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Evaluation of Herbicides and Their Combinations for Weed Management in Bread Wheat (*Triticum Aestivum L.*) In Southern Ethiopia

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Abstract: **Ineffective weed management in wheat is the main factor causing annual yield loss of 35 % in Ethiopia. Thus, a field experiment was conducted at two locations in southern Ethiopia during the main cropping season of 2013 to evaluate the efficacy of different herbicides and their combinations on weed dynamics, yield components and yield of bread wheat and to assess economic feasibility of herbicides for weed management in wheat. The treatments included, pendimethalin (0.70, 1.20 and 1.70 kg ha^{-1}), Pyroxsulam (Pallas 45OD 15, 20 and 25 g ha^{-1}), Isoproturon (1.0, 1.25 and 1.50 kg ha^{-1}), 2,4-DEE (0.40, 0.50 and 0.60 kg ha^{-1}), Pyroxsulam + 2,4-DEE (15, 10, 20 and 20 g ha^{-1} + 0.40, 0.50, 0.30 and 0.40 kg ha^{-1}), Isoproturon + 2,4-DEE (1.0, 0.75, 1.25 and 1.25 kg ha^{-1} + 0.40, 0.50, 0.30 and 0.40 kg ha^{-1}), hand weeding at three weeks after crop emergence, hand weeding at two and five weeks after crop emergence, weed free and weedy checks. The experiment was arranged in Randomized Complete Block Design with three replications. The experimental field was infested both with broad leaved and grassy weeds belonging to seventeen plant families out of which Asteraceae and Poceae being the most dominant. Isoproturon and 2,4-DEE were more effective on controlling the grassy and broad leaved weeds, respectively, while Pyroxsulam was more effective on both grassy and broadleaved weeds. Pallas 20 g ha^{-1} and its combinations (pallas 10 g ha^{-1} + 2,4-DEE 0.40 kg ha^{-1}) resulted in the lowest weed dry weight of 2.8 g m^{-2} and 6.06 g m^{-2} at Bobicho and Faate, respectively at harvest. The highest productive tillers of 252.3 and 250.6 per m^{2} were recorded in two hand weeding while the highest grains per spike of 52.3 and 52.6 were obtained in two hand weeding at Bobicho and Faate, respectively. The highest grain yields of 4700.9 and 4455.0 kg ha^{-1} were obtained in weed free treatment followed by Pallas 20 g ha^{-1} that gave grain yield of 4455.0 and 4031.4 kg ha^{-1} at Bobicho and Faate, respectively while the lowest grain yield was obtained in weedy check at both sites. Moreover, application of Pallas at 20 g ha^{-1} and two hand weeding resulted in maximum relative net returns of Birr 24,875.0 ha^{-1} and 23,833.0 ha^{-1} at Bobicho and Faate, respectively.**

Keywords: **Isoproturon; Pendimethalin; Pyroxsulam; Triticum aestivum L.; Weed dynamics.**

1. INTRODUCTION

Bread wheat is one of the major cereal crops in the Ethiopian highlands that lie between latitude of 6^{o} and 16^{o}N and longitude of 35^{o} and 42^{o} E and is widely grown from 1500 to 3000 masl. The most suitable areas for wheat production, however, fall between 1900 and 2700 masl (Hailu, 2003). In Ethiopia, wheat covered an area of 1,706,323.86 ha with a total production of 40,391, 13.674 tons with yield average of 2.35 t ha^{-1} during 2012/2013 main cropping season. In South Nation Nationalities People Region wheat covered an area of 123,369.52 ha with a total production of 2,903,66.6 95 t. In Hadiya and Wolaita zones, where this study done, bread wheat covered an area of 33,289.66 ha and 4,034.34 ha with respective production of 857, 34.991t and 58, 95.843 t, respectively (CSA, 2013).

Bread wheat plays a significant role in the national economy and currently its area of production and productivity is increasing. Moreover, it is one of the major cereals of choice in Ethiopia, dominating food habits and dietary practices, and is known to be a major source of energy and protein in the country (Hailu, 2003).

Weed infestation is the main bottleneck in crop production in Ethiopia, especially during the rainy season. The heavy rainfall encourages rapid and abundant growth of weeds and consequently, all agricultural crops are heavily infested with weeds in South Nation Nationalities People Region. Farmers in the country are aware of weed problem in their fields but often they cannot cope-up with heavy weed infestation during the peak-period of agricultural activities because of labor shortage, hence, most of their fields are weeded late or left un-weeded. Such ineffective weed management is considered as the main factor for low average yield of wheat resulting in average annual yield loss of 35% (Esheteu et al., 2006).

Manual weeding is the most widespread practice of weed control in Ethiopia; however, it is laborious, less effective and costly. Hand weeding though considered to be the most effective weed management tool, it is never an economical weed control method (Kassahun et al., 2004). Though the chemical method is being discouraged worldwide, its immediate effect and economic return cannot be ignored totally by the farmers of countries like Ethiopia especially in small cereals where hand weeding is difficult and laborious. Moreover, the ill effects of herbicides can be minimized through their judicious use at recommended doses. Further, weeds cannot effectively be managed merely through physical method due to crop mimicry. Uses of herbicides are most successful weed control technology ever developed (Stroud, 1989). They can also control those weeds which survive through mimicry, but the choice of the best herbicide, its proper time of application and proper dose are important considerations for lucrative returns (Marwat et al., 2005). However, the use of a single herbicide may cause shift in the weed flora in favor of the species that are not controlled, thus may increase the problem in future. Therefore, herbicide combinations are applied to broaden the spectrum of weeds controlled and sometimes combinations can give spectacularly good control at doses considerably below those normally applied in single application (Zahid et al., 2013).

Application of 2, 4-D has been recommended for the control of broadleaved weeds in wheat (Singh and Sharma, 1984). The use of Isoproturon gives effective control of grasses like Phalaris minor but provides partial control of broadleaved weeds (Bajpai et al., 1992). On the other hand, Pyroxsulam was more effective on controlling broadleaved weeds which reduced the weed population as compared to other herbicides and also it can control serious grassy weeds on wheat (Muhammad et al., 2007). In wheat, Pendimethalin of 0.75 kg ha^{-1} reduced weed dry matter and increased yield significantly (Kundra and Gill, 1990). However, there have been limited research efforts that evaluated different herbicides and their combinations for weed control in wheat crop production in the study areas. Therefore, the objectives of this study were to evaluate the efficacy of different herbicides and their combinations on weed dynamics, yield components and yield of bread wheat and to assess the economic feasibility of herbicides for weed management in wheat.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted during 2013 cropping season at Faate farmer`s field and Bobicho experimental sites in Wolaita and Hadiya Zones, respectively, in southern Ethiopia. Faate is located at 06º 52’ 42” N latitude, 37º 48’ 25.2” E longitude and altitude of 2252 masl. The soil is clay loam in texture and strongly acidic with pH of 5.1. The organic matter content of the soil was 3.5% (medium) and with low total nitrogen (0.23%) and low available P (2.3 mg kg^{-1}). Bobicho research sub-center is found in Hadiya zone about 3 km northwest of Hossana, the capital town of the zone. It is located on geographic coordinates of 07^0 34’14.6’’ N latitude, 37^0 50’ 06.1’’E longitudes and altitude of 2275 masl. The pH value of the surface soil was 4.23 and rated as strongly acidic. The organic matter and total nitrogen contents were 1.07% and 0.18%, which were rated as very low and low, respectively. Available phosphorus content was 1.5 mg kg^{-1} and rated as low. The soil was clay loam in texture. The seasonal total rainfall of 758.5 and 660.8 mm were recorded at Bobicho and Faate, respectively. The seasonal mean minimum and maximum temperature of 11.5, 19.6 and 14.9, 23.2 ^{0}C were recorded at Bobicho and Faate, respectively (Table 1).

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Table 1: Monthly average air temperature and rainfall at Bobicho and Faate during the crop growing season

Bobicho					Faate			
Temperature (°C)					Temperature (°C)			
Months	Max.(mm)	Min.	Ave.	Rainfall	Max.	Min.	Ave.	Rainfall (mm)
June	18.9	12.2	15.6	72.3	20.3	15.1	17.7	66.7
July	18.2	11.3	14.8	99.4	22.4	14.6	18.5	85.4
August	17.0	10.4	13.7	179.1	23.4	15.2	19.2	148.3
September	19.0	10.1	14.6	275.8	23.6	14.5	19.1	224.5
October	20.3	11.6	15.9	82.5	24.1	15.0	19.55	99.2
November	21.2	12.3	16.8	45.2	23.8	14.4	19.1	34.3
December	22.9	13.0	17.9	4.2	24.5	15.5	20.0	2.4
Mean temp.	19.6	11.5	15.6		23.2	14.9	19.0	
Total rainfall				758.5				660.8

Source: AARC Meteorological station and Hadiya Zone Agricultural Office

2.2 Treatments and Experimental Design

The twenty four treatments included were Pendimethalin (0.70, 1.20 and 1.70 kg ha^{-1}) , Pyroxsulam (Pallas 45OD 15, 20 and 25 g ha^{-1}), Isoproturon (1.0, 1.25 and 1.50 kg ha^{-1}), 2,4-DEE (0.40, 0.50 and 0.60 kg ha^{-1}), Pyroxsulam + 2,4-DEE (15, 10, 20 and 20 g ha^{-1}+ 0.40, 0.50, 0.30 and 0.40 kg ha^{-1}), Isoproturon + 2,4-DEE (1.0, 0.75, 1.25 and 1.25 kg ha^{-1} + 0.40, 0.50, 0.30 and 0.40 kg ha^{-1}), hand weeding at three weeks after crop emergence, hand weeding at two and five weeks after crop emergence, weed free and weedy checks. The experiment was conducted using Randomized Complete Block Design with three replications. A gross plot size of 3.0 m × 3.0 m and a net plot size of 2.25 m × 2.50 m were used.

