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\*Corresponding author: Bulti Merga,  
School of Plant Sciences, Haramaya  
University, Dire Dawa, P.O. Box 138,  
Dire Dawa, Ethiopia  
E-mail: [bultimerga@gmail.com](mailto:bultimerga@gmail.com)

Reviewing editor:  
Fatih Yildiz, Food Engineering and  
Biotechnology, Middle East  
Technical University, Ankara, Turkey

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## FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

# Integrated weed management in chickpea (*Cicer arietinum* L.)

Bulti Merga\*<sup>1</sup> and Nano Alemu<sup>1</sup>

**Abstract:** The poor competition ability of chickpea opens the door for weed to cause a serious yield loss. The experimental field is conducted to evaluate the integrated effects of pre-emergence herbicides and hand-weeding on weed control, yield components, yield, and their economic feasibility for cost effective weed control in chickpea. The experiment consisted of 12 treatments viz. pre-emergence s-metolachlor (1.0, 1.5 and 2.0 kg ha<sup>-1</sup>) and pendimethalin (1.0, 1.25 and 1.5 kg ha<sup>-1</sup>), each at three rates metolachlor, s-metolachlor + one-hand-weeding, pendimethalin + one-hand-weeding, two-hand-weeding, complete weed free and weedy checks arranged. The weed flora consisted of broadleaved and sedge with the relative densities of 95.24 and 4.76% at Haramaya district, and 93.72 and 6.28%, at Hirna district, respectively. Application of s-metolachlor and pendimethalin 1.0 kg ha<sup>-1</sup> each supplemented with hand weeding 5 WAE significantly ( $p \leq 0.01$ ) affected the broadleaved weeds, sedges and weed dry weight at both sites. S-metolachlor 1.0 kg ha<sup>-1</sup> supplemented with hand weeding 5 WAE gave the lowest total number of weeds (21.78 m<sup>-2</sup>) following the weed free check. Higher average grain yield (2344.41 kg ha<sup>-1</sup> or 234.441 g m<sup>-2</sup>) was produced with s-metolachlor 1.0 kg ha<sup>-1</sup> supplemented with one-hand-weeding 5 WAE following complete weed-free. The benefit gained from s-metolachlor and pendimethalin at 1.0 kg ha<sup>-1</sup> each



Bulti Merga

### ABOUT THE AUTHORS

Bulti Merga works in School of Plant Sciences, Haramaya University, Ethiopia currently performing duties of lecturer and researcher. Bultis' profession is Horticulture and Agronomy and Coordinator for Highland Crops Research Improvement. His key research area is on potato, carrot, other vegetables, and chickpea crops research improvement.

Nano Alemu is a lecturer and researcher at Haramaya University of School of Plant Sciences, Ethiopia. His research interest is on soil science and agronomy.

### PUBLIC INTEREST STATEMENT

Herbicides are useful in promoting food production by preventing weed damage that can occur at various stages of crop production. Moreover, herbicides are useful in controlling weed species such as broad leaved and sedge which competes with crops for essential nutrients, available water, harbor pathogens and insect pests to attack the main food crop, and barriers for harvesting crop and cause post-harvest losses through contamination of the crop products. Despite their benefit, they may cause adverse health effects including restlessness, neurotoxicity, breathing difficulties, unconsciousness, cancer and death if inhaled or swallowed by human being during application. At the same time, herbicide residues affect non-targeted organisms including aquatic life, bees, butterfly, birds, livestock and beneficial soil microorganisms. Communities should use herbicide responsibly by ensuring proper dosage and time of application, and abide to disposal guideline as stipulated by regulatory authorities.

supplemented with one hand weeding 5 WAE were greater than the value recorded from the weedy check by 216% and 198 %, respectively. S-metolachlor 1.0 kg ha<sup>-1</sup> supplemented with hand weeding 5 WAE treatments resulted in the highest grain yield and economic benefit. However, in case labour is constraint and s-metolachlor herbicide is timely available, pre emergence application of s-metolachlor at 2.0 kg ha<sup>-1</sup> should be the alternative to preclude the yield loss and to ensure maximum benefit. Herbicides application is an integral part of farmer's crop management in modern agricultural systems.

**Subjects: Environment & Economics; Biodiversity & Conservation; Ecology - Environment Studies**

**Keywords: chickpea; herbicides; application; weed**

### 1. Introduction

Chickpea is a valued crop and provides nutritious food for an expanding world population and will become increasingly important with climate change (Muehlbauer & Sarker, 2017). It is an annual legume which is the most important crop and the productivity is very low in Ethiopia. Chickpea is poor competitor to weeds because of slow growth rate and limited leaf development at early stage of crop growth and establishment (Ratnam, Rao, & Reddy, 2011). The bulk of the crop variety in the country is dominated by the sweet Desi type, and the Kabuli type is also grown in limited areas. In Ethiopia chickpeas are consumed widely fresh as green vegetables, sprouted, fried roasted and boiled. It is also ground into flour to make baby feed mixed with other cereals, soup bread and meat. It is also used to rehabilitate depleted fallow lands through utilizing crop rotation system. Chickpeas in Ethiopia hold fourth in the production and area coverage in the total pulse category. Ethiopia is Africa's leading producer of chickpea and the fourth largest in the world. One of the most popular dishes—shiro—is made from chickpea. Still, a lack of financial capital and technological know-how has kept the chickpea value chain from realizing its full potential. The occurrence of invasive and noxious weed species is the main challenges of all parts of countries over the world aims for crop production.

The main chickpea-producing countries over the World are India, Australia, Burma, Turkey, Russia, Pakistan, United States, Iran, Mexico, Tanzania, Canada, Argentina, Spain, Yemen, Syria, and Ethiopia found on the fourth rank having greatly increased production in recent years now accounts for over 3.67% of world production during 2017 crop growing season (FAOSTAT, 2019). Mean yields of chickpea have varied widely among producing countries and range from relatively low yields averaging 500–600 kg/ha in Iran, Malawi, Morocco, Pakistan, and Syria to relatively high yields in Ethiopia and Mexico. India, the largest producer has had stable mean yields of about 900 kg/ha and has a global share of 64.7%. The high yields 2000 kg/ha in Mexico are largely due to the fact that most of the crop is irrigated and grown over the cool winter season (FAOSTAT, 2019). Effective weed management technique is the fundamental to have strong agricultural sector which can be evaluated from field experiment that include various methods for choice and recommended by researchers for farmers.

In intensive agriculture, which largely depends on herbicides for weed control, indiscriminate use of herbicides could cause adverse changes on soil micro flora, poor quality crop production, human and animal health problems. So, integrated weed management is an only alternative for improving the pulse production. Non-chemical weed management is quite difficult in this crop. However scientists are doing their long strenuous efforts on this aspect (Mukherjee, 2007). The elongation of rainfall for consecutive seven days or above and intermittent light rain are not a suitable time for herbicide applications. The effects of intermittent light rain and dew presence at application of an herbicide are variable according to research findings on this subject and are not specifically addressed on most product labels. Some research suggest that the intermittent light rain and

the presence of dew on the leaf surface at application helps in the distribution and absorption of the herbicide. Other research indicates that if rainfall continue for more than a week and heavy dew is present before application, then high carrier (water) volumes (i.e. > 30 g.p.a.) will cause spray particles to bounce off the leaf surface resulting in reduced effectiveness. Additionally, the main problem is that the effective dose of the herbicide may have been reduced due to rain washing the herbicide off of the foliage. However, it is impossible to determine the resulting dose and whether a re-application is necessary. Moreover, some herbicide mode of actions are such that it may take several days to more than a week to determine if control has been reduced. Since most of our applications employ carrier volumes of less than 30 g.p.a., the presence light rainfall during herbicide application and the occurrence of dew on the leaf surface will likely not impact herbicide performance. Thus, targeting applications relative to the presence of light rainfall is of far less importance than proper herbicide rate, weed size, and spray nozzle selection. The actual reduced effectiveness will vary with the herbicide product, species targeted, and environmental conditions.

