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Effect of Pre-emergence Herbicides on Weeds, Nodulation and Yield of Cowpea [*Vigna unguiculata* (L.) WALP.] at Haik and Mersa in Wollo, Northern Ethiopia

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Abstract: The experiment was conducted at Mersa and Haik, northern Ethiopia during the 2014 main cropping season to assess the effect of pre-emergence s-metolachlor and pendimethalin on nodulation, and yield of cowpea. There were 12 treatments comprising: s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}); pendimethalin (1.0, 1.3 and 1.6 kg ha^{-1}), s-metolachlor at 1.0 kg ha^{-1} + hand weeding at 5 weeks after crop emergence (WAE), pendimethalin at 1.0 kg ha^{-1} + hand weeding at 5 WAE, one hand weeding at 2 WAE, two hand weeding at 2 and 5 WAE, weed free and weedy checks. The treatments were arranged in randomized complete block design with three replications. The minimum weed dry weight was registered with the application 2.0 kg ha^{-1} of s-metolachlor at both locations; however, at 55 DAE and at harvest, weeds accumulated significantly lower dry weight due to s-metolachlor 1.0 kg ha^{-1} and pendimethalin 1.0 kg ha^{-1} each pendimethalin superimposed with hand weeding at both locations. The interaction of location with weed management practices was significant on number and dry weight of nodules, number of pods plant^{-1}, grain and aboveground dry biomass yield and yield loss. The maximum grain yield (4277 kg ha^{-1}) was obtained in complete weed free treatment at Mersa which was statistically in parity with complete weed free and two hand weeding treatments at Haik and Mersa, respectively. Due to weed infestation throughout the crop growth, the highest yield loss (70.8%) was recorded at Haik while it was 47.5% at Mersa.

Keywords: Hand-Weeding, Pendimethalin, S-metolachlor, Weed- Free, Yield Loss

1. Introduction

Cowpea is one of the most important crop to the livelihoods of millions of relatively poor people in less developed countries of the tropics [1]. It is extensively grown in the lowlands and mid-altitude regions of Africa, sometimes as sole crop but more often intercropped with cereals such as sorghum or millet [2]. It is a good food security crop as it mixes well with other recipe [3]. Cowpea fixes atmospheric nitrogen through symbiosis with nodule bacteria [4]. It does well and is most popular in the semi-arid of the tropics where other food legumes do not perform well [5].

In Ethiopia, it is the least cultivated and scarcely distributed pulse crop in spite of its importance especially in dry lands. A number of weed species are affecting the yield by competing with the crop from germination to harvest [6], and this yield loss due to weeds in cowpea ranged from 12.7% - 60.0% [7]. Moreover, [8] reported that, the presence of weeds in cowpea reduced yield by 82% and a significant increase in yield of pods was noted by controlling weeds up to 45 days of sowing. Therefore, in order to enhance crop yield, weed control during this period is very important. The physical and mechanical approaches of weed control are very expensive as labour is usually unavailable during the peak periods of weed removal from the field [9]. Hand weeding required over 50% of the farmers' time leaving them with little or no time for other activities [10]. In this regard, the use of herbicides to control weeds in cowpea fields appears to be the other option [11].

According to [6] obtained significantly higher grain yield and net return of cowpea with pre-emergence application of (pendimethalin at 0.75 kg ha^{-1} + weeding at 5 weeks after planting) compared to other treatments. Also [12] reported that (pendimethalin at 1.0 kg ha^{-1}+ hand weeding at 30 days) after planting gave significantly higher cowpea grain yield, and the lowest weed density and biomass. Metolachlor has an excellent action against annual grasses and *Cyperus* species. Research with metolachlor in cowpeas resulted in yields comparable to those receiving the recommended two weeding [13]. However, the rate of s-metolachlor may depend upon soil types, rainfall and irrigation patterns, temperature, crops and weeds; nevertheless, 1.5 kg ha^{-1} of s-metolachlor has been used in pulse crops in Ethiopia [14]. Use of herbicides may therefore provide a timely and adequate alternative to hand weeding as this not only removes the drudgery associated with it but also lowers the cost of weeding and provides protection for crop against early weed competition when pre-emergence herbicides are used [10].

The chemicals that are being used in agriculture may disrupt the microbial communities in the soil and therefore affect the symbiotic relationship between nitrogen fixing Bacteria and legumes. Soil microorganisms like bacteria, fungi, algae, protozoa, actinomycetes and some nematodes have a vital role in maintaining the soil productivity. Soil microbial biomass is considered an active nutrient pool to plants. The common use of herbicides may negatively affect N fixation either directly by affecting Rhizobium, or indirectly by reducing photosynthate allocation to the nodules for N fixation, or by restricting root growth and hence the number of root sites available for infection [15].

The objectives of this study were to assess the effect of s-metolachlor and pendimethalin on weeds, nodulation, yield components and yield of cowpea as well as to investigate the possibilities of supplementing low doses of herbicides with hand weeding for effective weed control and their economic returns in cowpea.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at Sirinka Agricultural Research Center at Haik (11°21'N latitude and 39°38'E longitude; 1670 m. a. s. l. altitude) and Mersa (11°45'00" N latitude; 39°36'36"E longitude; 1860 m. a.s.l. altitude) experimental sites in northern Ethiopia during the 2014 main cropping season (July – October). The soil types of Mersa and Haik experimental fields were clay loam and clay respectively, and the pH level was 6.95 and 6.91 at Mersa and Haik, respectively. At Mersa, the organic carbon was 1.37%, and the total N was 0.09%, the available P of 12.17 mg kg^{-1} soil and CEC 53.44 cmol$_C$ kg^{-1} while 1.33%, 0.07%, 9.17 mg kg^{-1} soil and 33.44 cmol$_C$ kg^{-1} were respective values at Haik (Table 1)*. The total seasonal rainfall received during the crop season was 750.4 mm and 589.1 mm at Mersa and Haik with mean maximum and minimum temperatures of 28.6°C and 14.7°C, and 29.6 and 15.8°C, respectively. Soil sample preparation and analysis was done at Sirinka Agriculture Research Center.

Experimental Materials

The cowpea variety Asrat (IT 92KD-279-3) released by SRARC/ARARI 2001 was used in these experiments. The variety adapts well in moisture stress areas in the North East of Wollo and similar low land areas. This variety is suitable for an altitude range of 1450-1850 m.a.s.l. and rainfall of 660-1025 mm. It is bush and trailing type I. It attains maturity in 95-100 days [16].

