Effect of Weed Interference and Plant Density on Maize Grain Yield

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Abstract

Maize is one of most important food crop grown in Benishangul Gumuz Regional State, Ethiopia. However, its productivity is very low due to inappropriate weed and soil nutrient management and lower plant density. Thus, a field experiment was carried out during 2016/17 cropping season to evaluate effect of weeding frequency and plant densities on yield, and yield components of maize at Assosa Agricultural Research Centre. The treatments consisted of four levels of weeding frequencies (weedy check, once hand weeding, twice hand weeding and weed free) and four levels of plant densities (31,250,44,444, 53,333 and 62,500 plants ha^{-1}), which were factorial arranged in Randomized Complete Block Design (RCBD) with three replications. The results of the study revealed that grain yield was significantly (P<0.01) affected by the main effects of weeding frequency and plant density. The highest grain yields (7394.5, and 7273.6 kg ha^{-1}) were recorded for weed free and twice hand weeding, respectively and the lowest grain yield (918.9 kg ha^{-1}) from the weedy check. The highest grain yield (5485.8 kg ha^{-1}) was obtained at a plant density of 53,333 plants ha^{-1} and the lowest (4457.2 kg ha^{-1}) at a density of 31,250 plants ha^{-1}. Grain yield was much more reduced due to competition from weeds (87.5%) than due to low plant density (18%). Significant interaction effect of weeding frequency and plant density was observed on number of ears plant^{-1}, number of kernel rows ear^{-1}, above ground dry biomass and relative grain yield loss. Twice hand weeding and a plant density of 53,333 plants ha^{-1} would be some more suitable practices for attaining optimum grain yield for the hybrid maize BH 546 in the study area.

Keywords: Harvest index, nutrient removal by weeds, relative grain yield loss, weeding frequency

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world, ranking 3rd among other cereals after wheat and rice (FAOSTAT, 2014). It is the most important cereal crop in eastern and southern African countries accounting for over 29% of the total harvested area of annual food crops and 25% of the total caloric consumption (FAOSTAT, 2010). During, 2015/16 cropping season, about 2.1 million hectares of land was covered with maize with an estimated total production of about 7.15 million tons, with the national average productivity of 3.4 t ha^{-1} (CSA, 2016). Maize ranks 2nd after teff (*Eragrotis* *tef*) in area coverage but stood first in total production and yield per hectare (CSA, 2016). Owing to its importance in terms of having wider adaptation, higher total production and higher productivity, compared to other crops, maize has been selected as one of the high priority food security crops in the country.

Benishangul Gumuz is among the most suitable Region for maize production. The regional average productivity of maize was 3.56 t ha^{-1}, while in Assosa, one of the zone in the region, the average productivity of maize was only 2.83 t ha^{-1} (CSA, 2016). A number of factors contribute to the low productivity of maize in the zone, among which are the use of inappropriate agronomic practices such as: improper planting density (Workayehu, 2000; Sangoi, 2000; Abuzar et al., 2011), poor weed management (Soliman and Gharib, 2011; Ghanizadeh et al., 2010; Karimmojeni et al., 2010), inappropriate variety (Enujeke, 2013; Paudel, 2009), poor soil nutrient managements/ limited use of fertilizer inputs (Debelle et al., 2001; Negassa et al. 2011). Consequently, developing appropriate plant populations and better weed management options are among the core priority researchable area to tackle the challenges of low maize productivity in the region.

Maize productivity is most affected by the variations in plant density (Vega et al., 2001). Plant density affects maize yield through influencing yield components such as number of ears, number of kernels $ears^{-1}$, and kernel weight (Sangoi, 2000). Many authors reported that maize yields significantly varied with plant density with the grain yield increasing with increasing plant density (Bozorgi et al., 2011; Bakhtiar Gul et al., 2011; Gobeze et al., 2012; Chinyere, 2013). However, maize grains yield declines when the plant density increase beyond the optimum, primarily because of the decline in the harvest index and increased stem lodging (Sangoi, 2000).

Weeds are also considered as a major problem in most maize fields causing considerable maize grain yield loss (Silva et al., 2010; Soliman and Gharib, 2011; Ghanizadeh et al., 2010; Karimmojeni et al.; 2010). Subadi and Ma (2009) reported weed infestation as the most yield limiting factor in maize. Weeds poses an antagonistic effect on crop stand establishment and can compete for nutrients, water and light with the crop, ultimately affecting productivity and quality of the crop (Rajcan and Swanton, 2001; Deewan et al., 2017). Maize yield loss due to competition with weed for plant nutrient and other resources ranged from 66 to 90% (Dalley et al., 2006; Abouziena et al., 2007).