Weed competes with crops for essential nutrients, available water, intensity and durations of light used for photosynthesis, release of nutrients by the plant through fixation system, harbor pathogens and insect pests, and barriers for harvesting crop and cause post-harvest losses through contamination of the products.

Chickpea, being slow in its early growth and short stature plant, is highly susceptible to weed competition and often considerable losses may occur if weeds are not controlled at proper time and integrated weed management practices can be achieved by application of herbicides and hoeing twice at 20 and 40 days after the crop germination (Sunil, Shekara, Ashoka, Murthy, & Madhukumar, 2011).

The germination phase of the crop is the appropriate time when the herbicide is to be applied for weed management and become effective.

In the pulse crops especially in case of chickpea pendimethalin at 1000 g ha<sup>-1</sup> applied as pre-emergence is a very common herbicide which is used to control all type of weeds, but there is no herbicide available to be applied as post-emergence to control the emerging broad leaf weeds effectively (Santosh Dubey, Kumar, Singh, Partap, & Chaurasiya, 2018). Moreover, the management of weed in manual method has both advantage and disadvantages in which farmers not get always benefit, because weed is one the factors that cause of the significant loss on crop yield which is observed from the majority of people side like the Ethiopian country from the developing countries.

The chickpea, although is an important pulse crop yet no adequate information on effective weed management are available especially for eastern part of Ethiopia where sowing of chickpea is further delayed due to many problems. These constraints include; occurrence of newly emerged disease, insects, and the fear of continues rainfall which can enhance the weed growth and challenge the herbicide application to control weed from the main crop field. In the present time, some of the very effective high potency herbicide molecules have been developed which may be useful to control the wide spectrum of weeds in chickpea further, if their molecules are used in a combination may be more effective to control the wide spectrum weeds. The trait and morphology of weed are changed with the old techniques farmers were using and the use of herbicide chemicals with current conditions which enforced scientist to find new ways for controlling plant barriers and promote the crop productivity. Moreover, unwanted plants change the genetic characteristics and adapt with some herbicide chemicals used for weed becoming herbicide resistant.

Hence, present investigation was carried out to study the efficacy of different herbicides on mixed weed flora and their effect on growth and yield of chickpea. In chickpea weeds germinate and grow fast in many flushes so, application of one herbicide alone is not much effective and

economical weed control measure under such condition. Keeping in view this fact, this field trial having various herbicide types and manual weed controlling techniques was proposed to find out the suitable and effective weed management practice during critical period of crop-weed interference in chickpea. The crop yield loss caused by the weed is assumed greater than 20%, in Ethiopia. (Figure 1).

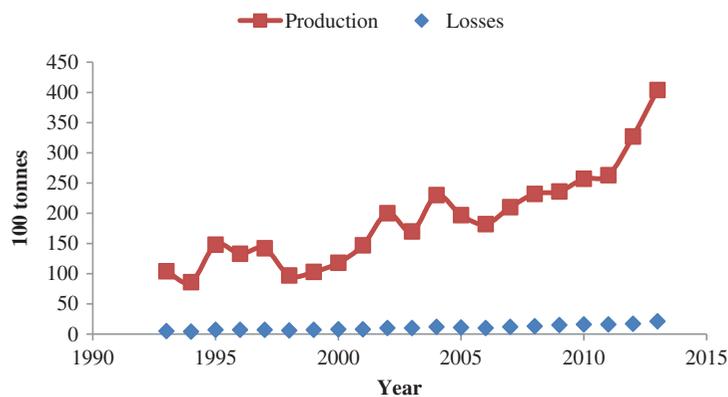
## 2. Materials and methods

### 2.1. Description of the study area

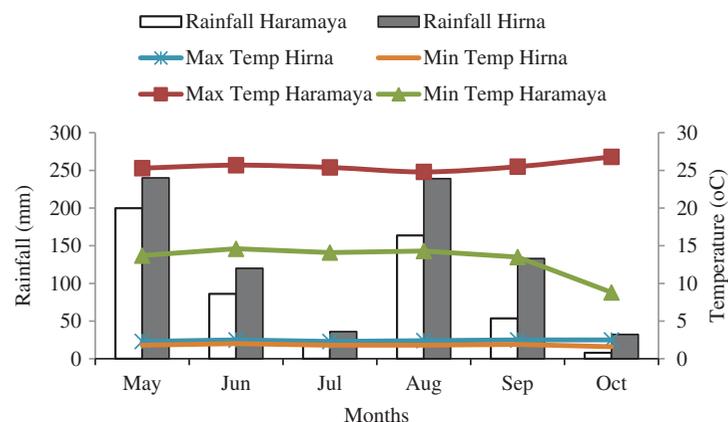
The field experiment was conducted during 2016 main rain season, at two locations, Haramaya University Rare Research farm and Hirna Research farm. Haramaya University Rare Research farm is located at 2020 m above sea level, 9°41'N latitude and 42°03'E longitude. The area receives an annual rainfall of 760 mm with bimodal rainfall pattern and average maximum and minimum temperatures of 26.8°C and 8.8°C, respectively (Figure 2). The area is representative of a sub-humid mid altitude agro-climatic zone. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October and accounts for about 45% of the total rainfall. The soil of the experimental site is a well-drained deep alluvial with a sub-soil stratified with loam and sandy loam (Tamire, 1973). The chemical properties of the soil indicated that the soil has organic carbon content of 1.15%, total nitrogen content of 0.11%, available phosphorus content of 18.2 mg kg soil<sup>-1</sup>, exchangeable potassium content of 0.65 c mol kg soil<sup>-1</sup> (255 mg exchangeable K kg soil<sup>-1</sup>), pH of 8.0. The physical properties of the soil indicated sand, silt, and clay contents of 63, 20, and 17 percentages respectively, which is sandy clay (Burga, Dechassa, & Tsegaw, 2014).

**Figure 1. The production quantity and losses of chickpea crop in Ethiopia.**

Source: FAOSTAT, 2019.  
 Available online: [http://www.fao.org/faostat/en/?fbclid=IwAR3XaS5Uk\\_q1\\_uFqVOH6uouvL2IcDHzeMgov2KFePADfjKUWMLtHBs3CdsM#compare](http://www.fao.org/faostat/en/?fbclid=IwAR3XaS5Uk_q1_uFqVOH6uouvL2IcDHzeMgov2KFePADfjKUWMLtHBs3CdsM#compare)



**Figure 2. Rainfall (mm), minimum and maximum temperatures (°C) recorded during the 2016 cropping season at Haramaya and Hirna districts (Source: Jigjiga Meteorological Station, Eastern Ethiopia).**



The field experiment was replicated at another research sub-station of the University, which is located in Tullo district at Hirna. This research sub-station is situated at a distance of about 150 km west of Haramaya University. Geographically, the site is located at 9°12' North latitude, 41°4' East longitude, and at an altitude of 1870 m above sea level. The area receives mean annual rainfall of 990 to 1010 mm. The mean maximum and minimum annual temperatures are 21.8°C and 8.6°C, respectively (Tekalign, 2011). During the experimental season of 2016 the mean maximum and minimum temperatures are 25°C and 8.6°C (Figure 2). The soil of Hirna is vertisol type with a silty clay texture, which contains 1.75% organic carbon, 0.18% total Nitrogen, 32 mg kg soil<sup>-1</sup> available Phosphorus, 0.68 cmol<sub>c</sub> kg soil<sup>-1</sup> exchangeable potassium, and has neutral soil pH of 7.09 (Tadesse, 2011).

