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Evaluation of Chemical and Cultural Methods of Weed Management in Potato (Solanum tuberosum L.) in Gishe District,North Shewa, Ethiopia

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Abstract
A field experiment was conducted in Gishe District, North Shewa, using irrigation during February to June in 2013. The objectives were to identify the most effective method of weed management in potato production as well as to assess the effect of herbicides and their rates of application on weeds and the crop. The treatments consisted of sixteen weed control methods, *viz*. atrazine (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0, 1.5 and 2.0 kg ha^{-1}), s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}), isoproturon (1.0, 1.5, 2.0 kg ha^{-1}), one hand weeding and hoeing 20 days after crop emergence (dae), two hand weeding 20 and 40 days after crop emergence (dae), complete weed free and weedy check. The experiment was laid out in randomized complete block design with three replications. Herbicides were applied as preemergence. The weed community comprised of grass (45.5%) and broadleaved (54.5%) weeds. Weed density and dry weight were significantly reduced by weed management methods. Isoproturon and pendimethalin on grass and atrazine on broadleaved weeds were more effective. Pendimethalin gave good control of *Snowdenia polystachya* while atrazine failed to control *Amaranthus hybridus* and *Chenopodium fasciculosum*. Application of isoproturon and pendimethalin each at 2.0 kg/ha, and hand weedings at 20 and 40 dae resulted in more than 80% weed control efficiency over the weedy check. Isoproturon and pendimethalin had higher herbicide efficiency index than atrazine and s-metolachlor. Weed management practices did not significantly influence days to emergence, number of stems/hill, plant height, number of unmarketable tuber/hill and specific gravity of potato tubers. On the other hand isoproturon at 1.5 and 2.0 kg/ha and pendimethalin at 1.5 kg/ha gave number of marketable tubers/hill statistically at par with complete weed free check. Marketable tuber weight/hill was maximum in complete weed free plot and had significantly higher total tuber weight/hill than other treatments. There was no significant difference in marketable and total tuber yield between complete weed free and isoproturon at 2.0 kg/ha and the latter treatment was also statistically in parity with pendimethalin at 2.0 kg/ha and two hand weeding at 20 and 40 dae. Unchecked weed growth throughout the crop growth period resulted in 62.1% loss in tuber yield which was reduced to 6.8, 10.3 and 12.4% with the application of isoproturon at 2.0 kg/ha, pendimethalin at 2.0 kg/ha and two handweeding at 20 and 40 dae, respectively. The cost-benefit analysis indidated that preemergence application of isoproturon at 2 .0 kg/ha was the best proposition for acceptable weed management in the study area under irrigated conditions.
Keywords: hand weeding, pre-emergence herbicides, *Solanum tuberosum*, tuber yield, weed density and dry weight.

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important food crops in the world. Among the root and tuber crops, potato ranks top followed by cassava, sweet potato and yams in volume of production and consumption and is produced in 140 countries(FAO, 2004) In volume of crop production, potato ranks fourth following wheat, maize, and rice in the world. It is regarded as a high-potential food security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops,like maize, sorghum *etc*. (Adane *et al.,* 2010). It is, a temperate-cool season crop, is grownup to 4000 m of altitude above sea level

Ethiopia is endowed with suitable climatic and edaphic conditions for potato production and has possibly the highest potential for potato production of any country in Africa and an estimated 70% of the 10 million hactars of the country's arable land is potentially suitable for potato production (FAO, 2008). However, still its production trend shows fluctuations with area coverage as well as productivity from year to year. The crop yield in Ethiopia is lower than that of most potato producing countries in Africa, like Egypt and Zimbabwe, which produced 21 and 16 t/ha, respectively (FAO, 2008). In Ethiopia potato covers an area of 69,784 ha and its production and yield were 785800 t and 11.26 t/ha respectively (FAO, 2008).

The low acreage and yield are attributed to diverse and complex abiotic, and biotic factors, of which weeds often pose a serious problem. It is well documented that uncontrolled weed growth does cause heavy yield losses in the major crops of Ethiopian agriculture (average 25-32%) (Fasil, 2006). Weeds have a direct influence on the affairs of humans more than any other pest in developing countries, like Ethiopia. They not only cause severe crop losses but also compel farmers and their families to spend a considerable proportaion of their time for weeding, limiting further development in other areas of the rural economy. The weed flora of Ethiopia is highly diverse and it is composed of a wide range of perennial and annual grasses and broadleaved weeds, sedges, parasitic and invasive weed species (Fasil, 2006).

In Ethiopia, weeds are controlled mainly by hand weeding, but also by good agricultural practices such as repeated and deep ploughing, delayed planting and crop rotations. Some mechanical weeding are also carried out, using simple traditional implements or some modern tools. All of which are neither adequate nor timely. Therefore, it is imperative to develop an efficient and economical way of management weeds through the use of herbicides (Kebede, 2000).

Weed management through chemicals results in better growth of crop and often improves yield of tubers than manual and mechanical means due to the elimination of mechanical damage to the plants and the reduction in moisture losses from the soil that follow cultivation (Atiq *et al*., 2009). Further the authors reported that chemical weed management is quicker and much less laborious by which large areas can be covered in a short time with limited amount of labor. Though, manual weeding is a traditional and common practice for management weeds in potato, marginalities of labor and prevalence of frequent rains many times prevent the timely management of weeds at critical periods of crop growth.

From the beginning of the growing season until plants reach a height of 25-30 cm, potato is very susceptible to weed infestation. Loss assessment studies revealed that most crops are highly sensitive to weed competition, especially early in their growth stages (Fasil, 2006).Therefore, preemergence weed control through herbicides plays a very vital role in order to preclude weed-crop competition at an early stage of the crop to come up with a successful crop production (Eberlein *et al*., 1997). Herbicide rates also vary under different environmental conditions and may differ in their ability to suppress different weeds.

Gaps and challenges despite the importance of potato crop in ethiopia county, less research attention is given to crops in general..Regarding weed problems, the following gaps are waiting to be filled urgently: 1) qualitative and quantitative determination of weeds in different agroecologies, 2) weed-crop competition studies for determination of economic threshold levels and critical weed-free periods, 3) appropriate cultural and chemical control methods against grass and broad-leaf weeds and development of integrated weed management strategies,4) appropriate frequency and time of hand weeding, and 5) creation of awareness among farmers about weeds.

There are a number of weed controlling methods in potato production. The commonly useful methods include cultural, mechanical and chemical methods. Though all these methods are applicable, weeds have been infesting potato tuber due to prolific seed production and non- pronounced break out. Besides, Irish potato (*Solanum tuberosum L.*), is widely grown in the country The Irish potato is grown on a land area of 50,000 hectares in Ethiopia (Tenaw et al., 2001). in the country agriculture It is becoming an important food and cash crop for small-scale farmers; howeve, high weed growth and infestation are dramatically decrease production and productivety of potato. To control weeds under through cultural and mechanical methods specially hand weeding is tedious and sometimes damages crop also (Tenaw *et al*., 1997). As a result, early weed competition in potato is high and results low crop yield. In this situation, using herbicides for the management of weeds is a better option than other weed control methods. Therefore, an experiment was conducted with the specific objectives to:

i) Assess the effect of herbicides and their rates of application on weeds and crop.
ii) Evaluate the effect of weeds on growth, yield components and yield of potato.
iii) iii) Find out the most effective method of weed management in potato.

2 .Materials and Methods

2.1. Description of the study area

A field experiment was conducted in Gishe District, North Shewa Zone of Amhara Regional State, Ethiopia, during February to June 2013 using irrigation. The site is situated at an altitude of 2710 m a.s.l. and 388 km North of Addis Ababa along Debrebrhan road.

The area receives mean annual rainfall of 1100 mm. The average annual maximum and minimum temperature are 22°C and 6°C, respectively.The main rainy season is from late June to early September which accounts for about 85 %t of the total rainfall, while the remaining 15 % is received from February to April. The soil type in the area is predominantly nitisols with pH 6.85 and organic matter content of 4.25%. The total nitrogen and available phosphorus was 8200 and 13.14 ppm, respectively.

2.2. Experimental materials

The potato variety Jalanie (CIP-37792-5) released in 2002 was used in the experiment, where the research was conducted It flowers and matures in 45-55 and 90-120 days after planting, respectively. It has whiteflowers and the tuber flesh color is yellowish. The plant attains a height of 66 cm. The yield at the Research Center and Farmers' field was 40.3 and 29.1 t ha^{-1}, respectively The variety was released by the Holetta Agricultural Research Center ,for mid and high altitude areas.