Table 1. *Description of herbicides used in the experiment.*

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

* Table 1 about the description of herbicide which used at the experiment

2.2. Treatments and Experimental Design

The experiment comprised of 12 treatments: s-metolachlor at (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0, 1.3 and 1.6 kg ha^{-1}), s-metolachlor at 1.0 kg ha^{-1} + hand weeding at 5 weeks after crop emergence (WAE), pendimethalin at 1.0 kg ha^{-1} + hand weeding at 5 WAE, one hand weeding at 2 WAE, two hand weeding at 2 and 5 WAE, weed free check and weedy check. The design of the experiment was randomized complete block with three replications. Two herbicide used at experiment (table 1)

2.3. Experimental Procedure and Management

The experimental field was ploughed to get a fine seedbed using tractor and the plots were leveled manually. The gross plot size was 3.6 m x 2.4 m (8.64 m^2). The path way between replications and plots were 1 and 0.5 m, respectively. The cowpea variety Asrat was planted on the 8th July and 13th of July, 2014 at Haik and Mersa, respectively. Fertilizer (100 kg DAP; 18 kg N+46 kg P_2O_5 ha^{-1}) was applied uniformly to each plot at the time of sowing. There were 6 rows spaced 60 cm apart and intra row spacing of 10 cm between plants.

The herbicides were applied as per the treatment in the assigned plots as pre-emergence within one day after planting. Herbicide spray volume with water as carrier was 450 ℓ ha^{-1}. Spraying was done with manually operated Knapsack sprayer (15 ℓ capacity) using flat-fan nozzle.

The outermost one row from each side was border row and the next one row on both sides was used for destructive sampling. In addition, 3 plants on each end of rows were also excluded to remove border effect. Thus, the net plot area was 2.4 m × 1.8 m (4.32 m^2). All the recommended practices except the treatments were followed to raise the crop. The crop was harvested on October 15 and 25, 2014 at Haik and Mersa, respectively. The harvested produce was sun-dried for 7-10 days and threshing and winnowing was done subsequently.

2.4. Data Collection and Analysis

Weeds

The aboveground weed dry weight/ biomass was recorded by throwing a quadrat (0.25 m × 0.25 m) randomly at two places in each plot at 20 DAE, 55 DAE and about 15 days before the expected harvest time. The aboveground weed dry weight/ biomass, the weeds falling within the quadrat were cut near the soil surface immediately after taking observation on weed count and placed into paper bags separately treatment (plot) wise. The samples were sun dried for 3-4 days and thereafter were placed in to an oven at 65°C temperature till their constant weight and subsequent dry weight was measured. The dry weight was expressed in g m^{-2}. Herbicide efficiency index (HEI) - It is weed killing potential of by herbicides treatments calculated or obtained by:

$$HEI = 100 – (x 100)$$

Where

A = dry weight of weed at herbicides treatment

B = dry weight of weed at weedy treatment

Crop

Bulk of roots of 5 randomly taken plants from the net area was carefully exposed at 50% flowering and uprooted for nodulation study. Roots were carefully washed using tap water on a sieve and nodules were separated and counted. Effectiveness of the nodules was checked by cutting the nodule for color judgment as percentage which is pink (effective) and cream white (ineffective). The nodules were being placed at 65°C in an oven to constant weight to determine nodule dry weight per plant. Plant height (cm) was taken with a ruler from 10 randomly selected and pre tagged plants in each net plot area from the base to the apex of the main stem at physiological maturity.

The number of pods $plant^{-1}$ was taken from the total pods of the above tagged plants at harvest. The total number of seeds from the above pods was taken and counted to average the number of seeds pod^{-1}. Out of seeds from the above, 100 seeds were counted and their weight was recorded at 10.5% moisture content for hundred seed weight (g). Harvest index (%) was determined as grain yield divided by the dry aboveground biomass of ten plants in each plot at physiological maturity. Treatment per plant dry biomass weight was multiplied by the number of plants in respective treatments. This was considered as the aboveground dry biomass weight. The grain weight obtained in ten plants was added to the final yield. The grain yield (kg ha^{-1}) was measured after threshing the sun dried plants harvested from each net plot and the yield was adjusted at 10.5% seed moisture content. Yield loss (%): The loss in seed yield was determined as a percentage of the difference between weeded plots (complete weed free) and yield in a particular treatment using the formula

$$YL = X 100$$

Where, YL =Yield loss, Y1 = Yield in complete weed free (CWF), Y2 = Yield in a particular treatment

Data on weed dry biomass; growth, yield attributes and yield were subjected to analysis of variance using GenStat 15.0 computer software [17]. Fisher's protected Least Significant Difference (LSD) test at 5% level of significance was used to separate the differences among treatment means ($P < 0.05$) [18]. As the F-test of the error variances for the parameters of the two sites was homogeneous, combined analysis of data was used. The weed data in both locations was not homogeneous hence combined analysis was not used.

2.5. Partial Budget Analysis

The concepts used in the partial budget analysis were the mean grain yield of each treatment in both locations, the field price of cowpea (sale price (Birr 15 kg^{-1}) minus the costs of harvesting, threshing and winnowing (Birr 165/ 100 kg) bagging (Birr 4.0 per 100 kg^{-1}) and transportation (Birr 5 per 100 kg^{-1}), the gross field benefit (GFB) ha^{-1} (the product of field price and the mean yield for each treatment), the field price of s-metolachlor 417 Birr kg^{-1}, cost of pendimethalin 620 Birr kg^{-1} (the herbicide cost plus the cost of transportation from the point of sale to the farm), the total costs that varied (TCV) included the sum of field cost of herbicide and its application (Spraying Birr 99 ha^{-1}). The net benefit (NB) was calculated as the difference between the GFB and the TCV. All costs and benefits were calculated on ha basis in Ethiopian Birr. Actual yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. There were optimum plant population density, timely labor availability and better management (e.g. weed control, better security) under experimental conditions [19].

3. Results and Discussion

3.1. Weed Parameters

3.1.1. Weed Dry Matter Weight

The analysis of variance showed highly significant ($P<0.05$) difference the influence of weed management practices on the weed dry matter at all the growth stages, in both locations.