## 2.2. Treatments and experimental design

The experiment consisted of 12 treatments viz. pre-emergence s-metolachlor (1.0, 1.5 or 2.0 kg ha<sup>-1</sup>), pendimethalin (1.0, 1.25 or 1.5 kg ha<sup>-1</sup>), s-metolachlor at 1.0 kg ha<sup>-1</sup> + hand-weeding at 5 weeks after crop emergence (WAE), pendimethalin + hand-weeding at 5 WAE, one-hand weeding at 2 WAE, two-hand weeding at 2 and 5 WAE, complete weed free and weedy checks. The herbicides used and their common, trade, and chemical names are shown in Table 1. The treatments were arranged in randomized complete block design with three replications.

## 2.3. Experimental procedure and management

The experimental field was ploughed and disked by a tractor. Land leveling was done manually prior to planting. The experimental fields were prepared to fine tilth. The gross plot size was 3.2 m × 2.4 m (7.68 m<sup>2</sup>) with 40 and 10 cm inter and intra-row spacing, respectively. Spacing of 0.6 and 1 m were allocated between plots and blocks, respectively. The Chickpea variety “Arerti” was planted on 10<sup>th</sup> and 14 July 2016 at Haramaya and Hirna, respectively. Fertilizer, diammonium phosphate (18% N; 46% P<sub>2</sub>O<sub>5</sub>) was drilled in furrows at the recommended rate of 100 kg ha<sup>-1</sup> at planting (Nigussie, Girma, Anchala, & Kirub, 2009). The herbicides were applied as per the treatment in the assigned plots one day after planting. Herbicide spray volume with water as carrier was 500 l ha<sup>-1</sup>. Spraying was done with Knapsack sprayer (15 l capacity) using flat-fan nozzle (XRC8004). Weeds were removed by hoeing as required in the case of weed free treatment. One row from each side of the plots and four plants from each end of the rows were considered as border. Harvesting was performed manually by pulling the selected plant from the soil when the foliage, stem and pods color of plant changed to golden brown and fully dried on November, 2016. Then, threshing was done by beating with stick. Thus, the net harvestable area was 2.4 m × 1.6 m (3.84 m<sup>2</sup>). Harvesting was done manually at harvest maturity on 11<sup>th</sup> and 29 November 2016 at Haramaya and Hirna, respectively. The biomass after harvest was sun dried for 10 days, threshing follows, and sorting were done subsequently.

## 2.4. Data Collection and Analysis

The weed flora present in the experimental fields was recorded from weedy check plots in each replication just before crop flowering by placing a quadrat (0.25 × 0.25 m) randomly at two spots in each replication and converted into m<sup>-2</sup>. The species were categorized according to their families with the aid of flora books (Melaku, 2008; Stroud & Parker, 1989). The weeds at this stage were also cut near to the ground and after three days of sun drying, the samples were oven dried at 65°C to a constant weight to determine aboveground dry weight.

**Table 1. Description of herbicides used for the experiments**

Common name	Trade name	Chemical name
S-metolachlor	Dual Gold 960 EC	[2-chloro-6-ethyl-N-(2-methoxy-1-methylethyl) acet-o-toluidide]
Pendimethalin	Stomp Extra 38.7% CS	[N-(1-ethylpropyl)-2, 6-dinitro-3, 4-xylidine]

CS = Capsule Suspension; EC = Emulsifiable Concentrate

Number of days to flowering was recorded as the number of days from planting to the time when 50% of the 10 pre-tagged plants which showed first flower. Days to 90% physiological maturity was recorded in each plot, as the number of days from planting to when 90% of the 10 pre-tagged plant leaves showed yellow colour and their pods turned yellow. Plant height (cm) was recorded from 10 randomly selected plants per plot before harvest from the base of plant to the tip of main stem and was expressed on per plant basis.

Total number of pods in 10 randomly selected plants in each plot was counted at harvest and expressed as the average number of pods plant<sup>-1</sup>. From these pods, the seeds were counted to determine the average number of seeds pod<sup>-1</sup>. Hundred seeds were counted from each plot, and their weight was recorded. Aboveground dry biomass weight was measured at physiological maturity after cutting 10 randomly sampled plants at ground level and sun dried. This was multiplied by the number of plants in the net plot area and converted into kg ha<sup>-1</sup>.

Grain yield (kg) was recorded from each net plot area. The moisture content was determined for each treatment and the grain yield was adjusted at 10%. Harvest index (%) was calculated as the ratio of grain yield to the total aboveground dry biomass yield. The data were subjected to analysis of variance (GLM procedure) using SAS software program version 9.2 (SAS (Statistical Analysis System) Institute. Inc, 2003). Homogeneity of variances was evaluated using the F-test as described by (Gomez, Gomez, & Gomez, 1984) and since the F-test has showed heterogeneity of the variances of the two sites one way analysis of variance (ANOVA) was done separately. Least significant difference (LSD) test at 5% probability level was employed to separate treatment means where significant treatment differences existed.

### **2.5. Partial budget analysis**

The partial budget analysis as described by CIMMYT [International Maize and Wheat Improvement Center] (1988) was done to determine the economic feasibility of the weed management practices. Economic analysis was done using the prevailing market prices for inputs at planting and for the outputs at the time of crop harvest. It was calculated by taking into account the additional input and labour cost involved and the gross benefits obtained from weed management practices. Average yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could obtain from the same weed management practices as described by (CIMMYT, 1988). The field price of Chickpea was calculated as (sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation). The total cost that varied included the sum of cost of herbicides and labour where hand weeding required. The net benefit was calculated as the difference between the gross field benefit (USD ha<sup>-1</sup>) and the total costs (USD ha<sup>-1</sup>) that varied.

## **3. Results and discussion**

### **3.1. Weed botanical composition**

Depending on the leaf morphology the weed species were categorized into two; broadleaved and sedges with the relative densities of 95.24 and 4.76% at Haramaya location, and 93.72 and 6.28%, at Hirna site, respectively (Table 2). The population of *Solanum nigrum* L. and *Medicago polymorpha* L. broadleaved were uplifted and score 10.82 and 10.39% at Haramaya while the similar leaf morphology of weed; *Commelina benghalensis* L. and *Galinsoga parviflora* Cav scored equal figure of 9.96%. Equal populations of weeds (10.88%) were detected from *Medicago polymorpha* L. and *Galinsoga ciliata* species which was categorized as high density at Hirna. *Oxalis corniculata* L. revealed low relative weed density (1.3%) at Haramaya while *parthenium hysterophorus* L. scored low relative weed density (2.51%) at Hirna experimental site. The only sedge weed species revealed from both experimental sites was (*Cyperus rotundus* L.) as presented in Table 2. Water is an agent used for successful placement and application of herbicide in selected area for weed management. Even-though the negative impacts of weed during non-cropping season is forgotten and neglected by agricultural and stakeholders, unwanted plants grown in main crop site during cropping season can cause critical and harmful impacts to the socioeconomic of farmers.

**Table 2. Species, families, Density (m<sup>-2</sup>) and relative density (%) of weeds found in weedy check plots at Haramaya and Hirna districts during the 2016 cropping season**

Weed species	Family	Weed life cycle	Haramaya		Hirna	
			WD (m <sup>-2</sup> )	RD (%)	WD (m <sup>-2</sup> )	RD (%)
<b>Broadleaved</b>						
<i>Argemone ochroleuca</i> L.	Papaveraceae	Annual	13	5.63	17	7.11
<i>Galinisoga ciliata</i>	Asteraceae	Annual	18	7.79	26	10.88
<i>Xanthium strumarium</i> L.	Asteraceae	Annual	17	7.36	21	8.79
<i>Commelina benghalensis</i> L.	Commelinaceae	Perennial	23	9.96	24	10.04
<i>Equisetum arvense</i> L.	Equisetaceae	Perennial	14	6.06	19	7.95
<i>Bidens pilosa</i> L.	Asteraceae	Annual	11	4.76	7	2.93
<i>Galinisoga parviflora</i> Cav.	Asteraceae	Annual	23	9.96	13	5.44
<i>Guizotia scabra</i> (Vis.) Chiou	Asteraceae	Perennial	9	3.90	17	7.11
<i>Parthenium hysterophorus</i> (L.)	Asteraceae	Perennial	21	9.09	6	2.51
<i>Medicago polymorpha</i> L.	Fabaceae	Perennial	24	10.39	26	10.88
<i>Oxalis corniculata</i> L.	Oxalidaceae	Perennial	3	1.3	12	5.02
<i>Plantago lanceolata</i> L.	Plantaginaceae	Perennial	14	6.06	10	4.18
<i>Solanum nigrum</i> L.	Solanaceae	Annual	25	10.82	14	5.86
<i>Amaranthus hybridus</i> L.	Amarantaceae	Perennial	5	2.16	12	5.02
Total				95.24		93.72
Sedge						
<i>Cyperus rotundus</i> L.	Cyperaceae	Perennial	11	4.76	15	6.28