2.3. Treatments and experimental design

Sixteen weed management practices, atrazine, isoproturon, pendimethalin and S-metolachlor, each in three level (1, 1.5 and 2 kg/ha) ,once and twice hand weeding and hoeing ,complete weed free and weedy checks were used as treatment variables.

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The plot size was 3.75 m x 3.0 m (11.25 m^2). There were 5 rows of potato in each plot. The outer most one row in each plot and one plant from each end of the rows were considered as border. Thus, the net plot size was 2.25 m x 2.4 m (5.4 m^2)

2.4. Management practices

i) Land preparation: The experimental field was ploughed twice to get fine seed bed and plots were leveled manually after the field layout was made.

ii) Planting: The well sprouted, medium sized (weight of 30 upto 79g) whole seed tubers with the sprout length of 1.5 to 2.5 cm (Lung′aho el.,2007) of the potato cultivar Jalenie were manually planted on 10^{th} February 2013 in inter- and intra row spacing of 75 and 30 cm, respectively at adepth of 10cm and coverde with soil.The space between adjcent.plots was 1 meter where as the space between adjcent blocks was 1.5meter.

iii) Fertilizer application: The fertilizer urea (46%N) and DAP (18%N; 46%P_2O_5) were applied with the recommended rates of 111 kg/ha N and 89.7 kg P_2O /ha(165 kg urea and 195 kg DAP each /ha)(Berga *et al.*, 1994). The whole dose DAP were applied by slightly opening the soil at each hill at the depth of 10 cm below and around the seed tuber at the time of planting. Half of the N and full dose of P_2O_5 was applied at the time of planting while the remaining N was split applied at pre flowering stage.

iv) Herbicide application: All the herbicidal treatments were applied as preemergence one day after planting of potato with knapsack sprayer using a spray volume of 450 l /ha.

v) Hand weeding and hoeing/complete weed free: Hand weeding (hand pulling and hoeing) was done in the assigned plots as per the treatment. Complete weed free plots were maintained by hand removing or pulling of weeds and /or frequent hand hoeing so that no weeds remain in the specified plots.

vi. Irrigation: Irrigation water was applied as much as and when required and mostly once in ten days.

vii) Dehaulming: The aboveground biomass was cut from the surface when the tubers were well developed approximately 15 days before the expected harvesting time.

viii) Harvesting: Plotwise harvesting was done by hand digging about 15 days after dehaulming, i.e. on June 28, 2013. The tubers were washed with water to remove the soil from the surface of each tuber and marketable tubers were separated

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2.5. Data collection

2.5.1. Weeds

Weed community: The weed floras present in the experimental field were recorded at 20 and 40 days after crop emergence and about 15 days before expected date of physiological maturity of crop. Weeds were identified and listed by respective scientific names in to their respective families and category. The weeds that were easy to identify were recorded in the field and catagorize with the help of taxonomists. Who have been working in.combolcha plant clinic. Those species which could not be identified were categorized by Combolcha plant clinic using books (FAO, 1989, IAR 1986).

Weed density and dry weight: These observations were recorded just before the first hand weeding and hoeing (20 days after crop emergence), second hand weeding and hoeing (40 days after crop emergence) and about 15 days before expected date of potato physiological maturity. A quadrat of 0.5 m x 0.5 m was placed randomly at two places in each plot and weed species were counted in each quadrate. The weed density thus recorded was categorized as broadleaved or grassy. The data were transformed by using the formula ($\sqrt{x}$ +0.5) to minimize the variation among the populations. While recording weed density, the weeds were also cut near the soil surface from each quadrat. The harvested weeds were placed into paper bags separately and sun dried before placing in an oven at a 65^0C temperature till constant weights and subsequently the dry weight of weeds were measured. Both density and dry weight were converted to square meter.

Relative density- It is defined as the dominance of particular weed species over other species in number in a mixture of weed population and expressed in percentage Category wise weeds,*i.e.* broadleaved and grass weed were counted and their relative densities were calculated as: ((Devasenapathy *et al.*, 2008).

$$RWD = \frac{NPW}{NPTW} \times 100$$

Where RWD= Relative weed density, NPW=Number of a particular weed species per unit area, NPTW= Number of total weed species per unit area

Weed control efficiency (WCE)
Weed control efficiency was calculated to determine the variation in the dry matter weight accumulated due to competition with the potato plants of the treated plot or to estimate the competitive ability of weed at different growth stages as compare to the weedy check (Walia, 2003) and was computed as:.

$$WCE = \frac{DWC - DWT}{DWC} \times 100$$

Where, WCE = Weed Control Efficiency, DWC = Dry weight of weeds in control plot and DWT = Dry weight of weeds in a particular treatment

Based on the data obtained from weeds and crops the following weed index was calculated

Weed Index (Relative yield loss)(%): It was measured with the help of the following formula as described by (Balasubramaniyan and Palaniappan, 2007).

$$WI = (\frac{X - Y}{X}) \times 100$$

Where WI= Weed Index, X= Yield in complete weed free and Y= Yield in a particular treatmen
Based on the data obtained from weeds and crops the following herbicide efficiency index (HEI) was calculated:
Herbicide Efficiency Index (HEI): It is a weed killing potential of herbicide treatments, its phytotoxicity on the crop
Crop
Days to emergence: The number of days from planting to 50% of sprouts in a plot was recorded.
Number of stems per plant: The total number of stems per hill was counted to find number of stems per plant based on five randomly taken plants from the net plot area in each plot.
Plant height (cm): The height of highest stem was measured from the ground level to the apex of stem before dehaulming based on five randomly taken plants from the net plot area in each plot.
Number of total and marketable tubers per plant: The total tuber number and the marketable tubers (≥ 25g) were counted in each sample plant and the average of five plants was taken as number of total and marketable tubers per plant based on five randomly taken plants from the net plot area in each plot.
Total and marketable tuber weight (g) per plant: Weight of total tuber number and the marketable tubers (≥ 25g) tubers were recorded to determine tuber weight per plant.s
Tuber size distribution:
This refers to the proportional weight of tubers in size categories. All tubers from five randomly taken plants were categorized into small (< 39 g); medium (39-75 g), and large (>75 g) according to (Lung'aho *et al*., 2007). The proportion of the weight of each tuber category was then being expressed in percentage.
Total and marketable tuber yield (kg/ha): It was recorded from the net plot area of each treatment converted in to yield per hectare (t/ ha).
Haulm weight (kg/ha): The dried haulm weight from the net plot area was measured and converted in to hectarege (kg/ha.)
Specific gravity of the tuber (SG): It was determined by the weight in air minus weight in water method. Five kilogram of tubers of all size and shapes was randomly taken from each plot. The tubers were washed with water. The samples, weight in air was recorded and then re -weighted by suspending in water. The specific gravity was calculated using the following formula (Kleinkopf *et al*., 1987)

$$\text{Specific gravity} = \frac{\text{Weight of tubers in air}}{\text{Weight of tubers in air - Weight of tubers in water}}$$

2.6. Soil Sampling and analysis
Representative soil samples were randomly taken at 0-30 cm depth from the experimental field just before planting to make one composite sample. The collected soil samples were air dried in wooden trays, ground and sieved to pass through a 2 mm sieve for analysis of physical and chemical characteristics. The samples were analyzed for soil texture (particle size) by using hydrometer method of Bouyoucos (Day 1965), pH was determined by using digital pH meter, total nitrogen by micro-Kjeldahl method (Dewis and Freitas, 1970), available phosphorus using Olsen method as described by Olsen and Dean (1965), organic matter by Walkley and Black method as described by Dewis and Freitas (1970) and soil cation exchange capacity (CEC) was determined by ammonium acetate method.

2.7. Statistical analysis
Data were subjected to analysis of variance (ANOVA) and least significant difference (LSD) test was performed to compared the treatment means as per the procedure descrided by Gomez and Gomez (1984) using SAS Statistical software (Version 9.1).Data on weed density were transformed by square root transformation method before conducting analysis of variance..

3. Results and Discussion

3.1 Weeds

3.1.1. Weed community

Eleven weed species belonging to six families were found to infest the experimental fields (Table 4). Out of the total weed species grass and broadleaved weeds constituted 45.5% and 54.5%, respectively.