At 20 DAE, minimum weed dry weight was registered with the application of 2.0 kg ha^{-1} of s-metolachlor at both locations (Table 2). Herbicide application at both sites resulted in significant reduction in weed dry weight over weedy check. With the increase in s-metolachlor application rates, the weed dry weight significantly decreased, while the results were inconsistent with the application of pendimethalin at both locations. Similarly, [20] reported that herbicide application decreased the dry biomass of weeds; however, this decrement depends on several factors, for example, duration of the crop, type of weed species, herbicides, fertilizer, etc. The rate of metolachlor application may depend upon soil types, rainfall and temperature. Similarly, [21] found that 1.5 kg ha^{-1} of this herbicide is to be effective for the control of weeds in common bean. [22] and [23] also concluded that dry weight of weeds was significantly reduced in herbicide treated plots.

At 55 DAE, weeds in plots treated with 1.0 kg $ha^{-1}$of s-metolachlor + hand weeding at 5 WAE and 1 kg ha^{-1} of pendimethalin + hand weeding at 5 WAE at both locations had accumulated significantly the lowest dry weight which might be due to the cumulative effect of herbicide and hand weeding (Table 2). [24] also obtained lower dry weight of weeds with 1.0 kg ha^{-1} of butachlor in combination with cultural practices, which was at par with weed free check. The result of this study was in agreement with earlier works by [25] and [26] who observed reduced weed dry weight when herbicide application in common bean was combined with one hand weeding. Better control of weeds at the early stages by applying 1.0 kg ha^{-1} of fluchloralin and subsequent removal of weeds by hand weeding at 40 DAE resulted in lesser weed count and weed dry weight [27].

It was also observed that application of pendimethalin resulted in significantly higher total weed dry weight than the other treatments, except weedy check at Haik and the extent of this variation was more at Haik than at Mersa. At Haik, the plots treated with pendimethalin alone were severely infested with *X. strumarium* which might have contributed to the higher weed dry weight. On the other hand, at Mersa while this weed was found to a very lesser extent, but the infestation of *C. benghalinsis* which was not controlled with pendimethalin contributed to higher weed dry weight. *X. strumarium* was tall growing, erect with semi woody stem while *C. benghalensis* covered the whole soil surface and the germination occurred over extended period of time. Thus, the difference in morphology and growth habit/canopy architecture of the two weeds possibly contributed to dry weight accumulation.

The results also revealed significant reduction in weed dry weight at 55 DAE with two hand weeding at 2 and 5 WAE as compared to one hand weeding at 2 WAE, and herbicides applied alone at this stage. The advantage of twice 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 were shorter in growth than the weeds that emerged after first hand weeding. Hand weeding controlled the emerged weeds and those that emerged later on might have failed to accumulate sufficient dry matter owing to the competition offered by the crop plants. Moreover, the weed seeds under depleted soil seed bank that might have been brought to the upper soil layer by hand weeding, though germinated and emerged later, but were in their initial growth stage thus accumulated less dry weight. There was great difference in weed dry matter between the locations under respective weed management practices which might be the result of difference in weed density and, the environment.

At the time harvest, the weed dry weight accumulation with the increasing rates of s-metolachlor application significantly decreased at Haik, but no significant difference was obtained between 1.5 and 2.0 kg ha^{-1} of s-metolachlor application at Mersa. In contrast, the application of 1.3 and 1.6 kg ha^{-1} pendimethalin had significantly higher weed dry weight than its lower rate at Haik, while the difference existed between these rates at Mersa was not significant. Moreover, the treatment with 1.0 kg ha^{-1}pendimethalin had weed dry weight statistically in parity with s-metolachlor rates at Mersa (Table 2). The occurrence of significantly higher weed dry weight with increased pendimethalin application at Haik might be owing to the presence of the severe infestation with *X. strumarium.* On the other hand, at Mersa, this weed was not found and the difference observed in weed dry weight was not significant. The data also depicted that the weedy check registered the highest weed dry weight which was significantly higher than other weed management practices.

Two hand weeding proved significantly better than one hand weeding in reducing weed dry weight at Haik whereas there was no significant difference at Mersa. The contrasting results might be due to the extent to which the weed species and or the density differed at both locations. Therefore, at Haik the weed suppression might have been enhanced by second hand weeding at 5WAE that kept the crop weed free during critical period of 35 DAS which offered prolonged and efficient weed control [28]; [29]. This suggested that due to lower weed density, soil type and most probably lower soil seed bank as well as species composition within community the critical period may shorter at Mersa than at Haik.

The results depicted that the application of s-metolachlor and pendimethalin at their lowest rates combined with one hand weeding provided prolonged weed control, and significant reduction in weed dry weight at harvest was observed like what was registered at earlier growth stages. Moreover, at Mersa, s-metolachlor combined with hand weeding was as effective as complete weed free treatment in reducing the weed dry weight at the time of harvest. The effectiveness of both herbicides applied alone decreased with the increase in crop growth stage and this was more pronounced in case of pendimethalin. This might be due to late emerging weeds in herbicide treated plots that may be the consequence of loss of activity of a herbicide (Table 2). At Haik, *X. strumarium* grew faster in the absence of inter-specific competition with other weed species especially in pendimethalin treated plots.

Table 2. *Effect of weed management practices in cowpea on weed dry biomass (g m^{-2}) at 20 and 55 days after emergence and at harvest of crop at Haik and Mersa in 2014 cropping season.*

	Weed Dry Biomass (g m^{-2})					
	20 DAE		**55 DAE**		**At harvest**	
	Haik	**Mersa**	**Haik**	**Mersa**	**Haik**	**Mersa**
Weed management practices						
S-metolachlor at 1.0 kg ha^{-1}	75.4^{f}	15.7^{d}	295.9^{e}	124.3^{c}	312.3^{d}	138.7^{b}
S-metolachlor at1.5 kg ha^{-1}	48.8^{g}	12.7^{e}	183.4^{f}	92.4^{e}	209.9^{e}	98.7^{c}
S-metolachlor at 2.0 kg ha^{-1}	22.0^{h}	10.3^{f}	124.2^{h}	82.3^{f}	146.9^{g}	102.0^{c}
Pendimethalin at1.0 kg ha^{-1}	108.5^{e}	14.7^{de}	504.9^{d}	116.3^{d}	541.0^{c}	130.2^{bc}
Pendimethalin at1.3 kg ha^{-1}	150.2^{c}	19.7^{c}	547.3^{c}	128.1^{bc}	574.4^{b}	142.1^{b}
Pendimethalin at 1.6 kg ha^{-1}	133.3^{d}	21.7^{c}	559.8^{b}	128.6^{b}	581.5^{b}	144.8^{b}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding at 5 WAE	71.8^{f}	14.4^{de}	27.3^{j}	21.5^{h}	43.5^{i}	29.0^{d}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding at 5 WAE	105.4^{e}	12.2^{ef}	27.4^{j}	25.7^{g}	38.1^{i}	32.3^{d}
One hand weeding at 2 WAE	172.6^{b}	21.5^{c}	142.4^{g}	116.9d	170.4^{f}	126.8^{bc}
Hand weeding at 2 and 5WAE	173.6^{b}	25.9^{b}	96.5^{i}	82.7^{f}	110.0^{h}	98.0^{c}
Weed free check	0.0^{i}	0.0^{g}	0.0^{k}	0.0^{i}	0.0^{j}	0.0^{d}
Weedy check	178.8^{a}	32.2^{a}	882.8^{a}	265.4^{a}	906.3^{a}	247.6^{a}
LSD (5%)	4.4	2.4	6.3	3.9	16.4	32.3
CV (%)	2.5	8.6	1.3	2.4	3.2	17.7