WD = Weeds density; RD = Relative density Note: The weed density was measured by placing a quadrat (1 m<sup>2</sup> size) randomly on the survey spots following the list quadrat method for each weed species. The relative density (RD) of weed species was calculated as;  $RD = \frac{\text{Number of individual weed species}}{\text{Total number of weed species}} \times 100$

Weed competes with crops for essential nutrients, available water, intensity and durations of light used for photosynthesis, release of nutrients by the plant through fixation system, harbor pathogens and insect pests and barriers for harvesting crop and cause post-harvest losses through contamination of the products. This ability of weed slows the genetic shift of a weed population exposed to intense selection pressures by ensuring that all the seedlings that germinate in any one year are not all from similar genetic backgrounds (Gulden & Shirtliffe, 2009).

One of the most important, yet often neglected weed management strategies is to reduce the number of weed seeds present in the field in which soil is used as a weed seed bank, and thereby limit potential weed populations during crop production can be accomplished by managing the weed seed bank found in soil (Hossain & Begum, 2015).

### **3.2. Relative density in percentage and total numbers of the sedges and broadleaved weeds**

#### **3.2.1. Sedge weeds density**

The sedge density was significantly ( $P < 0.01$ ) affected in response to weed management practices. The lower sedge density was observed in the plots treated with the application of s-metolachlor at  $1.0 \text{ kg ha}^{-1}$  supplemented with one hand weeding 5WAE at both sites, which was statistically similar with the weed free check at both sites (Table 3). Further, at Haramaya, no significant differences existed between s-metolachlor and pendimethalin both at  $1.0 \text{ kg ha}^{-1}$  supplemented with one hand weeding 5 WAE. Application of both s-metolachlor and pendimethalin herbicides at low dose ( $1.0 \text{ kg ha}^{-1}$ ) supplemented with one hand weeding at 5 WAE resulted in significantly lower sedge density than pendimethalin or s-metolachlor application alone.

The density of sedge decreased significantly with the increase in s-metolachlor and pendimethalin application rates at both sites except between s-metolachlor at  $1.5$  and  $2.0 \text{ kg ha}^{-1}$  rates at Hirna (Table 3). On the other hand, significant differences was existed between one and two hand-weeding at both sites and they were resulted in significant reduction in sedges densities over pendimethalin at  $1.0$ ,  $1.25$  and  $1.5 \text{ kg ha}^{-1}$  at Haramaya and pendimethalin at  $1.0$  and  $1.25 \text{ kg ha}^{-1}$  at Hirna.

#### **3.2.2. Broadleaved weeds density**

Broadleaved weed density showed a significance difference ( $P < 0.01$ ) due to different weed management practices. Similar to sedge density, lowest density of broadleaved weeds was recorded when s-metolachlor at  $1.0 \text{ kg ha}^{-1}$  supplemented with one hand weeding 5 WAE used at both sites. This was statistically as effective as weed free check and pendimethalin at  $1.0 \text{ kg ha}^{-1}$  integrated with one hand weeding 5 WAE at both sites, while the weedy check plots had the highest weed density (Table 3). The broadleaved weed density decreased with the increase in herbicide application rates at both sites except between pendimethalin at  $1.25$  and  $1.5 \text{ kg ha}^{-1}$  rates at Haramaya. Application of s-metolachlor at  $2.0 \text{ kg ha}^{-1}$  resulted in significant decrease of broadleaved weed density over s-metolachlor at  $1.0$  and  $1.5 \text{ kg ha}^{-1}$  at both sites. Two hand weeding at 2 and 5 WAE has significantly reduced the broadleaved weeds density over one hand weeding 5 WAE, s-metolachlor at  $1.0$ ,  $1.5$  and  $2.0 \text{ kg ha}^{-1}$ , pendimethalin at  $1.0$ ,  $1.25$  and  $1.5 \text{ kg ha}^{-1}$  rates but no significant differences existed between pendimethalin at  $1.0$  + one hand weeding 5 WAE at Haramaya (Table 3).

#### **3.2.3. Total weed density**

The total weed density was significantly ( $P < 0.01$ ) affected in response to weed management practices and site while its interaction with the sites had no significant effect. In this respect, the total weed density was significantly lower at Hirna. This might be due to lower temperature and rainfall at early crop emergence (Figure 2) and lower weed density at Hirna (Table 2) compared to Haramaya. The lower dose ( $1.0 \text{ kg ha}^{-1}$ ) of s-metolachlor and pendimethalin supplemented with one hand weeding were statistically similar but significantly reduced total weed density than other herbicides and hand weeding treatments (Table 4). Using of s-metolachlor and pendimethalin each with  $1.0 \text{ kg ha}^{-1}$  and one hand weeding 5 WAE were reduced the total weed density by 96.5% and 93.4%, respectively over weedy check.

**Table 3. Effects of weed management practices on density (m<sup>-2</sup>) and weed dry biomass (g m<sup>-2</sup>) of broadleaved weeds and Sedges in Chickpea at Haramaya and Hirna districts during the 2016 cropping season**

Weed management practices	Broadleaved weeds density		Sedges density		Dry weed density	
	Haramaya	Hirna	Haramaya	Hirna	Haramaya	Hirna
S-metolachlor 1.0 kg ha <sup>-1</sup>	34.92 <sup>e</sup>	51.38 <sup>e</sup>	46.67 <sup>f</sup>	36.74 <sup>d</sup>	139.2 <sup>f</sup>	134.91 <sup>e</sup>
S-metolachlor 1.5 kg ha <sup>-1</sup>	28.33 <sup>f</sup>	40.17 <sup>f</sup>	36.7 <sup>g</sup>	29.69 <sup>e</sup>	107.7 <sup>g</sup>	102.3 <sup>f</sup>
S-metolachlor 2.0 kg ha <sup>-1</sup>	23.73 <sup>g</sup>	34.61 <sup>g</sup>	29.21 <sup>h</sup>	24.58 <sup>e</sup>	82.71 <sup>h</sup>	81.83 <sup>f</sup>
Pendimethalin 1.0 kg ha <sup>-1</sup>	54.5 <sup>b</sup>	82.75 <sup>b</sup>	94.91 <sup>b</sup>	76.64 <sup>b</sup>	267.91 <sup>b</sup>	264.92 <sup>b</sup>
Pendimethalin 1.25 kg ha <sup>-1</sup>	49.42 <sup>c</sup>	67.2 <sup>c</sup>	80.29 <sup>c</sup>	51.92 <sup>c</sup>	228.82 <sup>c</sup>	190.6 <sup>c</sup>
Pendimethalin 1.5 kg ha <sup>-1</sup>	47.17 <sup>c</sup>	60.25 <sup>d</sup>	71.3 <sup>d</sup>	42.33 <sup>d</sup>	205.42 <sup>d</sup>	162.01 <sup>d</sup>
S-metolachlor 1.0 kg ha <sup>-1</sup> + 5 WAE	12.25 <sup>j</sup>	15.65 <sup>j</sup>	8.33 <sup>k</sup>	7.33 <sup>gh</sup>	19.3 <sup>k</sup>	17.5 <sup>hi</sup>
Pendimethalin 1.0 kg ha <sup>-1</sup> + 5 WAE	17.08 <sup>hi</sup>	18.87 <sup>hi</sup>	13 <sup>j</sup>	10.86 <sup>g</sup>	33.6 <sup>j</sup>	31.04 <sup>gh</sup>
One hand weeding at 2 WAE	45.5 <sup>d</sup>	57.83 <sup>d</sup>	58.17 <sup>e</sup>	38.22 <sup>d</sup>	169.8 <sup>e</sup>	147.8 <sup>de</sup>
Two hand weeding at 2 and 5 WAE	19.58 <sup>h</sup>	25.42 <sup>h</sup>	20.67 <sup>i</sup>	14.72 <sup>f</sup>	54.9 <sup>j</sup>	48.6 <sup>g</sup>
Weed free check	0 <sup>j</sup>	0 <sup>j</sup>	0 <sup>k</sup>	0 <sup>h</sup>	0 <sup>k</sup>	0 <sup>j</sup>
Weedy check	101.33 <sup>a</sup>	143.88 <sup>a</sup>	149.17 <sup>a</sup>	111.08 <sup>a</sup>	458.8 <sup>a</sup>	436.29 <sup>a</sup>
LSD (0.05)	4.95	6.33	6.94	7.21	18.64	23.10
CV (%)	10.885	11.542	13.551	15.033	12.144	13.19

