Effect of Integrated Weed Management Practices on Weeds Infestation, Yield Components and Yield of Cowpea [*Vigna unguiculata* (L.) Walp.] in eastern Wollo, Ethiopia

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ABSTRACT

Cowpea [*Vigna unguiculata* (L.) Walp.] is usually infested by a number of weed species that compete with the crop from germination to harvest, affecting the crop yield adversely. Therefore, an experiment was conducted at Sirinka and Jari, northern Ethiopia during the 2013 main cropping season (July-October). The objectives were to assess the effect of preemergence s-metolachlor and pendimethalin on weeds, and growth, yield components and yield of cowpea and to investigate the possibilities of supplementing low doses of herbicides with hand weeding for effective and cost effective weed management. There were 12 treatments ;comprising three rates of s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}) and pendimethalin (1.0, 1.3 and 1.6 kg ha^{-1}), s-meto + weed x 1(2WAE), pendi + weed x1 (2 WAE), weed x1 (2WAE), Weed x 2 (2 and 5 WAE), Weed free check and weedy check. The treatments were arranged in randomized complete blockdesign with three replications. The 78.6% of the weeds comprised in the experimental site were the broadleaved.At 20 dae, application of s-metolachlor at 2.0 kg ha^{-1} at both locations resulted in the lowest broadleaved weeds, sedge and total weed density.Pendimethalin failed to control *Commelina benghalensis* and *Xanthium strumarium*. At 55 dae, low rate of s-metolachlor and pendimethalin when superimposed with one handweeding were as effective as complete weed free in reducing the broadleaved weeds and sedge density. The minimum weed dry weight was registered with the application of s-metolachlor at 2.0 kg ha^{-1} in both the locations, however, at 55 days and at harvest weeds significantly accumulated lower dry weight due to s-metolachlor 1.0 and pendimethalin 1.0kg ha^{-1} each superimposed with handweeding at both the locations.The interaction of location with weed management practices was significant on days to 50% flowering and physiological maturity of the crop, 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 at Sirinka which was statistically at par with complete weed free at Jari and two handweeding at Sirinka. The highest yield loss (70.8%) was

recorded at Jari while it was 47.5% at Sirinka due to weed infestation throughout the crop growth. The highest gross benefit was obtained with the application of s-metolachlor at 1.0 kg ha^{-1} superimposed with handweeding followed by two handweeding at 2 and 5 wae.

1. INTRODUCTION(citations done based on SDI format)

Cowpea is of major importance to the livelihoods of millions of relatively poor people in less developed countries of the tropics [1]. It is grown extensively 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 atmosphere 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].

Cowpea is generally infested by a number of weed species that compete with the crop from germination to harvest, affecting the crop yield adversely [6]. Yield losses in cowpea due to weeds ranged from 12.7 - 60.0% [7]. [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 traditional approaches of weed control such as physical and mechanical are very expensive and labour is usually not available during the peak periods of weed removal from the field [9]. Handweeding required over 50% of the farmers' time leaving him and his family 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].

Herbicide use would improve the lives of farmers by eliminating the need for back-breaking labour. [6]obtained significantly higher grain yield and net return of cowpea with preemergence application of pendimethalin at 0.75 kg ha^{-1}+ weeding at 5 weeks after planting compared to other treatments. [12] reported that pendimethalin at 1.0 kg ha^{-1}+ hand weeding at 30 days after planting significantly gave a higher cowpea grain yield, weed density and biomass were the lowest in this treatment. 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} has been used in pulse crops in Ethiopia [14]. Use of herbicides may therefore provide a timely and adequate alternative to handweeding as this will not only remove the drudgery associated with it but also lower the cost of weeding and provide protection for crop against early weed competition when preemergence herbicides are used [10].

S -metolachlor and pendimethalin which are among the recently introduced herbicides in Ethiopia have not been widely evaluated in cowpea specifically in the study area. Hence, the objectives of this study were as to assess the effect of s-metolachlor and pendimethalin on weeds, growth, yield components and yield of cowpea and to investigate the possibilities of supplementing low doses of herbicides with handweeding 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 experimental sites at Jari (11°21'N latitude and 39°38'E longitude;1680 m. a. s. l. altitude) and Sirinka ($11^0 45' 00''$ N latitude; $39^0 36' 36''$E longitude; 1850 m. a.s.l. altitude) in Northern Ethiopia during the 2013 main cropping season(July –October).The soil of the experimental fields was clay loam and clay while the pH was 6.95 and 6.91 at Sirinka and Jari, respectively. At Sirinka the organic carbon was 1.37%, total N was 0.09 %, available P 12.17 mg kg^{-1}soil and CEC 53.44 $cmol_C$ kg^{-1} while respective values at Jari were 1.33, 0.07, 9.17 and 33.44. The total rainfall received during the crop season was 1073.4 and 992.4 mm at Sirinka and Jari with mean maximum and minimum temperatures of 26.6 and 13.9^0C, and28.1 and15.8^0C, respectively.

2.2.Treatments and experimental design

The plot size was 3.6 m x 2.4 m. The cowpea variety Asrat (IT 92KD-279-3) which is bush and trailing type I was planted at an inter- and intra- row spacing of 60 cm and 10 cm, on July 8 and

13, 2013 at Jari and Sirinka, 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 12 treatments comprising s-metolachlor at (1.0, 1.5 and 2.0 kg ha^{-1}), pendimethalin (1.0,1.3 and1.6 kg ha^{-1}), s-metolachlor at 1.00 kg ha^{-1} + handweeding at 5 weeks after crop emergence (wae), pendimethalin at 1,00 kg ha^{-1} + handweeding at 5 weeks after crop emergence (wae), one handweeding at 2 weeks after crop emergence (wae), two handweeding at 2 and 5 weeks after crop emergence (wae), weed free check and weedy check. The design of the experiment was randomized complete block design with three replications. The preemergence herbicides were applied at the specific rates using Knapsack sprayer one day after plantingusing flat-fan nozzle. The spray volume was 450 ℓ ha^{-1}. 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 excluded to remove border effect. Thus the net plot area was 2.4 m x 1.8 m. The crop was harvested on October 15 and 25, 2013 at Jari and Sirinka, respectively.