2.3 Experimental Materials

The bread wheat variety Kakaba was used for the experiment. It was released in 2010 and widely grown in the study areas. Days to maturity is to 90- 120 days and has potential yield from 3.3- 5.2 t ha^{-1}(MoA, 2010).The herbicides used for the study, shown in Table 2 below.

Table 2. Common, trade and chemical names of the tested herbicides

Common name	Trade name	Chemical name
2, 4 –DEE	Hit 44 (38EC)	2,4-D [(2,4-dichlorophenoxy) acetic acid]
Isoproturon	Isoguard 75WP	(N-4-isopropylphenyl) N', N'-dimethylurea)
Pallas 45 OD	Pyroxsulam (OD)	N-(5,7-dimethoxy[1,2,4]triazolo[1,5-a]pyrimidin-2-yl)-2-methoxy-4-(trifluoromethyl) pyridine-3-sulonamide
Stomp	Pendimethalin	N-(1-ethylpropyl)-2, 6-dinitro-3, 4-xylidine

2.4 Management of the Experiment

The land was prepared to fine tilth with oxen plough in the months of June and July. The plots were prepared as per the layout and leveled manually. The treatments were assigned randomly and the wheat was sown at seed rate of 150 kg ha^{-1} by drilling in furrow of 20 cm apart manually on July 15, 2013. The fertilizer at rate of 85 kg N and 46 kg P_2O5 ha^{-1} were applied in the form of Urea (46% N) and DAP (18% N and 46% P_2O_5). The whole of phosphorus through diammonium phosphate (DAP) and ½ of N were applied at the time of sowing while the remaining ½ of N in the form of urea was top dressed in two equal splits at tillering and panicle initiation stages as per the recommendation. Hand weeding and hoeing as per the treatment were done in the assigned plots at an appropriate time. The weeds in weed free plots were removed by hand pulling frequently to keep the plots free from the weeds. Plot wise harvesting was done at harvest maturity of the crop on November 25 & 26, 2013 at Bobicho and Faate, respectively. The produce was sun dried for eight days before threshing.

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The herbicides were applied as per the treatment in the assigned plots as pre-emergence within two days after planting/post-emergence at tillering stage of wheat. The amount of herbicides as per the treatment was calculated and measured using sensitive digital balance and measuring cylinder. Herbicide spray volume with water as carrier was 500 L ha^{-1}. Spraying was done with manually operated Knapsack sprayer (15 L capacity) using flat-fan nozzle.

2.5 Data Collection

Weeds

The weed populations were counted about 15 days before the expected harvest time. The category wise (broadleaved, grass and sedges) population count was taken using 0.2 m × 0.2 m quadrat thrown randomly at two places in each plot and was converted to per m^2. While recording, weed population the aboveground biomass was also harvested from each quadrat. The harvested weeds were placed into paper bags separately and sun dried before drying in oven at a 65 ^{0}C temperature till constant weight and subsequently the dry weights were measured.

Wheat

Yield components and yield

The total number of tillers was counted from five rows with the length of 1 m randomly taken in each net plot area at harvest and also the number of productive tillers (spike bearing tillers) were counted from meter square area in each net plot at harvest. Total aboveground dry biomass (kg ha^{-1}) was determined by taking the total weight of harvest from each net plot area after sun drying the whole aboveground biomass. The number of grains per spike was determined from randomly taken 20 spikes per plot. Thousand grains were counted from the bulk of threshed produce from the net plot area and their weight was recorded. Grain yield (kg ha^{-1}) was measured after threshing the sun dried plants harvested from each net plot and the yield was adjusted at 12.5% moisture content. Harvest index was determined as the grain yield to above ground dry biomass.

Parameters for Weed Control

Weed Control Efficiency (WCE) was calculated as:

$$\mathrm{WCE} = \frac{(\mathrm{WDC}-\mathrm{WDT})}{\mathrm{WDC}} \times 100$$

Where, WCE= Weed Control Efficiency; WDC=Weed dry matter in weedy check; and WDT= weed dry matter in a particular treatment

Weed Index (WI): It was calculated as: $\mathrm{WI} = (\frac{\mathrm{X}-\mathrm{Y}}{\mathrm{X}}) \times 100$

Where, WI = Weed Index; X = Yield in complete weed free; and Y = Yield in a particular treatment

Herbicide Efficiency Index (HEI): It was calculated as described by Chandresekaran et al. (2010).

$$\mathrm{HE} = \frac{\mathrm{YT}-\mathrm{YC}}{\mathrm{YC}}100 / \frac{\mathrm{WDT}}{\mathrm{WDC}}\mathrm{X}100$$

Where, YT= yield from treatment; YC= yield from control; WDT= weed dry matter in treatment; and WDC= weed dry matter in control.

2.6 Partial Budget Analysis

The partial budget analysis was done to determine the economic feasibility of the weed control methods. It was calculated by taking into account the additional input costs (variable costs) involved and the gross returns obtained from different weed control treatments. The variable cost also included the labor cost involved for harvesting, threshing and winnowing as their cost varied according to the yield obtained in a particular treatment. Actual yield was adjusted downwards to 10% of experimental yield to represents the farmer`s yield (CIMMYT, 1988). For determining gross returns the prevailing local market price 700 Birr/100 kg at the harvest of wheat was taken. The net returns were calculated by subtracting the cost of treatment from the gross returns as RNR = GR-VC, where, RNR = Relative net returns, GR = Gross returns, and VC = Variable cost as described by CIMMYT (1988) was used on the yield results.

2.7 Statistical Data Analysis

Collected data were subjected to the analysis of variance appropriate to the design using SAS version 9.2 (SAS, 2008). Mean separation was done using Fisher's protected Least Significance Difference (LSD) test at 5% level of significance. As the F-test for homogeneity of variances showed significant differences for the parameters, separate analysis was done for the locations.

3. RESULTS AND DISCUSSION

3.1. Weed Community

The experimental fields were found to be infested with weeds comprising of broadleaved, grassy and sedges. The flora in the experimental fields indicated that the weeds belonged to 17 families (Table 3).

Table 3: Weed community in the experimental field at both locations during 2013

Family	Weed species
Amaranthaaeae	Amaranthus graecizash L., Celosia trigyna L.
Asteraceae	Ageratum conyzoides L., Bidens pilosa L., Crassocephalum rubens (Jacq.), Galinsoga palviflora (Cav). ,Guizotia scabra (Vis.) Chiov., Tagetes minuta L., Spilanthes mauritiana (Rich.ex.), Sonchus asper (L.) Hill,
Boraginaceae	Cynoglossum lanceolatum L.
Capparidaceae	Cleome monophylla L.
Caryophyllaceae	Stellaria media (L.) Vill
Chenopodiaceae	Chenopodium procerum (Hochst ex.) Moq
Commelinaceae	Commelina benghalensis L.
Convolvuaceae:	Convolvulus arvensis L.
Cruciferae	Erucastrum arabicum Fisch
Euphorbiaceae	Acalypha crenata Horchst.ex.A.
Fabaceae	Medicago polymorpha L.
Labiatae	Leucas martinicensis L.
Plantaginaceae	Plantago lanceolata L.
Poaceae	Avena fatua L., Cynodon nlemtuensis Vanderyst., Digitaria abyssinica L. Eleusine indica L., Phalaris paradoxa L.
Resedaceae	Caylusea abyssinica L.
Solanaceae	Datura stramonium L.