CV = Coefficient of Variation, LSD = Least Significant Difference, WAE = Weeks after emergence, Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

**Table 4. Main effect of total weed density at Haramaya and Hirna districts as influenced by weed management practices during the 2016 cropping season**

Treatments	Total weed density
Site:	
Haramaya	231 <sup>b</sup>
Hirna	239 <sup>a</sup>
LSD (0.05)	8.00
Weed management practices:	
S-metolachlor 1.0 kg ha <sup>-1</sup>	84.855 <sup>f</sup>
S-metolachlor 1.5 kg ha <sup>-1</sup>	67.445 <sup>g</sup>
S-metolachlor 2.0 kg ha <sup>-1</sup>	56.065 <sup>h</sup>
Pendimethalin 1.0 kg ha <sup>-1</sup>	154.4 <sup>b</sup>
Pendimethalin 1.25 kg ha <sup>-1</sup>	124.415 <sup>c</sup>
Pendimethalin 1.5 kg ha <sup>-1</sup>	110.525 <sup>d</sup>
S-metolachlor 1.0 kg ha <sup>-1</sup> + one hand weeding 5 WAE	21.78 <sup>i</sup>
Pendimethalin 1.0 kg ha <sup>-1</sup> + one hand weeding 5 WAE	29.905 <sup>j</sup>
One hand weeding at 2 WAE	99.86 <sup>e</sup>
Two hand weeding at 2 and 5 WAE	40.195 <sup>e</sup>
Weed free check	0 <sup>k</sup>
Weedy check	252.73 <sup>a</sup>
LSD (0.05)	7.987
CV (%)	14.18

CV = Coefficient of Variation, LSD = Least Significant Difference, WAE = Weeks after emergence, Means in column followed by the same letter(s) are not significantly different at 5% level of significance.

The relative density (RD) of weed species was calculated as;

$$RD = \frac{\text{Number of individual weed species}}{\text{Total number of weed species}} \times 100$$

Similarly, (Sajid et al., 2012) reported the highest weeds density in weedy check; while, the lowest weeds density was noticed with application of s-metolachlor in pea (*Pisum sativum* L.). The significantly higher weed density with lowest s-metolachlor and pendimethalin application rate at both sites was in line with the finding of (Khan, Marwat, Khan, & Khan, 2003) who stated that reduced rates of herbicide are not advisable under heavy weed pressure. Moreover, at higher rates of application, absorption and translocation of the herbicide might have failed to keep pace with its metabolism compared to lower rates of application, thus weeds exposed to higher rate of herbicide application and proved more effective in reducing the density.

### 3.3. Weed dry weight

The effect of weed management practices on weed dry weight followed similar trends with broadleaved weeds and sedges at both sites. In line with this, the minimum weed dry weight was recorded with s-metolachlor 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE which was statistically in parity with weed free check at both sites (Table 3). Also the results revealed that application of 1.0 kg ha<sup>-1</sup> of s-metolachlor and pendimethalin each supplemented with one hand weeding has reduced weed dry weight by 96.4 and 93.3% at Haramaya and by 96.7 and 93.6% at Hirna, respectively over weedy check. Mostly the mechanism method used for unwanted plant control from the main crop land is mechanical techniques and herbicides in developed regions of the world while manual controlling method is taken as a trend due to the financial problem in many developing countries.

On the other hand, s-metolachlor 1.0 kg ha<sup>-1</sup> + one hand weeding 5 WAE gave significantly lower weed dry weight of 17.5g m<sup>-2</sup> at Haramaya and Hirna, in that order; compared to weed dry weight obtained with the application of s-metolachlor (1.0, 1.5 and 2.0 kg ha<sup>-1</sup>), pendimethalin (1.0, 1.25 and 1.5 kg ha<sup>-1</sup>) and one hand weeding 2 WAE under both sites. However, at Hirna, no significant difference observed between two hand weeding and pendimethalin 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE. The application of s-metolachlor (1.0, 1.5, and 2.0 kg ha<sup>-1</sup>) is performed better in weed control than pendimethalin at (1.0, 1.25 and 1.5 kg ha<sup>-1</sup>) across both sites. (Sajid et al., 2012) also reported better performance of s-metolachlor in reducing weed dry biomass as compared to pendimethalin, metribuzin and isoproturon in pea. (Agegnehu & Fessehaie, 2006) also reported that minimum dry biomass was recorded for pendimethalin, which was statistically comparable with s-metolachlor. At the same time as comparing one hand weeding at 2 WAE with two-hand weeding at 2 and 5 WAE, weed dry weight decreased similar to broadleaved weeds and sedge densities at both sites (Table 3). This might be due to the extent to which the weed species and or the density differed at both sites.

On the other hand, the higher weed dry weight in weedy check might also be due to higher weed density that provided an opportunity to the weeds to compete vigorously for nutrients, space, light, water and carbon dioxide resulting in higher biomass production. These results are in agreement with the findings of (Alfonso et al., 2013) and (Das & Yaduraju, 1999) who reported maximum weed dry weight in weedy check.

### 3.4. Crop phenology and growth

#### 3.4.1. Days to 50% flowering and 90% physiological maturity

Both days to 50% flowering and 90% physiological maturity were significantly influenced by weed management practices. Chickpea plants attained early average flowering date of 46.58 from experimental sites. The results revealed that under weed free check, days to flowering was statistically in parity with 1.0 kg ha<sup>-1</sup> of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE, two hand weeding at 2 and 5 WAE, s-metolachlor (1.5, and 2.0 kg ha<sup>-1</sup>) and one hand weeding at 2 WAE. In weedy check, the shading of crop plants by weeds might have reduced sunlight interception thus prolonged the vegetative growth resulting in delayed days to flowering (Table 5).

In line with this result, Sunday and Udensi (2013) identified that the plants in not weeded plots took the longest time to reach 50% flowering in cowpea. The influence of weed management practices on 90% days to physiological maturity was followed similar trend to 50% days to flowering at both sites. The physiological maturity of the crop was earlier by 11.17 and 10.33 days over low dose of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE at both sites.

#### 3.4.2. Plant height (cm)

The plants in weedy check plots attained significantly higher height (46.183 cm) than others weed management practices. This was followed by the application of two hand weeding at 2 and 5 WAE (41.90 cm) and one hand weeding at 2 WAE (41.03 cm) which did not show significant difference with the height measured in plots treated with pendimethalin at 1.0 kg ha<sup>-1</sup> + 5 WAE and s-metolachlor 1.0 kg ha<sup>-1</sup> + 5 WAE (Table 6).