Weed density (m-2) at 20 days after crop emergence

Weed density was significantly influenced ($p<0.05$) by herbicidal management practices. At 20 days after crop emergence, the highest ($5.73m^{-2}$) number of grass weeds was recorded in the weedy check plots, which were significantly reduced with the application of herbicides. Increasing the rates of herbicides resulted in reduction in grass weed density, however, it was significant with the application of isoproturon at 2.0 kg/ha over its lower rate (1.0 kg/ ha) and s-metolachlor at both1.5 and 2.0 kg/ha over s-metolachlor at 1.0 kg/ha, while no significant difference existed between the respective rates of atrazine and pendimethalin.

Similar to grass weeds, broadleaved weed density was also significantly influenced by different weed management treatments at 20 dae. At this stage of the crop, the highest ($5.14m^{-2}$) number of broadleaved weeds was also recorded from weedy check which was also significantly higher than the herbicide treatments.Among the herbicide treatments, significantly the lowest ($1.58\ m^{-2}$). broadleaved weed density was observed with the application of atrazine at 2.0 kg/ha Contrary to the grass weeds, there was no significant difference among respective herbicide rates (Table 5). This might be due to the control of narrow spectrum of broadleaved weeds present in the experimental field by the herbicides; consequently, no significant difference was found among the rates.The research data revealed that the total weed density was minimum with the application of isoproturon at 2.0 kg /ha ;however, it was statistically in parity with the application of isoproturon (1.0 and 1.5 kg/ha) and with all rates of pendimethalin and atrazine application rates. Application of s-metolachlor was not as effective as other herbicides; nevertheless, its higher rate i.e. 2.0 kg/ha had no significant difference with isoproturon (1.0 and 1.5 kg/ha) pendimethalin (1.0 and 1.5 kg/ha) and atrazine at 1.0 kg/ha. On the other hand, it was observed that with the increasing rates of all the herbicides there was reduction in the total weed density. At this stage all the herbicides resulted in significant reduction of total weed density over the weedy check.

Weed density (m-2) at 40 days after emergence

At 40 days after potato emergence, the minimum ($3.38\ m^{-2}$) grass weed density occurred with the application of isoproturon at 2.0 kg /ha which was significantly lower than the other herbicidal and cultural treatments. The maximum ($6.47\ m^{-2}$) grass density was found in the weedy check which was significantly reduced with the application of herbicidal and cultural treatments. Hand weeding at 20 days after crop emergence knocked down the emerged weeds and the subsequent weed flush could not reach a significant level; therefore, at this stage there was also no significant difference between the hand weeding treatments and herbicides except isoproturon (1.5 and 2.0 kg/ha) and pendimethalin at 2.0 kg/ha which had significantly lower grass density than hand weeding.

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Table 1. Effect of different weed management methods on weed density at 20 days after potato emergence

Weed management methods	Weed density (m^{-2}) at 20 days after crop emergence		
	Grass	Broadleaved	Total
Isoproturon 1 .0 kg ha^{-1}	4.02(15.66)^{bc}	2.92(8.00)^{de}	4.91(23.66)d^{e}
Isoproturon 1.5 kg ha^{-1}	3.85(14.33)^{bc}	2.67(6.66)^{de}	4.63(20.99)^{ef}
Isoproturon 2.0 kg ha^{-1}	3.32(10.50)^{c}	2.85 (7.66)^{de}	4.32(18.16)^{f}
Pendimethalin 1.0 kg ha^{-1}	3.89(14.66)^{bc}	3.08 (9.00)^{dc}	4.91(23.66)^{de}
Pendimethalin 1.5 kg ha^{-1}	3.72 (13.33)^{c}	3.18(9.66)^{dc}	4.84(22.99)^{def}
Pendimethalin 2 0 kg ha^{-1}	3.48(11.00)^{c}	2.85(7.66)^{de}	4.40(18.66)^{ef}
S-metolachlor 1.0 kg ha^{-1}	5.37(28.33)^{ba}	3.39(11.00)^{dc}	6.31(39.33)^{b}
S-metolachlor 1.5 kg ha^{-1}	4.34(18.33)^{bac}	3.48(11.66)^{dc}	5.52(29.99)^{c}
S-metolachlor 2.0 kg ha^{-1}	4.34(18.33)^{bac}	3.08(9.00)^{dc}	5.27(27.33)^{c}
Atrazine 1.0 kg ha^{-1}	4.34(18.33)^{bac}	1.96(3.33)^{e}	4.70(21.66)^{def}
Atrazine 1.5 kg ha^{-1}	4.14(16.66)^{bc}	1.87(3.00)^{e}	4.50(19.66)^{ef}
Atrazine 2.0 kg ha^{-1}	4.14 (16.66b)^{c}	1.58(2.00)e	4.40(18.66)^{ef}
Hand weeding and hoeing 20 days after crop emergence (dae)	5.70 (32.40)^{a}	5.03(24.80)^{ba}	7.59 (57.20)^{a}
Hand weeding and hoeing 20 and 40 days after crop emergence (dae)	5.70(32.00)^{a}	5.11(25.64)^{a}	7.62(57.64)^{a}
Complete weed free (CWF)	0.71 (-).00^{d}	0.71(-).00^{f}	0.71(--).00^{g}
Weedy check (WC)	5.73 (32.30)^{a}	5.14(26.00)^{a}	7.67(58.30)^{a}
LSD(0.05)	0.541	0.493	0.6825
CV(%)	7.8	9.9	8.0

Figures in parentheses are the original values, CV=coefficient of variation, LSD= least significant difference means with the same letters are no significantly diffrent,

Among different herbicides, the minimum(1.78 m^{-2}) number of broadleaved weeds was recorded with the application of atrazine at 2.0 kg/ha; which was significantly lower than other herbicide treatments in reducing broadleaved weed densit; however, significantly at par with atrazine at 1.5 kg/ha. This showed more effectiveness of atrazine than other herbicides in controlling broadleaved weeds. The density of broadleaved also decreased with the increase in herbicides application rates but was significant with the application of isoproturon at 1.5 and 2.0 kg/ha over its lowest rate and the application of atrazine at 2.0 kg/ha over atrazine at 1.0 kg/ha (Table 6).

Weedy check plots registered significantly higher (5.87 per m^{-2}). broadleaved weed density than the other treatments At 40 days after crop emergence all the treatments significantly reduced total weed density over weedy check. Among the herbicidal treatments, application of atrazine at 2.0 kg/ha resulted in lowest (4.81/m^2) total weed density which was statistically in parity with the other rates of atrazine, isoproturon at 1.5 and 2.0 kg/ha and pendimethalin at 2.0 kg/ha.

Hand weeding at 20 dae had no significant difference from isoproturon and s-metolachlor each at 1.0 kg/ha while two hand weeding proved more effective and in addition, had no significant difference with pendimethalin and s-metolachlor each at 1.5 kg/ha. However, higher total weed density in hand weeding might be due to the fact that the hand weeding knocked down the emerged weeds and at the same time made possible to bring the weed seeds from lower to upper soil layer. Due to the availability of favorable environmental conditions, especially the temperature and aeration in the top soil stratum, might have triggered the germination and emergence of weeds. This result agrees with the finding of Sharma *et al*. (2000) who reported significantly higher weed density from hand weeded plots. The total weed density was also significantly higher in weedy check than the other treatments.

Table 2 . Effect of different weed management methods on weed density at 40 days after potato emergence in Gishe during 2013 cropping season