Possible interaction effects of plant density and competition from weeds have also been reported (Abd-El-Samie, 2001; Maqbool et al., 2006). Plant density plays important role in the competitive balance between weeds and maize. Weed density and other measures of weed abundance usually decrease as crop density increase (Singh and Singh, 2006). The growth of weeds decreases significantly in the order of increasing frequency of weeding. The integration of proper plant density and weed control practice had a positive effect on maize grain yield (Acciares and Zuluaga, 2006; Abouziena et al., 2008).

In Ethiopia there are different recommendations of maize plant densities depending on maize cultivar and rainfall condition of the areas. The optimum maize plant density recommended by the research system varied from 44, 444 plants per hectare (75 cm X 30 cm single seed per hill) to 53,333 plants per hectare (75 cm X 25 cm single seed per hill), depending on the cultivar (EARO, 2004). The government extension program in consultation with the Agricultural Transformation Agency (ATA), however, recommended a plant population of 62,250 plants per hectare (80 cm X 40 cm with two seeds placed 5 cm apart). On the other hand, results of a baseline survey conducted on 700 farmers indicated that the surveyed farmers on average maintain only 52% of the plant density recommended by MoANR (unpublished data). The effects of using different planting densities on yields and yield components of maize crop was not studied and documented in the region. Moreover, information on the extent to which plant density interacts with weeds in influencing maize growth and yield and the extent of grain yield loss due to weeds is not known. Thus, the present investigation was aimed at assessing the effect of weeding frequencies and plant densities on maize grain yield of hybrid maize BH546, and to investigate if weeding frequency interacts with plant density in influencing maize grain yield and other crop in the study area.

Materials and Methods

Description of the experimental site

The experiment was conducted on station at Assosa Agricultural Research Centre during the 2016 main cropping season. The research centers is located at about 670 km West from Addis Ababa. It is located at altitude of 1566 m.a.s.l and lies in a geographic coordinate of 10^{o}02′57" N latitude and 34^{o}33'26"E longitudes. It is characterized as having hot humid agro-climate suitable for maize production with mean annual rainfall of 1316 mm per annum, minimum and maximum temperature of the area was 16.03^{O}C minimum and 31.02^{O}C, respectively. The predominant soil type is Nitisols (AsARC, 2014).

Treatment set up

Four levels of plant densities, 44,444 (75 cm x 30 cm single seed /hill), 53,333 (75 cm x 25 cm single seed/hill), 62,500 (80 cm x 40 cm and two seeds/hill 5 cm apart) and 31,250 (80 cm x 40 cm and one seed/hill) and four weeding frequencies (weedy check, weed free, once hand weeding (at 1st nitrogen top dressing) and twice hand weeding (at 1st and 2nd nitrogen top dressing) were factorially combined to make a total of 16 treatments. The treatments were laid out in RCBD design with three replications. A hybrid maize variety, BH546, was used as a test crop. The plot size was 4.5 m x 4 m ($18m^2$). Four central rows were considered as net harvestable plot. The outer most row on both sides of each plot was considered as border and was not sampled. The recommended dose 92kg nitrogen (Urea, 46% nitrogen) was applied in split at 21 days after sowing (the first application at 4 leaf stages) and half dose of nitrogen was applied 48 days after sowing (the second at knee height stage).

Data collected during the study include:

Number of ears/cobs per plant: was recorded by counting all the ears /cobs from five randomly selected plants of the net plot area at harvest.

Number of kernels per ear/cobs: was recorded from five randomly selected ears/cobs from the net plot area and the result of each ear was summed and divided by the number of sampled ears to reach at the number of the kernels per ear.

Number of kernel rows per ear*:* was counted for five representative ears and the average value was recorded for each plot.

Above ground dry biomass yield (kg ha-1): was determined from the net harvestable area by cutting the maize stalk at ground level and sun drying for two weeks to a constant weight and the value was converted to kilogram per hectare.

Grain yield (kg ha-1): Grain yield at 12.5% moisture level was determined using the cob weights obtained from the net harvestable area according to the following formula:

$$Grain\ yield\ (kg\ ha-1) = Cob\ weight * \frac{(100-M)}{(100-12.5)} * 0.81$$

Where, M is the measured moisture content in grain at harvest

Harvest index: was calculated as the ratio of the grain yield per net plot to the total biological yield per net plot multiplied by 100.