Grishin (2001) reported a great demand for light, space, moisture and nutrients by plants with similar morphology and physiology. In agreement with present result, (Hock, Knezevic, Martin, & Lindquist, 2006) found differences in plant height due to various intensities of weed competition with crop plants.

**Table 5. Effect of weed management practices on average days to flowering and physiological maturity of Chickpea at Haramaya and Hirna districts during the 2016 cropping season**

Weed management practices	Days to flowering	Days to physiological maturity
S-metolachlor 1.0 kg ha <sup>-1</sup>	51.000 <sup>c-e</sup>	112.500 <sup>d-f</sup>
S-metolachlor 1.5 kg ha <sup>-1</sup>	52.000 <sup>bd</sup>	113.833 <sup>b-f</sup>
S-metolachlor 2.0 kg ha <sup>-1</sup>	50.167 <sup>de</sup>	115.500 <sup>b-e</sup>
Pendimethalin 1.0 kg ha <sup>-1</sup>	53.167 <sup>ab</sup>	116.583 <sup>b</sup>
Pendimethalin 1.25 kg ha <sup>-1</sup>	53.000 <sup>a-c</sup>	116.000 <sup>bc</sup>
Pendimethalin 1.5 kg ha <sup>-1</sup>	51.833 <sup>b-d</sup>	115.833 <sup>b-d</sup>
S-metolachlor 1.0 kg ha <sup>-1</sup> + 5 WAE	47.833 <sup>fg</sup>	111.500 <sup>fg</sup>
Pendimethalin 1.0 kg ha <sup>-1</sup> + 5 WAE	49.333 <sup>ef</sup>	112.333 <sup>ef</sup>
One hand weeding at 2 WAE	50.167 <sup>de</sup>	112.833 <sup>c-f</sup>
Two hand weeding at 2 and 5 WAE	50.250 <sup>de</sup>	115.500 <sup>b-e</sup>
Weed free check	46.583 <sup>g</sup>	108.833 <sup>g</sup>
Weedy check	54.667 <sup>a</sup>	122.667 <sup>a</sup>
LSD (0.05)	2.30	2.91
CV (%)	2.80	1.62

CV = Coefficient of Variation, LSD = Least Significant Difference, WAE = Weeks after Emergence, Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

### 3.5. Yield components and yield

#### 3.5.1. Number of chickpea plant at harvest

Site and weed management practices had significant influence ( $P < 0.01$ ) on number of chickpea plant ha<sup>-1</sup>. The crop stand was significantly higher by 6.35% at Hirna than at Haramaya. The lowest total weed density as well as weed dry weight at Hirna than at Haramaya might have contributed for the higher survival of crop plants (Tables 3 and 4). Weed free check gave the highest number of chickpea plant ha<sup>-1</sup> (227,864.58) which was significantly vary with s-metolachlor at 2.0 kg ha<sup>-1</sup>, s-metolachlor at 1.0 kg ha<sup>-1</sup> + one hand weeding 5 WAE, pendimethalin at 1.0 kg ha<sup>-1</sup> + one hand weeding 5 WAE and two hand weeding at 2 and 5 WAE (Table 6). Manual method of weed control consumes the time and cost of crop production by more than 50% and become the challenging barriers not change the livelihood of farmers and taking down the development of many emerging nations with the attraction for similar to earth gravity.

There was high number of chickpea plant at s-metolachlor at 2.0 kg ha<sup>-1</sup> but this treatment did not show significant differences with s-metolachlor at 1.0 kg ha<sup>-1</sup> and s-metolachlor at 1.5 kg ha<sup>-1</sup>. Further, the plants in weedy check had the lowest number of chickpea plant ha<sup>-1</sup> (147,570.31), which was significantly lower than the other weed management practices.

#### 3.5.2. Number of seeds per pod

Number of seeds pod<sup>-1</sup> revealed variations on the sites; weed management practices and their interaction. The highest number of seeds per pod (3.73) was obtained from the weed free check plots. This was followed by s-metolachlor 1.0 kg ha<sup>-1</sup> + one hand weeding at 5 WAE, which had statistically non-significant with s-metolachlor 1.0 kg ha<sup>-1</sup>, s-metolachlor 1.5 kg ha<sup>-1</sup>, pendimethalin 1.0 kg ha<sup>-1</sup>, one hand weeding 5 WAE, and two hand weeding at 2 and 5 WAE (Table 7). The development of more and healthy leaves under low weed infestation might have also helped to improve the photosynthetic efficiency of the crop and supported large number of pods (Hodgson & Blackman, 2005). Most weeds have a capacity to absorb water and uptake nutrients from soil with more efficient use than agricultural crop due to their adaptability to excess heat and waterless conditions.

**Table 6. Average Number of chickpea plant ( $ha^{-1}$ ), Plant height (cm), Seeds per pod and hundred seed weight (g) of Chickpea as influenced by the main effects of sites and weed management practices during the 2016 cropping season**

Factors	Number of chickpea plant ( $ha^{-1}$ )	Plant height (cm)	Pods per plant	Hundred seed weight (g)
Sites:				
Haramaya	184010 <sup>b</sup>	40.44 <sup>a</sup>	43.9889 <sup>a</sup>	39.4167 <sup>a</sup>
Hirna	196488 <sup>a</sup>	37.14 <sup>b</sup>	41.7889 <sup>b</sup>	34.3583 <sup>b</sup>
LSD (0.05)	12,478	0.8135	1.5959	0.7978
Weed management practices:				
S-metolachlor 1.0 kg $ha^{-1}$	206,705.73 <sup>b-d</sup>	32.267 <sup>j</sup>	42.667 <sup>ef</sup>	37.133 <sup>ef</sup>
S-metolachlor 1.5 kg $ha^{-1}$	211,588.54 <sup>bc</sup>	34.000 <sup>ij</sup>	52.533 <sup>bc</sup>	37.683 <sup>e</sup>
S-metolachlor 2.0 kg $ha^{-1}$	215,929.69 <sup>b</sup>	34.767 <sup>hi</sup>	41.567 <sup>fg</sup>	38.183 <sup>de</sup>
Pendimethalin 1.0 kg $ha^{-1}$	167,101.56 <sup>gh</sup>	36.133 <sup>gh</sup>	30.000 <sup>h</sup>	31.783 <sup>i</sup>
Pendimethalin 1.25 kg $ha^{-1}$	174,153.65 <sup>fg</sup>	37.033 <sup>fg</sup>	32.767 <sup>h</sup>	33.483 <sup>hi</sup>
Pendimethalin 1.5 kg $ha^{-1}$	183,377.60 <sup>ef</sup>	38.567 <sup>ef</sup>	37.933 <sup>g</sup>	35.633 <sup>fg</sup>
S-metolachlor 1.0 kg $ha^{-1}$ + 5 WAE	188,260.42 <sup>e</sup>	39.567 <sup>de</sup>	56.133 <sup>b</sup>	41.967 <sup>b</sup>
Pendimethalin 1.0 kg $ha^{-1}$ + 5 WAE	203,450.52 <sup>cd</sup>	40.167 <sup>c-e</sup>	40.100 <sup>fg</sup>	40.417 <sup>bc</sup>
One hand weeding at 2 WAE	198,026.04 <sup>d</sup>	41.033 <sup>cd</sup>	45.733 <sup>de</sup>	34.950 <sup>gh</sup>
Two hand weeding at 2 and 5 WAE	158,963.54 <sup>h</sup>	41.900 <sup>c</sup>	49.500 <sup>cd</sup>	39.900 <sup>cd</sup>
Weed free check	227,864.58 <sup>a</sup>	43.900 <sup>b</sup>	60.900 <sup>a</sup>	44.383 <sup>a</sup>
Weedy check	147,570.31 <sup>i</sup>	46.183 <sup>a</sup>	24.833 <sup>i</sup>	27.133 <sup>j</sup>
LSD (0.05)	8687.5	1.9927	3.9092	1.9542
CV (%)	4.38	4.41	7.83	20.38

CV = Coefficient of Variation, LSD = Least Significant Difference, WAE = Weeks after Emergence, NS = Not Significant, Means in column followed by the same letter(s) are not significantly different at 5% level of significance.

