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Effect of weeding frequency and interval on onion (*Allium cepa* L.) bulb yield grown under irrigation condition at Arba Minch, Southern Ethiopia

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ABSTRACT: Field experiment was conducted at Arba Minch during 2017 and 2018 cropping seasons under irrigation condition to determine the effect of weeding frequency and interval on weeds and bulb yield of onion. The experiment was laid out in factorial arrangement in randomized complete block design with three replications and comprised of 18 treatments: four weeding frequencies (2, 3, 4 and 5 times) and four weeding intervals (at 10, 13, 17 and 25 days) compared with weedy and weed-free checks. Results showed that all the parameters considered in this study were significant ($p<0.05$) among the treatments. The lowest weed density (27.33 m^{-2} in 2017 and 24.26 m^{-2} in 2018) and dry weed biomass weight (0.83 t ha^{-1} in 2017 and 0.82 t ha^{-1} in 2018) were recorded in the weed free check without statistical difference with the values received from weeding interval at 10, 13 and 17 for four and five times weeding frequency in both cropping seasons. The highest weed control efficiency (83.70% in 2017 and 82.82% in 2018) was computed in the weed free plots. In the 2017 cropping season, the highest marketable bulb yield (32.8 t ha^{-1}) was recorded in the weed free check, which was statistically similar with the result obtained in four and five times weeding frequency at 10, 13 and 17 days weeding interval. Similar trends were observed during 2018 cropping season. Thus, three to five times frequency of weeding at 10 days weeding interval could be recommended in the study area for efficient weed management and optimization of the bulb yield and profits in onion production.

Keywords: *Allium cepa*, bulb yield, weeding frequency, weed density, weed free check, weed species.

INTRODUCTION

Onion (*Allium cepa* L.) is an important vegetable crop grown in the tropics and subtropics of the world where suitable conditions are available (Brewster, 2008; Fatih, 2018). In Ethiopia, onion grows in diverse agro-ecological conditions and constituted 14.67% of the cultivated area and 7.07% of the vegetable crop produced by small-scale farmers in 2016/17 main cropping season (CSA, 2017). It is grown mainly as cash crop and used as salad and value addition purpose for different dishes in Ethiopia and in Gamo zone in particular. In Ethiopia, onion production is increasing in different parts of the country due to its vital role in small-scale production systems as it serves as one component of commercialization of rural and urban peoples where it helped to generate daily income and helps them to improve their livelihood. Onion contributes to the national economy through export products like bulbs and cut flowers (Joosten et al., 2011).

Despite its importance, the national (9.8 t ha^{-1}) and Gamo zone (9.08 t ha^{-1}) average yield of onion under farmers conditions is lower (CSA, 2017) than its potential yield (30.0 t ha^{-1}) (Lemma and Shimeles, 2003). According to the baseline survey conducted by Simion et al. (2018), diseases, insect pests and weed are among the major constraints of onion production in Gamo zone. Moreover, weed causes a serious effect on the size of onion yields and it is identified as a major bottle neck in vegetable crops production next to diseases and insect pests (Lemma and Shimeles, 2003; Haile et al., 2016). Weed compete with onion for light, nutrient, water, space and also act as host plant of several harmful insects and pathogens and considerably reduce the yield, quality and value of the crop through increased production and harvesting costs (Uygur et al., 2010). Onion has very poor competitive ability with weeds due to its inherent characteristics: short stature, non-branching habit, sparse foliage, shallow root system and extremely slow growth in initial stages, which facilitate rapid growth of weeds (Ramalingam et al*.,* 2013). As a result, weed interference has reduced onion yield up to 40 to 80% in the world (Patel et al.,1983; Singh, 1983; Khatam et al., 2012) and 68 to 73% in Ethiopia (Etageneghu and Ahemed, 1985; Lemma and Shimeles, 2003; Grief, 2015) of the total production.

Weed management is one of the most important agricultural production practices. A number of weed management practices have been reported, including use of cultural, mechanical, herbicidal and the use of organic and inorganic mulches (Pushpa and Choudhary, 2019). To manage weeds effectively, weed management should contest with the specific problems under field condition. Hence, basic information on weed and crop ecology is needed to appropriately predict the impact of weeds on the crop yield. Many onion growers in the developing countries are not aware of many aspects regarding weed interference, frequency of weeding and the right time for weed removal (Akobundu, 1998). The first weed emergence time differed from place to place and varies according to the species ecological requirements (Forcella et al., 1997). Bond and Burton (1996) reported that the relative time of crop-weed emergence, the time of weed removal and frequency of weeding can strongly influenced crop production.