3.1.1. Weed Density

Analysis of variance indicated highly significant ($P<0.01$) difference in density of weeds among herbicides rate, combinations and hand weeding at wheat harvest. It was found that at wheat harvest among different herbicides rates, combinations and hand weeding; significantly the lowest density of broadleaved weeds (4 m^{-2}) and (5.6 m^{-2}) were recorded in combinations of Pyroxsulam 20 g + 2,4-DEE 0.40 kg ha^{-1} and Pyroxsulam 20 g + 2,4-DEE 0.30 kg ha^{-1} at Bobicho and Faate, respectively (Table 4). In general, as the rate of herbicides increased, the density of grassy weeds decreased in all herbicides treatments. Moreover, herbicides combinations showed better weed reduction in comparison with single type of herbicides. This result is in agreement with the work of Fazal et al. (2012) who reported that the combinations of herbicides such as 2, 4-DEE and Isoproturon had significantly reduced the infestation of serious grassy weed species infestation on spring wheat.The total weed density had shown significant variation with herbicide rates, combinations and hand weeding between the locations at crop harvest. The lowest total weed density (7.3 m^{-2}) and (11 m^{-2}) were recorded from Pyroxsulam 20 g + 2,4-DEE 0.40 kg ha^{-1} at Bobicho and Faate, respectively (Table 4). With the increase in herbicide application rates, the density of total weed populations decreased significantly in case of both post-emergence and pre-emergence herbicides across the locations.

At crop harvest, all post emergence herbicides had shown lower total weed density than pre-emergence herbicides across the locations. This indicated that they had better controlling efficiency over pre-emergence herbicides. This might be due to late emerging weeds in pre-emergence herbicide treated plots that might be the consequence of loss of activeness of a herbicide. Moreover herbicides, might not stay for longer could not stay periods in the soil. In contrast these, the effect of pre-emergence herbicide on total weed density, in case of post emergence herbicides application recorded significantly the lowest total weed density at crop harvest across the locations (Table 4).

Table 4. Effect of herbicides, their combinations and hand weeding on weed density per m^2 in bread wheat at Bobicho and Faate, southern Ethiopia

	Bobicho			Faate		
Treatments	Grassy	Broad leaved	Total	Grassy	Broad leaved	Total
Pyroxsylam 15 g ha^{-1}	13.7^{f}	22.6^{d}	36.3^{efg}	15.3^{efg}	24.0^{c}	39.3^{e}
Pyroxsylam 20 g ha^{-1}	4.0^{i}	11.3^{hi}	15.3^{l}	5.3^{k}	11.0^{hij}	16.3^{l}
Pyroxsylam 25 g ha^{-1}	2.3^{i}	7.0^{j}	9.3^{mn}	2.6^{l}	8.0^{kjl}	10.6^{m}
2,4-DEE 0.40 kg ha^{-1}	22.6^{c}	11.3^{hi}	33.9^{g}	19.0^{d}	13.0^{fgh}	32.0^{hg}
2,4-DEE 0.50 kg ha^{-1}	26.0^{b}	10.6^{i}	36.6^{efg}	27.3^{c}	10.0^{kji}	37.3^{efg}
2,4-DEE 0.60 kg ha^{-1}	18.0^{d}	7.0^{j}	25.0^{j}	27.3^{c}	8.3^{kjl}	35.6^{fg}
Isoproturon 1.00 kg ha^{-1}	17.6^{de}	21.3^{d}	38.9^{e}	18.3^{d}	22.6^{c}	40.9^{e}
Isoproturon 1.25 kg ha^{-1}	14.0^{f}	18.3^{e}	32.3^{hi}	15.0^{fg}	23.3^{c}	38.3^{e}
Isoproturon 1.50 kg ha^{-1}	8.6^{h}	11.0^{i}	19.6^{k}	10.0^{ji}	14.0^{efgh}	24.0^{kj}
Pendimethalin 0.70 kg ha^{-1}	28.0^{b}	33.3^{b}	61.3^{b}	30.0^{b}	32.0^{b}	62.0^{b}
Pendimethalin 1.20 kg ha^{-1}	26.6^{b}	25.6^{c}	52.2^{c}	26.0^{d}	25.0^{c}	51.0^{c}
Pendimethalin 1.70 kg ha^{-1}	15.0^{f}	22.0^{d}	37.0^{ef}	13.6^{gh}	23.0^{c}	36.6^{efg}
Pyro 15 g +2,4-DEE 0.40 kg ha^{-1}	8.6^{h}	17.0^{ef}	25.6^{j}	10.0^{ji}	16.0^{def}	26.0^{ji}
Pyro10 g + 2,4-DEE 0.50 kg ha^{-1}	8.0^{h}	12.0^{ghi}	20.0^{k}	8.3^{j}	12.0^{ghi}	20.3^{k}
Pyro 20 g +2,4-DEE 0.30 kg ha^{-1}	4.0^{i}	5.6^{kj}	9.6^{mn}	4.3^{kl}	5.6^{l}	9.9^{m}
Pyro 20 g + 2,4-DEE 0.40 kg ha^{-1}	3.3^{i}	4.0^{k}	7.3^{n}	4.0^{kl}	6.0^{l}	10.0^{m}
Isop 1.0 kg + 2,4-DEE 0.40 kg ha^{-1}	15.0^{f}	14.6^{fg}	29.6^{i}	15.3^{efg}	15.0^{efg}	30.3^{hi}
Isop 0.75 kg + 2,4-DEE 0.5 kg ha^{-1}	15.6^{ef}	18.0^{e}	33.6^{hg}	16.6^{def}	19.0^{d}	35.6^{fg}
Isop 1.25 kg + 2,4-DEE 0.3 kg ha^{-1}	11.3^{g}	14.0^{hg}	25.3^{l}	12.0^{hi}	17.3^{de}	29.3^{hi}
Isop 1.25 kg + 2,4-DEE 0.4 kg ha^{-1}	9.0^{h}	11.0^{i}	20.0^{k}	9.0^{j}	12.0^{ghi}	21.0^{k}
One hand weeding	19.3^{d}	27.6^{c}	46.9^{d}	17.6^{de}	25.6^{c}	43.2^{d}
Two hand weeding	3.0^{i}	7.0^{j}	10.0^{m}	3.0^{kl}	7.0^{kl}	10.0^{m}
Weedy check	101.6^{a}	191.6^{a}	293.2^{a}	101.0^{a}	173.6^{a}	274.6^{a}
Weed free check	-	-	-	-	-	-
LSD (5%)	2.30	2.97	3.61	2.61	3.60	4.76
CV (%)	8.51	8.30	5.36	9.30	10.21	6.99

Means followed by the same letter with in column are not significantly different at 5% level of significance,

Pyro. = Pyroxsylam, Isop.= Isoproturon, CV= Coefficient variation, LSD =Least significant difference

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This result is in agreement with the finding of Mishra et al. (2006) who reported that optimum moisture in the soil is the main factors to get effective weed control from pre-emergence herbicides. This result revealed that application of 2, 4-DEE at right time of weed growth and crop could reduce the population of broad leaved weed population in wheat. This result was in line with the finding of Nano et al. (2012) who reported 2, 4-DEE to be ineffective in reducing the population of grassy weeds but effectively controlled broad leaved weed population in bread wheat. Thus, it can be a better option for highly broadleaved weed infested fields in the periods of labor shortage. The result also revealed that the lower rates of herbicides combination showed better efficiency than higher rates of herbicide applied alone. The superiority of two hand weeding over one hand weeding might be due to reduced soil seed bank as well as the weeds that emerged after second hand weeding at five weeks after emergence were shorter in growth than the weeds that emerged after one hand weeding at two weeks after crop emergence.

3.1.2 Weed dry weight

The result revealed that at crop harvest there was high reduction in weed dry weight by herbicides rates, their combinations and hand weeding. Plots which were treated with pendimethalin showed the highest amount of grassy weed dry weight next to weedy check (Table 6). This might be due to late emerging weeds in herbicide treated plots that might be the consequence of loss of activeness of a herbicide. This result indicated that 2, 4-DEE had less efficiency for grassy weed control but when the rate increased, dry weight of grassy weeds decreased. In agreement with this result, Ahmad and Shaikh (2012) reported that the increased rate of 2, 4-DEE above the recommended rate had been shown lower dry weight of grassy weeds though it was selective for broad leaved weeds. Because of broad spectrum nature, Pyroxsulam showed better efficiency on serious grassy weed species like Avena fatua L., and Palaris minor L. and broad leaved dry matter weight. This result is in conformity with the work of Frehiwot et al. (2012) who reported that Pyroxsylam 20 g ha^{-1} reduced the dry weight of serious grassy weeds on bread wheat. The result also revealed that dry weight reduction was due to less accumulation of dry matter which was resulted from low densities as well as low competition for nutrients.

The lowest total weed dry matter weight (2.8 g m^{-2}) and (5.5 g m^{-2}) were recorded from Pyroxsulam 20 g + 2,4-DEE 0.30 kg ha^{-1} and Pyroxsulam 20 g + 2,4-DEE 0.40 kg ha^{-1} at Bobicho and Faate, respectively (Table 6). This result is in agreement with the work of Ashrafi et al. (2009) who reported that Pyroxsulam 10 g + 2,4-DEE 0.40 kg ha^{-1} combination had given better wheat competition for development resources, crop growth, early space covering, light interception might have effectively controlled the weeds. Similarly, Beverly and Jeffrey (2013) reported that Isoproturon 1kg ha^{-1} + 2,4-DEE 0.70 kg ha^{-1} combination had better weed controlling efficiency for all categories of weeds and other way of avoiding weed shift of mimicry weed species in wheat.