The lowest number of seeds per pod (3.03) was recorded from weedy check, which was significantly lower than all other interactions across both sites (Table 7). These results are in line with Hadi, Ghassemi-Golezani, Khoei, Valizadeh, and Shakiba (2006) who observed an increased number of pods  $plant^{-1}$  where weed population was reduced by management techniques. Similarly, (Pereira et al., 2015) and (Melaku, 2008) stated that the number of pods produced per plant or maintained to final harvest depends on a number of environmental and management practices.

### 3.5.3. Hundred seed weight (HSW)

Sites and weed management practices interaction significantly ( $P < 0.01$ ) influenced hundred seed weight. The highest seed weight (44.38 g) was obtained from weed free check while the lowest seed weight was revealed from the weedy check (27.13 g) (Table 6). Among the weed control treatments, application of 1.0 kg  $ha^{-1}$  of s-metolachlor supplemented with one hand weeding 5 WAE gave the highest seed weight (41.967 g), followed by application of 1.0 kg  $ha^{-1}$  pendimethalin supplemented with one hand weeding 5 WAE, two hand weeding at 2 and 5 WAE, s-metolachlor at 2.0 and 1.5 kg  $ha^{-1}$ . However,

**Table 7. Interaction effect of site and weed management practices on number of pods plant<sup>-1</sup>, grain and aboveground dry biomass yield (kg ha<sup>-1</sup>) and yield loss (%) in Chickpea at Haramaya and Hirna districts during the 2016 cropping season**

T	Grain yield (kg ha <sup>-1</sup> )	Grain yield (g/m <sup>2</sup> )	Above ground dry biomass (kg ha <sup>-1</sup> )	Harvest index (%)	Yield loss (%)
T1	1764.82 <sup>ef</sup>	176.482 <sup>ef</sup>	4253.7 <sup>ef</sup>	41.489 <sup>a</sup>	24.722
T2	1926.38 <sup>e</sup>	192.638 <sup>e</sup>	4797 <sup>de</sup>	40.158 <sup>a</sup>	17.831
T3	1983.05 <sup>de</sup>	198.305 <sup>de</sup>	5032.2 <sup>d</sup>	39.407 <sup>ab</sup>	15.414
T4	1332.06 <sup>i</sup>	133.206 <sup>i</sup>	3135.9 <sup>gh</sup>	42.478 <sup>a</sup>	43.181
T5	1480.31 <sup>hi</sup>	148.031 <sup>hi</sup>	4011 <sup>f</sup>	36.906 <sup>a-c</sup>	36.858
T6	1660 <sup>fg</sup>	166 <sup>fg</sup>	3699 <sup>fg</sup>	44.877 <sup>a</sup>	29.193
T7	2197.89 <sup>b</sup>	219.789 <sup>b</sup>	6243.9 <sup>ab</sup>	35.201 <sup>a-c</sup>	6.250
T8	2110.89 <sup>bc</sup>	211.089 <sup>bc</sup>	6448.5 <sup>a</sup>	32.735 <sup>a-c</sup>	9.961
T9	1122.37 <sup>gh</sup>	112.237 <sup>gh</sup>	3878.7 <sup>f</sup>	28.937 <sup>c</sup>	52.126
T10	1344.53 <sup>cd</sup>	134.453 <sup>cd</sup>	5760.6 <sup>c</sup>	23.340 <sup>c</sup>	42.650
T11	2344.41 <sup>a</sup>	234.441 <sup>a</sup>	5033.3 <sup>d</sup>	46.578 <sup>a</sup>	0
T12	999.79 <sup>j</sup>	99.979 <sup>j</sup>	2622 <sup>h</sup>	38.131 <sup>a-c</sup>	57.354
LSD (0.05)	52.475	52.475	212.44	0.0441	
CV (%)	7.57	7.57	11.52	9.93	

T: Treatments, CV = Coefficient of Variation; LSD = Least Significant Difference; T1 = S-metolachlor 1.0 kg ha<sup>-1</sup>; T2 = S-metolachlor 1.5 kg ha<sup>-1</sup>; T3 = S-metolachlor 2.0 kg ha<sup>-1</sup>; T4 = Pendimethalin 1.0 kg ha<sup>-1</sup>; T5 = Pendimethalin 1.25 kg ha<sup>-1</sup>; T6 = Pendimethalin 1.5 kg ha<sup>-1</sup>; T7 = S-metolachlor 1.0 kg ha<sup>-1</sup> + one hand weeding 5 WAE; T8 = Pendimethalin 1.0 kg ha<sup>-1</sup> + one hand weeding 5 WAE; T9 = One hand weeding at 2 WAE; T10 = Two hand weeding at 2 and 5 WAE; T11 = Weed free check; T12 = Weedy check; WAE = Weeks After Emergence; Means in column and row of same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

two hands weeding at 2 and 5 WAE did not vary significantly with one hand weeding 2 WAE (Table 6). Similarly, (Peer et al., 2013) reported that effect of different weed management practices might have resulted in attaining variable hundred seed weight. Meanwhile, significantly lower hundred seed weight (37.30 g) was recorded from Weedy check plots. In agreement with these findings, Peer et al. (2013) and Mekonnen, Sharma, Tana, and Nigatu (2015) observed lowest number of hundred seed weight of soybean in weedy check plots.

#### 3.5.4. Grain yield

Chickpea grain yield was significantly ( $P < 0.01$ ) influenced by the site, weed management practices and their interaction. The highest grain yield (2344.41 kg ha<sup>-1</sup> or 234.441 g m<sup>2</sup>) was obtained from complete weed free plot. However, as comparing the weed control treatments, the highest grain yield (2197.89 kg ha<sup>-1</sup> or 219.789 g m<sup>2</sup>) was recorded with s-metolachlor 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE, which was statistically in parity with pendimethalin 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE and two hand weeding at 2 and 5 WAE at the experimental sites and weed free check (Table 7). Furthermore, interaction effect revealed that no significant difference was existed among the grain yield obtained with two-hand weeding at 2 and 5 WAE and 1.0 kg ha<sup>-1</sup> of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE at Haramaya and one hand weeding 2 WAE. Excessive rain and irrigation is the suitable springboard for weed growth and become obstacles for the effective weed management.

Avola, Tuttobene, Gresta, and Abbate (2008) verified that chemical control determine a significant depressive effect on plant height and grain yield (25% less than manual weeding and untreated plots), mainly resulted a lower number of seeds to germinate that determine a plant density lower than the planned one. Similarly, Kumar and Singh (2010) observed some morphological changes in plants while

**Table 8. Partial budget analysis to estimate net benefit for weed management practices of Chickpea averaged over sites in 2016 cropping season**

Weed Management Practices	Average Yield (kg ha <sup>-1</sup> )	Adjusted Yield (kg ha <sup>-1</sup> )	Gross benefit (USD ha <sup>-1</sup> )	Total variable Cost (USD ha <sup>-1</sup> )	Net benefit (USD ha <sup>-1</sup> )
S-metolachlor 1.0 kg ha <sup>-1</sup>	1764.82	1588.34	1216.96	26.28	1190.68
S-metolachlor 1.5 kg ha <sup>-1</sup>	1926.38	1733.74	1328.36	30.96	1297.40
S-metolachlor 2.0 kg ha <sup>-1</sup>	1983.05	1784.75	1367.44	35.65	1331.79
Pendimethalin 1.0 kg ha <sup>-1</sup>	1332.06	1198.85	918.54	50.34	868.20
Pendimethalin 1.25 kg ha <sup>-1</sup>	1480.31	1332.28	1020.77	58.7	962.07
Pendimethalin 1.5 kg ha <sup>-1</sup>	1660	1494	1144.68	67.06	1077.62
S-metolachlor 1.0 kg ha <sup>-1</sup> + 5 WAE	2197.89	1978.10	1515.58	85.77	1429.81
Pendimethalin 1.0 kg ha <sup>-1</sup> + 5 WAE	2110.89	1899.80	1455.59	109.83	1345.76
One hand weeding at 2 WAE	1122.37	1010.13	773.94	118.98	654.96
Two hand weeding at 2 and 5 WAE	1344.53	1210.08	927.14	178.47	748.67
Weedy check	999.79	899.81	689.42	0	689.41