Growth and development of weeds can be suppressed by time interval and weeding frequencies. For this reason, for every crop, there is a need to determine the frequency of weeding and time interval when weeds need to be managed in order to prevent reduction in crop yield. Previous studies indicated that weeding frequency and interval significantly influence the infestation by weeds and the performance of crop grown due to their competition for natural resources (Tenaw et al., 1997; Rezene and Kedir, 2008; Rahman et al., 2011; Kumar, 2014). Inquiries on combined role of weeding frequency and interval against weed management and yield of onion might generate information suited for use as a practical component of weed management strategy. However, no information is available at Arba Minch, Southern Ethiopia on how frequency of weeding and time of interval affects weeds in onion or suit into an integrated weed management strategy under irrigation condition. Additionally, the effects of weed management practices vary with weed species, soil types, soil moisture, crop type and varieties, weather conditions and the interest of the growers. Therefore, this study was conducted to determine the effect of weeding frequency and interval on weeds and bulb yield of onion under irrigation condition at Arba Minch, Southern Ethiopia.

MATERIALS AND METHODS

Description of experimental site

Field experiment was conducted during 2017 and 2018 cropping seasons at Arba Minch in Southern Ethiopia under irrigation condition. Arba Minch is known with onion producing areas in the southern Ethiopia along with Abaya and Chamo lakes. The area is geographically positioned at 06º06'841" N latitude, 037º35'122" E longitude with an altitude of 1216 meter above sea level (Figure 1). Bimodal rainfall pattern is the major characteristics of the study area, short rainy season (March and April) and main rainy season (mid-August to mid-November). The details of weather data for the experimental site are presented in Table 1. In addition, the area is characterized with moderately alkaline, low organic contents (1.05%) and black sandy-loam in the soil type (MoANR and EATA, 2016).

Treatments, design of experiment and management procedures

The experiment was comprised of 18 treatments: four weeding frequencies (with 2, 3, 4 and 5 times) and four weeding intervals (at 10, 13, 17 and 25 days) compared with weedy check and weed-free check. The experiment was laid out in factorial arrangement in randomized complete block design replicated three times. The size of the unit plot was 2.4 m width x 2.4 m length, and consisted of six rows with spacing of 40 cm between rows. A spacing of 1.5 and 2.0 m was used to separate each plot and block respectively.

Seed of onion variety, *Bombey Red*, was sown at the rate of 4.0 kg ha^{-1} on a well-prepared seedbed at nursery on 04 August 2017 and 10 August 2018 cropping seasons. The main field total experimental area was ploughed three times with oxen driven implements. The clods were pulverized and crop stubbles were removed to facilitate the planting operation. Sixty days after sowing, vigorous and healthy onion seedlings with three to four true leaves were transplanted on 04 October 2017 and 10 October 2018 at 10 cm interval along the rows. Except for treatments, irrigation and nutrient management were performed to all plots uniformly and manually when necessary. Recommended fertilizer rate of 200 kg ha^{-1} of NPS was applied in rows at transplanting and 100 kg ha^{-1} of Urea was side dressed at 35 days after planting (EARO, 2004). Chlorpyrifos 48% EC at the rate of 0.2 L ha^{-1} (EARO, 2004) sprayed uniformly to all experimental plots for the control of onion Thrips which occurred during experimental seasons. A total of two sprayings were carried out per

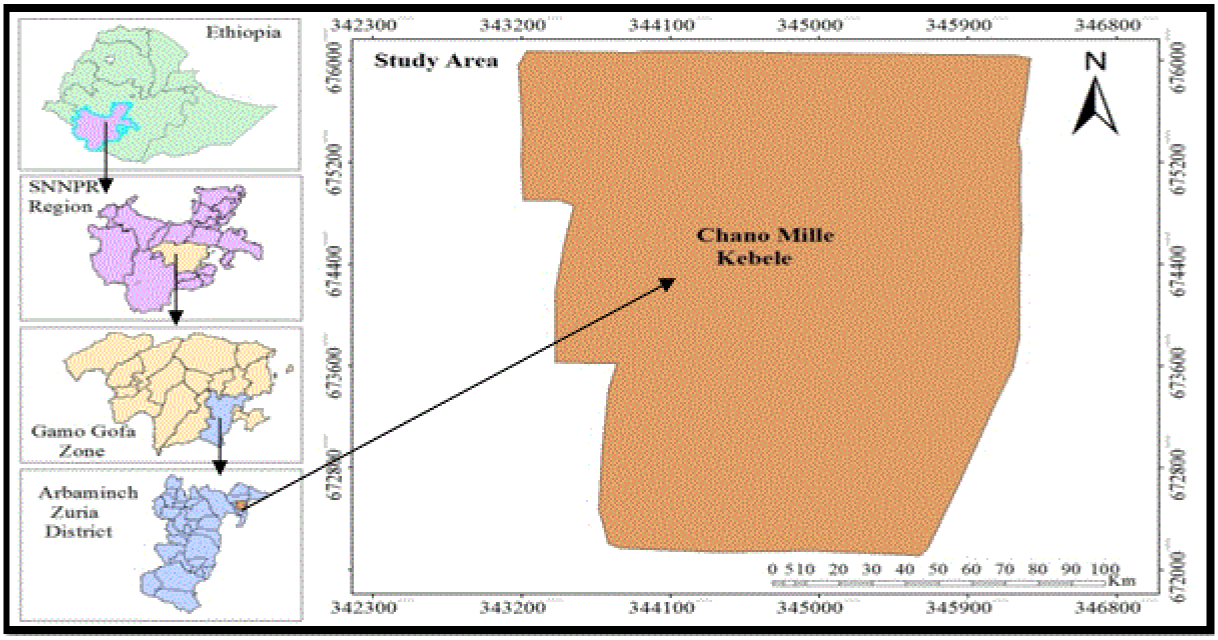

Figure 1. Map of the study area.

season during experiment.