In contrast, plots which were treated with pendimethalin rates showed the highest total weed dry weight next to weedy check. This highest dry weight was due to more number of total weed densities (Table 5). Pyroxsulam had better weed control efficiency of broad spectrum especially for controlling serious weeds like Galinsoga palviflora (Cav), Guizotia scabra (Vis.) Chiov. and from grassy weeds Avena fatua L., Phalaris paradoxa L. and Phalaris minor L. which were serious at the study sites. This result agrees with the finding of Singh et al. (2013) recorded that the highest weed control efficiency and the lowest common grassy weed species in irrigated wheat cultivation.

The superiority of two hand weeding over one hand weeding might be due to reduced soil seed bank as well as the weeds that emerged after second hand weeding at five weeks after crop emergence was shorter in growth than the weeds that emerged after one hand weeding at two weeks after crop emergence. In line with this result, Dawit et al. (2011) stated that two hand weeding, correctly timed, provided excellent weed control in common bean production and reduced total weed dry weight over one hand weeding and herbicides alone. While hand weeding is much more difficult and slower at peak rain fed because of high weed densities and similarity between crop and grassy weed seedlings.

Table 5. Effect of herbicides, their combinations and hand weeding on weed dry weight (g m^{-2}) in bread wheat at Bobicho and Faate, southern Ethiopia

	Bobicho			Faate		
Treatments	Grassy	Broad leaved	Total	Grassy	Broad leaved	Total
Pyroxsylam 15 g ha^{-1}	8.53^{d}	13.00^{bc}	21.53^{cd}	9.60^{c}	12.26^{bcd}	21.86^{bc}
Pyroxsylam 20 g ha^{-1}	5.96^{f}	8.00^{e}	13.96^{gh}	7.30^{fg}	8.23^{ef}	15.53^{e}
Pyroxsylam 25 g ha^{-1}	1.30^{ghi}	4.90^{gh}	6.20^{kl}	2.30^{hij}	4.90^{hi}	7.20^{hgi}
2,4-DEE 0.40 kg ha^{-1}	10.66^{c}	5.00^{gh}	16.66^{fg}	13.30^{b}	6.00^{fgh}	29.30^{cd}
2,4-DEE 0.50 kg ha^{-1}	12.67^{b}	5.50^{fg}	18.17^{ef}	8.60^{def}	5.03^{hgi}	14.63^{e}
2,4-DEE 0.60 kg ha^{-1}	8.00^{d}	2.80^{ji}	10.80^{1h}	7.60^{efg}	3.40^{i}	11.00^{f}
Isoproturon 1.00 kg ha^{-1}	11.00^{c}	11.30^{cd}	23.30^{bc}	9.00^{cde}	12.00^{cbd}	21.00^{bc}
Isoproturon 1.25 kg ha^{-1}	8.33^{d}	10.67^{d}	19.00^{de}	8.40^{cdef}	11.00^{cd}	19.40^{cd}
Isoproturon 1.50 kg ha^{-1}	2.76^{gh}	5.06^{fgh}	8.28^{jk}	3.30^{hi}	4.63^{hi}	7.93^{gh}
Pendimethalin 0.70 kg ha^{-1}	10.67^{c}	14.33^{b}	25.00^{b}	9.56^{c}	13.00^{cb}	22.56^{b}
Pendimethalin 1.20 kg ha^{-1}	8.00^{de}	10.27^{d}	18.27^{ef}	8.30^{cdef}	10.00^{de}	18.30^{d}
Pendimethalin 1.70 kg ha^{-1}	3.46^{g}	12.00^{cd}	15.46^{ef}	3.56^{h}	11.00^{cd}	14.56^{e}
Pyro 15 g +2,4-DEE 0.40 kg ha^{-1}	2.23^{ghi}	3.30^{hji}	5.53^{lk}	1.90^{ij}	3.66^{hi}	5.56^{hgi}
Pyro 10 g + 2,4-DEE 0.50 kg ha^{-1}	3.53^{g}	4.20^{ghi}	7.73^{jk}	1.96^{ij}	3.86^{hi}	5.82^{hgi}
Pyro 20 g +2,4-DEE 0.30 kg ha^{-1}	0.80^{ji}	1.86^{kj}	2.66^{1nm}	1.50^{kj}	2.67^{i}	4.17^{hi}
Pyro 20 g + 2,4-DEE 0.40 kg ha^{-1}	1.33^{ghi}	1.80^{kj}	3.13^{lm}	1.90^{ij}	3.00^{i}	4.90^{i}
Isop 1.0 kg + 2,4-DEE 0.40 kg ha^{-1}	6.56^{ef}	8.03^{e}	14.59^{g}	6.36^{g}	8.00^{ef}	14.36^{e}
Isop 0.75 kg + 2,4-DEE 0.5 kg ha^{-1}	7.73^{de}	7.00^{f}	14.73^{fg}	8.00^{cdef}	7.30^{fg}	15.30^{e}
Isop 1.25 kg + 2,4-DEE 0.3 kg ha^{-1}	2.76^{gh}	5.00^{gh}	8.76^{jk}	3.16^{hi}	5.00^{hgi}	8.16^{g}
Isop1.25 kg + 2,4-DEE 0.4 kg ha^{-1}	2.76^{gh}	12.00^{cd}	15.76^{g}	2.83^{hij}	4.86^{hi}	7.69^{hg}
One hand weeding	1.73^{j}	7.50^{e}	9.23^{ji}	9.30^{cd}	14.00^{b}	24.80^{b}
Two hand weeding	0.46^{j}	3.23^{hji}	3.69^{lm}	3.23^{hi}	4.30^{hi}	7.53^{g}
Weedy check	29.00^{a}	66.33^{a}	95.33^{a}	29.30^{a}	74.00^{a}	103.30^{a}
Weed free check	-	-	-	-	-	-
LSD (5%)	1.50	1.95	3.01	1.53	2.37	2.47
CV (5%)	14.06	13.13	11.07	13.99	14.97	8.41

Means followed by the same letter with in column are not significantly different at 5% level of significance,

Pyro. = Pyroxsulam, Isop.= Isoproturon, CV= Coefficient variation, LSD =Least significant difference

Weed Index

Weed index measures the efficacy of a particular treatment compared with a weed free check and is expressed as percentage of yield potential under weed free check thus higher weed index means greater loss of yield due to weeds. The lowest weed index of 4.30% and 4.56% were recorded from two hand weeding at Bobicho and Faate, respectively (Table 6). While the highest weed indices were recorded from weedy check. This result indicated that herbicides had controlled weed and gave better weed control and reduced yield loss of crop indispensably. This result was in agreement with the study of Rakiba et al. (2011) who reported that the highest weed index was found in control plots and the lowest weed index in weed free plots. Generally, result of weed index indicated that herbicides rates, their combinations and hand weeding had shown better efficacy.

Weed control efficiency

The highest weed control efficiencies of 97.4%) and 95.26%) were recorded from Pyroxsulam 20 g + 2, 4-DEE 0.30 kg ha^{-1} and Pyroxsulam 20 g + 2, 4-DEE 0.40 kg ha^{-1} at Bobicho and Faate, respectively following the complete weed free (Table 6). The higher weed control efficiency with these treatments could be attributed to the lower weed population as well as dry matter accumulation of weeds in these treatments. This result revealed that herbicides rate, their combinations and hand weeding had better weed control efficiencies. These results corroborate with the findings of Saini and Angiras

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(2012) who reported the highest weed control efficiency at all the stages of crop growth with herbicides combinations and mechanical weeding alone.

Herbicide Efficiency Index

It is weed killing potential of herbicides treatments and their phytotoxicity on the crop .The result on herbicide efficiency index indicated that the weed killing potential of herbicides and their combinations were showed possible phytotoxicity on the wheat. Like higher weed control efficiency achieved under a particular treatment, the herbicide efficiency index also increased and the weed index decreased showed that higher weed index resulted due to poor weed control. The crop weed competition was markedly reduced by weed control treatments as is evident from the significant decrease in weed population, dry matter accumulation, weed killing efficiency, weed control efficiency and weed control index. This result agrees with the study of Mirza et al. (2013) who reported that the herbicide efficiency index were increased when the rates of herbicides increased and directly related with weed control efficiency thus higher herbicide efficiency index showed better weed control efficiency and lower weed index.