2.3.Data Collection and Analysis

Data on weed community, weed density, weed dry biomass; crop phenology, growth, yield attributes and yield were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) version 9.2 software. Fisher's protected Least Significant Difference(LSD) values were used to separate differences among treatment means ($P < 0.05$). Combined analyses of data were used based on homogeneity test.

2.4. Partial Budget Analysis

The concepts used in the partial budget analysis were the mean grain yield under each treatment at both locations, the field price of the crop (sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation), the total costs that varied included the sum of field cost of herbicide and its application. Actual yield was adjusted downward by 10% to represent the difference between the experimental yield and the yield farmers could get from the same treatment (CIMMYT, 1988).

3. RESULTS AND DISCUSSION

3.1. Effect of Weed Management Practices on Weeds

3.1.1. Weed community

The major weeds in the experimental fields were the broadleaved, while sedges were found to a lesser extent**.** There was only one grass species present at Sirinka to a very limited extent thus this weed was merged with sedges for describing the results. The parasitic weed broomrape (*O. cerenata*)wasfound at Jari in plots infested with *X. strumarium* only. The remaining weeds were found at both locations.The weed flora present in the experimental fields is presented in Table 1.

Table 1. Weed community recorded in cowpea, at the experimental sites during cropping season 2013

Common name	Weed species	Family	Life form (category)
Spiny pigweed	*Amaranthus spinosus* L.	Amaranthaceae	Annual (broadleaved)
Smooth pigweed	*A. hybridus* L.	Amaranthaceae	Annual (broadleaved)
Hairy beggar ticks	*Bidens pilosa* L.	Asteraceae	Annual (broadleaved)
Benghal day flower	*Commelina benghalensis* L.	Commelinaceae	Annual (broadleaved)
Yellow nutsedge	*Cyperus esculentus* L.	Cyperaceae	Annual(sedge)
Purple nutsedge	*C. rotundus* L.	Cyperaceae	Perennial(sedge)
Jimsonweed	*Datura stramonium* L.	Solanaceae	Annual (broadleaved)
Small flower galinsoga	*Galinsoga parviflora* Cav.	Asteraceae	Annual (broadleaved)
Broomrape	*Orobanchecrenata* Forsk.	Orobanchaceae	Annual (broadleaved)
Woodsorrel	*Oxalis latifolia* Kunth.	Oxalidaceae	Annual (broadleaved)
Bristly foxtail	*Seteria verticillata* (L.) Beauv.	Poaceae	Annual (grass)
Black nightshade	*Solanum nigrum* L.	Solanaceae	Annual (broadleaved
Wild marigold	*Tagetes minuta* L.	Asteraceae	Annual (broadleaved)
Common cocklebur	*Xanthium strumarium*	Asteraceae	Annual (broadleaved)

3.1.2. Weed density

Weed density at 20 days after crop emergence

Weed density showed a significant difference ($P \leq 0.01$) due to different weed management practices. At 20 dae, application of s-metolachlor at 2.0 kg ha^{-1} at Jari and Sirinka resulted in the lowest broadleaved weed density. Further, at Sirinka, no significant differences existed between s-metolachlor at 1.5 kg ha^{-1}, pendimethalin 1.0 kg ha^{-1} + handweeding at 5 wae, and pendimethalin at 1.0 kg ha^{-1}. The density of broadleaved weeds decreased with the increase in s-metolachlor application rates but no significant difference was observed between 1.0 and 1.5 kg ha^{-1} rates (Table 2). This trend was not found for pendimethalin wherein pendimethalin at 1.0 kg ha^{-1} recorded the minimum weed density which was significantly lower than pendimethalin at 1.3 kg ha^{-1} but in parity with pendimethalin at 1.6 kg ha^{-1}. One handweeding at 2 wae, two handweeding at 2 and 5 wae and pendimethalin at 1.3 kg ha^{-1} had recorded higher weed density, but the weedy check plots showed appreciably highest broadleaved weeds density than the other weed management practices at both the locations.

At 20 days after crop emergence, the sedge density at Jari was the minimum in s-metolachlor at 2.0 kg ha^{-1} treated plots which had no significant difference with its lower rates, and s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5 wae. Application of s–metolachlor proved superior to pendimethalin in controlling the sedges; nevertheless the performance of pendimethalin was significantly better than weedy check. At Sirinka also the application of s-metolachlor at 2.0 kg ha^{-1} resulted in the lowest sedge population and was statistically at par with s-metolachlor at 1.5 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1}, and low dose of both the herbicides superimposed with one handweeding at 5 wae.

The total weed density was lowest with the application of s- metolachlor at 2.0 kg ha^{-1}at Jari while at Sirinka, the lowest total weed density was obtained with s-metolachlor at 2.0 kg ha^{-1}but had no significant difference with s-metolachlor at 1.5 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae and pendimethalin at 1.0 kg ha^{-1}.The increasing s-metolachlor application rates decreased total weed density but no significant difference existed between 1.0 and 1.5 kg

ha^{-1} at Jari. In contrast, pendimethalin at 1.0 kg ha^{-1}resulted in significant decrease in total weed density over its higher rates. In the experimental field, it was observed that the application of pendimethalin failed to control *C. benghalensis* and at lower rate of its application there might be more inter specific competition between the weeds thereby resulting in reduced overall weed density while under higher rates, the weeds other than *C. benghalensis* were alsocontrolled thus reducing inter specific competition. Further, this in turn might have provided greater opportunity to *C. benghalensis* to germinate in larger amount. At Sirinka also the total weed density decreased with the increase in s-metolachlor application rate but in variance with Jari no significant difference was observed between 1.5 and 2.0 kg ha^{-1}rates. The effect of pendimethalin on total weed density at Sirinka was similar to that of Jari. The significant reduction in weed density with lowest pendimethalin application rate at both the location was in contrast to the findings of [17]who stated that reduced rates of herbicide are not advisable under heavy weed pressure. However, it seemed that the weed species and their composition also determined the effectiveness of the herbicide. At both locations, the total weed density was significantly higher in weedy check than the other weed management practices; however, the results depicted higher weed pressure at Jari than at Sirinka.