Data collection

Weed parameters

Mixed weed population were used to determine weed density (WD in m^{-2}), weed control efficiency (WCE in %) and dry weed biomass weight (DBW in t ha^{-1}). Weed species recording were done on 1 m x 1 m quadrate from each plot prior to weeding practice; the sample quadrate size was 1 m^2. Quadrate was placed randomly in each plot and randomly selected sites were marked with the help of sticks in order to locate them for later recording, three sample quadrates per plot were examined. Weed species record and identification was made using weed identification book illustrated and organized by Stoud and Parker (1989) within the plots. The weed species found within the sample quadrates were sorted into their respective groups. Weed density (WD) and weed control efficiency (WCE) data were calculated with the following procedures as designed by Das (2008).

$$\mathrm{WD}\ (\mathrm{m}^{-2}) = \frac{\text{Total number of WS found in the plot}}{\text{Unit area of the plot}}$$

$$\mathrm{WCE}\ (\%) = \frac{\text{DBW in CT} - \text{DBW in a weed CT}}{\text{DBW in CT}}$$

Where, WS: Weed species, DBW: Dry weed biomass weight; WD: Weed density; WCE: Weed control efficiency; CT: Control treatment.

Weed samples were harvested at ground level for DBW measurements from each plot within an area of 1 m^2. The weeds were collected and sun dried for five to six days, and afterward they were put into an oven at 70°C until a constant reading was maintained to measure DBW. Dry weed biomass weight (DBW) was measured after complete drying of weeds.

Growth and yield parameters

Data on marketable bulb yield and growth attributes (plant height and number of leaves per plant) were collected from the central four rows of each plot to avoid border effects. Plant height was measured at physiological maturity using a ruler from the soil surface to the tip of the longest leaves and expressed in cm. Number of leaves per plant was determined from counts at physiological maturity. Plant height and number of leaves per plant were evaluated on 15 randomly taken plants in each plot and calculated as the average value. Marketable bulb yield was determined by weighing marketable bulbs obtained from each net plot and converted to t ha^{-1}.

Data analysis

The collected data were subjected to analysis of variance to determine the treatment effects using SAS software version 9.2 (SAS, 2009). The treatment means were separated using Fishers protected least significance difference (LSD) test at 5% probability level following the

Table 1. Monthly mean maximum and minimum temperature, rainfall and relative humidity of Arba Minch areas in Southern Ethiopia during 2017 and 2018 cropping seasons.

Month	2017 cropping season[1]				2018 cropping season[1]			
	Temperature (ºC)		Rainfall (mm)	Relative humidity (%)	Temperature (ºC)		Rainfall (mm)	Relative humidity (%)
	Maximum	Minimum			Maximum	Minimum		
January	39.86	17.83	95.50	45.93	32.85	15.96	1.50	40.76
February	36.43	16.47	37.50	39.72	35.05	16.09	2.70	36.29
March	44.49	19.99	27.00	39.07	34.00	19.10	57.10	42.73
April	35.33	18.98	42.20	60.37	32.11	18.24	122.40	59.07
May	37.36	18.77	57.00	61.30	29.45	18.88	177.50	69.07
June	31.90	17.88	95.50	56.00	NA	NA	NA	NA
July	38.45	18.05	45.80	NA	25.90	18.31	40.57	56.04
August	37.60	18.29	41.90	56.83	23.22	18.67	72.48	57.32
September	36.31	17.09	65.70	49.00	25.73	17.48	91.37	69.02
October	37.83	16.54	143.10	53.73	27.60	18.16	161.01	64.54
November	36.66	15.85	103.20	43.23	27.78	16.02	110.92	63.72
December	NA	NA	NA	NA	NA	NA	NA	NA
Mean	37.47	17.79	754.40	45.93	29.37	17.69	837.55	55.86

[1]NA= Data not available from meteorological station at the research center during the study periods. The data were obtained from National Meteorological Agency, Hawassa Branch (2018).

procedures described by Gomez and Gomez (1984). The two seasons were considered as different environments because of the significant variation in weather conditions and cropping years during the study period (Table 1). As the F-test of the error variances for the parameters measured of the two seasons was heterogeneous, the data were presented independently for each season.