Weed management methods	Weed density (m^{-2}) at 40 days after crop emergence		
	Grasses	Broadleaved	Total
Isoproturon 1.0 kg ha^{-1}	$4.74(22.00)^{cb}$	$4.03(15.80)^{cb}$	$6.18(37.80)^{b}$
Isoproturon 1.5 kg ha^{-1}	$3.96(15.20)^{ed}$	$3.27(10.20)^{fg}$	$5.10(25.40)^{hg}$
Isoproturon 2 .0 kg ha^{-1}	$3.38(14.30)^{e}$	$3.19(9.66)^{g}$	$4.98(24.30)^{h}$
Pendimethalin 1.0 kg ha^{-1}	$4.49(19.66)^{cb}$	$3.67(13.00)^{ced}$	$5.75(32.66)^{ced}$
Pendimethalin 1.5 kg ha^{-1}	$4.60(20.66)^{cb}$	$3.53(12.00)^{fed}$	$5.75(32.66)^{ced}$
Pendimethalin 2.0 kg ha^{-1}	$4.14(16.66)^{cd}$	$3.44(11.33)^{fed}$	$5.33(27.99)^{hgfed}$
S-metolachlor 1.0 kg ha^{-1}	$4.81(22.66)^{b}$	$3.49(11.66)^{fed}$	$5.90(34.32)^{ced}$
S-metolachlor 1.5 kg ha^{-1}	$4.71(21.66)^{cb}$	$3.29(10.33)^{fg}$	$5.70(31.99)^{cfed}$
S-metolachlor 2.0 kg ha^{-1}	$4.63(21.00)^{cb}$	$3.24(10.00)^{fg}$	$5.58(30.66)^{gfed}$
Atrazine 1.0 kg ha^{-1}	$4.81(22.66)^{b}$	$2.12(4.00)^{h}$	$5.21(26.66)^{hgfe}$
Atrazine 1.5 kg ha^{-1}	$4.81(22.66)^{b}$	$1.96 (3.33)^{ih}$	$5.15(25.99)^{hgf}$
Atrazine 2.0 kg ha^{-1}	$4.53(20.00)^{cb}$	$1.78(2.66)^{i}$	$4.81(22.66)^{h}$
Hand weeding and hoeing 20 days after crop emergence(dae)	$4.93(23.82)^{b}$	$4.06 (16.00)^{b}$	$6.34(39.82)^{b}$
Hand weeding and hoeing 20 and 40 days after crop emergence(dae)	$4.98(24.33)^{b}$	$3.81(14.00)^{cbd}$	$6.23 (38.33)^{cb}$
Complete weed free(CWF)	$0.71(-).00^{f}$	$0.71(-).00^{j}$	$0.71 (-).00^{i}$
Weedy check(WC)	6.47(41.33)a	$5.87(34.00)^{a}$	$8.71(75.33)^{a}$
LSD(0.05)	0.501	0.268	0.545
CV%	6.8	5.00	6.00

Figures in parentheses are the original values, CV=coefficient of variation, LSD= least significant difference at 5% level of significance, means with the same letters are no significantly diffrent,.

Table 3. Effects of different weed management methods on weed density at harvest of the crop in Gishe during 2013 cropping season

Weed management methods	Weed density (m^{-2}) at harvest of crop		
	Grasses weed	Broadleaved weed	Total weed
Isoproturon 1.0 kgha^{-1}	$5.01(24.66)^{cde}$	$3.29 (10.33)^{fe}$	$5.96 (34.99)^{dfe}$
Isoproturon 1.5 kg ha^{-1}	$4.71(21.66)^{fgde}$	$3.03 (8.66)^{f}$	$5.55 (30.32)^{hg}$
Isoproturon 2.0 kg ha^{-1}	4.19(17.00)g	$3.29(10.33)^{fe}$	$5.27 (27.33)^{h}$
Pendimethalin 1.0 kg ha^{-1}	4.60(20.66)fge	$3.81(14.00)^{dc}$	$5.90 (34.66)^{fge}$
Pendimethalin 1.5 kg ha^{-1}	$4.74 (22.00)^{fde}$	$3.94 (15.00)^{c}$	$6.12 (37.00)^{dfec}$
Pendimethalin 2.0 kg ha^{-1}	$4.30(18.00)^{fg}$	$3.59 (12.00)^{de}$	$5.56 (30.40)^{hg}$
S-metolachlor 1.0 kg ha^{-1}	$5.34(28.00)^{cb}$	$4.02(15.66)^{c}$	$6.64 (43.66)^{c}$
S-metolachlor 1.5 kg ha^{-1}	$5.15(26.00)^{cd}$	$3.94(15.00)^{c}$	$6.44 (41.00)^{dc}$
S-metolachlor 2.0 kg ha^{-1}	$5.15(26.00)^{cd}$	$3.81(14.00)^{dc}$	$6.36 (40.00)^{dce}$
Atrazine 1.0 kg ha^{-1}	$5.05(25.00)^{cde}$	$2.55(6.00)^{g}$	$5.61 (31.001)^{lfg}$
Atrazine 1.5 kg ha^{-1}	$5.15(26.00)^{cd}$	$2.55(6.00)^{g}$	$5.70 (32.00)^{hfg}$
Atrazine 2.0 kg ha^{-1}	$4.98 (24.33)^{cdc}$	$1.97(3.39)^{h}$	$5.31(27.72)^{h}$
Hand weeding and hoeing at 20 days after crop emergence (dae)	$5.87 (34.00)^{b}$	$5.10(25.40)^{b}$	$7.74 (59.40)^{b}$
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	$4.38 (18.66)^{fg}$	$3.08 (9.00)^{f}$	$5.31(27.66)^{h}$
Complete weed free (CWF)	$0.71(-).00^{h}$	$0.71(-).00^{i}$	$0.71 (-).00^{i}$
Weedy check (WC)	$7.54 (56.33)^{a}$	$6.47 (41.40)^{a}$	$9.91(97.73)^{a}$
LSD(0.05)	0.490	0.381	0.503
CV(%)	6.1	6.6	5.1

Figures in parentheses are the original values, CV=coefficient of variation, LSD= least significant difference at 5% level of significance means with the same letters are no significantly diffrent,

Atrazine at 2.0 kg/ha continued to perform better than other treatments and resulted in significantly lower (1.97 m^{-2}) broadleaved weed density than the other treatments. It was also revealed that there was no significant difference among the respective herbicide rates in case of isoproturon, pendimethalin and s-metolachlor. This was probably due to the dissipation of herbicides in the soil, which might be due to microbial activity and the adsorption in the soil colloids. Hand weeding twice at 20 and 40 dae, resulted in statistically at par with broadleaved density due to isoproturon but significantly superior to pendimethalin and s-metolachlor application at this stage. At crop harvest, the application of isoproturon at 2.0 kg/ha gave lowest total weed density, which was statistically in parity with its lower rate (1.5 kg/ha), pendimethalin at 2.0 kg/ha, all rates of atrazine and hand weeding and hoeing at 20 and 40 dae. Two hand weeding at 20 and 40 dae also proved significantly better (5.33 (weeds/m^2) than one hand weeding, at 20 dae (7.74 weeds/m^2) as well as the application of isoproturon at 1.0 kg/ha (5.96 (weeds/m^2) pendimethalin at 1.0(5.9 weeds/m^2) and 1.5 kg/ha(6.12 weeds/m^2) and s-metolachlor at all the rates of application with the density of 6.64, 6.44, 6.36 weeds/m^2 respectively to the ascending rate of s-metolachlor The emerged weeds after first hand weeding were uprooted during the second hand weeding and the developed crop canopy might have not allowed the resurgence of new weeds. Like at other growth stages, weedy check plot had also significantly higher (9.91) total weed density than the other treatments at crop harvest (Table 7).

3.1.3. Weed Relative density

The data on relative density of different weed categories indicated that grass weeds were more dominant than broadleaved weeds under all weed management methods (Table 8). Among all the weeds,*Snowdenia polystachya* was found to be the most dominant weed which might have contributed to the higher relative weed density. One hand weeding 20 dae resulted in lowest relative density of grass weeds, but was statistically at par with the weed density due to pendimethalin at 1.0 kg/ha, s-metolachlor, isoproturon at 2.0 kg/ha and atrazine and s-metolachlor at all rates of application.

Though not significant, application of pendimethalin proved better than other herbicides in reducing the grass relative weed density. This might be probably due to the more effectiveness of this herbicide in controlling *Snowdenia polystachya.* than other treatments.On the other hand, atrazine application at 1.5 and 2.0 kg/ha significantly reduced broadleaved weeds infestation and resulted in significantly lower relative weed density (19.36 and 18.75% respectively) than the other treatments. However, it failed to control *A hybridus* and *C. fasciculosum.* The variation in relative weed density might be the resultant of more or less effectiveness of the treatments on one or the other type of weeds present in the experimental field. The results of this experiment are similar to the findings of Sharma *et al*, (2000) and Sharma *et al*.(2004) who reported effective management of grass weeds with pendimethalin and metolachlor. However, it is pertinent to mention that relative weed density merely showed the composition and/or proportion of different weed categories present under different treatments and, therefore, it may not be the weed killing ability of a particular treatment against a particular category of weeds. Hand weeded and weedy check plots also showed higher relative weed density of grass than broadleaved weeds that indicated greater infestation of grass than broadleaved weeds in the experimental field. This might be probably due to higher build up of grass seed bank in the experimental field. Hence, there was comparatively lower broadleaved weed relative density in weedy check which might be due to the result of inter-specific competition among the weed species.