Weed density at 55 days after crop emergence

At 55 days after crop emergence, the density of broadleaved weeds was minimum due to the application of pendimethalin at 1.0 kg ha^{-1}superimposed with one handweeding at 5 wae at Jari. However, it did not have a significant difference with s-metolachlor at 1.0 kg ha^{-1}combined with one handweeding at 5 wae and two handweeding at 2 and 5 wae. The results also depicted that low rate of s-metolachlor and pendimethalin when combined with one handweeding were as effective as complete weed free in reducing the broadleaved weed density. Like at 20 dae, the broadleaved weed density also decreased with the increase in s- metolachlor application rates whereby 1.5 and 2.0 kg ha^{-1}rates did not differ significantly but registered significant reduction in density over 1.0 kg ha^{-1}rate. In case of pendimethalin, the results remained inconsistent. Two handweeding proved significantly better than one handweeding in reducing the broadleaved weed density. This might partially be due to the late emerging *X. strumarium* which infested the

plots after one handweeding was resorted. On the other hand, one handweeding was found to bring significant reduction in broadleaved weed density over pendimethalin at all its rates.

At Sirinka, application of s-metolachlor at 1.0 kg ha^{-1}+ one handweeding at 5 wae was gave the lowest weed density which did not differ significantly with two handweeding. Both of these practices were found to be significantly better than other weed management practices. The application of higher rates (1.5 and2.0 $kgha^{-1}$) of s-metolachlor gave significant reduction in density over its lower application rates while in case of pendimethalin at higher rates (1.3 and 1.6 $kgha^{-1}$) it increased significantly over the lower rate. Further, the poor control of these weeds with herbicide alone might be due their bigger seed size which enabled them to emerge from deeper soil layer as the weeds emerging from deeper layers (herbicide free zone) are selective to applied herbicide due to positional selectivity.

Late emergingweed *X. strumarium* was not controlled by both of these herbicides which may be due to bigger seed size that enabled it to germinate from deeper soil depth in herbicide free zone thus escaping the herbicide interference in the germination process. On the other hand, pendimethalin failed to control *C. benghalensis*. However, when the low dose of herbicides was superimposed with handweeding at 5 wae, it might have contained the infestation by these weeds resulting in significantly lower broadleaved weed density than the herbicides alone. Moreover, the infestation of *X. strumarium* was more persistent at Jari that might have contributed to higher weed density at that location than at Sirinka.

The sedges population was lowest in pendimethalin at 1.0 kg ha^{-1}+ one handweeding at 5 wae at Jari which did not differ significantly with s-metolachlor at 1.0 kg ha^{-1} combined with one handweeding at 5 wae, s- metolachlor at 2.0 kg $ha^{-1}$and two handweeding at 2 and 5 wae. All these practices were statistically at par with complete weed free. At Sirinka, low dose of both s-metolachlor and pendimethalin each superimposed with one handweeding resulted in the lowest sedges population which had no significant difference with s-metolachlor at 2.0 kg ha^{-1}, one and two handweeding. Both at Jari and Sirinka weedy check had significantly higher density than the other weed management practices.

At 55 dae, the total weed density was lowest with the application of pendimethalin at 1.0 kg ha^{-1}+ one handweeding, however, it had no significant difference with s-metolachlor at 1.0 kg ha^{-1}+ one handweeding and two handweeding at 2 and 5 wae at Jari. At Sirinka, application of s-metolachlor at 1.0 kg ha^{-1}+ one handweeding registered the minimum total weed density which was significantly lower than the other weed management practices. Though, at Jari no significant difference in total weed density was found between pendimethalin at 1.0 kg ha^{-1}+ one handweeding, s-metolachlor at 1.0 kg ha^{-1}+ one handweeding and complete weed free but at Sirinka significant variation was observed between these treatments (Table 2). In total weed density also the trend due to s-metolachlor and pendimethalin application was similar to that of broadleaved weeds and sedges at both the locations.

Weed density at harvest

The broadleaved weed density at crop harvest obtained due to application of s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5 wae, pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae, s-metolachlor at 2.0 kg ha^{-1} and two handweeding at 2 and 5 wae was statistically in parity with complete weed free and resulted in significantly lower density than the other weed management practices at Jari (Table 3). Also, at Sirinka a similar trend was observed in addition no significant difference was found with one handweeding at 2 wae. The effect of weed management practices

Table 2. Effect of weed management practices in cowpea on weed density (m^{-2}) at 20 and 55 days after crop emergence (dae) at Jari and Sirinka