Economic feasibility analysis

After taking into consideration of the fixed and variable inputs and their corresponding rates, the cost incurred on each treatment was computed. Based on the pooled data obtained from both cropping seasons, cost-benefit analysis was performed using partial budget analysis following the standard procedures described by CIMMYT (1988). Cost and benefit of each treatment were analyzed partially through considering the variable costs available for the respective treatments. The variable costs included seed of onion, weeding, insecticide cost and labour cost. Price of onion bulb (ETB kg^{-1}) was obtained from prevailing local market for each season and used their pooled price (17 ETB kg^{-1}) for the cost-benefit analysis and then the input cost and sale revenue were computed on hectarage basis. Cost of labor was 50 Birr per man per day for weeding and insecticide applications. However, the cost of onion seed, weeding and insecticide varied year after year but the mean value was used for economic analysis. In addition, relative percent of yield loss from each plot was calculated using the formula suggested by Robert and James (1991):

$$\text{Relative yield loss (\%)} = \frac{\text{Ybt} - \text{Ylt}}{\text{Ybt}} \text{x } 100$$

Where: Ybt is the yield of best treatment (maximum protected plot) and Ylt is the yield of lower treatments.

RESULTS AND DISCUSSION

Weed species

During 2017 and 2018 cropping seasons, the assessment made in the weed flora identification in the experimental plots revealed that there were 18 major weed species (Table 2). These identified weed species fell into seven different families and 13 genera. The identified weed species comprised of annual (12 species) and perennial (6 species) in their life cycle and could also be categorized into broadleaf (13 species), grasses (3 species) and sieges (2 species) in their nature of growth habit. The dominant weed species family was Asteraceae with five species, followed by Poaceae and Amaranthaceous, each with three species. Out of the identified weed species, 39% were classified as

Table 2. Weed species and their taxonomical characteristics in onion field under irrigation condition at Arba Minch in Southern Ethiopia during 2017 and 2018 cropping seasons.

Family name	Scientific name	Common name	Classification	Life form	Category	Life cycle
Asteraceae	*Xanthium strumarium*	Cocklebur	Dicot	Herb	Broad leaf	Annual
Asteraceae	*Galinsoga parviflora*	Gallant soldier	Dicot	Herb	Broad leaf	Annual
Asteraceae	*Bidenspilosa*	Black jack	Dicot	Herb	Broad leaf	Perennial
Poaceae	*Digitariaternata*	Crabgrass	Monocot	Grass	Grass	Annual
Poaceae	*Brachiariaeruciformis*	Signal grass	Monocot	Herb	Grass	Annual
Euphorbiaceae	*Acalyphacrenata*	Copperleaf	Dicot	Shrub	Broad leaf	Annual
Euphorbiaceae	*Euphorbia heterophylla*	Milkweed	Dicot	Herb	Broad leaf	Annual
Tiliaceae	*Corchorusolitorius*	Jew's mallow	Dicot	Shrub	Broad leaf	Annual
Cyperaceae	*Cyperusesculentus*	Yellow nut sedge	Monocot	Siege	Siege	Perennial
Cyperaceae	*Cyperusrotundus*	Nut siege	Monocot	Siege	Siege	Perennial
Poaceae	*Eragrostiscilianensis*	Stink grass	Monocot	Grass	Grass	Annual
Commelinaceae	*Commelinabenghalensis*	Wandering Jew	Monocot	Herb	Broad leaf	Perennial
Commelinaceae	*Commelinalatifolia*	Water maker	Monocot	Herb	Broad leaf	Perennial
Amaranthaceae	*Amaranthus graecizans*	Mediterranean amaranth	Dicot	Herb	Broad leaf	Annual
Amaranthaceae	*Amaranthus hybridus*	Green amaranth	Dicot	Herb	Broad leaf	Annual
Amaranthaceae	*Amaranthus spinosus*	Spiny amaranth	Dicot	Herb	Broad leaf	Annual
Asteraceae	*Launaeacornuta*	Wild lettuce	Dicot	Herb	Broad leaf	Perennial
Asteraceae	*Parthenium hysterophorus*	Congress weed	Dicot	Herb	Broad leaf	Annual

monocots and the rest were dicots (61%).

Xanthium strumarium, *Galinsoga parviflora, Bidens pilosa, Brachiaria eruciformi*, *Digitaria ternate, Amaranthus hybridus*, *Cyperus esculentus* and *Acalyphacrenata* were the most predominant species followed by the rest of weed species in the plots (Table 2). During 2017 and 2018 cropping seasons, the itemized major weed species were amongst the major invasive species in relation to socially, environmentally and economically to the farming communities in the study area. Most of the weed species identified in the present study were in line with Bekele et al. (2006), Sankar et al. (2015) and Terfa (2018) who reported that the weed species found in onion field were comprised of a wide range of annual, biennial and perennial in life cycle and broad leaved, grasses and sieges in nature of growth habit.