CV = coefficient of variation, LSD = least significant difference, DAE = days after crop emergence, WAE = weeks after emergence, Means in coloumns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

At both locations, weeds accumulated higher dry weight in weedy check plots and it was significantly higher than the other weed management practices (Table 2). The higher weed dry weight in weedy check might be due to higher weed density that provided an opportunity to the weeds to compete vigorously for nutrients, space, light, water and carbon dioxide resulting in higher biomass production. Application of herbicides not only reduced the density of weeds but also suppressed the weed growth bringing about lower dry weight. These results are in agreement with the findings of [30] and [31] who reported maximum weed dry weight in weedy check. [32] reported that the weeds that germinated earlier or at the same time as the crop emergence, offered a serious competition as they got an opportunity to establish and accumulate dry weight faster than the crop.

3.1.2. Herbicide Efficiency Index

Herbicide efficiency index (HEI**)** reflects the effectiveness of applied herbicide in securing yield loss against weed competition. It expresses the tolerance of weeds to different herbicide treatments as well as their efficiency to eradicate the weeds. A higher HEI value is required for efficient weed management [33].

Table 3. *Effect of weed management practices in cowpea on weed control efficiency (%) and herbicide efficiency index (%) at Haik and Mersa in 2014 cropping season.*

	Herbicide / hand weeding efficiency index (%)	
Location (L)	Haik	Mersa
Weed management practices		
S-metolachlor at 1.0 kg ha^{-1}	1.6^{c}	0.3^{de}
S-metolachlor at 1.5 kg ha^{-1}	3.8^{c}	1.0^{cd}
S-metolachlor at 2.0 kg ha^{-1}	6.5^{c}	1.0^{cd}
Pendimethalin at 1.0 kg ha^{-1}	1.9^{c}	0.3^{de}
Pendimethalin at 1.3 kg ha^{-1}	0.3^{c}	0.4^{de}
Pendimethalin at 1.6 kg ha^{-1}	0.2^{c}	0.2^{de}
S-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	47.0^{a}	5.8^{a}
Pendimethalin at 1.0 kg ha^{-1} + hand weeding at 5 WAE	40.1^{a}	4.6^{b}
One hand weeding at 2 WAE	5.5^{c}	0.7^{de}
Two hand weeding at 2 and 5 WAE	16.9^{b}	1.8^{c}
Weed free check	0.0^{c}	0.0^{e}
Weedy check	0.0^{c}	0.0^{e}
LSD (5%)	7.7	0.9
CV (%)	17.5	28.8

CV = coefficient of variation, LSD = least significant difference, DAE = days after crop emergence, WAE = weeks after emergence, Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

Analysis of variance showed that effect of weed management practices significantly ($P<0.01$) influenced on herbicide efficiency index. Among the weed management practices the highest herbicides efficiency index (47.0%) was recorded from s-metolachlor 1 kg ha^{-1}+ hand weeding at 5 WAE at Haik followed by pendimethalin at 1.0 kg ha^{-1}

supplemented with one hand weeding (40.1%), but the lowest value was recorded at pendimethalin at 1.6 kg ha^{-1} application (Table 3). The higher HEI with increasing rates of s-metolachlor herbicide application but not for pendimethalin.

3.2. Crop Parameters

3.2.1. Growth Parameters

Number and dry weight of nodules

Main effect of the weed management practices was significant on total number of nodules. While in addition to weed management practices the effective number of nodules and nodule dry weight plant^{-1} of cowpea were alsosignificantly influenced by location.

Weed free plots resulted in maximum number of nodules (85.8 plant^{-1}) which was statistically in parity with one hand weeding at 2 WAE, and two hand weeding at 2 and 5 WAE. On the other hand, herbicides either applied alone or supplemented with one hand weeding resulted in significant reduction in total number of nodules plant^{-1} over the cultural methods of weed control (Table 4). Similar trend was also observed in weedy check. The effective number of nodules also depicted results similar to total number of nodules with the exception that the number of nodules plant^{-1} obtained under one hand weeding at 2 WAE was statistically in parity with pendimethalin at 1.0 kg ha^{-1} and s-metolachlor at 1.0 kg ha^{-1} supplemented with hand weeding at 5WAE. In contrast to total number of nodules, there was significant difference in effective number of nodules plant^{-1} between the locations and at Mersa it was 22.0% higher than at Haik.

Like effective number of nodule plant^{-1}, nodule dry weight was also significantly higher at Mersa than at Haik. Further, the results revealed that weed free check gave the highest (50.2 mg plant^{-1}) nodule dry weight followed by 46.3 mg plant^{-1} obtained from two hand weeding at 2 and 5 WAE both being statistically at par. The result of this study was in line with the study of [34] and [35] who reported in mung bean, maximum number of nodules and nodule dry weight was obtained with complete weed free check followed by two hand weeding.

Application of pendimethalin at 1.6 kg ha^{-1} resulted in minimum (15.3 mg plant^{-1}) nodule dry weight that was statistically at par with pendimethalin at 1.3 kg ha^{-1}. With the increase in herbicide application rates there was reduction in nodule dry weight. Thus lower dose of herbicide supplemented with hand weeding resulted in considerable increase in nodule dry weight over herbicide application alone. Hand weeding might have stirred soil thereby resulting in better aeration for the development of *rhizobia*.