Table 6: Effect of herbicides, their combinations and hand weeding on weed index (WI), weed control efficiency (WCE) and herbicides efficiency index (HEI) in bread wheat at Bobicho and Faate, southern Ethiopia

	Weed impact assessment at crop harvest					
	Bobicho			Faate		
Treatments	Weed index (%)	Weed control eff. (%)	HE. Index	Weed index (%)	Weed control eff. (%)	HE. index
Pyroxsylam 15gha^{-1}	7.14^{l}	79.50^{jk}	4.72^{ijkl}	11.06^{l}	80.8^{ijk}	5.83^{jkli}
Pyroxsylam 20gha^{-1}	5.33^{m}	87^{g}	7.73^{gh}	9.49^{ml}	86.9^{g}	8.77^{hg}
Pyroxsylam 25gha^{-1}	7.13^{l}	94.16^{cd}	16.71^{d}	9.1^{m}	93.6^{bcde}	18.64^{bc}
2,4-DEE0.40 kgha^{-1}	18.43^{d}	84.73^{gh}	4.8^{ijkl}	18.1^{efg}	82.4^{ijh}	5.43^{jkli}
2,4-DEE 0.50 kgha^{-1}	15.76^{ef}	82.16^{i}	4.5^{ijkl}	17.3^{ghi}	87.93^{g}	8.06^{ghij}
2,4-DEE 0.60 kgha^{-1}	15.00^{eg}	89.43^{f}	7.64^{gh}	16.9^{hij}	90.4^{f}	10.35^{fg}
Isoproturon1.00 kgha^{-1}	18.46^{d}	78.43^{k}	3.36^{kl}	21.2^{cd}	81.1^{ijk}	4.66^{k}
Isoproturon1.25 kgha^{-1}	16.81^{de}	81.70^{ji}	4.14^{ijkl}	19.2^{efg}	82.76^{hi}	5.41^{kji}
Isoproturon 1.50 kgha^{-1}	13.84^{gh}	92.40^{de}	10.95^{ef}	15.96^{ji}	93.03^{cd}	14.54^{de}
Pendimethalin 0.70 kgha^{-1}	22.33^{b}	75.80^{l}	2.66^{ml}	23.36^{b}	79.43^{kl}	4.03^{k}
Pendimethalin 1.20 kgha^{-1}	23.43^{b}	82.46^{hi}	3.53^{jkl}	22.63^{cb}	83.4^{h}	5.12^{ji}
Pendimethalin 1.70 kgha^{-1}	20.46^{c}	85.03^{g}	4.56^{ijkl}	19.53^{ed}	86.76^{g}	6.95^{ijkl}
Pyro 15g +2,4-DEE 0.40 kg ha^{-1}	10.83^{ji}	94.06^{cd}	15.16^{d}	15.16^{kj}	94.5^{bcd}	19.49^{abc}
Pyro10g + 2,4-DEE 0.50 kg ha^{-1}	10.01^{j}	92.56^{ed}	12.18^{d}	15.5^{ji}	94^{bcde}	17.05^{cd}
Pyro 20g +2,4-DEE 0.30 kg ha^{-1}	9.83^{kj}	97.40^{b}	34.72^{a}	13.26^{k}	94.9^{bc}	21^{ab}
Pyro 20g + 2,4-DEE 0.40 kg ha^{-1}	8.25^{kl}	96.50^{b}	27.69^{b}	15.16^{kj}	95.26^{b}	22.33^{a}
Isop1.0kg +2,4-DEE0.40kg ha^{-1}	10.66^{ji}	86.33^{g}	6.51^{hgi}	10.73^{ml}	86.76^{g}	8.53^{ghi}
Isop0.75kg +2,4-DEE0.5 kgha^{-1}	12.36^{hi}	85.03^{g}	5.73^{ijk}	17.2^{hi}	86.43^{g}	7.18^{ghijk}
Isop1.25kg +2,4-DEE0.3 kg ha^{-1}	13.86^{gh}	92.36^{de}	11.09^{ef}	20.53^{de}	92.73^{de}	12.33^{ef}
Isop1.25kg +2,4-DEE0.4kg ha^{-1}	11.13^{ji}	85.80^{g}	6.20^{hgi}	20.1^{de}	93.3^{cde}	13.67^{e}
One hand weeding	13.76^{gh}	90.46^{ef}	8.69^{fg}	20.2^{de}	79.0^{l}	4.34^{k}
Two hand weeding	4.3^{1n}	95.70^{bc}	24.20^{c}	4.56^{n}	92.53^{e}	17.86^{bc}
Weedy check	52.48^{a}	-	-	58.03^{a}	-	-
Weed free	-	100^{a}	-	-	100^{a}	-
LSD (5%)	1.75	2.27	2.74	1.91	1.90	3.16
CV (%)	7.50	1.63	17.65	6.74	1.36	19.14

Means followed by the same letter with in column are not significantly different, Pyro.= Pyroxsylam , Isop.= Isoproturon, CV= Coefficient variation, LSD =Least significant difference

3.2. Crop Components

3.2.1. Yield Components and Yield

The herbicides rates, their combinations and hand weeding had highly significant ($p < 0.01$) effect on number of total tillers at both locations. The highest number of total tillers of 261.3 m^{-2} and 254 m^{-2} were recorded in two hand weeding next to weed free at Bobicho and Faate, respectively ($P<0.01$) (Table 6). However, there was no significant difference with Pyroxsulam 20 g + 2, 4-DEE 0.40 kg ha^{-1} at both sites. This might be due to better weed control efficiency of these treatments compared to the rest of the weed control treatments so as to help in providing sufficient space for tiller emergence. On the other hand, plots treated with pre-emergence herbicide pendimethalin 0.70 kg ha^{-1} showed lower total tiller number than other treatments except weedy check. This was due to poor weed control efficiency of pendimethalin 0.70 kg ha^{-1} especially grassy weeds. In contract to single herbicides, combination of 2,4-DEE with Isoproturon gave higher total tiller number. This was due to the fact that their combination controlled weed effectively and showed higher weed control efficiency and increased herbicide efficiency index (Table 6). This result is in agreement with the study of Zahid et al. (2013) reported that effective weed control methods could reduce dry matter of weed and increased number of productive tillers of wheat.

Like that of the total number of tillers, the highest number of productive tillers of 252.3 m^{-2} and 250.6 m^{-2} were recorded in two hand weeding next to complete weed free at Bobicho and Faate, respectively (Table 6). The highest number of productive tillers per unit area from two hand weeding might be due to higher number of total tiller number and low densities of weeds. Thus, the competition between weed and crop were low for resources and enhanced productive tiller emergence. Hand weedings gave higher number of productive tillers over herbicides rate alone by creating good soil condition for tillering. This result indicated that early weed control in the crop could enhance number of total and productive tiller per unit area by reducing weed competition. This might be due to removal of weeds at early stage and removal of after emerged weed community and had not contributed much competition with wheat. In line with this result, Ologbon and Yusuf (2012) reported that two hand weeding gave better weed control efficiency when compared to the rest of the weed control treatments so as to help in providing sufficient space for tiller emergence.

Table 7. Effect of herbicides, their combinations and hand weeding on total tillers per m^2 and productive tillers per m^2 of bread wheat at Bobicho and Faate, southern Ethiopia

	Bobicho		Faate	
Treatments	Total tillers	Productive tillers	Total tillers	Productive tillers
Pyroxsylam 15 g ha^{-1}	221.3^{f}	211^{kj}	213.6^{g}	206^{defg}
Pyroxsylam 20 g ha^{-1}	245.3^{c}	239^{cde}	237^{cd}	226.3^{bcd}
Pyroxsylam 25 g ha^{-1}	241.6^{cd}	232.6^{defg}	234.3^{de}	227^{bcd}
2,4-DEE 0.40 kg ha^{-1}	193^{j}	183.3^{n}	186.6^{kl}	181^{hji}
2,4-DEE 0.50 kg ha^{-1}	201.3^{i}	190.3^{mn}	184^{ml}	174.6^{kji}
2,4-DEE 0.60 kg ha^{-1}	205^{hi}	195.3^{kl}	196.6^{jki}	190^{ghi}
Isoproturon 1.00 kg ha^{-1}	201^{ij}	192^{mn}	193.3^{kjl}	186.3^{ghij}
Isoproturon 1.25 kg ha^{-1}	211^{gh}	203.3^{kl}	202.3^{jhi}	194.6^{fghi}
Isoproturon 1.50 kg ha^{-1}	231^{e}	221.3^{hi}	224^{f}	217^{cde}
Pendimethalin 0.70 kg ha^{-1}	166^{l}	154.3^{p}	154.3^{n}	146.6^{ml}
Pendimethalin 1.20 kg ha^{-1}	170.6^{kl}	161.3^{op}	163^{n}	155.3^{kl}
Pendimethalin 1.70 kg ha^{-1}	177.6^{k}	170.3^{o}	175^{m}	166^{klj}
Pyro 15 g + 2,4-DEE 0.40 kg ha^{-1}	237.6^{cde}	232.3^{efg}	231.3^{def}	224.3^{bcd}
Pyro 10 g + 2,4-DEE 0.50 kg ha^{-1}	235.6^{de}	229.3^{fgh}	225.6^{ef}	186^{ghji}
Pyro 20 g +2,4-DEE 0.30 kg ha^{-1}	245.3^{c}	238.33^{cdef}	233^{def}	226.3^{bcd}
Pyro 20 g + 2,4-DEE 0.40 kg ha^{-1}	254.6^{b}	247.6^{abc}	247^{bc}	243.6^{ab}
Isop 1.0 kg +2,4-DEE0.40 kg ha^{-1}	214.3^{fg}	202^{kl}	206^{hgi}	195.3^{fghi}