Weed density

The interaction effect of frequency of weeding and weeding interval in weed management of onion showed significant ($p<0.01$) difference for weed density among treatments in both 2017 and 2018 cropping seasons (Table 3). In the 2017 cropping season, the highest weed density was recorded in the weedy check (121 m^{-2}) due to no removal of weeds during the growing periods. However, the value found from weedy check was statistical in parity with the values obtained from weeding interval at 10, 13, 17 and 25 for two and three times and at 25 days interval for four and five times of weeding frequency during 2017 cropping season. Similar trends were observed during 2018 cropping season. In contrast, the lowest weed density was recorded in the weed free check (27.33 m^{-2} in 2017 and 24.26 m^{-2} in 2018) as a result of proper weed removal during the crop growing period, which was statistical in parity with the values received from weeding interval at 10, 13 and 17 for four and 10, 13, 17 and 25 for five frequency of weeding in the two cropping seasons (Table 3). The more weed density in an area of 1 m^2 might be due to enough soil moisture, which favoured weeds to emerge from soil seed bank. Bond and Burton (1996), Akobundu (1998) and Rahman et al. (2012) reported that frequency of weeding and appropriate time of weed removal could significantly affected weed infestation. Similarly, Ravinder et al.

Table 3. Interaction effect of weeding frequency and interval on weed density, dry weed biomass weight and weed control efficiency on weed management of onion under irrigation condition at Arba Minch in Southern Ethiopia during 2017 and 2018 cropping seasons.

Weeding frequency	Weeding interval	Treatments					
		2017 cropping season			2018 cropping season		
		WD (m^{-2})	DBW (t ha^{-1})	WCE (%)	WD (m^{-2})	DBW (t ha^{-1})	WCE (%)
Two times	At 10 days	104.67^{ab}	3.54^{c-e}	31.08^{d-f}	101.60^{a-c}	1.32^{ab}	20.34^{fg}
	At 13 days	109.67^{ab}	3.82^{c-e}	25.68^{e-g}	106.61^{ab}	1.31^{ab}	18.06^{g}
	At 17 days	111.67^{ab}	4.75^{a-c}	7.56^{f-h}	108.60^{ab}	1.39^{ab}	17.35^{gh}
	At 25 days	115.33^{ab}	5.01^{ab}	2.43^{gh}	112.25^{ab}	1.39^{ab}	13.57^{gh}
Three times	At 10 days	74.00^{a-f}	2.29^{e-g}	58.65^{a-c}	70.92^{a-f}	1.00^{b-d}	36.05^{ef}
	At 13 days	77.00^{a-e}	2.50^{ef}	55.41^{b-d}	73.92^{a-e}	1.00^{b-d}	24.81^{e-g}
	At 17 days	80.67^{a-d}	2.99^{d-f}	51.35^{cd}	77.60^{a-e}	1.11^{a-c}	24.69^{e-g}
	At 25 days	87.67^{a-d}	3.06^{d-f}	41.89^{c-e}	84.60^{a-d}	1.25^{a-c}	21.14^{fg}
Four times	At 10 days	42.67^{d-g}	1.06^{gh}	79.73^{ab}	39.60^{d-g}	1.41^{fg}	64.64^{b-d}
	At 13 days	52.33^{c-g}	1.11^{gh}	79.73^{ab}	49.27^{c-g}	0.48^{fg}	59.52^{cd}
	At 17 days	67.33^{b-g}	1.11^{gh}	78.38^{ab}	64.27^{b-g}	0.63^{d-g}	58.67^{d}
	At 25 days	72.67^{a-f}	2.01^{f-h}	60.86^{a-c}	69.60^{a-f}	0.97^{b-d}	38.75^{e}
Five times	At 10 days	30.33^{fg}	1.04^{gh}	79.73^{ab}	27.27^{fg}	0.28^{fg}	78.62^{ab}
	At 13 days	36.67^{fg}	1.04^{gh}	79.73^{ab}	33.60^{e-g}	0.42^{fg}	76.19^{a-c}
	At 17 days	67.33^{b-g}	1.11^{gh}	78.38^{ab}	64.27^{b-g}	0.56^{e-g}	70.40^{a-d}
	At 25 days	72.33^{a-g}	1.81^{f-h}	64.86^{a-c}	69.27^{a-g}	0.83^{c-f}	67.78^{a-d}
Weedy check	No weeding at all	121^{a}	5.14^{a}	0.00^{h}	118^{a}	1.67^{a}	0.00^{h}
Weed free check	Weeded for long time	27.33^{g}	0.83^{h}	83.7^{a}	24.26^{g}	0.21^{g}	82.82^{a}
WF * WI		**	**	**	**	**	**
Mean		75.35	2.51	51.09	75.35	0.85	45.97
LSD (5%)		3.07	1.29	25.29	3.07	0.42	17.47
CV (%)		22.09	31.23	29.89	22.09	29.55	24.55

Means followed by the same letters within each column are not significantly different. WD = weed density in m^{-2}; DBW = Dry weed biomass weight in t ha^{-1}; WCE= Weed control efficiency in %; WF= Weeding frequency; WI = Weeding interval; WF * WI = Interaction effect of Weeding frequency x Weeding interval; * and ** = Significant at p ≤ 0.05 and 0.01, respectively; CV = Coefficient of variation (%); and LSD = Least significant difference at $p < 0.05$ probability level.