Relative grain yield loss (%): Relative grain yield loss was calculated for a particular treatment as the ratio of the difference between the maximum grain yield and the grain yield of the treatment divided by the maximum grain yield multiplied by 100:

$$Relative\ Yield\ loss = \frac{MY-YT}{MY} * 100$$

Where, MY= maximum grain yield,
YT = grain yield from a particular treatment.

Weed biomass harvested for each treatment were oven dried, and analyzed for N, P and K content at Holeta Agricultural Research Center.

Data Analysis

The data was analyzed using Statistical Analysis System (SAS) version 9.3 Software (SAS institute, 2002). The analysis of variance (ANOVA) was computed based on PROC GLM procedure and when ANOVA shows the absence of significant interaction effects between factors, mean separation was carried out separately for both factors. However, when ANOVA shows the presence of interaction effects of the factors for that parameter, mean separation was carried out for the combined treatments. The means were separated according to Tukey's test at α=5% level of significance.

Results and Discussion

The ANOVA showed that there was a significant main effect of both weeding frequency and plant density (P<0.05) on harvest index and grain yield. The number of ears plant^{-1}, number of kernel rows ear^{-1}, above ground dry biomass and relative grain yield loss were significantly affected by the main effects of weeding frequency and plant density as well as by their interaction (P<0.01) (Table 1).

Table 1. Levels of significance for yield and some yield components of maize as affected by weeding frequencies, plant densities and their interaction

Source of variations	Yield and Yield components of maize					
	NEPP	NKRPE	AGDB	GY	HI	RYL
Weeding Frequency (WF)	**	**	**	**	**	**
Plant Density (PD)	**	ns	**	**	**	*
WF X PD	**	*	**	ns	ns	*

Effect of weeding frequency on grain yield and nutrient removal

Grain yield: Grain yield significantly increased with the increase in weeding frequency from no weeding to complete weeding (Fig.1). Weeding frequency showed significant positive correlation with grain yield (r=0.69**) but significant negative correlation (r=-0.70**) with relative grain yield loss (Table 6). The highest grain yield (7394.5 kg ha^{-1}) was obtained from weed free plot and the lowest (918.9 kg ha^{-1}) from the weedy check plot with a substantial reduction of (87.5%) grain yield due to competition from weeds. There was a mean grain yield increase of 440.2%, 691.5% and 804.7% due to once hand weeding, twice hand weeding and weed free plot, respectively over the weedy check indicating that weed is the most yield limiting biotic factors as also suggested by Tollenaar et al., (1994) and Rajcan and Swanton, (2001). Grain yield, however, did not significantly differ between twice hand weeding and weed free indicating that twice hand weeding would be sufficient to obtain optimum grain yield without significant grain yield loss. The higher grain yield at higher weeding frequency might be due to the lower weed competition with the crop for nutrients, water and light (Rajcan and Swanton, 2001; Deewan *et al*., 2017), allowing the plants to accumulate more biomass and hence more photosynthate which upon translocation to the sink resulted in more yield components and hence in more grain yields. On the other hand, the severe reduction in grain yield of the crop in the weedy check plot could be attributed to the severe weed competition with the crop for light, water and nutrients (Carruthers et al., 1998 in Silva et al 2007; Rajcan and Swanton, 2001; Deewan et al., 2017). When weeds are not properly controlled, the removal of nutrients by the weeds has an impact on the amount of nutrient taken up by the crop, thus ultimately reducing plant leaf area and dry matter accumulation (Sreenivas and Satyanarayana, 1996 in Silva et al, 2007). This conclusion is further supported by the suggestion of Rajcan and Swanton, (2001), who reported that nitrogen deficiency symptoms develop earlier in maize infested with weeds than that has been cleared of weeds, implying severe N depletion in the soil in the case of maize planted under no weed control. The results of the present study also complies with the reports of Silva et al. (2010), Soliman and Gharib (2011), Ghanizadeh et al. (2010) and Karimmojeni et al. (2010), who also observed an increase in grain yield of maize with the decrease in weed density.

Harvest Index*:* The harvest index is an assimilate allocation coefficient to grain production and is significantly increased with the increase in weeding frequency from no weeding to complete weeding, implying that the coefficient of assimilate allocation to grain formation was remarkably affected by the weeding frequency. The highest harvest index (54.35%) was recorded for twice hand weeding and the lowest (20.41%) for the control. However, there was no significant difference between twice hand weeding and weed free plot (Fig. 3A). Abd-El-Samie (2001), observed that twice hand weeding (21 and 35 DAP) significantly increased harvest index of a hybrid maize compared with only once hand weeding (21 DAP) and the weedy check, which agrees with the current finding. Aryannia et al., (2013) similarly reported higher harvest index in maize grown under weed free than maize grown under weed infestation.