Table 4. Effect of different weed management methods on weed relative density, in Gishe during 2013 cropping season

Weed management methods	Relative weed density (%)	
	Grass	Broadleaved
Isoproturon 1.0 kg ha^{-1}	70.48^{cb}	29.52^{d}
Isoproturon 1.5 ha^{-1}	71.15^{b}	28.85^{d}
Isoproturon 2 0 kg ha^{-1}	62.60^{cbd}	37.40^{bac}
Pendimethalin 1.0 kg ha^{-1}	59.61^{cd}	40.39^{ba}
Pendimethalin 1.5 kg ha^{-1}	59.46^{cd}	40.54^{ba}
Pendimethalin 2.0 kg ha^{-1}	59.21^{cd}	40.79^{ba}
S- metolachlor 1.0 kg ha^{-1}	64.13^{cbd}	35.87^{bc}
S- metolachlor at 1.5 kgha^{-1}	63.41^{cbd}	36.59^{bac}
S -metolachlor at 2.0 kg ha^{-1}	63.41^{cbd}	36.59^{bac}
Atrazine 1.0 kg ha^{-1}	65.00^{cbd}	35.00^{bdc}
Atrazine 1.5 kg ha^{-1}	80.64^{a}	19.36^{e}
Atrazine 2.0 kg ha-^{1}	81.25^{a}	18.75^{e}
Hand weeding and hoeing at 20 days after crop emergence (dae)	57.24^{d}	42.76^{a}
Hand weeding and hoeing at 20 and 40 days after crop emergence	67.46^{cb}	32.54^{dc}
Complete weed free (CWF)	0.00^{e}	0.00^{f}
Weedy check (WC)	57.64^{d}	42.36^{a}
LSD(0.05)	8.984	6.046
CV (%)	8.8	10.4

CV=coefficient of variation, LSD= least significant difference means with the same letters are no significantly diffrent,

Weed dry weight

The aboveground weed dry matter weight was significantly influenced by different treatments at all the crop growth stages (Appendix 6).

Aboveground dry weight of weed at 20 days after potato emergence

The results revealed significantly lower (3.6g $m^{-}2$) weed dry matter recorded with the application of isoproturon at 2.0 kg ha^{-1} treated plots than the other treatments. On the other hand, weedy check plots recorded significantly higher (15.267g m^{-2}) aboveground weed dry weight than all other treatments at 20 dae (Table 9).These results are in agreement with the findings of Shakoor *et al*. (1986) and Hafeezullah (2000) who observed that dry matter of weeds from the weedy check plots was significantly greater than chemically treated plot.

Aboveground weed dry weight at 40 days after potato emergence

The weed dry matter weight was significantly ($p <0.05$) affected by all weed control treatments . Maximum dry weight (97.31g m^{-2}) of weeds was recorded in weedy check plots which were significant as compared to other treatments. Like at 20 days after crop emergence, application of isoproturon at 2.0 kg ha^{-1} had the lowest weed dry weight which was statistically in parity with pendimethalin at 2.0 kg/ha. Further, application of pendimethalin at 2.0 kg/ha did not show significant difference from isoproturon at 1.5 kg/ha, pendimethalin (1.0 and 1.5 kg/ha) and s-metolachlor (1.5 and 2.0 kg/ha).

The results were more or less in the contrary to weed density under different treatments at 40 dae (Table 6). Despite lower weed density at 40 dae, the weeds might have accumulated more dry matter in response to lower density. Therefore, it is not necessarily that more density means more dry matter weight and thus, low density might have higher dry weight also due to reduced intra specific competition among the weed species. At this crop growth stage the hand weeding treatments resulted in higher weed dry weight than the herbicide treated plots (46.67 g/m^2)

Although the first flushes of germinated weeds were controlled with hand weeding, the weed seeds might have been brought to the upper soil surface during the process of hand weeding. This might have placed weeds at advantage for better soil aeration and other growth factors that resulted in their quicker growth and development; consequently, there by more dry matter accumulation.However, maximum dry weight in weedy check plots might be the result of very high weed density and vigorous weed growth that offered severe competition to the crop for growth resources. These results are consistent with earlier investigation (Khan, 1990) who reported significantly higher weed dry weight in weedy check than the treated plots.

Weed dry weight at physiological maturity of potato

The weed dry biomass was significantly ($p \leq 0.05$) reduced due to weed management practices at physiological maturity of the crop (Appendix 7, Table 9)). The application of isoproturon at 2.0 kg/ha continued to show its positive effect on reducing the weed dry weight. But it was found to be statistically in parity with pendimethalin at 2.0 kg/ha and hand weeding at 20 and 40 dae (Table 9). Twice hand weeding i.e at 20 and 40 dae also proved significantly superior in reducing the weed dry weight to one hand weeding at 20 dae, isoproturon and pendimethalin each at 1.0 kg/ha and s-metolachlor and atrazine at all application rate. This was dueto probably the uprooting of the second flush of weeds with hand weeding at 40 dae. After this, the growth of newly emerged weeds might have been contained by the well developed crop canopy that restricted solar radiation to the weeds. In addition the crop root system might have also offered severe underground completion to the weeds. Thus, the emerged weeds might have failed to accumulate sufficient dry matter. It was also noted that there was no significant difference in weed dry weight between s-metolachlor rates but unlike at 40 dae, atrazine at 1.5 and 2.0 kg/ha significantly reduced weed dry weight over its lowest rate i.e. 1.0 kg/ha. The results revealed that weeds in weedy check plots gave significantly highest (124.86 g $^{-2}$) dry weight of all other treatments.

Table 5. Effect of weed control methods on dry weight of weeds in potato in Gishe during 2013 cropping season

Weed management methods	Weed dry weight (g /m^2)		
	At 20 days after crop emergence	At 40 days after crop emergence	At harvest
Isoproturon 1.0 kg ha^{-1}	6.23^{cbd}	25.13^{c}	32.40^{d}
Isoproturon 1.5 kg ha^{-1}	4.60e^{f}	18.35^{de}	25.74^{d}
Isoproturon 2 .0 kg ha^{-1}	3.60^{f}	12.40^{e}	17.93^{i}
Pendimethalin 1 .0 kg ha^{-1}	5.61^{cebd}	21.60^{dc}	28.54^{egdf}
Pendimethalin 1.5 kg ha^{-1}	5.40^{ced}	21.20^{dc}	25.04^{eghf}
Pendimethalin 2.0 kg ha^{-1}	5.20^{ed}	18.00^{de}	21.20^{ghf}
S-metolachlor 1.0 kg ha^{-1}	6.40^{cb}	26.52^{c}	33.60^{d}
S-metolachlor 1.5 kg ha^{-1}	6.17^{cbd}	22.02^{c}	31.52^{d}
S-metolachlor 2.0 kg ha^{-1}	5.80^{cbd}	21.60^{dc}	30.72^{edf}
Atrazine 1 .0 kg ha^{-1}	6.52^{b}	26.40^{c}	44.00^{c}
Atrazine 1.5 kg ha^{-1}	6.50^{b}	25.80^{c}	34.58^{d}
Atrazine 2.0 kg ha^{-1}	6.03^{cbd}	25.40^{cb}	33.86^{d}
Hand weeding and hoeing at 20 days after crop emergence (dae)	15.60^{a}	45.73^{b}	64.67^{b}
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	15.30^{a}	46.67^{b}	22.6^{ih}
Complete weed free (CWF)	0.00^{g}	0.00^{f}	0.00^{j}
Weedy check (WC)	15.27^{a}	97.31^{a}	124.86^{a}
LSD(0.05)	0.992	5.947	5.658
CV%	8.3	12.6	9.5

CV=coefficient of variation, LSD= least significant difference at 5% level of significance means with the same letters are no significantly diffrent,

3.2. Crop

Yield Components

Tuber number per plant

Marketable tuber number per plant

Marketable tuber number per plant of potato was significantly influenced by different weed management practices .The result showed that the highest (15.33/plant) number of marketable tuber number was obtained when the crop was kept weed free throughout the growth period (Table 11). This treatment; however, did not register significant difference with the number of tubers obtained with the application of isoproturon at 1.5 and 2.0 kg/ha and pendimethalin at 1.5 kg/ha . On the other hand the minimum number of marketable tubers (4.67/plant) was found in the weedy check which was significantly lower than the other weed management practices except one hand weeding at 20 dae. This might be due to the significantly higher weed density and total weed dry weight that exerted severe competition not only above but belowground also with the crop for growth factors resulting in reduced tuber number/plant.