Table 4. *Effect of weed management practices on plant height (cm) total number of nodules, effective number of nodules and nodule dry weight (mg plant $^{-1}$) of cowpea at Haik and Mersa in 2014 cropping season.*

Treatments	Plant height (cm)	Total number of nodules plant $^{-1}$	Effective number of nodules plant $^{-1}$	Nodule dry weight (mg plant $^{-1}$)
Location				
Haik	68.1^{a}	52.9	16.8^{b}	28.2^{b}
Mersa	60.6^{b}	52.6	20.5^{a}	34.4^{a}
LSD (5%)	3.8	NS	2.1	2.5
Weed management practices				
S-metolachlor at 1.0 kg ha^{-1}	64.0	47.5^{bc}	16.8^{c-e}	27.7^{e-g}
S-metolachlor at 1.5 kg ha^{-1}	65.5	45.2^{b-d}	17.0^{c-e}	24.1^{g}
S-metolachlor at 2.0 kg ha^{-1}	61.5	34.8^{cd}	16.7^{c-e}	23.0^{g}
Pendimethalin at 1.0 kg ha^{-1}	66.5	53.0^{b}	18.7^{bc}	27.0^{fg}
Pendimethalin at 1.3 kg ha^{-1}	68.2	32.2^{d}	13.0^{de}	15.5^{h}
Pendimethalin at 1.6 kg ha^{-1}	62.5	40.5^{b-d}	12.0^{e}	15.3^{h}
S-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	62.8	53.8^{b}	19.0^{bc}	38.3^{cd}
Pendimethalin at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	61.5	50.7^{b}	17.8^{cd}	32.8^{d-f}
One hand weeding at 2 WAE	64.5	74.0^{a}	23.5^{ab}	41.5^{bc}
Two hand weeding at 2 and 5 WAE	60.0	74.5^{a}	27.2^{a}	46.3^{ab}
Weed free check	62.3	85.8^{a}	25.8^{a}	50.2^{a}
Weedy check	73.6	41.0^{b-d}	16.3^{c-e}	33.7^{de}
LSD (5%)	NS	14.4	5.1	6.1
CV (%)	12.5	23.5	23.7	16.9

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after crop emergence;
NS = not significant; Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

The lower number of total and effective nodules and nodule dry weight plant $^{-1}$ in response to herbicide application might be due to detrimental effect of herbicides on nodulation of cowpea plant. This is in line with the findings of [36] and [37] who stated that the common use of herbicides may negatively affect nodulation either directly by affecting *Rhizobium*, or indirectly by reducing photosynthate allocation to the nodules for N fixation, or by restricting root growth and hence the number of root sites available for infection. Weed infestation may also restrict the root growth of the crop due to underground competition for space, nutrients and moisture ultimately resulting in reduced sites for nodule development.

In general, s-metolachlor application proved better than pendimethalin. The lower effect of s-metolachlor rates on nodulation of cowpea than pendimethalin of this study is in agreement with the report of [38] who suggested that the effect of herbicides when applied in soil is influenced by its adsorption by the soil and many other factors including volatilization, photodecomposition, leaching, and degradation by soil microorganisms, resulting in the reduced availability of these chemicals leading from little to no effect on *rhizobia* as observed in s-metolachlor herbicides. Also other studies showed that pendimethalin when applied under field conditions significantly decreased nodulation on soybean [39]. The extent of herbicide effects varied significantly with location, indicating that environmental factors play a key role in determining the extent of herbicide damage. For example: soil moisture availability appears to be a key factor influencing plant health, herbicide uptake and metabolism, nodulation, and ultimately the ability of the plant to recover from a stress of herbicide application as the temperature was higher at Haik than Mersa.

Plant height

Analysis of variance showed that the plant height was significantly ($P<0.01$) affected due to location while the weed management practices and its interaction with location had no significant effect. The plants at Haik experimental site had significantly higher height by 12.3% than that of Mersa (Table 4). The higher temperature at Haik might have triggered growth resulting in increased plant height. More sunlight penetration to the crop plants also made photosynthates available, however, no significant difference in plant height was found between the weed management practices despite a great variation in weed density and dry weight (Table 2). In contrast, [40] and [41] found differences in plant height due to various intensities of weed competition with crop plants.

3.2.2. Yield Components, Yield and Harvest Index

Number of pods per plant

The analysis of variance showed significant ($P<0.05$) effect of location while weed management practices and their interaction had significant effect on number of pods plant^{-1}. The interaction effect revealed highest number of pods plant^{-1} (22.4) obtained with the application of s-metolachlor at 1.0 kg ha^{-1} + one hand weeding at 5 WAE at Haik was statistically similar to the weed free check at both locations (Table 5, 6). Furthermore, the results showed that weed free check had also no significant difference in number of pods plant^{-1} obtained with the treatment of 1.0 kg ha^{-1} of pendimethalin + one hand weeding at 5 WAE both at Haik and Mersa as well as with the treatment of 1.0 kg ha^{-1} of s-metolachlor + one hand weeding at 5 WAE at Mersa. Two hand weeding at 2 and 5 WAE when interacted with location proved to be significantly better than one hand weeding at 2 WAE at both locations.

The application of 1.0 kg ha^{-1} of pendimethalin and 1.0 kg ha^{-1} of s-metolachlor, each accompanied with one hand weeding resulted in significant increase in number of pods plant^{-1} as compared to the application of these herbicides alone which was on account of prolonged weed control with hand weeding. This result is in line with the work of [6] who earlier stated that application of pendimethalin at 3.75 l ha^{-1}+ hand weeding at 5 weeks after sowing significantly gave higher mean values of yield components of cowpea. The more vigorous leaves under low infestation level helped to improve the photosynthetic efficiency of the crop and supported a large number of pods as reported from the work done earlier [41]; [42]. The lowest number of pods plant^{-1} (7.7) was observed in weedy check plots at Haik which was significantly lower than the other interactions, except the interaction of 1.0 kg ha^{-1} and at 1.3 kg ha^{-1} of pendimethalin at the same location. This might be due to the significantly more weed density and total weed dry weight (Table 2) in these treatments at Haik. The long season weed interference might have also resulted in shade effect that reduced the irradiance predominantly in the photosynthetically active region of the spectrum and the irradiance is a major ecological factor that influences plant growth [43].

These results are also in line with [44] who observed an increased number of pods plant^{-1} where weed population was reduced by management techniques. Similarly, [45] stated that the number of pods produced per plant or maintained to final harvest depends on a number of environmental and management practices including proper weed management.