	Weed density (M^{-2})											
	20 dae						55 dae					
	Broadleaved		Sedges		Total		Broadleaved		Sedges		Total	
Weed management practices	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor 1.0 kg ha^{-1}	112.0^{d}	50.67^{cd}	13.33^{cde}	10.67^{de}	125.3^{d}	61.33^{d}	90.7^{d}	58.67^{d}	26.67^{e}	21.33^{cd}	117.3^{e}	80.00^{d}
S-metolachlor 1.5 kg ha^{-1}	82.7^{d}	32.00^{e}	8.00^{def}	8.00^{de}	90.7^{d}	40.00^{e}	50.7^{e}	34.67^{ef}	10.67^{f}	16.00^{de}	61.3^{f}	50.67^{e}
S-metolachlor 2.0 kg ha^{-1}	40.0^{e}	26.67^{e}	2.67^{ef}	5.33^{ef}	42.7^{e}	32.00^{e}	34.7^{ef}	40.00^{e}	5.33^{fg}	13.33^{ef}	40.0^{fg}	53.33^{e}
Pendimethalin 1.0 kg ha^{-1}	152.0^{c}	34.67^{e}	21.33^{c}	8.00^{de}	173.3^{c}	42.67^{e}	192.0^{c}	85.33^{c}	58.67^{c}	26.67^{c}	250.7^{c}	112.00^{c}
Pendimethalin 1.3 kg ha^{-1}	192.0^{ab}	61.33^{abc}	66.67^{a}	13.33^{cd}	258.7^{ab}	74.67^{c}	224.0^{b}	106.67^{b}	72.00^{b}	37.33^{b}	296.0^{b}	144.00^{b}
Pendimethalin 1.6 kg ha^{-1}	176.0^{bc}	66.67^{ab}	53.33^{b}	24.00^{ab}	229.3^{b}	90.67^{ab}	181.3^{c}	101.33^{b}	53.33^{c}	37.33^{b}	234.7^{c}	138.67^{b}
S-metolachlor 1.0 kg ha^{-1}+ handweeding at 5 wae	109.3^{d}	48.00^{d}	8.00^{def}	8.00^{de}	117.3^{d}	56.00^{d}	10.7^{gh}	18.67^{g}	2.67^{g}	8.00^{f}	13.3 ^{hi}	26.67^{g}
Pendimethalin 1.0 kg ha^{-1} + handweeding at 5 wae	149.3^{c}	32.00^{e}	18.67^{cd}	8.00^{de}	168.0^{c}	40.00^{e}	8.0^{gh}	29.33^{f}	0.00^{g}	8.00^{f}	8.0^{hi}	37.33^{f}
One handweeding at 2 wae	210.7^{a}	58.67^{bcd}	64.00^{ab}	18.67^{bc}	274.7^{a}	77.33^{c}	109.3^{d}	42.67^{e}	37.33^{d}	10.67^{ef}	146.7^{d}	53.33^{e}
Two handweeding at 2 and 5 wae	208.0^{ab}	61.33^{abc}	61.33^{ab}	21.33^{ab}	269.3^{a}	82.67^{bc}	24.0^{fg}	26.67^{fg}	5.33^{fg}	13.33^{ef}	29.3^{gh}	40.00^{f}
Weed free check	0.0^{f}	0.0^{f}	0.00^{f}	0.00^{f}	0.0^{f}	0.00^{f}	0.0^{h}	0.00^{h}	0.00^{g}	0.00^{g}	0.0^{i}	0.00^{h}
Weedy check	213.3^{a}	72.00^{a}	72.00^{a}	26.67^{a}	285.3^{a}	98.67^{a}	330.7^{a}	152.00^{a}	98.67^{a}	45.33^{a}	429.3^{a}	197.33^{a}
LSD (5%)	32.65	11.73	11.53	5.65	34.81	12.75	22.00	9.13	7.96	5.97	24.95	9.84
CV (%)	14.1	15.3	21.0	26.4	12.1	13.0	12.4	9.3	15.2	17.8	10.9	7.5

CV= coefficientof variation; LSD= least significant difference; 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

on sedges density was similar to broadleaved weeds at Jari, however, in addition application of s- metolachlor at 1.5 kg $ha^{-1}$was also in statistical parity.At Sirinka, application of s–metolachlor alone, pendimethalin at 1.0 kg ha^{-1}, low dose of these herbicides combined with handweeding and handweeding treatments were statistically at par with each other and complete weed free except s-metolachlor and pendimethalin each at 1.0 kg ha^{-1}. All these weed management practices reduced sedge density significantly over other treatments. Density of both broadleaved weeds and sedges were lower at crop harvest than at 55 days after crop emergence. This might be due to the competitive effect of the crop especially for the solar radiation. In line with this result, [18] described that plants with large leaf area indices have a competitive advantage and normally out-compete plants with smaller leaf areas.

The total weed density was significantly reduced with the application of s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5 wae, pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae, s-metolachlor at 2.0 kg ha^{-1} and two handweeding at 2 and 5 wae over other weed management practices at Jari while at Sirinka, one handweeding had also similar effect. All these practices were statistically at par with complete weed free in reducing total weed density (Table 3). Handweeding uprooted the emerged weeds and later on the emerging weeds had been suppressed by the crop canopy resulting in decreased weed density at crop harvest. The weedy check plots resulted in significantly more total weed density than all other weed management practices that could be attributed to unchecked growth of early and late emerging weeds, while application of herbicide or handweeding caused mortality of weeds resulting in lower weed density at harvest. [19]; [20];[9]have also reported a maximum weed density in weedy check and weed control methods like application ofherbicides and handweeding and hoeing significantly deceased weed density over weedy check.

3.1.3 .Weed dry matter weight

The weed dry matter weight was highly significantly influenced by weed management practices at all the growth stages in both the locations.

Table 3. Effect of weed management practices in cowpea on weed density at harvest and on weed dry biomass yield at different growth stages of crop at Jari and Sirinka