(2001) and Jilani et al. (2007) demonstrated that weed infestation on onion field was lower due to frequently weeded at the right time of weed removal. Season wise comparisons indicated that the overall weed density was higher during 2017 than 2018 cropping season, which could be explained by the prevailing relatively better weather condition for weed growth in the growing period during 2017 cropping year (Table 1).

Dry weed biomass weight

Analysis of variance revealed that significant ($p<0.01$) differences were observed among the treatments evaluated in weed management of onion for dry weed biomass weight (DBW) in both 2017 and 2018 cropping seasons (Table 3). The highest DBW was recorded in the weedy check plots with 5.14 t ha^{-1} in 2017 and 1.67 t ha^{-1} in 2018, which was statistical in parity with the values obtained from weeding interval at 17 and 25 for two times frequency of weeding during 2017 cropping season and weeding interval at 10, 13, 17 and 25 for two times and at 17 and 25 for three times weeding frequency during 2018 cropping season. Conversely, the lowest DBW of 0.83 t ha^{-1} in 2017 and 0.82 t ha^{-1} in 2018 was noted in the weed free plots. However, the value obtained from weed free plots was statistically similar with the values found from weeding interval at 10, 13, 17 and 25 for all frequency of weeding during 2017 and 10, 13 and 17 for four and five times weeding frequency during 2018 cropping season. Comparing the two years, there was higher DBW in 2017 than 2018 cropping year. Keeping the plots with weed-free using proper frequency of weeding and appropriate time of weed removal resulted in lower weed dry biomass weight (Table 3). Similarly, Nandal and Ravinder (2002), Rahman et al. (2012) and Tripathy et al. (2013) reported that integrated weed management of onion including cultural practices with proper weeding frequency and at the right time of weed removal proved to be effective in the weed parameters measured.

Weed control efficiency

Weed control efficiency (WCE) was significantly ($p<0.01$) influenced by the interaction effect of weeding frequency and weeding interval in weed management of onion in both 2017 and 2018 cropping seasons (Table 3). Most of the evaluated weed control treatments caused significant reduction in weed infestation as compared to the weedy check. Based on the weed dry biomass weight on weed free plots, highest WCE (83.70% in 2017 and 82.82% in 2018) was computed in the weed free plots in both cropping seasons. However, the value found in weed free plots was statistically at parity with four and five times weeding frequency in combination with weeding interval at 10, 13, 17 and 25 during 2017 cropping season. Similar trends were perceived during 2018 cropping season. However, the lowest WCE (0.00%) was demonstrated in the treatment plots of weedy check/without weed control (Table 3). Just in case of weed management tactics, cultural weed control tactics through proper frequency of weeding in combination with the right time of weed removal found to be effective to keep the weed infestations during the critical crop growth period. Channapagoudar and Biradar (2007), Zubiar et al. (2009) and Rahman et al. (2011) also noticed that higher WCE was obtained with hand weeding throughout the crop-growing season as compared to weedy check in onion crop.

Plant height, number of leaves per plant and yield parameters

In both 2017 and 2018 cropping years, interaction effect of frequency of weeding and weeding interval in weed management of onion significantly ($p<0.05$) altered plant height (PH), number of leaves per plant (NLP) and marketable bulb yield (MBY) of onion (Table 4). The tallest values of PH (44.14 cm in 2017 and 62.66 cm in 2018) and maximum NLP (8.88 n<u>o</u> $plant^{-1}$ in 2017 and 13.66 n<u>o</u> $plant^{-1}$ in 2018) were recorded in the weed free check, which were statistically not different with the rest of the treatment combinations except for the weedy check and two times frequency of weeding at 10 and 13 on PH and 10, 13, 17 and 25 on NLP weeding interval in both cropping seasons.

In the 2017 cropping season, the highest MBY (32.80 t ha^{-1}) was recorded in the weed free check; however, the result obtained in the weed free check was statistically similar with the result obtained in four and five times frequency of weeding at 10, 13 and 17 weeding interval. Conversely, the lowest (13.90 t ha^{-1}) was recorded in the weedy check plots, which was statistically equivalent to the values obtained from two and three times (at 10, 13, 17 and 25 weeding interval) and four and five times (at 25 weeding interval) of weeding frequency during 2017 cropping season. Similar trends were observed during 2018 cropping season. The possible reason for highest MBY in these treatments might be due to lesser crop-weed competition at earlier and later stages of growth such as more availability of space, light, moisture and nutrients to the onion plants, which induces greater number of leaves per plant.

