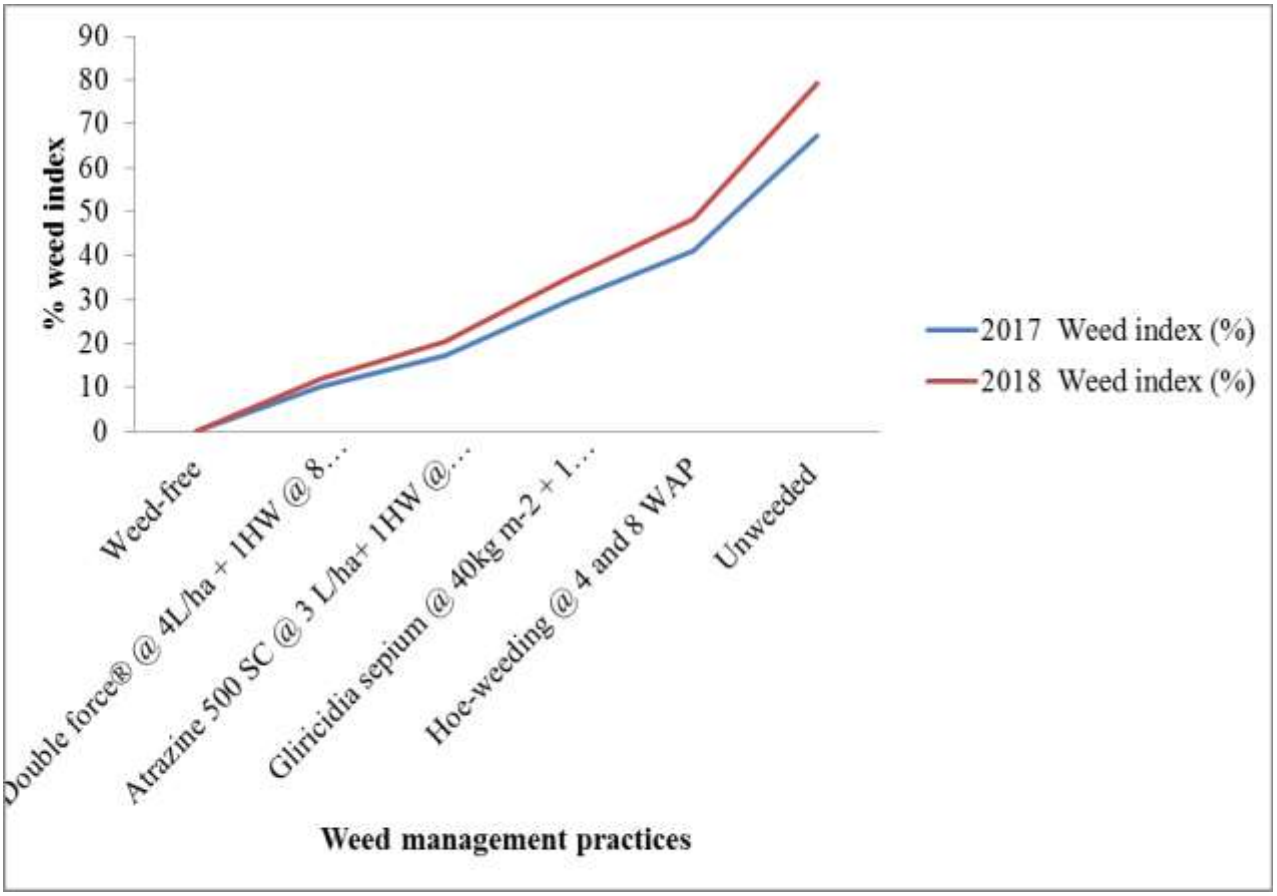

Figure 1. Effect of weed management practices on weed index of maize during 2017 and 2018 cropping years.

Table 15. Cost of maize production and economic returns ha^{-1} (SLL ha^{-1}) as influenced by the different weed management practices in 2017 and 2018 cropping years

Treatment	Grain yield t ha^{-1}		Variable cost of production (SLL ha^{-1})		Mean	Total revenue (SLL ha^{-1})		Mean	Gross margin (SLL ha^{-1})
	2017	2018	2017	2018		2017	2018		
Weed-free check	5.33	5.33	7,550,000	7,550,000	7,550,000	37,310,000	37,310,000	37,310,000	29,760,000
Double force® at 4 L ha^{-1} + one hoe weeding at 8 WAP	4.30	4.63	4,430,000	4,430,000	4,430,000	30,100,000	32,410,000	31,255,000	26,825,000
Atrazine 500 SC at 3 L ha^{-1} + one hoe weeding at 8 WAP	3.76	3.86	4,460,000	4,460,000	4,460,000	26,320,000	27,020,000	26,670,000	22,210,000
Gliricidia sepium at 40kg m^{-2} + one hoe weeding at 8 WAP	3.53	3.36	4,500,000	4,500,000	4,500,000	24,710,000	23,520,000	24,115,000	19,615,000
Two hoe weeding at 4 and 8 WAP	2.60	2.60	6,150,000	6,150,000	6,150,000	18,200,000	18,200,000	18,200,000	12,050,000
Weedy check	1.16	1.16	350,000	350,000	350,000	8,120,000	8,120,000	8,120,000	7,770,000

Prevailing unit price of maize t ha-1 = SLL 7,000,000.00. SLL 850.00 = 1 US Dollar
Gross margin (SLL ha-1) = Total revenue (SLL ha-1) – Variable cost (SLL ha-1)
Variable costs (VC) are expenditures on Land preparation, planting material, cost of planting, cost of herbicide application, cost of herbicides, cost of Gliricidia application, cost of Gliricidia sepium leaves, weeding, feeding, harvesting and transportation.
Total revenue (TR) = Maize yield (t ha-1) × Unit price of Maize (SLL t ha-1).

Conclusion

According to the outcomes of this study, weed-free check showed superiority in controlling weed density, weed dry matter and higher control efficiency and grain yield when compared to the other treatments. But it requires involvement of intense labour with its associated tediousness which renders it inefficient, uneconomical and unfeasible in increasing productivity of maize. The results indicated that weeds can meaningfully decrease the grain yield in maize which may result to economic loss. Among the herbicidal treatments, Double force® at 4 L ha-1 plus one hoe weeding at 8 WAP showed better performance in controlling weeds and increasing maize productivity, which may be attractive and adopted by small scale farmers in southern Sierra Leone.

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Conflicts of Interest

The authors have declared no potential conflicts of interest with respect to the publication of this article.

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