	Weed density (m^{-2})						Weed dry biomass weight (g m^{-2})					
	Broadleaved		Sedges		Total		20 dae		55 dae		At harvest	
Weed management practices	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor 1.0 kg ha^{-1}	107.67^{d}	38.67^{c}	29.00^{d}	4.33^{d}	136.7^{d}	43.00^{c}	75.4^{f}	15.77^{d}	295.9^{e}	124.27^{c}	312.3^{d}	138.7^{b}
S-metolachlor 1.5 kg ha^{-1}	61.67^{e}	20.67^{e}	11.33^{e}	3.00^{de}	73.0^{e}	23.67^{e}	48.8^{g}	12.73^{e}	183.4^{f}	92.40^{e}	209.9^{e}	98.7^{c}
S-metolachlor 2.0 kg ha^{-1}	12.00^{f}	3.00^{fg}	1.33^{f}	1.67^{de}	13.3^{f}	4.67^{fg}	22.0^{h}	10.27^{f}	124.2^{h}	82.30^{f}	146.9^{g}	102.0^{c}
Pendimethalin 1.0 kg ha^{-1}	152.00^{c}	29.33^{d}	40.67^{c}	4.33^{d}	192.7^{c}	33.67^{d}	108.5^{e}	14.47^{de}	504.9^{d}	116.33^{d}	541.0^{c}	130.2^{bc}
Pendimethalin 1.3 kg ha^{-1}	176.00^{b}	52.00^{b}	55.33^{b}	13.67^{c}	231.3^{b}	65.67^{b}	150.2^{c}	19.77^{c}	547.3^{c}	128.07^{bc}	574.4^{b}	142.1^{b}
Pendimethalin 1.6 kg ha^{-1}	146.67^{c}	52.00^{b}	39.33^{c}	17.67^{b}	186.0^{c}	69.67^{b}	133.3^{d}	21.67^{c}	559.8^{b}	128.60^{b}	581.5^{b}	144.8^{b}
S-metolachlor 1.0 kg ha^{-1}+ handweeding at 5 wae	1.33^{f}	2.67^{fg}	1.33^{f}	3.00^{de}	2.7^{f}	5.67^{f}	71.8^{f}	14.40^{de}	27.3^{j}	21.50^{h}	43.5^{i}	29.0^{d}
Pendimethalin 1.0 kg ha^{-1} + handweeding at 5 wae	1.33^{f}	5.00^{f}	0.00^{f}	3.00^{de}	1.3^{f}	8.00^{f}	105.4^{e}	12.23^{ef}	27.4^{j}	25.70^{g}	38.1^{i}	32.3^{d}
One handweeding at 2 wae	54.67^{e}	2.67^{fg}	12.67^{e}	2.33^{de}	67.3^{e}	5.00^{fg}	172.6^{b}	21.56^{c}	142.4^{g}	116.90d	170.4^{f}	126.8^{bc}
Two handweeding at 2 and 5 Wae	5.33^{f}	3.67^{fg}	2.67^{f}	2.67^{de}	8.0^{f}	6.33^{f}	173.6^{b}	25.90^{b}	96.5^{i}	82.73^{f}	110.0^{h}	98.0^{c}
Weed free check	0.00^{f}	0.00^{g}	0.00^{f}	0.00^{e}	0.0^{f}	0.00^{g}	0.0^{i}	0.00^{g}	0.0^{k}	0.00^{i}	0.0^{j}	0.0^{d}
Weedy check	289.33^{a}	92.00^{a}	80.67^{a}	24.33^{a}	370.0^{a}	116.33^{a}	178.8^{a}	32.20^{a}	882.8^{a}	265.40^{a}	906.3^{a}	247.6^{a}
LSD (5%)	16.12	4.64	7.84	3.37	20.28	5.42	4.38	2.43	6.30	3.96	16.36	32.30
CV (%)	11.3	10.9	20.3	29.9	11.2	10.1	2.5	8.6	1.3	2.4	3.2	17.7

CV= coefficientof **v**ariation, LSD= least significant difference, dae= days after emergence wae= weeks after emergenceMeans in coloumns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

At 20 dae, the minimum weed dry weight was registered with the application of s-metolachlor at 2.0 kg ha^{-1} at both locations (Table 3).Herbicide application at both places resulted in significant reduction in weed dry weight over weedy check. With the increase in S-metolachlor application rates, the weed dry weight decreased significantly, while the results were inconsistent with pendimethalin application at 20 and 55 dae at both locations. At 55 days after crop emergence weeds in plots treated with s-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 wae and pendimethalin at 1 kg ha^{-1} + handweeding at 5 wae at both locations accumulated significantly the lowest dry weight which might be due to the cumulative effect of herbicide and handweeding (Table 3). [21] also obtained lower dry weight of weeds with butachlor at 1.0 kg ha^{-1} in combination with cultural practices, which was at par with weed free check. The results also revealed significant reduction in weed dry weight with two handweeding compared to one handweeding and herbicides applied alone at this stage. The advantage of twice handweeding over one handweeding might be due to reduced soil seed bank as well as the weeds that emerged after second handweeding were shorter in growth than the weeds that emerged after first handweeding. Handweeding controlled the emerged weeds and those that emerged later on might have failed to accumulate sufficient dry matter due to the competition offered by the crop plants 55 dae. Further, the weed seeds under depleted soil seed bank that might have been brought to the upper soil layer by handweeding, 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, the environment. [22] also reported that herbicide application decreased the dry biomass of weeds; however, this decrease depends on several factors e.g. 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, [23]found that 1.5 kg ha^{-1} of this herbicide to be effective for the control of weeds in common bean. At crop harvest also similar effect of weed management practices was observed (Table 3). [9]and [24]also concluded that dry weight of weeds was significantly reduced in herbicide treated plots.

At 55 days after crop emergence weeds in plots treated with s-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 wae and pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae at both locations accumulated significantly the lowest dry weight which might be due to the cumulative effect of herbicide and hand weeding (Table 3). At crop harvest also similar effect of weed management practices was observed (Table 3). [21]also obtained lower dry weight of weeds with butachlor at 1.0 kg ha^{-1} in combination with cultural practices, which was at par with weed free check. [9] and [24]also concluded that dry weight of weeds was significantly reduced in herbicide treated plots. Also the result of this study was in agreement with earlier work of [25]and [26]who observed reduced weed dry weight when herbicide application in common bean was combined with one handweeding. Better control of weeds at the early stages by fluchloralin 1.0 kg ha^{-1} and removal of weeds subsequently by hand weeding at 40 days after crop emergence resulted in lesser weed count and weed dry weight [27]. Handweeding controlled the emerged weeds and that emerged later on might have failed to accumulate sufficient dry matter due to the competition offered by well grown crop plants. Further, 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.

At harvest, the weed dry weight accumulation with the increasing rates of s-metolachlor application decreased significantly at Jari, but at Sirinka no significant difference was obtained between s- metolachlor at 1.5 and 2.0 kg ha^{-1}. In contrast, pendimethalin at 1.3 and 1.6 kg ha^{-1} recorded significantly higher weed dry weight than its lower rate at Jari, while at Sirinka no significant difference existed between the rates. Moreover, pendimethalin at 1.0 kg ha^{-1} had weed dry weight statistically in parity with s-metolachlor rates at Sirinka (Table 3). The significantly higher weed dry weight with increased pendimethalin application at Jari might be due to the severe infestation with *X. strumarium.* On the other hand at Sirinka, this weed was not found and no significant difference inweed dry weight was observed.The data also depicted that the weedy check registered the highest weed dry weight which was significantly higher than other weed management practices.

Two handweeding proved significantly better than one handweeding in reducing weed dry weight at Jari whereas at Sirinka there was no significant difference. The contrasting resultsmight be due to the extent to which the weed species and or the density differed at the locations. The results depicted that the application of s-metolachlor and pendimethalin at their lowest rates combined with one handweeding provided prolonged weed control and like at earlier growth stages registered significant reduction in weed dry weight at harvest. Moreover, at Sirinka s-metolachlor combined with handweeding was as effective as complete weed free in reducing the weed dry weight at harvest.