Season-wise comparisons showed that the overall PH, NLP and MBY were higher during 2018 than 2017 cropping season, which might have been explained by the prevailing weather condition that favoured the higher weed infestations that suppressed the growth of onion and resulted in lower measured of crop parameters during 2017 cropping year (Table 1). From the obtained results, it is possible to understand that weed management of onion through manual weeding for appropriate frequency of weeding at the right weeding interval played an important role in increasing onion bulb yield, which could be attributed to their favourable effects on bulb yield contributing parameters such as number of leaves per plant. As noticed by Shah et al. (1996), Dhananivetha et al. (2017) and Pushpa and Choudhary (2019), accurate manual weeding through frequency of weeding and at the right time of weed removal significantly reduced weed infestations and better in increasing the onion growth and yield parameters when compared with weedy check plots.

Economic feasibility and relative yield loss analysis

There were variations among the evaluated treatment

Table 4. Effect of weeding frequency and interval on plant height, number of leaf per plant and bulb yield of onion at Arba Minch in Southern Ethiopia during 2017 and 2018 cropping seasons.

Weeding frequency	Weeding interval	Treatments					
		2017 cropping season			2018 cropping season		
		PH (cm)	NLP	MBY (t ha^{-1})	PH (cm)	NLP	MBY (t ha^{-1})
Two times	At 10 days	35.92^{a-c}	5.55^{b-d}	20.20^{f-i}	49.66^{cd}	16.33^{ab}	17.70^{d-g}
	At 13 days	35.90^{a-c}	5.21^{b-d}	18.00^{g-i}	49.11^{cd}	15.99^{ab}	13.70^{e-g}
	At 17 days	33.83^{bc}	4.33^{cd}	17.40^{g-i}	48.33^{cd}	15.77^{ab}	12.20^{e-g}
	At 25 days	33.76^{bc}	4.10^{cd}	15.30^{hi}	46.77^{cd}	14.55^{b}	10.70^{fg}
Three times	At 10 days	38.29^{a-c}	6.66^{a-d}	22.90^{d-g}	51.40^{b-d}	16.66^{ab}	2.03^{b-g}
	At 13 days	38.28^{a-c}	6.66^{a-d}	21.90^{e-g}	50.44^{b-d}	16.77^{ab}	2.00^{b-g}
	At 17 days	38.22^{a-c}	6.42^{a-d}	20.80^{f-h}	49.99^{b-d}	16.44^{ab}	1.97^{b-g}
	At 25 days	38.14^{a-c}	6.32^{a-d}	20.50^{f-h}	49.77^{b-d}	16.33^{ab}	1.85^{c-g}
Four times	At 10 days	42.71^{ab}	8.20^{ab}	29.90^{ab}	57.33^{a-c}	20.27^{a}	28.20^{a-c}
	At 13 days	41.49^{a-c}	7.05^{ab}	29.50^{a-c}	57.22^{a-c}	19.27^{ab}	27.20^{a-d}
	At 17 days	39.40^{a-c}	7.09^{ab}	28.10^{a-e}	54.99^{a-d}	18.88^{ab}	22.00^{a-c}
	At 25 days	39.25^{a-c}	6.97^{a-d}	23.60^{c-g}	53.00^{a-d}	17.77^{ab}	20.70^{c-e}
Five times	At 10 days	43.81^{a}	8.88^{a}	31.90^{a}	60.83^{a}	21.21^{a}	31.00^{ab}
	At 13 days	42.71^{ab}	8.20^{ab}	31.30^{ab}	57.44^{a-c}	20.66^{a}	29.00^{ab}
	At 17 days	40.32^{a-c}	7.43^{ab}	28.30^{a-d}	56.11^{a-d}	19.11^{ab}	24.70^{a-d}
	At 25 days	39.35^{a-c}	7.00^{a-d}	25.70^{b-f}	54.77^{a-d}	18.00^{ab}	20.80^{c-g}
Weedy check	No weeding at all	33.32^{c}	3.66^{d}	13.90^{i}	44.00^{d}	13.66^{b}	10.70^{fg}
Weed free check	Weeded for long time	44.14^{a}	8.88^{a}	32.80^{a}	62.66^{a}	21.22^{a}	39.00^{a}
WF * WI		*	**	**	**	**	*
Mean		38.46	6.50	23.90	52.99	17.77	20.90
LSD (5%)		8.98	3.03	0.62	11.12	5.55	1.02
CV (%)		14.11	28.24	15.72	12.67	18.81	17.01

Means followed by the same letters within each column are not significantly different.PH = Plant height in cm; NLP = Number of leaf per plant; WF= Weeding frequency; WI = Weeding interval; WF * WI = Interaction effect of Weeding frequency x Weeding interval; * and ** = Significant at p ≤ 0.05 and 0.01, respectively; CV = Coefficient of variation (%); and LSD = Least significant difference at $p < 0.05$ probability level.

combinations in net benefit (NB), marginal rate of return (MRR) and relative yield losses (RYL) (Table 5). The pooled results of the 2017 and 2018 cropping seasons exhibited that weed free check gave the highest NB (536458.30 ETB ha^{-1}) and followed by weeding frequency of five times (473568.00 ETB ha^{-1}) and four times (438153.50 ETB ha^{-1}) at weeding interval of 10 days in the two cropping seasons, respectively. Conversely, the

Table 5. Economic feasibility and relative yield loss of weeding frequency and interval of onion under irrigation at Arba Minch in Southern Ethiopia during 2017 and 2018 cropping seasons.