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Isop 0.75 kg + 2,4-DEE0.5 kg ha^{-1}	220^{f}	213^{ji}	210.3^{gh}	201^{efgh}
Isop 1.25 kg + 2,4-DEE0.3 kg ha^{-1}	235.3^{de}	228.6^{gh}	227.6^{def}	219.3^{cde}
Isop 1.25 kg + 2,4-DEE0.4 kg ha^{-1}	245.6^{c}	242^{bcd}	234.6^{de}	227.3^{cde}
One hand weeding	256.3^{b}	251.3^{ab}	247^{bc}	241.3^{abc}
Two hand weeding	261.3^{b}	252.3^{a}	254^{ab}	250.6^{a}
Weedy check	136.3^{l}	109.6^{q}	134.6^{o}	127.3^{m}
Weed free	275^{a}	250^{ab}	259^{a}	255.3^{a}
LSD (5%)	8.19	9.61	10.02	22.75
CV (%)	15.00	15.20	13.00	14.00

Means followed by the same letter with in column are not significantly different at 5% level of significance,

Pyro. = Pyroxsulam, Isop. = Isoproturon, CV= Coefficient variation, LSD =Least significant difference

Number of Grains per Spike

The effect of herbicides rates, their combinations and hand weeding was significant on the number of grain per spike at both experimental sites. The highest number of grains per spike of 55 and 52.6 were recorded from weed free and two hand weeding at Bobicho and Faate, respectively (Table 7) while the lowest number of grains per spike of 32.3 and 33 were observed in weedy check at Bobicho and Faate, respectively. Manual hoeing or hand weeding showed significantly higher number of grains per spike over the herbicides alone and their combinations. This result indicated that early weed control in the crop could enhance number of grains per spike by reducing weed competition. This result is in agreement with Rana et al. (2010) reported that the removal of weeds from wheat at 20 days after crop emergence could increase the yield components and yield. On the other hand, later weeding and hoeing after critical period of weed control would not enhance yield components and yield but mainly create conducive environment for harvesting. If weeds were well controlled during the critical period, the crop will be so far advanced, and at the end of it new weed seedlings are no longer detrimental to the yield components of crop.

On the other hand, herbicides combination showed significant difference between them and higher number over plots treated herbicides alone. This was due to better weed control efficiency that combinations had provided and lower weed index. In line with this result, Adel and Ali (2013) reported that pyroxsulam could be used as mixed with wheat broad-leaf herbicides such as 2, 4-DEE and its efficiency is more than dual-purpose herbicides. Thus the results showed that the mixture of these two herbicides had a higher efficiency than the conventional mixture of Isoproturon and 2, 4-DEE (Table 7). Higher number of grains per spike was due to the increase of fertile spikes and the number of productive tillers. The significantly higher number of grains might be the result of easily accessible growth factors (nutrient, moisture and light) for individual plant that retained more flowers and higher net assimilation rate in the absence of competition from weeds. Also the development of more and vigorous leaves under low weed infestation might have helped to improve the photosynthetic efficiency of the crop and supported higher number of grains. Moreover, in complete weed free treatment, the spikes were healthy and completely filled as against shriveled and few grain in weedy check. This was because of the effect of the competition for limited nutrients available, ultimately resulting in reduced grain filling of the spike. The poor grain filling due to presence of weeds was reported to be due to reduced tillering, ear formation, and stem weight and height reduction in wheat (e.g. Fazal et al., 2012). The severe weed competition between the weeds and crop in weedy check prominently reduced the nutrient mobility towards grains which might have affected the grain development potential of the wheat crop.

Thousand grain weight (g)

The effect of herbicides rates, their combinations and hand weeding showed significant effect on thousand grain weight both at Bobicho and Faate. The highest thousand grain weights of 36.6 g and 36 g were recorded in pyroxsulam 20 g + 2, 4-DEE 0.40 kg ha^{-1} next to complete weed free at Bobicho and Faate, respectively (Table 8) while the lowest thousand grain weights of 31.33 g and 33 g were observed in weedy check at Bobicho and Faate, respectively. The highest thousand grain weight recorded from weed free check might be due to availability of more space for better light interception, more nutrients available and moisture for crops' grain development, as compared to high weed density. In conformity with this result, Khalid et al. (2010) reported that the more and vigorous leaves under weed free environment that had improved the supply of assimilate to be stored in the grain.

Total above ground dry biomass

The highest total above ground dry biomasses of 11,300 kg ha^{-1} and 10,873.3 kg ha^{-1} were recorded in weed free check at Bobicho and Faate, respectively (Table 8). In contrast, the lowest total above ground dry biomasses of 6432.6 kg ha^{-1} and 6457 kg ha^{-1} were recorded in weedy check at Bobicho and Faate, respectively. Similarly, Muhammad et al. (2013) reported that the higher biological yield of the crop was due to the better weed control of the treatment under reference, enabled the better utilization of the resources by the wheat crop. Likewise, Mizan et al. (2009) reported that the increased dry matter weight of the crop was highly governed by the length of weed free period.This was in fact of that their combination were showed higher weed control efficiency and increased herbicide efficiency index (Table 8). In conformity with this result, Muhammad et al. (2013) reported that the highest biological yield in those plots which were treated with the mixture of Isoproturon1.25 kg + 2,4-DEE0.40 kg ha^{-1} while the lowest in weedy check. Hand weeding twice showed significantly higher above ground dry biomass over herbicides rates alone. This result indicated that early weed control in the crop could enhance total above ground biomass by reducing weed competition. Removing weeds from crop fields earlier could reduce competition and can contribute to higher dry biomass than late weeding. This result is in agreement with Shrestha et al. (2010) reported that the removal of weeds from wheat at 20 and 35 days after wheat emergence could boost the yield components and yield.

Table8. Effect of herbicides, their combinations and hand weeding on number of grains spike^{-1}, 1000 grain weight (g) and total above ground biomass (kg ha^{-1}) at Bobicho and Faate, southern Ethiopia

	Bobicho			Faate		
Treatments	Grains spike^{-1}	1000 grain weight (g)	Above biomass	Grains spike^{-1}	1000 grain weight (g)	Above biomass
Pyroxsulam 15 g ha^{-1}	49.3^{bcde}	34.66^{def}	10123.3^{d}	49.6^{ab}	35^{bcd}	9918.3^{f}
Pyroxsulam 20 g ha^{-1}	50.6^{bcd}	35^{de}	10112.3^{d}	48.6^{ab}	34.3^{efg}	9909^{fg}
Pyroxsulam 25 g ha^{-1}	52^{abc}	35^{de}	10138.3^{d}	49.6^{ab}	34.8^{cdef}	9893.6^{g}
2,4-DEE 0.40 kg ha^{-1}	50^{bcd}	35.33^{cd}	9931^{fg}	52.3^{ab}	34.4^{ef}	9425^{j}
2,4-DEE 0.50 kg ha^{-1}	49.3^{bcde}	34.33^{ef}	9842.6^{i}	51.3^{ab}	35^{cde}	9437^{j}
2,4-DEE 0.60 kg ha^{-1}	49.3^{bcde}	35.33^{cd}	9782.3^{j}	50.0^{ab}	34^{fg}	9488.3^{i}
Isoproturon 1.00 kg ha^{-1}	48^{de}	35^{de}	9988^{e}	52.6^{a}	35^{bcd}	9419^{j}
Isoproturon 1.25 kg ha^{-1}	47.6^{de}	35^{de}	8994^{k}	52.6^{a}	35^{bcd}	9506.6^{hi}
Isoproturon 1.50 kg ha^{-1}	47.6^{de}	35.33^{cd}	9973.3^{ef}	51.3^{ab}	35^{bcd}	9521.6^{h}
Pendimethalin 0.70 kg ha^{-1}	46^{e}	34.33^{ef}	8989.6^{k}	49.0^{ab}	34.4^{ef}	8809.3^{n}
Pendimethalin 1.20 kg ha^{-1}	48.6^{cde}	35^{de}	9873^{i}	48.6^{ab}	33.4^{gh}	8821.6^{n}
Pendimethalin 1.70 kg ha^{-1}	48.6^{cde}	36.66^{b}	10123.3^{d}	50.0^{ab}	34^{fg}	9915.3^{fg}
Pyro 15 g + 2,4-DEE 0.40 kg ha^{-1}	49.6^{bcd}	34.66^{edf}	10183.6^{c}	50.0^{ab}	36^{b}	10005.6^{b}
Pyro10 g + 2,4-DEE 0.50 kg ha^{-1}	51bcd	34^{f}	9985^{e}	50.0^{ab}	35.6^{bc}	9991^{bcd}
Pyro 20 g +2,4-DEE 0.30 kg ha^{-1}	49.6^{bcd}	35^{de}	10203.3^{c}	48.6^{ab}	35^{cde}	9980^{cd}
Pyro 20 g + 2,4-DEE 0.40 kg ha^{-1}	51^{bcd}	36^{bc}	10127.6^{d}	48.6^{ab}	35^{bcd}	9949.6^{e}
Isop1.0 kg + 2,4-DEE 0.40 kg ha^{-1}	50.6^{bcd}	34^{f}	10002.6^{e}	50.0^{ab}	35^{bcd}	9972^{de}
Isop 0.75 kg + 2,4-DEE0.50 kgha^{-1}	49.6^{bcd}	36^{bc}	9988^{e}	51.6^{ab}	34.5^{def}	8970^{l}
Isop1.25 kg +2,4-DEE 0.30 kg ha^{-1}	48.6^{cde}	35^{de}	9972.3^{ef}	50.6^{ab}	35.4^{bcd}	8885.3^{m}
Isop1.25 kg + 2,4-DEE0.40 kg ha^{-1}	50.6^{bcd}	36^{bc}	9918.6^{gh}	52.0^{ab}	35^{bcd}	9000^{k}
One hand weeding	51.6^{abc}	35^{ed}	9885.3^{hi}	51.0^{ab}	35^{bcd}	8776^{o}
Two hand weeding	52.3^{ab}	36^{bc}	10293.3^{b}	52.6^{a}	35^{bcd}	10003^{bc}
Weedy check	32.3^{f}	31.33^{g}	6432.6^{l}	33.0^{c}	33^{h}	6457^{p}
Weed free	55^{a}	37.66^{a}	11300^{a}	52.0^{ab}	37^{a}	10873.3^{a}
LSD (5%)	3.36	0.84	43.49	3.72	0.95	23.16
CV (%)	9.01	6.00	17.23	11.21	4.90	15.43