The data also indicated that also increases in herbicide application rates in case of isoproturon, s-metolachlor and atrazine there was an increased the number of marketable tubers/plant. Application of isoproturon at 2.0 kg /ha gave a significant increase in number of tubers over isoproturon at 1.0 kg/ha, while no significant difference existed between isoproturon 1.0 and 1.5 kg/ha. On the other hand, there was no significant difference in number of tubers/plant among respective application rates of s-metolachlor, atrazine and pendimethalin. When comparing hand weeding treatments, it was observed that two hand weeds proved significantly superior to one hand weeding in enhancing the number of marketable tubers/plant.

Unmarketable tuber number per hill

Unmarketable tuber number did not showed significant (p >0.05) difference among different weed control treatments that varied from 3.67 and 6.00/plant .

Table 6. Effect of different weed management methods in potato marketable, unmarketable and total tuber number per hill in Gishe during 2013 cropping season

Weed management methods	Number of tubers / hill		
	Marketable	Unmarketable	Total
Isoproturon 1.0 kg ha^{-1}	9.33^{edc}	4.33	13.66^{dcc}
Isoproturon 1.5 kg ha^{-1}	12.33^{bac}	4.33	16.66^{bac}
Isoproturon 2 .0 kg ha^{-1}	13.33^{abc}	6.00	19.33^{ba}
Pendimethalin 1.0 kg ha^{-1}	11.00^{bdc}	4.33	15.33^{bd}
Pendimethalin 1.5 kg ha^{-1}	12.33^{bac}	4.00	16.33^{bdac}
Pendimethalin 2.0 kg ha^{-1}	11.67^{bdc}	4.67	16.35^{bdac}
S-metolachlor 1.0 kg ha^{-1}	9.33^{edc}	4.33	13.66^{dec}
S-metolachlor 1.5 kg ha^{-1}	10.33^{bdc}	4.33	14.66^{dec}
S-metolachlor 2 .0 kg ha^{-1}	11.33^{bdc}	4.33	15.66^{bdc}
Atrazine 1.0 kg ha^{-1}	8.67^{ed}	4.33	12.67^{de}
Atrazine 1.5 kg ha^{-1}	9.33^{edc}	4.00	13.33^{dec}
Atrazine 2.0 kg ha^{-1}	10.00^{dc}	3.67	13.67^{dec}
Hand weeding and hoeing at 20 days after crop emergence (dae)	6.67^{ef}	4.33	11.00^{fe}
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	10.67^{bdc}	4.00	14.67^{dec}
Complete weed free (CWF)	15.33^{a}	4.33	19.67^{a}
Weedy check (WC)	4.67^{f}	4.00	8.67^{f}
LSD(0.05)	3.377	NS	3.856
CV%	19.5	12.8	15.7

CV=coefficient of variation, LSD= least significant difference; NS= not significant at 5% level of significance, means with the same letters are no significantly different

Total marketable tuber per hill

The analysis of variance showed that number of total tubers /plant was significantly affected by the weed management practices (Appendix 7). The highest(19.67/plant) number of total tubers was found by keeping the plots weed free throughout the crop growth period(Table 11); however, it did not have a significant difference with isoproturon (at 1.5 and 2.0 kg/ha) and pendimethalin (at 1.5 and 2.0 kg/ha). On the other hand, keeping the plots weedy throughout the growing season resulted in the lowest (8.67 /plant) number of total tubers/plant which was statistically in parity with one hand weeding at 20 dae(11 tubrs/plant). The results on the effect of different rates of herbicides application depicted an increasing trend in total tubers/plant with increasing rates of herbicide application. While there was a significant increase in number of total tubers/plant with isoproturon at 2.0 kg/ha over 1.0 kg/ha, but no significant difference existed between rates of 1.0 and 1.5 kg/ha. However, in case of pendimethalin, s-metolachlor and atrazine, there was no significant difference among their respective rates of application. It was also found that unlike marketable tubers/plant, no significant difference in total number of tubers/plant was observed between one and two hand weeding (Table 11).

Fresh tuber weight per hill

Marketable tuber weight

Fresh tuber weight per hill showed significant ($p<0.05$) difference among different weed control treatments. The highest (831.4g /hill) of marketable tuber weight was recorded in complete weed free plot, which was significantly better than the other treatments except the application of isoproturon at 2.0 kg /ha(Table 12). The plants raised under complete weed free environment were free from weed competition, thus utilized the available resources to their maximum benefit, resulting in increased tuber weight. Also, the more and vigorous leaves under weed free environment might have improved the supply of assimilates to be stored in the tubers, hence the weight of potato increased. Similarly, this practice along with the application of isoproturon at 2.0 kg/ha also resulted in higher number of marketable tubers/plant than the other treatments (Table 11) which might have contributed to the increased marketable tuber weight. The minimum marketable tuber weight (280 g/hill) obtained in weedycheck plot was statistically at par with one hand weeding 20 dae and atrazine at 1.0 kg/ha. The significantly lower number of tubers/hill under these treatments than the other treatments probably resulted in lower marketable tuber weight.

Among the herbicidal treatments, the highest (798.8 g/hill) marketable tuber weight obtained from the application of isoproturon at 2.0 kg/ha was statistically in parity with pendimethalin at 2.0 kg/ ha (733.7/hill). When comparing these treatments due to other herbicidal treatments, no significant effect of pendimethalin at 2.0 kg/ ha was obtained with isoproturon application at 1.5 kg/ha but isoproturon at 2.0 kg/ha gave a significant increase over other treatments.

Total tuber weight

Total tuber weight per plant showed highly significant ($p< 0.05$) difference among different weed control treatments. The results revealed significant increase in total tuber weight by keeping the plots completely weed free(921.1 g/hill) throughout the growth period over other treatments.

Among herbicidal treatments, application of isoproturon at 2.0 kg/ha recorded significantly higher (841.1g/hill) total tuber weight than the other treatments. On the other hand, total tuber weight increased significantly with the successive increase in herbicides application rates in case of isoproturon, s-metolachlor and pendimethalin, while in case of atrazine application at 2.0 kg/ha recorded significant increase only over 1.0 kg/ha (Table 12). Hand weeding at 20 and 40 dae resulted in a significant increase in total tuber weight over isoproturon at 1.0 kg/ha, pendimethalin at 1.0 kg/ha, s-metolachlor and atrazine, and hand weeding at 20 dae. Keeping the plots weedy (358.0g/hill) resulted in significant reduction in total tuber weight, which was 61.1% over complete weed free (Table 12).

Proportional weight of small, medium and large tuber per plan

Proportional weight of tuber in size categories per plant was found to be varying among all the treatments. Analysis of variance indicated that there was significant ($p<0.05$) difference in proportion of small, medium and large tuber weight among the treatments .

Table 7. Effect of different weed management methods on marketable, unmarketable and total tuber weight (g)/ hill in Gishe during 2013 cropping season

Weed management Methods	Weight of tuber (g)/ hill		
	Marketable	Unmarketable	Total
Isoproturon 1.0 kgha^{-1}	378.7^{e}	65.0^{g}	443.7^{ih}
Isoproturon 1.5 kg ha^{-1}	690.1d^{c}	78.7^{cbd}	768.8^{d}
Isoproturon 2 .0 kg ha^{-1}	798.8^{ba}	42.3^{h}	841.1^{b}
Pendimethalin 1.0 kg ha^{-1}	574.0^{d}	76.0^{fcebd}	650.0^{f}
Pendimethalin 1.5 kg ha^{-1}	654.8^{c}	72.0^{fegd}	726.8^{e}
Pendimethalin 2.0 kg ha^{-1}	733.7^{b}	71.0^{feg}	804.7^{c}
S-metolachlor 1.0 kg ha^{-1}	372.8^{e}	81.3^{b}	454.1^{h}
S-metolachlor 1.5 kg ha^{-1}	522.7^{d}	65.7^{g}	588.4^{g}
S-metolachlor 2.0 kg ha^{-1}	562.9^{d}	70.3^{fg}	633.2^{f}
Atrazine 1.0 kg ha^{-1}	337.5^{e}	75.0f^{cebd}	412.5^{h}
Atrazine 1.5 kg ha^{-1}	360.0^{e}	78.7^{cbd}	438.7^{h}
Atrazine 2.0 kg ha^{-1}	372.0^{e}	79.3^{cb}	451.3^{h}
Hand weeding and hoeing at 20 days after crop emergence (dae)	335.2^{e}	74.0^{fced}	409.2^{h}
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	656.8^{c}	75.0^{fcebd}	731.8^{e}
Complete weed free (CWF)	831.4^{a}	90.0^{a}	921.4^{a}
Weedy check (WC)	280.0 f	78.0^{cebd}	358.0 ^{j}
LSD(0.05)	72.45	6.90	30.96
CV%)	8.30	5.40	3.10

Table 8. Effect of different weed management methods on the percentage of small, medium and large tuber weight per plant in Gishe during 2013 crpping season.