Number of seeds per pod

The number of seeds pod^{-1} had a significant effect due to locations while weed management practices and its interaction with location were not significant. At Mersa, the seed number pod $^{-1}$ was significantly higher by 10.4% than at Haik. Despite a difference of 2.7 seeds pod^{-1} the weed management practices did not show any significant difference (Table 5). In agreement with this result, [46] obtained the lowest number of seeds pod^{-1} in cowpea at weedy check.

Hundred seed weight The effect of locations and treatments was significant while their interaction had no significant effect on 100 seed weight. The seeds at Mersa had significantly higher weight by 7.6% than at Haik. The grains under complete weed free plots recorded the highest weight (13.1 g) which was statistically at par with two hand weeding at 2 and 5 WAE, pendimethalin at 1.0 kg ha^{-1} + one hand weeding at 5 WAE, s-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WAE, pendimethalin at 1.3 kg ha^{-1} and s-metolachlor 2.0 kg ha^{-1} (Table 5). The plants raised under complete weed free environment utilized available resources to their maximum benefit leading to increased seed weight. Also, the more and vigorous leaves under weed free environment might have improved the supply of assimilate to be stored in the seed, hence, the weight of 100 grains increased. The lowest 100 grain weight (11.4 g) was observed in weedy check. However, it was in par with one hand weeding at 2 WAE and 1.5 kg ha^{-1} of s-metolachlor (Table 5). This is consistent with [47] who stated that cowpea plants in unwedded plots gave the lowest 100 seed weight. However, [48] reported no significant difference in grain weight due to weed management practices in common bean.

Table 5. *Effect of weed management practices on crop stand (ha^{-1}), number of seeds pod^{-1}, hundred seed weight (g) and harvest index (%) of cowpea at Haik and Mersa in 2014 cropping season.*

Factors	Crop stand (ha^{-1})	Number of seeds pod^{-1}	Hundred seed weight (g)	Harvest index
Location				
Haik	98251^{b}	12.0^{b}	11.9^{b}	28^{b}
Mersa	106224^{a}	13.3^{a}	12.8^{a}	31^{a}
LSD (5%)	4830.1	0.8	0.3	0.01
Weed management practices				
S-metolachlor at 1.0 kg ha^{-1}	92978^{d}	12.0	12.4^{bc}	24de
S-metolachlor at1.5 kg ha^{-1}	96065^{cd}	13.1	11.8^{cd}	30^{c}
S-metolachlor at 2.0 kg ha^{-1}	105324^{bc}	12.7	12.6^{ab}	29^{c}
Pendimethalin at1.0 kg ha^{-1}	95293^{cd}	12.8	12.2^{bc}	27^{cd}
Pendimethalin at1.3 kg ha^{-1}	93750^{cd}	12.5	12.7^{ab}	24de
Pendimethalin at 1.6 kg ha^{-1}	101466^{cd}	11.7	12.3^{bc}	25de
S-metolachlor at 1.0 kg ha^{-1}+hand weeding at 5 WAE	120756^{a}	13.4	12.7^{ab}	35^{b}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding at 5 WAE	117284^{a}	13.6	12.5^{ab}	37^{b}
One hand weeding at 2 WAE	90664^{d}	12.7	12.0^{b-d}	29^{c}
Two hand weeding at 2 and 5 WAE	114969^{ab}	12.6	12.5^{ab}	36^{b}
Weed free check	120370^{a}	13.7	13.1^{a}	41^{a}
Weedy check	77932^{e}	11.0	11.4^{d}	22^{e}
LSD (5%)	11831.3	NS	0.7	0.03
CV (%)	10.0	13.1	4.7	9.1

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after emergence; NS = not significant; Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

Grain yield.

Cowpea grain yield was significantly influenced by the location, weed management practices and their interaction. The highest grain yield (4277 kg ha^{-1}) was obtained in complete weed free at Mersa which was statistically at par with complete weed free at Haik and two hand weeding at Mersa. Further, the yield obtained with complete weed free treatment at Haik and two hand weeding at Mersa had no significant difference with the application of 1.0 kg ha^{-1} of s-metolachlor + hand weeding at 5 WAE and 1.0 kg ha^{-1} of pendimethalin + hand weeding at 5 WAE at Mersa. This can be ascribed to fact that the effective control of weeds led to the favourable environment for growth and photosynthetic activity of the crop. It was also found that with the increasing rate of s-metolachlor application there was an increase in yield, but no significant variation was observed between 1.5 and 2.0 kg ha^{-1}of s- metolachlor application at both locations (Table 6). But these treatments gave significant yield increase over 1.0 kg ha^{-1} of s- metolachlor application which was 22.5% and 33.0%, 18.7% and 22.7% over 1.0 kg ha^{-1} of s-metolachlor, respectively, at Haik and Mersa.

The increasing rates of pendimethalin showed significant reduction in yield with the application of 1.3 and 1.6 kg ha^{-1} of pendimethalin over its lower rate at Haik. In contrast, at Mersa, results were inconsistent and no significant difference existed among the rates. At Haik, 1.0 kg ha^{-1}of s-metolachlor + hand weeding at 5 WAE gave significant yield increase over 1.0 kg ha^{-1} of pendimethalin + hand weeding at 5 WAE, while these weed management practices were statistically in parity at Mersa. This is related with many factors that influence the effectiveness of herbicides. Likewise, the effects of herbicides are affected by the type and rates of its application, health and stages of plant growth, and other environmental variables. However, at both the locations, two hand weeding proved significantly better than one hand weeding (Table 6).

Weedy crop throughout the growing period resulted in the lowest grain yield, but at respective locations did not have a significant difference with 1.3 and 1.6 kg ha^{-1} of pendimethalin at Haik, and 1.0 and 1.6 kg ha^{-1} of pendimethalin as well as 1.0 kg ha^{-1} of s-metolachlor at Mersa. While comparing weedy check at Mersa with weed management practices at Haik, the data (Table 6) revealed that weedy check plots had significantly higher yield than 1.0 kg ha^{-1} of s- metolachlor, 1.3 and 1.6 kg ha^{-1} of pendimethalin while it was statistically non-significant with 1.5 and 2.0 kg ha-1 of s- metolachlor, 1.0 kg ha^{-1} of pendimethalin and one hand weeding at 2 WAE (Table 6). This was probably due to more weed pressure at Haik which hindered the growth and development of the crop thereby reduction in yield to such an extent.