Nutrient Uptake/removal by weeds: The nutrient uptake considerably varied among the weeding frequencies. The total nitrogen removed by the weeds was 33.5, 22.3 and 6.5 kg ha^{-1} N for the control, once and twice hand weeding, respectively. The total phosphorus removed by the weeds were 10.4, 6.9 and 1.75 kg ha^{-1} P, for the control, once hand weeding and twice hand weeding, respectively. Likewise, the total potassium removed by the weeds were 87.3, 58.0 and 14.7 kg ha^{-1} K, for the control, once hand weeding and twice hand weeding, respectively (Fig 1). The nutrients removed by the maize crop were not determined hence we could not compare with the nutrient taken up by the maize crop. There was no any nutrient uptake for the weed free plot as all the weed species were totally removed. In Ethiopia, the recommended NPK for maize is 92-46-0; weeds removed 36.4 and 22% of the recommended nitrogen and phosphorus, respectively if the crop is left unweeded, while these could be reduced to 6 and 3.8 % if farmers practice twice hand weeding, respectively. Weeds comparatively removed more K than the other nutrients. Under complete infestation, weeds were able to remove as high as 87 kg ha^{-1} K from the soil resulting in the mining of considerable amount of this nutrient from the soil. Twice hand weeding however, can reduce the amount of K removal by weeds down to 15 kg ha^{-1} during the crop growth period, while complete weed removal tackles the problem of K mining by weeds. Similar to the current finding, Lehoczky and Reisinger, (2003) also reported considerable amount of nutrients removal by the competing weed species which was higher compared to the nutrient removed by the crop itself.

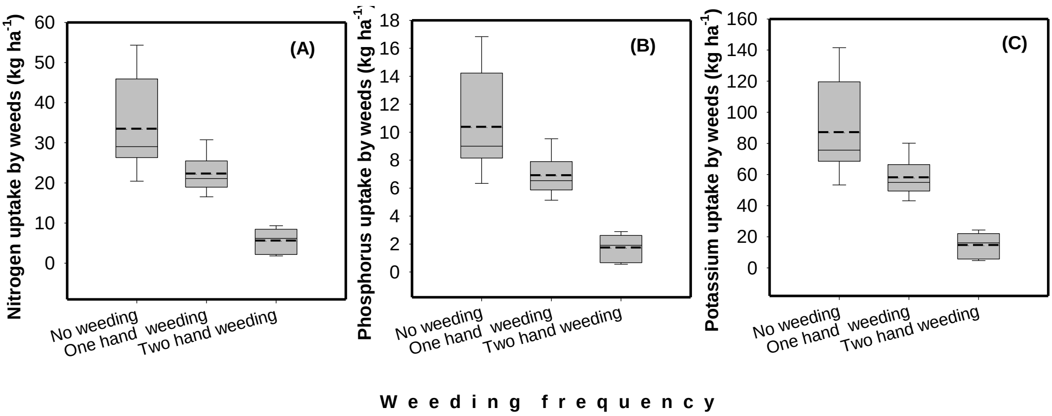

Figure 1: Amount of Nitrogen (A), phosphorus (B) and Potassium (C) removed by competing weed species *(The solid line is the median and dashed line is the mean; the box boundaries indicate the upper and lower quartiles, the error bars indicate the 90th and 10th percentiles)*