Weed management methods	Tuber weight based on size categories /plant (%)		
	Small (25-39 g)	Medium (40-75g)	Large (>75 g)
Isoproturon 1.0 kg ha^{-1}	9.3^{f}	52.0^{c}	38.7f^{e}
Isoproturon 1.5 kg ha^{-1}	6.4^{i}	41.9^{fe}	51.7^{cb}
Isoproturon 2.0 kg ha^{-1}	3.6^{j}	61.3^{b}	35.1^{f}
Pendimethalin 1 kg ha^{-1}	8.4g^{fg}	46.2^{d}	45.4^{d}
Pendimethalin 1.5 kg ha^{-1}	7.3g^{fh}	38.4^{f}	54.3^{b}
Pendimethalin 2.0 kg ha^{-1}	6.6^{ih}	40.8^{fe}	52.6^{b}
S-metolachlor 1.0 kg ha^{-1}	12.0^{e}	48.3^{dc}	39.7^{e}
S-metolachlor 1.5 kg ha^{-1}	8.2^{gifh}	46.1^{d}	45.7^{d}
S-metolachlor 2 .0 kg ha^{-1}	7.3^{gih}	39.5^{f}	53.2^{b}
Atrazine 1.0 kg ha^{-1}	15.0^{c}	62.3^{ba}	22.7^{g}
Atrazine 1.5 kg ha^{-1}	14.0^{dc}	62.0^{ba}	24.0^{g}
Atrazine 2.0 kg ha-^{1}	13.0^{de}	65.7^{a}	21.3^{g}
Hand weeding and hoeing at 20 days after crop emergence (dae)	26.0a	25.7^{h}	48.3^{cd}
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	9.1^{gf}	44.8^{de}	46.1^{d}
Complete weed free (CWF)	7.4^{gih}	24.8^{h}	67.8^{a}
Weedy check (WC)	21.3^{b}	33.0^{g}	45.7^{d}
LSD(0.05)	1.667	4.09	3.72
CV (%)	9.100	5.40	5.10

It was found that among different treatments, significantly the minimum (3.6 %) percent of small tuber size was recorded in isoproturon at 2.0 kg/ha, followed by isoproturon at 1.5 kg / ha (6.4%), while the maximum (26%) percent of small tuber size was obtained in hand weeding at 20 dae which was even significantly higher than weedy the check.The proportion of medium tuber size was highest (65.7%) with the application of atrazine at 2.0 kg/ha which was statistically in parity with its lower rates of application.

The lowest medium sized tuber distribution resulted by keeping the plot weed free which was statistically similar to hand weeding at 20 dae. Though the small sized tuber proportion decreased with the increase in herbicide application rates, significant difference was observed with isoproturon while pendimethalin and atrazine each at 2.0 kg/ha gave significant increase over 1.0 kg/ha. On the other hand, s-metolachlor at 1.5 and 2.0 kg/ha registered significant increase over 1kg/ha.

The highest large tuber size weight (67.8%) was recorded from complete weed free, checks, while the lowest (21.3%).was obtained from atrazine 2 kg /ha treatments, which was significantly at party with respective rate of atrazine, i.e at the rate of 1 and 1.5 kg/ha (22.7 and 24.% respectively) One hand weeding at 20 dae as well as weedy check had significantly larger proportion of small sized tubers than the other treatments. This indicated that the competition offered by the weeds had more repercussion on tuber development, thus ending up with more small sized tubers. This also demonstrated that there might have been influenced on underground apart from aboveground weed competition.

Dry haulm yield (kg ha^{-1})

Significant variation ($p<0.05$) in aboveground dry biomass of potato was obtained due to the treatments (Table 14). The highest (3933 kg ha^{-1}) total dry biomass was obtained in complete weed free plot, which was statistically in parity with hand weeding, isoproturon and pendimethalin each at 2.0 kg/ha.Mizan *et al*. (2009) reported that the increased dry matter weight of the crop was highly governed by the length of weed free period. However, high production of haulm dry matter might not necessarily be of great value when the tuber yield is considered. The higher aboveground dry weight in these treatments might be due to better condition in soil aeration that improved the competitive ability of the crop and favored more vegetative growth, thus the lower dry weight indicated that the crop plants in those treatments encountered one or other kind of stresses. However, it was not necessarily that higher haulm yield may convert into higher tuber yield as the weeds not only compete above but belowground also. The haulm dry weight also increased with the increase in herbicide application rates but this increase was not found to be significant (Table 14). It was also found that the lowest (1648 kg/ha) haulm dry yield recorded in weedy check was statistically in parity with s-metolachlor at 1.0 kg/ha (2233kg/ha) and atrazine at all its rates (2163, 2189 and 2221kg/ha respectively).

Tuber yield

Marketable tuber yield

Marketable tuber yield of potato showed ($p<0.05$) significant difference due to different weed management treatments.The maximum (32.73 t/ha) marketable tuber yield was realized from complete weed free plots, which was significantly higher than the yield obtained from all the treatments except isoproturon at 2.0 kg/ha. It was also found that application of isoproturon at 2.0 kg/ha, which gave the highest (30.50 t/ha) tuber yield among the herbicides was also statistically in parity with pendimethalin at 2.0 kg/ha (29.37 t/ha) and two hand weeding at 20 and 40 dae (28.67 t/ha).

The marketable tuber yield also increased with the increase in herbicide application rates, but it was significant with the successive increase in rates of isoproturon, whereas in case of pendimethalin, application at 2.0 kg/ha was significantly better than 1.0 and 1.5 kg/ha. Despite yellowish color at the time of crop emergence, and then some slight chlorotic symptoms at the crop leaf margins' were observed during 5-15 days after emergence in a plot treated with all rate of atrazine but the leaf of the crop were rapidly recovered. On the other hand, s-metolachlor at 1.5 and 2.0 kg/ha was found to be significantly better than 1.0 kg/ha. Contrary to this, atrazine application rates were found to be statistically at par with each other (Table 15). Hand weeding at 20 and 40 dae significantly enhanced marketable tuber over one hand weeding, atrazine, s-metolachlor, isoproturon (at 1.0 and 1.5 kg/ha) and pendimethalin (at 1 and 1.5 kg/ha).The lowest(12.4 t/ha) marketable tuber yield obtained in weedy check plots was statistically in parity with hand weeding at 20 dae. The significantly lower marketable tuber number (Table 11) and weight (Table 12) might have contributed to the lower marketable tuber yield in these treatments.

Tuber yield is considered to be a product of three major processes: radiation interception, conversion of intercepted radiation to dry matter and the partitioning of dry matter between tuber and the rest of plant (Harvis, 1992). However, in this experiment the intensity of weediness due to the effect of treatments might have resulted in a difference in competitiveness of the crop for growth resources especially nutrients, solar radiation and space there by affecting the marketable yield.

Unmarketable tuber yield

Like marketable tuber yield the unmarketable tuber yield showed a highly significant ($p < 0.01$) difference among all treatments. The complete weed free treated plots had the highest (3.77 t/ha) under size and damage tuber yield, followed by atrazine 2 kg per treated plot (3.55 t/ha).

Total tuber yield (t/ha)

Similar to the results obtained in case of marketable tuber yield, the total tuber yield was also highest (36.50 t/ha) in complete weed free plots, however it did not differ significantly with isoproturon at 2.0 kg/ha (34.01 t/ha) (Table 15).

The variation in total tuber yield in response to the herbicidal rates was similar to marketable yield (Table 15). The lowest total tuber yield (14.61 t/ha) was obtained from weedy check, which was significantly lower other than one hand weeding at 20 dae. On the other hand, one hand weeding at 20 dae had no significant difference in total tuber yield from sall rates of atrazine applications.