Table 6. *Interaction effect of location and weed management practices on number of pods plant^{-1}, and grain yield (kg ha^{-1}) in cowpea in 2014 cropping season.*

	Number of pods plant^{-1}		Grain yield (kg ha^{-1})	
Weed management practices	**Haik**	**Mersa**	**Haik**	**Mersa**
S-metolachlor at 1.0 kg ha^{-1}	12.1^{h-j}	12.7^{h-j}	1750^{l}	2595^{h-j}
S-metolachlor at1.5 kg ha^{-1}	16.0^{d-f}	11.5^{ij}	2144^{kl}	3080^{e-g}
S-metolachlor at 2.0 kg ha^{-1}	13.1^{g-i}	17.1^{c-e}	2327^{i-k}	3185^{d-f}
Pendimethalin at 1.0 kg ha^{-1}	10.7^{i-k}	14.5^{f-h}	2373^{i-k}	2582^{h-j}
Pendimethalin at 1.3 kg ha^{-1}	8.0^{l}	12.8^{h-j}	1322^{m}	2696^{g-i}
Pendimethalin at 1.6 kg ha^{-1}	8.7^{kl}	15.3^{e-g}	1282^{m}	2555^{h-k}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding at 5 WAE	22.4^{a}	19.1^{bc}	3595^{cd}	3769^{bc}
Pendimethalin at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	19.3^{bc}	18.9^{bc}	3017^{fg}	3614^{bc}
One hand weeding at 2 WAE	15.3^{e-g}	15.8^{d-f}	2312^{i-k}	2969^{f-h}
Two hand weeding at 2 and 5 WAE	18.1^{cd}	19.0^{bc}	3452de	3864^{a-c}
Weed free check	20.8^{ab}	20.7^{ab}	3907^{ab}	4277^{a}
Weedy check	7.7^{l}	10.6^{jk}	1134^{m}	2241^{jk}
LSD (%) L x WMP	2.5		422.0	
CV (%)	10.0		9.3	

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after emergence; Means in columns and row of same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

The yield obtained at Mersa in general, was significantly higher than at Haik under most of their respective weed management practices. The higher yield might be partially due to the higher in number of pods plant^{-1} and seeds pod^{-1} at Mersa. In line with this result, [49] obtained significant increase in yield with the application of pendimethalin at 0.75 kg ha^{-1} supplemented with one hand weeding 45 days after sowing in black gram. Similar conclusion has also been drawn by [50] that proper weed management gave higher yields of crops. The phenomenon involved in crop yield increase as affected by different weed control method has already been well described by [51], [6] and [52]. [47] also stated that the yield and yield components of cowpea were also affected by weed control methods. This confirms the adverse effects of the weeds on the cowpea crop production sites as reported earlier by [53].

Aboveground dry biomass yield

Like grain yield, the aboveground dry biomass yield was also highly significantly affected by location, weed management practices and their interaction. The highest aboveground dry biomass yield (10797 kg ha^{-1}) was obtained in 1.0 kg ha^{-1} of s-metolachlor + one hand weeding at 5 WAE treated plots at Haik which was statistically at par with two hand weeding at 2 and 5 WAE at the same location (9831 kg ha^{-1}), s-metolachlor at all the application rates (9815 to 10694 kg ha^{-1}), pendimethalin at 1.5 kg ha^{-1}, low rates of s-metolachlor and pendimethalin combined with one hand weeding at 5 WAE, one hand weeding and weed free check at Mersa (Table 7). Weedy check plots had the lowest aboveground dry biomass yield among the treatments at respective locations, which was statistically at par with pendimethalin at 1.3 and 1.6 kg ha^{-1} at Haik. At Mersa, the aboveground dry biomass yield in weedy check was significantly lower than s-metolachlor at 2.0 kg ha^{-1} and two hand weeding at 2 and 5 WAE only.

Table 7. *Interaction effect of location and weed management practices on aboveground dry biomass yield (kg ha^{-1}) and yield loss (%) in cowpea in 2014 cropping season.*

	Aboveground dry biomass yield (kg ha^{-1})		Yield loss (%)	
Weed management practices	**Haik**	**Mersa**	**Haik**	**Mersa**
S-metolachlor at 1.0 kg ha^{-1}	7408^{fg}	10082^{a-c}	55.4^{b}	39.4^{c-e}
S-metolachlor at1.5 kg ha^{-1}	7185^{gh}	9815^{a-d}	44.7^{cd}	28.0^{fg}
S-metolachlor at 2.0 kg ha^{-1}	7780^{fg}	10694^{ab}	39.9^{c-e}	25.6^{gh}
Pendimethalin at1.0 kg ha^{-1}	8957de	9136^{c-e}	39.2^{c-e}	39.6^{c-e}
Pendimethalin at1.3 kg ha^{-1}	6157^{hi}	9763^{a-d}	66.1^{a}	36.9^{d-f}
Pendimethalin at 1.6 kg ha^{-1}	5932^{i}	9059^{c-e}	67.1^{a}	40.1^{c-e}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding at 5 WAE	10797^{a}	9949^{a-d}	7.9^{ij}	11.8^{i}
Pendimethalin at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	8161^{e-g}	9753^{a-d}	22.7^{gh}	15.3^{hi}
One hand weeding at 2 WAE	8382^{ef}	9733^{a-d}	40.1^{c-e}	30.5^{e-g}
Two hand weeding at 2 and 5 WAE	9831^{a-d}	10438^{ab}	11.6^{i}	9.5^{ij}
Weed free check	9566^{b-d}	10113^{a-c}	0.0^{j}	0.0^{j}
Weedy check	5661^{i}	9043^{c-e}	70.9^{a}	47.5^{bc}
LSD (%) L x WMP	1079.0		10.5	
CV (%)	7.4		19.6	

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after emergence; Means in columns and row of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

As [54] reported that the increased dry matter weight of the crop was highly governed by the length of weed free period. While comparing the individual treatments in general, the aboveground dry biomass yield was higher at Mersa than Haik. However, high production of total dry matter might not necessarily be of great value when the grain comprises a part of the plant. Though, the higher aboveground dry biomass in complete weed free and hand weeded plots may be due to better condition in soil rhizosphere that improved the competitive ability of the crop and favored more vegetative growth.