Effect of plant density on grain yield and harvest index

Grain yield: Plant density is one of the most important cultural practices affecting grain yield, as well as other important agronomic attributes of this crop (Workayehu, 2000; Sangoi, 2000; Abuzar et al., 2011). Many authors reported that maize yield significantly varied with plant density (Bozorgi et al., 2011; Lashkari et al., 2011; Bakhtiar Gul *et al*., 2011; Gobeze *et al*., 2012; Chinyere, 2013; Milander, 2015). In the current study, plant density significantly influenced ($P<0.01$) grain yield, with the densities of 44,444, 53,333 and 62,500 plants ha^{-1}, all resulting in significantly higher grain yield than the lowest plant density of 31,250 plants ha^{-1}. Grain yield was reduced by18.2% due to the lower plant density of 31,250. This result complies with the reports of Subedi and Ma (2009), who also reported a grain yield reduction of 8-13% due to adopting low plant population. However, the plant density they rated as low was still double the density we rated as low, and this could be the reason for the difference in the level of yield reduction due to low plant density between the two studies. The lowest grain yield (4457.2 kg ha^{-1}) was obtained from the plant density of 31,250 plants ha^{-1} and the optimum grain yield (5485.8 kg ha^{-1}) from the plant density of 53,333 plants ha^{-1} and increasing the density beyond that tended to non-significantly reduce the grain yield (Fig. 2). This observation is in line with the reports of Tokatlidis and Koutroubas (2004), who ascribes such reduction in grain yield as the plant density increases beyond the optimum to the increased barrenness of plants as a result of the adverse effect of high plant density on the interval of pollen shading and silking creating non-synchronization and hence resulting up in low grain yield. The decline in the grain yield when plant density is increased beyond the optimum may also be related to the decline in the harvest index and increased stem lodging (Tollenaar *et al.,* 1997) since such higher plant density represent intense interplant competition for incident photosynthetic photon flux density, soil nutrients and soil water ultimately resulting in limited supplies of carbon and nitrogen, consequently resulting in increased chance of barrenness and decreased kernel number per plant and kernel size (Lemcoff and Loomis, 1994). Chinyere (2013) reported that plant density of 53,333 plants ha^{-1} resulted in the highest grain yield followed by plant density of 66,667 plants ha^{-1}, which supports our finding. In line with the current observation, Gobeze *et al.* (2012), Bozorgi *et al*. (2011), Luque *et al.* (2006) and Bakhtiar Gul *et al*. (2011) all reported higher maize grain yields at higher plant density than at lower density.

Harvest index: The expression of the physiological efficiency and ability with which plant converts the total dry matter it accumulated into economic yield is known as the harvest index

(HI).The results of the current study revealed that plant density had significant (P<0.01) effect on harvest index with the highest harvest index of 48.11% observed at a lower plant density of 31,250 plants ha^{-1} and the lowest harvest index of 39.99% at the highest plant density of 62,500 plants ha^{-1} (Fig. 3B). However, HI did not significantly differ between the two plant densities (44,444 and 53,333 plants ha^{-1}) (Fig. 3B). The lowest harvest index observed at the highest plant density could be ascribed to the fact that at the highest plant density, the intense intra-specific competition led to greater proportional reductions in grain yield than total above-ground dry matter accumulation, resulting in a reduced harvest index. In line with the current observation, Sharifi et al. (2009) and Lashkari et al. (2011) also observed significantly reduced harvest index with increasing plant density in maize. Contrary to the current observation and to many other reports Aryannia et al., (2013), however did not observed any significant effect of plant density on maize harvest index.

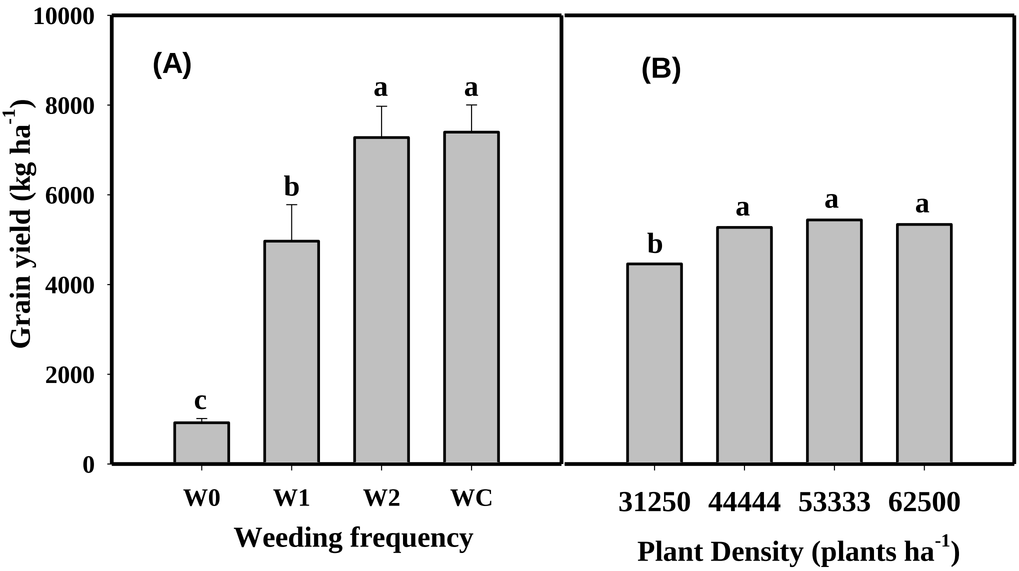

Figure 2: Main effect of weeding frequency (A) and plant density (B) on grain yield