The effectiveness of both the 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 activeness of a herbicide (Table 3). At Jari, *X. strumarium* grew faster in the absence of inter-specific competition with other weed species especially in pendimethalin treated plots.

At both locations, weeds accumulated higher dry weight in weedy check plots and it was significantly higher than other weed management practices (Table 3). 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 resulting in lower dry weight. These results are in agreement with the findings of [19]and [28]who reported maximum weed dry weight in weedy check. [29]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 matter weight faster than the crop.

3.2. Effect of Weed Management Practices on Crop Phenology and GrowthYield Attributes and Yield

3.2.1. Crop Phenology and Growth

Days to 50% flowering

Days to 50% flowering was significantly influenced by the location, weed management practices and their interaction. It was observed that at Sirinka the application of s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5 wae resulted in significantly earlier flowering than Jari. This was followed by the combination of pendimethalin at 1.0 kg ha^{-1}+ one handweeding at 5 wae at the same location which was statistically at par with the application of s-metolachlor at 1 kg ha^{-1}+ handweeding at five wae at Jari. The 50% flowering was delayed when weeds wereallowed to grow uninterrupted at both the locations. However, this delay was significant at Sirinka. In conformity with this result, [30] also identified that the plants in unweeded plots took the highest time to reach 50% flowering. In general, application of either s-metolachlor at 1.0 kg ha^{-1} or pendimethalin at 1.0 kg ha^{-1} each combined withone handweeding at 5wae resulted in enhanced 50% flowering at both locations. This is in line with the findings of [31], who stated that treating plots with chemical and supplementing with hand weeding at intervals helped to reduce number of days to flowering and maturity.

Days to 90 % physiological maturity

The effect of location, treatments and their interaction had a significant effect on days to 90% physiological maturity of the crop. The data revealed enhanced maturity (83 days) with the application of s-metolachlor at 2.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5wae, pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae and weed free check at Jari which was significant over the other interactions. At Sirinka, the application of s-metolachlor at 2.0kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 wae, pendimethalin at 1.0 kg ha^{-1} +hand weeding at 5 wae and weed free check resulted in 92 days to attain the physiological maturity which was significantly early at the same location but was delayed compared to the other treatments at Jari. Thusthe number of days to physiological maturity was earlier by 9 days at Jari than at Sirinka. Moreover, the maturity of plants at Sirinka was significantly delayed under all the treatments compared to Jari which could be due the differences in amount and distribution rain fall and temperature and elevation.

Unlike days to 50% flowering, the number of days required by the plants to attain physiological maturity in weedy check plots was statistically at par with the plants grown in plots treated with all the rates of pendimethalin alone, s- metolachlor at 1.0 and 1.5 kg ha^{-1}, and one handweeding at 2 wae at Jari.

Table 4. Interaction of location and weed management practices on days to flowering and physiological maturity of cowpea during 2013 cropping system

Weed management practices	Days to 50% Flowering		Days to physiological maturity	
	Jari	Sirinka	Jari	Sirinka
S-metolachlor at 1.0 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
S-metolachlor 1.5 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
S-metolachlor 2.0 kg ha^{-1}	59.0^{e}	57.3^{f}	83.0^{e}	92.0^{b}
Pendimethalin 1.0 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
Pendimethalin 1.3 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
Pendimethalin 1.6 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
S-metolachlor 1.0 kg ha^{-1}+ handweeding at 5 wae	56.7^{g}	55.0^{h}	83.0^{e}	92.0^{b}
Pendimethalin 1.0 kg ha^{-1} + handweeding at 5 wae	57.7^{f}	56.3^{g}	83.0^{e}	92.0^{b}
One handweeding at 2 wae	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
Two handweeding at 2 and 5 wae	61.0^{d}	62.0^{c}	83.7^{d}	94.0^{a}
Weed free check	57.3^{f}	55.7^{h}	83.0^{e}	92.0^{b}
Weedy check	63.0^{b}	64.0^{a}	85.0^{c}	94.0^{a}
LSD (5%) L x WMP	0.63		8.0	
CV(%)	0.6		0.3	

CV= coefficientof **v**ariation; LSD= least significant difference; wae= weeks after emergence. Means in coloumn and row of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

At Sirinka, the results were similar but no significant difference existed between weedy check and two handweeding at 2 and 5 wae. The result was in agreement with the findings of [31], who stated that treating plots with chemical and supplementing with handweeding at intervals helped to reduce number of days to maturity.

Plant height

The data (Table 5) showed that the plant height was significantly affected due to location while the weed management practices and its interaction with location had no significant effect.

Table 5.. Effect of location and weed management practices on plant height of cowpea during 2013 cropping season

Treatments	Plant height (cm)
Location	
Jari	68.07[a]
Sirinka	60.60[b]
LSD (5%)	3.82
Weed management practices	
S-metolachlor 1.0 kg ha^{-1}	64.04
S-metolachlor 1.5 kg ha^{-1}	65.53
S-metolachlor 2 kg ha^{-1}	61.49
Pendimethalin 1.0 kg ha^{-1}	66.52
Pendimethalin 1.3 kg ha^{-1}	68.20
Pendimethalin 1.6 kg ha^{-1}	62.51
S-metolachlor 1.0 kg ha^{-1}+ hand weeding at 5 wae	62.87
Pendimethalin 1.0 kg ha^{-1} + hand weeding at 5 wae	61.47
One hand weeding at 2 wae	64.56
Two hand weeding at 2 and 5 wae	60.06
Weed free check	62.26
Weedy check	73.58
LSD (5%)	NS
CV (%)	12.51

CV= coefficientof **v**ariation; LSD= least significant difference; wae= weeks after emergence; NS= not significant; Means in coloumn followed by the same letter(s) are not significantly different at 5% level of significance

The plants at Jari attained significantly higher height by 12.3% than at Sirinka. The higher temperature at Jari might have triggered growth resulting in increased plant height. More sunlight penetration to the crop plants also made photosynthates more 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; Table 3). In contrast, [32]obtained differences in plant height due to various intensities of weed competition with crop plants.