Means followed by the same letter(s) within column are not significantly different at 5% level of significance, Pyro. = Pyroxsulam, Isop.= Isoproturon, TAG = Total above ground, CV= Coefficient variation, LSD =Least significant difference

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Grain Yield

The herbicides rates, their combinations and hand weeding had shown significant effect on the grain yield. The lowest grain yield of 2469.6 kg ha^{-1} and 2076.6 kg ha^{-1} were recorded in weedy check at Bobicho and Faate, respectively, while the highest grain yields of 5223.3 kg ha^{-1} and 4950 kg ha^{-1} were recorded in weed free check (Table 9). The grain yields obtained in weed free plots were significantly higher than all the treatments. Furthermore; the grain yield of higher herbicides rates had shown increment over lower rates. This might be due to high density of the weed in lower rate resulted from less weed control efficiency and high weed index. The more and vigorous leaves under weed free environment that might have improved the supply of assimilate to be stored in the grain, hence, the 1000- grain weight increased. The plants raised under weed free environment were free from weed competition thus utilized the available resources to its maximum benefit resulting in increased grain weight, more number of productive tillers per unit area, number of grains per spike and then finally grain yield. The results showed that the combinations of Pyroxsulam and 2,4-DEE had a higher efficiency than the conventional mixture of Isoproturon and 2, 4-DEE (Table 9). In line with this result, Adel and Ali (2013) reported that pyroxsulam can be used as mixed with wheat broad-leaf herbicides such as 2, 4-DEE and its efficiency is more than dual-purpose herbicides.

In contrast to this, significantly low number of productive tillers per unit area, grains per spike and 1000-grain weight resulted in significantly low yield in weedy check plots as compared to other treatments. The results further revealed that uncontrolled weed growth was found to reduce the yield of bread wheat by 52.48 and 58.03% as compared to weed free at Bobicho and Faate, respectively (Table 9). These results were the higher yield loss than average yield loss of 35% national wheat yield loss report, due to weed infestation. This might be due to high seasonal rainfall distribution in the study area, thus encourages high weed density and more weed dry weight accumulation.

Harvest Index

The effect of herbicides rate, their combinations and hand weeding had shown significant effect on the harvest index. The lowest harvest index of 38.39% and 32.16% were recorded in weedy check at Bobicho and Faate, respectively while the highest harvest index of 48.95% and 47.21% were recorded in Pyroxsulam 20 g ha^{-1} and two hand weeding at Bobicho and Faate, respectively (Table 9). The variation in harvest index under different treatments might be due to variation in number of total tillers, number of grains per spike, 1000 grain weight and the grain yield. In agreement with this result, Nano (2012) reported that twice hand weeding showed the highest harvest index (46%) than other treatments on the same variety.

Table 9. Effect of herbicides, their combinations and hand weeding on grain yield (kg ha^{-1}) and harvest index (%) at Bobicho and Faate, southern Ethiopia

	Bobicho		Faate	
Treatments	Grain yield (kg ha^{-1})	Harvest index (%)	Grain yield (kg ha^{-1})	Harvest index (%)
Pyroxsulam 15 g ha^{-1}	4850^{c}	47.90^{bcd}	4400^{e}	44.36^{cd}
Pyroxsulam 20 g ha^{-1}	4950^{b}	48.95^{a}	4479.3^{cd}	45.20^{b}
Pyroxsulam 25 g ha^{-1}	4850^{c}	47.83^{cd}	4500^{c}	45.48^{b}
2,4-DEE 0.40 kg ha^{-1}	4256.6^{k}	42.86^{k}	4053.3^{kj}	43.00^{f}
2,4-DEE 0.50 kg ha^{-1}	4400^{ij}	44.70^{j}	4093.3^{ji}	43.37^{ef}
2,4-DEE 0.60 kg ha^{-1}	4440^{hi}	45.38^{ghi}	4113.3^{hgi}	43.35^{ef}
Isoproturon 1.00 kg ha^{-1}	4258^{k}	42.63^{k}	3900^{mn}	41.40^{h}
Isoproturon 1.25 kg ha^{-1}	4345^{j}	48.31^{abc}	4000^{kl}	42.07^{hg}
Isoproturon 1.50 kg ha^{-1}	4500^{hg}	45.12^{ji}	4160^{hgi}	43.68^{def}
Pendimethalin 0.70 kg ha^{-1}	4058.3^{m}	45.14^{jhi}	3793.3^{o}	43.06^{f}
Pendimethalin 1.20 kg ha^{-1}	4000^{m}	40.51^{l}	3830^{no}	43.41^{ef}
Pendimethalin 1.70 kg ha^{-1}	4154.3^{l}	41.03^{l}	3983.3^{kl}	40.17^{i}
Pyro 15 g +2,4-DEE 0.40 kg ha^{-1}	4655.7^{de}	45.72^{ghi}	4200^{g}	41.97^{hg}
Pyro 10 g + 2,4-DEE 0.50 kg ha^{-1}	4700^{d}	47.07^{e}	4183.3^{hg}	41.87^{hg}

Pyro 20 g +2,4-DEE 0.30 kg ha^{-1}	4710^{d}	46.16^{fg}	4293.3^{f}	43.01^{f}
Pyro 20 g + 2,4-DEE 0.40 kg ha^{-1}	4792.6^{c}	47.32^{de}	4200^{g}	42.21^{g}
Isop 1.0 kg +2,4-DEE0.40 kg ha^{-1}	4665de	46.63^{ef}	4418.3^{de}	44.30^{cd}
Isop 0.75 kg +2,4-DEE 0.5 kg ha^{-1}	4576.3^{f}	45.81^{gh}	4100^{ji}	45.70^{b}
Isop 1.25 kg +2,4-DEE 0.3 kg ha^{-1}	4500^{hg}	45.12^{ghi}	3933.3^{ml}	44.26^{cd}
Isop 1.25 kg +2,4-DEE0.4 kg ha^{-1}	4643^{e}	46.81^{ef}	3956.6^{ml}	43.96^{de}
One hand weeding	4503^{g}	45.55^{ghi}	3950^{ml}	45.00^{bc}
Two hand weeding	4998^{b}	48.55^{ab}	4723.3^{b}	47.21^{a}
Weedy check	2469.6^{n}	38.39^{m}	2076.6^{p}	32.16^{j}
Weed free check	5223.3^{a}	46.22^{fg}	4950^{a}	45.52^{a}
LSD (5%)	60.85	0.69	72.39	0.74
CV (%)	12.3	7.8	14.2	11.1

Means followed by the same letter with in column are not significantly different at 5% level of significance,

Pyro. = Pyroxsulam, Isop. = Isoproturon, CV= Coefficient variation, LSD = Least significant difference

3.3. Partial Budget Analysis

In this study, fixed costs were not considered and the highest total variable cost of 6535 birr ha^{-1} and 6185 Birr ha^{-1} were recorded from Pyroxsulam 25 g ha^{-1} at Bobicho and Faate, respectively. Whereas; the highest net return of 25,289.4 Birr ha^{-1} and 23,833.0 Birr ha^{-1} were recorded from two hand weeding at Bobicho and Faate, respectively, following to the weed free check (Table 9 &10). Further, the relative net returns increased with increasing herbicide application rates that was due to better control of weeds that consequently resulted in increased grain yield. Moreover, there was variation between two experimental sites in relative net returns. This might be most probably due to better control of weeds that consequently resulted in increased grain yield though total variable costs were equal. On the other hand, herbicides combination had shown better relative returns over herbicides rates used alone. In line with this result, Muhammad et al. (2013) stated that herbicide combinations controlled weed infestation effectively on bread wheat and gave higher yield that related directly with higher relative net return. All weed control treatments gave higher net benefit over weedy check.