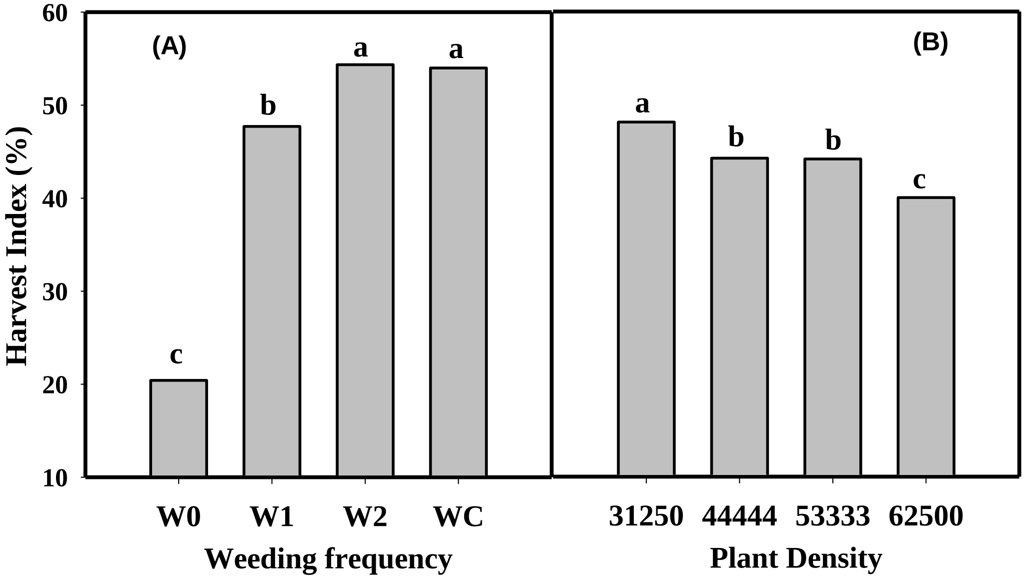

Figure 3: Main effect of weeding frequency (A) and plant density (B) on harvest index

Interaction effect of plant density and weeding frequency on different traits

Number of ears plant-1: Weed frequency and plant density had significant interaction effects on number of ears plant^{-1}, number of kernel rows ear^{-1}, above ground dry biomass yield and relative grain yield loss (Table 1). The highest number of ears plant^{-1} was obtained when maize was planted at the lowest plant density and the weeds were completely avoided or at least when the crops are twice weeded. On the other hand, the lowest number of ears plant^{-1} was obtained when the crop was left weed infested nevertheless of the plant density or at the highest plant density regardless of the weeding frequencies (Table 2). At the lowest plant density, the number of ears plant^{-1}tended to increase with the increase in weeding frequencies. The increase in the number of ears plant^{-1} with the increase in weeding frequency might be attributed to better uptake of nutrients due to reduced weed-crop competition for nutrients, leading to the formation and translocation of more photo assimilates from the source to the sink (grains), forming more cobs plant^{-1}. The number of ears plant^{-1} tended to decrease with the increase in plant density, perhaps due to the intense inter-plant competition for soil resources (nutrients and water) and light thus reducing the photosynthetic capability of plants. In line with current result, Maqbool et al. (2006) also observed significant interaction effect of weed control levels and plant density on number of ears plant^{-1} in maize.

Table 2. Interaction effects of weeding frequencies and plant densities on number of ears per plant of maize

Weeding frequency	Plant Densities (plants ha^{-1})				
	31250	44444	53333	62500	Mean
Weedy check	0.87^{d}	0.87^{d}	1.0^{cd}	0.93^{cd}	0.92
Once hand weeding	1.13^{bcd}	1.0^{cd}	1.0^{cd}	1.0^{cd}	1.03
Twice hand weeding	1.47^{ab}	1.2^{bcd}	1.07^{cd}	1.0^{cd}	1.25
Weed free	1.67^{a}	1.27^{bc}	1.13^{bcd}	1.0^{cd}	1.27
Mean	1.34	1.09	1.05	0.98	
LSD (0.05) Weeding frequency × PD = 0.39			CV (%) = 11.67		

Means in rows and columns followed by the same letter are not significantly different at p = 0.05 levels of significance

Number of kernel rows ear^{-1}: The highest number of kernel rows ear^{-1} was obtained when the maize crop was weeded once, twice and completely, at all plant densities (Table 3). The number of kernel rows ear^{-1} was lower at all plant densities when the plot was left weed infested. The increasing tendency in the number of kernel rows ear^{-1} with the increase in weeding frequency at all plant densities might be due to the lower competition for nutrients, water, and light from weeds, allowing the plants to accumulate more biomass with higher capacity to convert the photo assimilates into sink resulting in more kernel rows ear^{-1}. Similar result was reported by Abd-El-Samie (2001), who also observed a significantly interaction effect between plant density and weed management in influencing the number of kernel rows ear^{-1} in maize.