Weeding frequency	Weeding interval	Treatments						
		Bulb yield (t ha^{-1})	AY (t ha^{-1}) 10% down	TVC (ETB ha^{-1})	GI (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)	RYL (%)
Two times	At 10 days	19.00	17.10	3771.10	290700	286928.90	26.18	47.08
	At 13 days	15.90	14.31	3771.10	243270	239498.90	-78.75	55.71
	At 17 days	14.80	13.32	3771.10	226440	222668.90	59.05	58.77
	At 25 days	13.00	11.70	3771.10	198900	195128.90	51.74	63.79
Three times	At 10 days	21.60	19.44	3771.10	330480	326708.90	86.63	39.83
	At 13 days	21.00	18.90	7076.50	321300	314223.50	44.40	41.50
	At 17 days	20.30	18.27	7076.50	310590	303513.50	42.89	43.45
	At 25 days	19.50	17.55	7076.50	298350	291273.50	41.16	45.68
Four times	At 10 days	29.10	26.19	7076.50	445230	438153.50	61.92	18.94
	At 13 days	28.40	25.56	8382.00	434520	426138.00	50.84	20.89
	At 17 days	25.10	22.59	8382.00	384030	375648.00	44.82	30.08
	At 25 days	22.20	19.98	8382.00	339660	331278.00	39.52	38.16
Five times	At 10 days	31.50	28.35	8382.00	481950	473568.00	56.50	12.26
	At 13 days	30.20	27.18	11687.50	462060	450372.50	38.53	15.88
	At 17 days	26.50	23.85	11687.50	405450	393762.50	33.69	26.18
	At 25 days	23.30	20.97	11687.50	356490	344802.50	29.50	35.10
Weedy check	No weeding at all	12.30	11.07	0.00	188190	188190.00	0.00	65.74
Weed free check	Weeded for long time	35.90	32.31	12811.70	549270	536458.30	41.87	0.00

Mean unit price of onion bulb per kilogram was 17 ETB at the time of selling during 2017 and 2018 cropping seasons. AY = Adjusted yield down to 10%; TVC = Total variable cost, input costs; GI = Gross income; NB = Net benefit; and RYL = Relative yield lose in percent.

lowest NB of 222668.90, 195128.90 and 188190.00 ETB ha^{-1} were recorded from two times of frequency of weeding at weeding interval of 17, 25 and weedy check plots in both cropping seasons, respectively. The higher NB from the aforementioned treatments could be accredited to high bulb yield and the low NB was attributed to low bulb yield. The highest MRR was computed from three times (86.63%) and followed by four times (61.92%) frequency of weeding at 10 days weeding interval in the two cropping seasons. However, the least MRR (-0.73 and -0.01%) was calculated from two times frequency of weeding at 17 and 25 days weeding interval in the two cropping years (Table 5). Therefore, from the economic point of view, it was apparent that the use of three, four and five times weeding frequency at 10 days weeding interval were the most profitable among all other treatments and could be recommended for the farmers.

In both 2017 and 2018 cropping years, RYL varied among the evaluated treatments (Table 5). The highest RYL of up to 58.82, 63.78 and 65.63% was calculated from two times frequency of weeding at 17 and 25 days of weeding interval and weedy check as compared to the maximum managed plots (0.00) in the two cropping years. The losses in bulb yield could be attributed to the severe infestation of weeds at full-growth stage of the plant, which gradually retarded the growth through resource competition and reduced the yield obtained from of the crop. Under severe infestation, onion plants are almost devoid of leaves at early crop growth stages due to withering and drying of the leaves and led to considerable yield losses. Yield losses of 40 to 80% due to severe weed infestation have been reported in onion crop in different parts of the world (Singh, 1983; Khatam et al., 2012; Patel et al., 2012).

Conclusion and recommendation

Based on the results of present study, it was concluded that management of weed in onion crop with either three or four or five times frequency of weeding at 10 days weeding interval was more convenient and economically feasible for weed control in onion field under irrigation condition. Thus, it could be recommended to onion growers in the study area and vicinity with similar agro-ecological conditions for efficient management of weeds and optimization of the bulb yield and profits in onion production under irrigation condition.

CONFLICT OF INTEREST

The authors declared that they have no conflict of interest.

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