3.2.3. Effect of Weed Management Practices on Yield Attributes and Yield

Stand Count at harvest

The stand count at harvest was significantly influenced by location and weed management practices, but their interaction had no significant effect (Table 6). The final crop stand was significantly higher at Sirinka than at Jari. The higher weed density as well as weed dry weight at Jari than at Sirinka (Table 2; Table 3) might have contributed for the lower survival of crop plants. The highest stand count was recorded from the treatment s-metolachlor at 1.0 kg ha^{-1}+ one handweeding at 5 wae (120756 plants ha^{-1}) which was statistically in parity with weed free check (120370 plants ha^{-1}), pendimethalin 1.0 kg ha^{-1}+ one handweeding at 5 wae (117284 plants ha^{-1}) and two handweedings at 2 and 5 wae (114969 plants ha^{-1}). All these treatments except two handweeding at 2 and 5 wae resulted in significant increase in final crop stand over the other treatments while two handweeding at 2 and 5 wae did not have such difference with s- metolachlor at 2.0 kg ha^{-1}. Comparatively higher survival of the plants observed under these weed management practices could be due to better weed control. The significantly lower plant stand was obtained in weedy check than the other treatments.

Number of pods per plant

The location, weed management practices and their interaction had significant effect on number of pods $plant^{-1}$. The interaction effect revealed highest number of pods $plant^{-1}$ was obtained with the application of s-metolachlor at 1.0 kg ha^{-1} + one handweeding at 5 wae at Jari which was statistically similar to the weed free check at both locations (Table 7). Further, the results showed that weed free check had also no significant difference in number of pods $plant^{-1}$ obtained with pendimethalin at 1.0 kg ha^{-1}+ one hand weeding at 5 wae both at Jari and

Sirinka as well as with s-metolachlor at 1.0 kg ha^{-1}+ one hand weeding at 5 wae at Sirinka. Two handweedings at 2 and 5 wae when interacted with the location did not show significant difference but proved significantly better than one handweeding at 2 wae at both locations.

The application of pendimethalin and s-metolachlor at 1.0 kg ha^{-1}, each accompanied with one handweeding resulted in significant increase in number of pods $plant^{-1}$ over the application of these herbicides alone which may be attributed to the prolonged weed control due to handweeding. 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 might have helped to improve the photosynthetic efficiency of the crop and supported a large number of pods as has been reported from the work done earlier [33]. The lowest number of pods $plant^{-1}$ was observed in weedy check plots at Jari which was significantly lower than the other interactions except the interaction of pendimethalin at 1.0 kg and at 1.3 kg ha^{-1} at the same location. This might be due to the significantly more weed density and total weed dry weight (Table 3) in these treatments at Jari. The season long 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 [34].

These results are in line with those of [35]who observed increased number of pods $plant^{-1}$ where weed population was reduced by management techniques. Similarly, [36]stated that the number of pods produced per plant or maintained to final harvest depends on a number of environmental and management practices.

Number of seeds per pod

The number of seeds $pod^{-1}$was significantly affected due to locations and at Sirinka the pods had 10.4% higher number of seeds compared to Jari. Despite a difference of 2.66 seeds $pod^{-1}$the weed management practices did not show a significant difference (Table 6). Though the competition among different treatments for the limited resources might have been present resulting in reduced grain filling, it seemed that this reduction failed to bring significant

change in number of seeds pod^{-1}. However, in agreement with the findings of [30] this study also indicated lowest number of seeds pod^{-1}in weedy check.

Table 6. Effect of weed mangment practices on crop stand, number of seeds, hundred seed weight and harvest index of cowpea at Jari and Sirinka

Factors	Crop stand (ha^{-1})	Number of seeds pod^{-1}	Hundred grain weight (g)	Harvest index
Location				
Jari	98251^{b}	12.01^{b}	11.90^{b}	0.28^{b}
Sirinka	106224^{a}	13.26^{a}	12.82^{a}	0.31^{a}
LSD (5%)	4830.1	0.78	0.27	0.013
CV (%)	10.0	13.05	4.70	9.10
Weed management practices				
S-metolachlor 1.0 kg ha^{-1}	92978 ^{d}	12.03	12.39^{bc}	0.24^{de}
S-metolachlor 1.5 kg ha^{-1}	96065^{cd}	13.08	11.80^{cd}	0.30^{c}
S-metolachlor 2.0 kg ha^{-1}	105324^{bc}	12.74	12.64^{ab}	0.29^{c}
Pendimethalin 1.0 kg ha^{-1}	95293^{cd}	12.85	12.24^{bc}	0.27^{cd}
Pendimethalin 1.3 kg ha^{-1}	93750^{cd}	12.56	12.66^{ab}	0.24^{de}
Pendimethalin 1.6 kg ha^{-1}	101466^{cd}	11.36	12.32^{bc}	0.25^{de}
S-metolachlor 1.0 kg ha^{-1}+ hand weeding at 5 wae	120756 ^{a}	13.40	12.68^{ab}	0.35^{b}
Pendimethalin 1.0 kg ha^{-1} + hand weeding at 5 wae	117284 ^{a}	13.60	12.55^{ab}	0.37^{b}
One handweeding at 2 wae	90664 ^{d}	12.72	12.05^{bcd}	0.29^{c}
Two handweeding at 2 and 5 wae	114969^{ab}	12.57	12.52^{ab}	0.36^{b}
Weed free check	120370 ^{a}	13.68	13.11^{a}	0.41^{a}
Weedy check	77932 ^{e}	11.02	11.44^{d}	0.22^{e}
LSD (5%)	11831.3	NS	0.67	0.032
CV (%)	10.0	13.05	4.7	9.10

CV= coefficientof **v**ariation; LSD= least significant difference; wae= weeks after emergence; NS= not significant; Means in coloumn of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

Hundred grain weight

The effect of locations and treatments was .highly significant (P< 0.01) while their interaction had no significant effect on 100 seed weight. The seeds at Sirinka had significantly higher weight by 7.7% than at Jari. The grains under complete weed free plots recorded the highest weight which was statistically at par with two hand weeding at 2 and 5wae, 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}. The lowest 100 grain weight was observed in weedy check however, it was in parity with one hand weeding at 2 wae and s-metolachlor 1.5 kg ha^{-1}(Table 6). The plants raised under complete weed free environment were free from weed competition, thus utilized the available resources to their maximum benefit resulting in increased seed weight. Also, the more and vigorous leaves under weed free environment that improved the supply of assimilate to be stored in the seed, hence, the weight of 100 grains increased. This is in agreement with[38]who stated that cowpea plants in the plots received chemical weeding + one handweeding at 35 days after planting gave the highest 100 seed weight and this was significantly different from the lowest value produced from plants in unweeded plots. This observation is also in line with the work of [6]who reported that application of pendimethalin at 3.75 l ha^{-1}+ one handweeding at 5 weeks after sowing significantly gave higher mean values on yield and yield components of cowpea. However,[40]reported no significant difference in grain weight due to weed management practices in common bean.