Table 3. Interaction effects of weeding frequencies and plant densities on number of kernel rows per ear

Weeding frequency	Plant Densities (plants ha^{-1})				
	31250	44444	53333	62500	Mean
Weedy check	10.5^{c}	12.4^{b}	12.3^{bc}	12.0^{bc}	11.8
Once hand weeding	14.7^{a}	14.8^{a}	14.5^{a}	14.4^{a}	14.6
Twice hand weeding	15.7^{a}	15.3^{a}	15.1^{a}	14.9^{a}	15.3
Weed free	16.0^{a}	15.7^{a}	15.6^{a}	15.1^{a}	15.6
Mean	14.2	14.6	14.4	14.1	
LSD (0.05) Weeding frequency × PD = 1.83				CV (%) = 4.22	

Means in rows and columns followed by the same letter are not significantly different at p = 0.05 levels of significance

Above ground dry biomass*:* The above ground dry biomass yield ha^{-1} was the highest for maize planted at higher densities of 62,500 and 53333 plants ha^{-1} and weeded either twice or completely but was the lowest at the lowest plant density of 31,250 ha^{-1} that is left weed infested (Table 4). At a plant density of 62,500 ha^{-1}, complete and twice hand weeding produced the highest above ground dry biomass yield compared to the other two weed management levels (weedy check and once hand weeding). In general, the above ground dry biomass yield of maize increased with increasing plant density and weeding frequency. Decreasing the weeding frequency from weed free to twice, once and absence of weeding resulted in the decrease of above ground dry biomass yield by 1.8, 31.8 and 204%, respectively. The severe reduction in the dry biomass yield when weeds are allowed to compete with the crop could be ascribed to competition of weeds with the crop for light, water, nutrients and space thus, negatively affecting crop growth (Dalley *et al.*, 2006). The dry biomass yield consistently increased with increasing level of weeding frequency at all plant densities although there was no significance difference between twice hand weeding and weed free plot (Table 4). The increase in the biomass yield with the progressive weed control levels could be attributed to the fact that the absence of competition from weed allowed the crop to utilize all soil resources (nutrients and water), ultimately making more photosynthate and hence higher dry matter accumulation. The results of the current study complies with the reports of Bakhtiar Gul *et al.* (2009), Abouziena *et al.* (2008) and Abd_El-Samie (2001), who also observed that planting maize at higher density and controlling weeds through twice hand weeding (at 30 and 45 days after emergence) significantly increased biomass yield ha^{-1}.

Table 4. Interaction effect of weeding frequencies and plant densities on the above ground dry biomass

Weeding frequency	Plant Densities (plants ha^{-1})				
	31250	44444	53333	62500	Mean
Weedy check	4544.5h	6881.5gh	6700.0gh	7263.9g	6348
Once hand weeding	11032.4f	15103.7e	14859.3e	17765.8cd	14690
Twice hand weeding	15766.7de	18642.0bc	20891.4ab	20556.5ab	18964
Weed free	15592.6de	18969.1bc	20814.8ab	21839.8a	19304
Mean	11734.2	14896.3	15816.4	16856.5	

LSD (0.05) Weeding frequency × PD = 2621.4 CV (%) = 5.8

Key: Means in rows and columns followed by the same letter are not significantly different at p = 0.05 levels of significance