The variation in yield was due to differences in weed index, weed control efficiency and herbicide efficiency. The treatments having higher weed control efficiency and herbicide efficiency index and lower weed index, in general, resulted in higher potato yield. However, improved soil environment under hand weeding might have also contributed to higher yield than the yield in untreated plots. When comparing the yield gained due to weed management practices, the results were similar to weed index.The results further revealed that uninterrupted weed growth was found to reduce the yield by 59.96 % over complete weed free check

Table 10. Effect of different weed management methods in potato on marketable, unmarketable and total tuber yield per hectar in Gishe during 2013 cropping season

Weed management methods	Total tuber yied (t/ha)		
	Marketable	Unmarketable	Total
Isoproturon 1 .0 kg ha-1	21.23d	2.81[f]	24.04[e]
Isoproturon 1.5 kg ha-1	25.67c	3.28[bedc]	28.95d[c]
Isoproturon 2.0 kg ha-1	30.50ba	3.51[bac]	34.01[ba]
Pendimethalin 1 .0 kg ha-1	25.55c	3.20[fbedc]	28.75[dc]
Pendimethalin 1.5 kg ha-1	26.03c	3.02[fed]	29.05[dc]
Pendimethalin 2 .0 kg ha-1	29.37b	2.97[fed]	32.34[b]
S-metolachlor 1.0 kg ha-1	16.83e	2.87[fe]	19.70[f]
S-metolachlor 1.5 kg ha-1	22.00d	2.81[f]	24.81[e]
S-metolachlor 2.0 kg ha-1	23.70dc	2.93[fed]	26.63[de]
Atrazine 1 .0 kg ha-1	15.00fe	3.33[bdc]	18.33[gf]
Atrazine 1.5 kg ha-1	15.51fe	3.45[bac]	18.96[gf]
Atrazine 2.0 kg ha-1	15.90fe	3.55[ba]	19.45[gf]
Hand weeding and hoeing at 20 days after crop emergencence (dae)	13.57fg	2.87[fc]	16.44[gh]
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	28.67ab	3.11[fedc]	31.71[bc]
Complete weed free (CWF)	32.73ga	3.77[a]	36.50[a]
Weed check (WC)	12.40g	2.21[c]	14.61[h]
LSD(0.05)	2.378	0.407	3.251
CV (%)	6.40	7.9	7.70

CV=coefficient of variation, LSD= least significant difference at 5% level of significance,
means with the same letters are no significantly diffrent

3.4. Impact Assessment of the Treatments

To provide the logistic support to the impact assessment of different treatments, weed index and herbicide efficiency index were calculated.

Table 11. Effect of weed control methods in potato on weed control efficiency, weed index and herbcide efficiency index in Gishe during 2013 cropping season

Weed management methods	WCE	Relative yield loss	HEI
Isoproturon 1.0 kg ha-1	74.1f[g]	35.1[d]	2.48[e]
Isoproturon 1.5 kg ha-1	79.4[cde]	31.9[d]	4.76[c]
Isoproturon 2.0 kg ha-1	85.6[b]	6.8[h]	9.24[a]
Pendimethalin 1.0 kg ha-1	77.1f[de]	21.9[f]	4.23[dc]
Pendimethalin 1.5 kg ha-1	79.9[cd]	20.5[f]	4.93[c]
Pendimethalin 2.0 kg ha-1	83.0[cb]	10.3[hg]	7.14[b]
S-metolachlor 1 .0 kg ha-1	73.1[fg]	48.5[c]	1.29[f]
S-metolachlor 1.5 kg ha-1	74.8[fg]	32.8[d]	2.76[e]
S-metolachlor 2.0 kg ha-1	75.4[fge]	27.6[e]	3.34[de]
Atrazine 1 .0 kg ha-1	64.8[h]	54.2[b]	0.72[gf]
Atrazine 1.5 kg ha-1	72.3[g]	52.6cb	1.07[f]
Atrazine 2.0 kg ha-1	72.9[g]	51.4[cb]	1.22[f]
Hand weeding and hoeing at 20 days after crop emergence (dae)	48.2[i]	58.5[a]	--
Hand weeding and hoeing at 20 and 40 days after crop emergence (dae)	81.9[cb]	12.4[g]	--
Complete weed free (CWF)	100.0[a]	0.0[i]	--
Weedychek	0.00[j]	4.16[a]	1.03
LSD(0.05)	4.15	4.16	1.03
CV(%)	3.5	7.56	22.97

means with the same letters are no significantly different, CV=coefficient of variation, LSD= least significant difference at 5% level of significance

3.4.1. Relative yield loss (Weed index)

The data (Table 15) indicated that the relative yield loss in marketable tuber yield due the presence of weeds ranged from 6.8 to 62.1%. Uninterrupted weed growth resulted in a reduction of 62.1, 59.3 and 57.8 and 56.7% loss in marketable yield over complete weed free, isoproturon at 2.0 kg, pendimethalin at 2.0 kg /ha and two hand weeding at 20 and 40 dae, respectively.The result is also consistent with the findings of Lal and Gupta (1984) and Atiq *et al*. (2009) who reported 10-80% yield loss due to weed infestation in potato. Among the herbicide treatments application of isoproturon at 2.0 kg/ha resulted in the lower (6.83 %) yield reduction than complete weedfree plot and this was followed by pendimethalin at 2.0 kg/ha (11.39%), indicating the effectiveness of these treatments in controlling the weed and realizing higher yield. In general, loss in yield decreased with increasing application of herbicide application rates. Similarly, Tripathi *et al*. (1989) reported a yield loss of 16 to 76% in potato. Among the herbicide application isoproturon at 2.0 kg/ha resulted in the lower (7.3%) yield reduction than complete weed free plot and this was followed by pendimethalin at 2.0 kg/ha (8.8%), indicating the effectiveness of these treatments in controlling the weed and realizing the higher yield. In general, loss in yield decreased with increasing application of herbicide application rates.

3.4.2. Herbicide Efficiency Index

The results on herbicide efficiency index (HEI) the trend showing that the weed killing potential of a herbicide and its possible phytotoxicity on crop indicated a higher herbicide efficiency index with increasing rates of herbicide application. Like higher weed control efficiency achieved under a particular treatment, the herbicide efficiency index also increased and the weed index decreased that showed that higher weed index resulted due in to poor weed control. The highest herbicide efficiency was obtained in isoproturon at 2 kg /ha (Table 16).

3.4.3.. Weed Control Efficiency

As far as the weed control efficiency (WCE) was concerned, the maximum(85.6%) weed control efficiency was calculated from isoproturon at 2.0 kg ha^{-1}, followed by the application of pendimethalin at 2.0 kg ha^{-1} (83.0%). On the other hand, hand weeding and hoeing at 20 dae treated plot had the least efficient weed control (Table 16). Weed control efficiency also registered an increase with increasing herbicide application rates that showed that at higher herbicide aplication rates weeds succumbed more which might have happened as a result of weeds could not keep pace with the herbicide metabolism inside the plant resulting in better control. This result is also consistent with the finding of Sharma *et al*. (2000) and Channappagoudar *et al*. (2008) who reported that the efficiency of herbicides increased with the increasing rates of herbicide applications.

4. Summary and Conclusion

Weeds interfere with agricultural operations and reduce the production potential of crop plants. Different weed management methods have been used to suppress weeds, but physical and herbicidal methods are more frequently used for their control. The efficiency of a given chemical is limited only to controlling certain weed species and it can vary with the weed density, time of weed emergence, crop management practices, cropping system and the environmental conditions under which the crop is grown. Thus, it is important to conduct location specific experiments on weed management. Therefore, this research was conducted under irrigation at Gishe District North Shewa, Ethiopia from February to June in 2013, with the objectives to evaluate the effect of weeds on growth, yield components and yield of potato, and to find out the most effective method of weed management involving herbicides and cultural methds in potato production. Sixteen treatments, *viz*. preemergence herbicide including atrazine (1.0, 1.5 and 2.0 kg/ha), pendimethalin (1.0, 1.5 and 2.0 kg /ha), s-metolachlor (1.0, 1.5 and 2.0 kg /ha) and isoproturon (1, 1.5, 2.0 kg/ha), one hand weeding and hoeing at 20 dae, two hand weeding at 20 and 40 dae, complete weed free and weedy check were evaluated in a randomized complete block design (RCBD) with three replications.

The weed flora in the experimental plots comprised of by both broadleaved and grass weeds. Most of the weeds belonged to Poaceae family followed by Asteraceae. Grass and broadleaved constituted 45.5 and 54.5% of the total weed flora, respectively.

In general, it can be concluded from the finding of this experiment that preemergence application of isoproturon at 2.0 kg/ha followed by pendimethalin at 1.5.0 kg/ha is the best proposition for acceptable weed management and results highest return under irrigated conditions in the study area. In the event of sufficient and cheap availability of farm laborer, twice hand weeding each at 20 and 40 dae is the best alternative. Therfore, it needs further research,with the experiments consisting of even higher rate of chemicals than the highest rate applied in this study and hand weeding and hoeing at different growth stage of crops should be conducted to arrive at a conclusive recommendation.

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