Table 10: Effect of herbicides, their combinations and hand weeding on relative economic returns at Bobicho, southern Ethiopia

Treatments	Average Yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (Birr ha-$^{1)}$	TVC (Birr ha^{-1})	Net benefit (Birr ha^{-1})	Cost benefit ratio(C: B)
Pendimethalin 0.70 kg ha^{-1}	4058.3	3652.5	25567.5	4286.3	21281.2	0.167
Pendimethali 1.20 kg ha^{-1}	4000.0	3600.0	25200.0	4348.0	20852.0	0.172
Pendimethalin1.7 kg ha^{-1}	4154.3	3738.9	26172.3	4622.3	21550.0	0.176
Isoproturon1.0 kg ha^{-1}	4258.0	3832.2	26825.4	4474.0	22351.4	0.166
Isoproturon 1.25 kg ha^{-1}	4345.0	3910.5	27373.5	4600.0	22773.5	0.168
Isoproturon 1.5 kg ha-1	4500.0	4050.0	28350.0	4794.0	23556.0	0.169
2,4-DEE 0.40 kg ha^{-1}	4256.6	3830.9	26816.3	4356.6	22459.7	0.162
2,4-DEE 0.50 kg ha^{-1}	4400.0	3960.0	27720.0	4510.0	23210.0	0.162
2,4-DEE 0.60 kg ha^{-1}	4440.0	3996.0	27972.0	4560.0	23412.0	0.163
Pyroxsulam 15 g ha^{-1}	4850.0	4365.0	30555.0	5885.0	24670.0	0.192
Pyroxsulam 20 g ha^{-1}	4950.0	4455.0	31185.0	6310.0	24875.0	0.202
Pyroxsulam 25 g ha^{-1}	4850.0	4365.0	30555.0	6535.0	24020.0	0.213
Pro 15 g + 2,4-D 0.40 kg ha^{-1}	4655.7	4190.2	29331.4	5730.7	23600.7	0.195
Pro 10 g + 2,4-D 0.50 kg ha^{-1}	4700.0	4230.0	29610.0	5460.0	24150.0	0.184
Pro 20 g + 2,4-D 0.30 kg ha^{-1}	4710.0	4239.0	29673.0	6100.0	23573.0	0.205

Pro 20 g + 2,4-D 0.40 kg ha^{-1}	4792.6	4313.4	30193.8	6192.6	24001.2	0.205
Iso 1 kg +2,4-D 0.40 kg ha^{-1}	4665.0	4198.5	29389.5	4921.0	24468.5	0.167
Iso 0.75 kg + 2,4-D 0.50 kg ha^{-1}	4576.3	4118.7	28830.9	4803.3	24027.6	0.166
Iso 1.25 kg + 2,4-D 0.30 kg ha^{-1}	4500.0	4050.0	28350.0	4785.0	23565.0	0.168
Iso 1.25 kg +2,4-D 0.40 kg ha-^{1}	4643.0	4178.7	29250.9	4938.0	24312.9	0.168
One hand weeding	4503.0	4052.7	28368.9	5253.0	23115.9	0.185
Two hand weeding	4998.0	4498.2	31487.4	6198.0	25289.4	0.198
Weedy check	2469.6	2222.6	15558.2	2469.6	13088.6	0.158
Weed free check	5223.3	4700.9	32906.3	7623.3	25283.0	0.231

Local market price of bread wheat was 700.00 Birr/100 kg (1 USD = 19.01 Birr) and net income was the product of market price and adjusted grain yield, TVC =Total variable cost

Table 11: Effect of herbicides, their combinations and hand weeding on relative economic returns at Faate, southern Ethiopia

Treatments	Average Yield kg ha^{-1}	Adjusted yield kg ha^{-1}	Gross benefit (Birr ha-$^{1)}$	TVC (Birr ha^{-1})	Net benefit (Birr ha-1)	Cost benefit Ratio (C: B)
Pendimethalin 0.70 kg ha^{-1}	3793.3	3413.9	23897.3	4021.3	19876.0	0.168
Pendimethali 1.20 kg ha^{-1}	3830.0	3447.0	24129.0	4178.0	19951.0	0.173
Pendimethalin1.7 kg ha^{-1}	3983.3	3584.9	25094.3	4451.3	20643.0	0.177
Isoproturon1.0 kg ha^{-1}	3900.0	3510.0	24570.0	4116.0	20454.0	0.167
Isoproturon 1.25 kg ha^{-1}	4000.0	3600.0	25200.0	4255.0	20945.0	0.168
Isoproturon 1.5 kg ha-1	4160.0	3744.0	26208.0	4454.0	21754.0	0.169
2,4-DEE 0.40 kg ha^{-1}	4053.3	3647.9	25535.3	4153.3	21382.0	0.162
2,4-DEE 0.50 kg ha^{-1}	4093.3	3683.9	25787.3	4203.3	21584.0	0.162
2,4-DEE 0.60 kg ha^{-1}	4113.3	3701.9	25913.3	4233.3	21680.0	0.163
Pyroxsulam 15 g ha^{-1}	4400.0	3960.0	27720.0	5435.0	22285.0	0.196
Pyroxsulam 20 g ha^{-1}	4479.3	4031.4	28219,8	5839.3	22380.5	0.206
Pyroxsulam 25 g ha^{-1}	4500.0	4050.0	28350.0	6185.0	22165.0	0.218
Pro 15 g + 2,4-D 0.40 kg ha^{-1}	4200.0	3780.0	26460.0	5275.0	21185.0	0.199
Pro 10 g + 2,4-D 0.50 kg ha^{-1}	4183.3	3764.9	26354.3	4943.3	21411.0	0.187
Pro 20 g + 2,4-D 0.30 kg ha^{-1}	4293.3	3863.9	27047.3	5683.3	21364.0	0.121
Pro 20 g + 2,4-D 0.40 kg ha^{-1}	4200.0	3780.0	26460.0	5600.0	20860.0	0.211
Iso 1 kg +2,4-D 0.40 kg ha^{-1}	4418.3	3976.5	27835.5	4674.3	23161.2	0.167
Iso 0.75 kg + 2,4-D 0.50 kg ha^{-1}	4100.0	3690.0	25830.0	4327.0	21503.0	0.167
Iso 1.25 kg + 2,4-D 0.30 kg ha^{-1}	3933.3	3539.9	24779.3	4218.3	20561.0	0.170
Iso 1.25 kg +2,4-D 0.40 kg ha-^{1}	3956.6	3560.9	24926.3	4251.6	20674.7	0.170
One hand weeding	3950.0	3555.0	24885.0	4700.0	20185.0	0.188
Two hand weeding	4723.3	4250.9	29756.3	5923.3	23833.0	0.199
Weedy check	2076.6	1868.9	13082.3	2076.6	11005.7	0.158
Weed free check	4950.0	4455.0	31185.0	7350.0	23835.0	0.235

Local market price of bread wheat was 700.00 Birr/100 kg (1 USD = 19.01 Birr) and net benefit was the product of market price and adjusted grain yield, TV =Total variable cost

4. CONCLUSION

Wheat productivity is remarkably reduced by weed infestation in the highland agro-ecology like in the study areas. Farmers in the study are aware of weed problem in their fields but often they cannot cope-up with heavy weed infestation during the peak-period of agricultural activities because of labor shortage, hence most of their fields are weeded late or left un-weeded. Such ineffective weed management is considered as the main factor for low yield of wheat resulting in yield loss of up to 58.6% when there is uninterrupted weed growth. Herbicidal weed management in this regard is indispensable approach to increase crop productivity especially when there is labor shortage. The result of this study clearly indicated that all the herbicide treatments resulted in significantly better crop yield than untreated check. Specially, the combinations of herbicides gave significantly higher yields than applying herbicides rates alone and one hand weeding. In general, Isoproturon and 2,4-DEE were more effective in controlling grassy and broad leaved weeds respectively, while Pyroxsulam 20 g ha^{-1} was more effective in controlling both grassy and broadleaved weeds. None of herbicides application showed phyto-toxicity symptoms on crop except of 2, 4-DEE 0.60 kg ha^{-1} burning of leaves till one week after spraying. Pyroxsulam and its combinations resulted in lower weed dry matter at harvest. Likewise, crop growth, yield attributes and yield were significantly influenced by weed control treatments. It is better to use two hand weeding at two and four weeks after crop emergence for higher yield and maximum relative net returns under availability of labor. In case where there was labor shortage, Pyroxsulam 20 g ha^{-1} could give better yield and relative net returns.

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