Harvest index The results of both treatment revealed that the location and weed management practices had a significant influence on crop harvest index. The crop grown at Mersa had significantly higher harvest index than at Haik. Highly significant harvest index was observed as compared to the weed management practices found when the crop was kept weed free throughout the growing season (Table 4). This was followed by pendimethalin 1.0 kg ha^{-1} + hand weeding at 5 WAE, s-metolachlor 1.0 kg ha^{-1}+ hand weeding at 5 WAE and two hand weeding at 2 and 5 WAE. The weedy check had the lowest harvest index (22%) that did not significantly differ with 1.0 kg ha^{-1} of s-metolachlor, 1.3 kg ha^{-1} of pendimethalin and 1.6 kg ha^{-1} of pendimethalin treatments. This lower harvest index might be due to severe weed competition with the crop for the growth factors, which restricted the growth and development of the crop in weedy check plots. Further, severe weed interference (Table 2 and 3) might have decreased root/shoot ratio increased vegetative growth duration (Table 3) and allocation of more assimilates for shoot rather than root growth. Likewise, the photosynthetic activity might be more during the vegetative phase of crop growth that contributed towards more total dry matter production, but the pace of this photosynthetic rate might have registered much higher decline due to disintegration of nodules with the initiation of pod development resulting in lower harvest index.

Yield loss Analysis of variance demonstrated significant influence of location, weed management practices and their interaction on yield loss. The weeds under different weed management practices caused variability in the amount of grain yield loss in cowpea. The highest yield loss (70.8%) was recorded in weedy check at Haik. This was statistically in parity with the loss registered with the application of 1.3 kg ha^{-1} of pendimethalin and 1.6 kg ha^{-1} of pendimethalin at the same location. All these weed management practices recorded a significant yield loss compared to other treatments. At Mersa, the yield loss (47.5%) was also highest in weedy check, but it did not show significant variation with the loss accrued from the application of s- metolachlor at all rate, 1.0 kg ha^{-1} pendimethalin and one hand weeding at 2 WAE at Haik, and 1.0 kg ha^{-1} of s- metolachlor and 1.0 and 1.6 kg ha^{-1} of pendimethalin. The application of 1.0 kg ha^{-1} of s-metolachlor combined with one hand weeding 5 WAE resulted in the lowest yield loss which was statistically similar with two hand weeding at 2 and 5 WAE at both experimental sites, as well as 1.0 kg ha^{-1} of s- metolachlor and 1.0 kg ha^{-1} of pendimethalin were both combined with one hand weeding 5 WAE at Mersa. Moreover, it was observed that the yield loss due to s-metolachlor 1.0 kg ha^{-1} superimposed with one hand weeding 5 WAE at Haik and two hand weeding at 2 and 5 WAE at Mersa were not significant as compared to complete weed free at both locations (Table 7).

This observation is consistent with the work of [6] and [8] who reported that the presence of weeds reduced yield by (82%). On the other hand, [7]; [55] and [56] found that there existed 12.7% - 60.0%, 40% - 60% and 25% - 60% reduction in potential yield of cowpea due to weeds, respectively. This difference in reduction in cowpea yield reported by various researchers might be due to the differences in weed flora, crop varieties and environmental conditions prevailing in the study area. Therefore, the difference in time of weed removal might have contributed to this variation in yield. The herbicides might have dissipated soon from the soil under the influence of environmental conditions prevailing during the crop season.

3.3. Partial Budget Analysis

The result of the partial budget analyses showed that two hand weeding accrued 4.2 and 13.4% higher total variable cost than 1.0 kg ha^{-1} of pendimethalin and 1.0 kg ha^{-1} of s - metolachlor both superimposed with hand weeding, respectively at both sites (Table 8). On the other hand the highest gross as well as net benefits were obtained with the application of 1.0 kg ha^{-1} of s-metolachlor at + hand weedings, followed by two hand weeding at 2 and 5 WAE and 1.0 kg ha^{-1} of pendimethalin + hand weeding. In agreement with the result, most studies showed that, applying herbicide or herbicide plus manual weeding was more economical than manual or hand weeding alone [57].

Table 8. *Partial budget analysis of weed management practices in cowpea based on total variable cost in 2014 cropping season.*

Weed management practices	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1}) 10% down	Total variable cost (ETB ha^{-1})	Gross benefit (ETB ha^{-1})	Net benefit (ha^{-1})
S-metolachlor at 1.0 kg ha^{-1}	2172.4	1955.2	3935	29328	25393
S-metolachlor at1.5 kg ha^{-1}	2612.1	2350.9	4841	35264	30423
S-metolachlor at 2.0 kg ha^{-1}	2756.0	2480.4	5283	37206	31923
Pendimethalin at1.0 kg ha^{-1}	2477.5	2229.8	5589	33447	27858
Pendimethalin at1.3 kg ha^{-1}	2009.0	1808.1	5339	27122	21783
Pendimethalin at 1.6 kg ha^{-1}	1918.6	1727.4	5581	25911	20330
S-metolachlor at 1.0 kg ha^{-1}+hand weeding at 5 WAE	3682.0	3313.8	6828	49707	42879
Pendimethalin at 1.0 kg ha^{-1}+hand weeding at 5 WAE	3315.8	2984.2	7430	44763	37333
One hand weeding at 2 WAE	2640.5	2376.5	5620	35648	35649
Two hand weeding at 2 and 5 WAE	3658.4	3292.6	7742	49380	41638
Weedy check	1687.3	1518.6	2642	22779	20137

Cost of hand weeding and hoeing 2 WAE 45 persons, 5 WAE 16 persons @Birr 33 person^{-1}, ETB= 0.0498 USD

4. Conclusion

The experimental fields were found to be infested both with broadleaved weeds and sedges. Weed dry weight was significantly reduced by herbicide application. S-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with hand weeding at 5 WAE and two hand weeding at 2 and 5 WAE resulted in significant reduction in weed dry weight accumulation at both the locations. The weed dry weed weight and herbicide efficiency index were significantly higher at Mersa while weed control efficiency was higher at Haik. Plants attained significantly higher height at Haik. The effective number and weight of nodules per plant were significantly higher in hand weeded and complete weed free plots than herbicide treated and weedy check plots. Further, at Mersa the yield components were significantly higher than at Haik. Application of s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with hand weeding at 5 WAE and two hand weeding at 2 and 5 WAE were found to enhance yield components and in most of the cases were statistically in parity with complete weed free at both the locations. Complete weed free resulted in significant increase in yield except over two hand weeding at Mersa which further had no significant difference with s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with one hand weeding. However, at Haik two hand weeding was significantly better than pendimethalin at 1.0 kg ha^{-1}+ hand weeding at 5 WAE. Therefore, these best performing treatments were found to prohibit the possible yield loss. In conclusion based on economic analysis application of s-metolachlor + hand weeding at 5WAE followed by two hand weeding at 2 and 5 WAE seemed to be the most promising treatments for achieving higher yield of cowpea in the study area.

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