Relative grain yield loss: The relative grain yield loss was significantly influenced by the interaction effect of weeding frequency and plant density. Relative grain yield loss was the highest for weedy check regardless of the plant densities and was the lowest for twice hand weeding and weed free plot at all plant densities (Table 5). This indicates that twice hand weeding is sufficient to avoid any grain yield loss due to weeds. Planting maize at 31,250 plants ha^{-1} without controlling weeds resulted in significantly the highest (88.2%) relative grain yield loss. Similarly, at the plant density of 44,444 plants ha^{-1}, relative grain yield loss was significantly the highest for weedy check, followed by once weeding. Twice hand weeding and weed free resulted in lower grain yield loss (Table 5). Likewise, at the plant density of 53,333 plants ha^{-1}, the highest relative grain yield loss was observed for weedy check followed by once hand weeding. Relative grain yield loss, for the same plant density didn't significantly differ between twice hand weeding and weed free. This indicates that at a plant density of 53,333 plants ha^{-1}, twice hand weeding is sufficient to significantly reduce weed biomass and hence avoid any competition for resources. At the highest plant density of 62,500 plants ha^{-1}, the highest relative grain yield loss was observed for weedy check, followed by once hand weeding. However, there was not significant difference between twice hand weeding and weed free plot. Thus, twice hand weeding was as effective as weed free in increasing maize grain yield (Table 6). Dalley *et al*. (2006) and Abouziena *et al*. (2007) reported maize grain yield loss ranging between 66-90% while Villasana *et al*. (2004) reported 90% maize grain yield loss due to competition from weeds, which also agrees with our current observation.

Table 5. Interaction effect of weeding frequency and plant densities on Relative grain yield loss

Weeding frequency	Plant Densities (plants ha^{-1})				
	31250	44444	53333	62500	Mean
Weedy check	88.2^{a}	87.7^{a}	87.9^{a}	86.7^{a}	87.57
Once hand weeding	40.4^{b}	27.1^{c}	38.3^{bc}	27.0^{c}	32.92
Twice hand weeding	3.6^{d}	2.4^{d}	1.3^{d}	1.2^{d}	1.73
Weed free	0.0^{d}	0.0^{d}	1.6^{d}	0.0^{d}	0.33
Mean	33.1	29.3	31.1	28.73	

LSD (0.05) Weeding frequency × PD = 11.58 CV (%) = 12.33

Means in rows and columns followed by the same letter are not significantly different at p = 0.05 levels of significance

Association among grain yield and other growth parameters

Grain yield showed significant positive relationship with plant density (Table 6). The increase in grain yield with increasing plant density from 31,250 to 44,444 plants ha^{-1} could be ascribed to the difference in the number of harvested cobs $plant^{-1}$, and number of kernels ear^{-1}, number of kernels row^{-1} and number of kernel rows ear^{-1} as could be evidenced from the significant positive relationship between these parameters (Table 6), ultimately differing in the weights of the harvested cobs from the net plots. Although this conclusion was drawn based on observed data it is also supported by the suggestion of Emam (2001), who concluded that number kernels ear^{-1} and number of kernels row ear^{-1} are the most important determinants of maize grain yield in response to plant density.

Table 6. Linear correlation coefficients (r) among of growth parameters yield and yield related traits of maize.

	P	W	Ryl	EL	NKPE	NKPR	NKRPE	GY	AGBM
P									
W	0.0**								
Ryl	-0.03ns	-0.71**							
EL	-0.52**	0.49**	-0.67**						
NKPE	-0.12*	0.61**	-0.94**	0.75**					
NKPR	-0.08ns	0.61**	-0.95*	0.72**	0.96**				
NKRPE	-0.02ns	0.64**	-0.88**	0.69**	0.91**	0.86**			
GY	-0.12ns	0.69**	-0.98**	0.59**	0.91**	0.92**	0.85**		
AGBM	-0.42*	0.63**	-0.89**	0.39**	0.78**	0.79**	0.78**	0.93**	
HI	-0.22ns	0.72**	-0.94**	0.74**	0.93**	0.95**	0.86**	0.91**	0.73**

Key: **, *, Correlation is significant at the 0.01 and 0.05 significance level, respectively; ns=insignificant

Conclusion

Weeding frequency and plant densities and their interaction significantly influenced yield and yield components of maize. Harvest index and grain yield were highly affected by the main effects of weeding frequency and plant density. The number of ears $plant^{-1}$, number of kernel rows ear^{-1}, above ground dry biomass and relative grain yield loss were significantly affected by the interaction effect of weeding frequency and plant density. Grain yield was much more reduced due to competition from weeds (87.5%) than due to low plant density (18%) as a consequence of serious weed-crop competition for nutrients. Weeds were able to remove 33.5, 10.4 and 87 kg ha-1 N, P and K, respectively if the field was left completely weed infested. The nutrients removed by weeds were more or less similar to what the crop was supposed to remove to give optimum grain yield. Based on this study, it can be concluded that twice hand weeding and a plant density of 53,333 plants ha^{-1} would be optimum practices for attaining economically feasible grain yield for the hybrid maize BH 546. The results of this study also dictate that greater attention should be given to weed management to considerably narrow the maize yield gaps in the study area.

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