WAE = Weeks after crop emergence; Cost of pendimethalin and s-metolachlor 33.44 and 9.37 USD kg<sup>-1</sup>, respectively; Spraying 16.90 USD ha<sup>-1</sup>; Cost of hand weeding and hoeing 2 WAE 48 persons, 35 DAE 24 persons @USD 2.48/person; Sale price of Chickpea 0.88 USD kg<sup>-1</sup>; Field price of Chickpea 0.77 USD kg<sup>-1</sup>; Cost of harvesting, Threshing and winnowing 7.66 USD 100 kg<sup>-1</sup>; Packing and material cost 0.27 USD 100 kg<sup>-1</sup> and Transportation 0.32 USD 100 kg<sup>-1</sup>.

testing herbicides alone and in combination with other tank mix. Khan, Zaidi, and Aamil (2004) also found a significant reduction in shoot length under the application of herbicide isoproturon and 2,4-D. Barker (2007) reported that the lowest plant height in herbicides treated plots was might be due to the fact that herbicides greatly reduced the weed infestation, but affect the plant by reducing the plant height and other growth parameters. The pre-emergence herbicides when applied to the soil that make the upper soil layer toxin that not only affect the weed seed germination but also inhibit the crop growth as well to a certain extend. Drew, Gupta, and Roget (2008) reported that when legumes are exposed to several herbicides, reduced the nodulation and nitrogen fixation in these crops. Alvi, Perveen, Naqvi, and Shaukat (2003) observed a remarkable reduction in protein content of *Vigna radiata* (L. R. Wilczek) with the application of Atrazine.

### 3.5.5. Aboveground biomass yield

The interaction of weed management practices and the sites revealed highly significant differences on aboveground biomass. The interaction of weed free check with sites gave highest aboveground dry biomass (6448.5 kg ha<sup>-1</sup>), while the lowest value was obtained from weedy check (Table 7). The increased aboveground dry biomass in pendimethalin 1.0 kg ha<sup>-1</sup> + 5 WAE treatment might be due to the crop plants utilized the resources more efficiently that resulted in higher final crop stand (Table 6). However, increase in both herbicides rates did not bring a significant increase of aboveground dry biomass yield at both sites.

### 3.6. Harvest index

The interaction effect of weed management practices and the sites revealed significantly highest harvest index (46.578%) with weed free check and pendimethalin 1.5 kg ha<sup>-1</sup>. This had statistically in parity with the harvest index obtained in the interaction of the same site with application of pendimethalin 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE and two hand weeding at 2 and 5 WAE (Table 7). The result also showed no significant variation in harvest index between Haramaya and Hirna when pendimethalin at 1.0 kg ha<sup>-1</sup> was applied. Furthermore, at both sites, no significant difference existed among all rates of s-metolachlor applications whereas similar trends were not observed with rates of pendimethalin applications.

### 4. Yield loss

The amount of grain yield loss in Chickpea was affected by weeds in various weed management practices. As comparing weed management practices with each other, the highest yield loss (57.354%) was observed in weedy check plots over weed-free check. The next yield loss (52.126%) was obtained from the one hand weeding at 2 WAE, while comparing to weed free check, the lowest yield loss (6.25%) was recorded from s-metolachlor 1.0 kg ha<sup>-1</sup> supplemented by one hand weeding at 5 WAE (Table 7). In generally, the minimum yield loss was recorded with the application of 1.0 kg ha<sup>-1</sup> of s-metolachlor and pendimethalin each supplemented with one hand weeding 5 WAE at both sites. As the applied rates of both s-metolachlor and pendimethalin increases, the percent of the yield loss due to weeds under both sites become decreases. In line with this finding Tesfay Amare (2014) reported that the presence of weeds reduced grain yield by 82% over complete weed free check.

### 5. Partial budget analysis

An economic analysis on the combined results using the partial budget procedure (CIMMYT, 1988) was done due to grain yield was significantly affected (Table 7) by weed management practices. The results in Table 8 of this study showed that the two-hand weeding at 2 and 5 WAE had maximum (178.47 USD ha<sup>-1</sup>) total variable cost. This was followed by one hand weeding at 2 WAE (118.98 USD ha<sup>-1</sup>) and pendimethalin at 1.0 kg ha<sup>-1</sup> (109.83 USD ha<sup>-1</sup>) integrated with one hand weeding 5 WAE. The higher cost with hand weeding and hoeing than the other treatments was due to the difference in the cost incurred for manual weeding. The highest (1429.81 USD ha<sup>-1</sup>) gross benefit was obtained when 1.0 kg ha<sup>-1</sup> of s-metolachlor supplemented with one hand weeding at 5 WAE was used. This was followed by pendimethalin 1.0 kg ha<sup>-1</sup> + one hand weeding 5 WAE (1345.76 USD ha<sup>-1</sup>) and s-metolachlor 2.0 kg ha<sup>-1</sup> (1331.79 USD ha<sup>-1</sup>). The higher gross income in these treatments than in the other treatments was due to their higher yield. In the system of manageable agriculture improvement, it is fundamental to create enhanced techniques for weed control, which ought to give better preparations at financially practical dimensions without influencing the condition.

The lowest (689.42 USD ha<sup>-1</sup>) gross return was recorded in the weedy check plots. Similar to the gross benefit, the highest (1515.58 USD ha<sup>-1</sup>) net benefit was obtained with the application of s-metolachlor 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE. This was followed by pendimethalin 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding 5 WAE (1455.59 USD ha<sup>-1</sup>) and s-metolachlor 2.0 kg ha<sup>-1</sup> (1367.44 USD ha<sup>-1</sup>). The highest benefit in these treatments was due to the increased gross benefit despite their higher variable input cost. Similar results were also obtained when total variable input cost of the treatments was considered.

### 6. Conclusions

Application of 1.0 kg ha<sup>-1</sup> of s-metolachlor and pendimethalin each integrated with one hand weeding at 5 WAE are the most appropriate methods for effective weed management and economic benefit of Chickpea. Thus, controlling weeds with application of s-metolachlor and pendimethalin each at 1.0 kg ha<sup>-1</sup> supplemented with one hand weeding at 5 WAE proved to increase the grain yield and economic benefit of Chickpea. Nevertheless, in case labour is constraint and s-metolachlor herbicide is timely available, pre-emergence application of s-metolachlor at 2.0 kg ha<sup>-1</sup> should be the alternative to preclude the yield loss and to ensure maximum benefit. The results of this study further imply that, if farmers are unable to carrying out weeding at early stage due to labour competition, low dose of

herbicides at early stage are the best alternative they could use for enhancing the yield of the crop in the study area later on they can supplement with hand weeding. In developing countries the use of chemical herbicide is the choice with no options due to its high productivity for which control and reduce the crop loss that increase the land crop productivity which expected to feed fast growing population.

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#### Competing Interests

The authors declare no competing interests.

#### Author details

Bulti Merga

E-mail: [bultimerga@gmail.com](mailto:bultimerga@gmail.com)<sup>1</sup>

Nano Alemu<sup>1</sup>

E-mail: [nanoalemu2001@gmail.com](mailto:nanoalemu2001@gmail.com)

<sup>1</sup> School of Plant Sciences, Haramaya University, Dire Dawa, Ethiopia.

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