Grain yield

Cowpea grain yield was significantly (P<0.01) influenced due to location, weed management practices and their interaction. The maximum grain yield (4277 kg ha^{-1}) was obtained in complete weed free at Sirinka which was statistically at par with complete weed free at Jari and two handweeding at Sirinka. Further, the interaction effect showed that the yield obtained with complete weed free at Jari and two handweeding at Sirinka had no significant difference with the application of s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5 wae and pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae at Sirinka. 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 s- metolachlor at 1.5 and 2.0 kg ha^{-1} at both locations (Table 7). But these treatments depicted significant yield increase over s- metolachlor at 1.0 kg ha^{-1} which was 22.5% and 33.0%, 18.7% and 22.7 % over s- metolachlor at 1.0 kg ha^{-1}, respectively at Jari and Sirinka.

Theinteraction effect of location with increasing rates of pendimethalin showed significant reduction in yield with the application of pendimethalin at 1.3 and 1.6 kg ha^{-1} over its lower rate at Jari. In contrast, at Sirinka, results were inconsistent and no significant difference existed among the rates. At Jari, s-metolachlor at 1.0 kg ha^{-1}+ handweeding at 5 wae gave significant yield increase over pendimethalin at 1.0 kg ha^{-1} + handweeding at 5 wae, while these weed management practices were statistically in parity at Sirinka. However, at both the locations, two handweeding proved significantly better than one handweeding (Table 7).

Weedy crop throughout the growing period resulted in the lowest grain yield, but at respective locations did not have a significant difference with pendimethalin at 1.3 and 1.6 kg ha^{-1} at Jari, and pendimethalin at 1.0 and 1.6 kg ha^{-1} as well as s-metolachlor at 1.0 kg ha^{-1} at Sirinka. While comparing weedy check at Sirinka with weed management practices at Jari, the data (Table 5) revealed that weedy check plots had significantly higher yield than s- metolachlor at 1.0 kg ha^{-1}, pendimethalin at 1.3 and 1.6 kg ha^{-1} while it was statistically at par with s-metolachlor at 1.5 and 2.0 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1} and one handweeding at 2 wae (Table 7). The yield obtained at Sirinka in general, was significantly higher than at Jari under most of their respective weed management practices. This difference might have been partially due the differences that existed in number of pods plant $^{-1}$and seeds pod^{-1}between the locations. In line with this, [41]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 [42]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 [43], [44], [45]and[6]. [38]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 [46].

Aboveground dry biomass yield

The highest aboveground dry biomass yield (10797 kg ha^{-1}) was obtained in s-metolachlor at 1 kg ha^{-1}+ one hand weeding at 5 wae treated plots at Jari which was statistically at par with two handweedings 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 handweeding at 5 wae, one handweeding and weed free check at Sirinka (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 Jari. At Sirinka, the aboveground dry biomass yield in weedy check was significantly lower than s-metolachlor at 2.0 kg ha^{-1} and two handweedings at 2 and 5 wae only. [47] reported that the increased dry matter weight of the crop was highly governed by the length of weed free period. Generally, the aboveground dry biomass yield was higher at Sirinka than Jari while comparing the individual treatments.

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.

Table 7. Interaction effect of location and weed management practices on number of pods plant^{-1}**,** grain and aboveground dry biomass yield(kg ha^{-1}), and yield loss (%) of cowpea during main cropping season in 2013

	Number of pods plant^{-1}		Grain yield (kg ha^{-1})		Aboveground dry biomass yield (kg ha^{-1})		Yield loss (%)	
Weed management practices	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor 1.0 kg ha^{-1}	12.11^{hij}	12.70^{hij}	1750^{l}	2595^{hij}	7408^{fg}	10082^{abc}	55.4^{b}	39.4^{cde}
S-metolachlor 1.5 kg ha^{-1}	16.00^{def}	11.50^{ij}	2144^{kl}	3080^{efg}	7185^{gh}	9815^{abcd}	44.7^{cd}	28.0^{fg}
S-metolachlor 2.0 kg ha^{-1}	13.11^{ghi}	17.13^{cde}	2327^{ijk}	3185^{def}	7780^{fg}	10694^{ab}	39.9^{cde}	25.6^{gh}
Pendimethalin 1.0 kg ha^{-1}	10.67^{ijk}	14.53^{fgh}	2373^{ijk}	2582^{hij}	8957de	9136^{cde}	39.2^{cde}	39.6^{cde}
Pendimethalin 1.3 kg ha^{-1}	8.00 ^{l}	12.83^{hij}	1322^{m}	2696^{ghi}	6157^{hi}	9763^{abcd}	66.1^{a}	36.9 ^{def}
Pendimethalin 1.6 kg ha^{-1}	8.67^{kl}	15.33^{efg}	1282^{m}	2555^{hijk}	5932^{i}	9059^{cde}	67.1 ^{a}	40.1^{cde}
S-metolachlor 1.0 kg ha^{-1}+ hand weeding at 5 wae	22.44^{a}	19.07^{bc}	3595^{cd}	3769^{bc}	10797^{a}	9949^{abcd}	7.9^{ij}	11.8^{i}
Pendimethalin 1.0 kg ha^{-1} + hand weeding at 5 wae	19.33^{bc}	18.97^{bc}	3017^{fg}	3614^{bc}	8161^{efg}	9753^{abcd}	22.7^{gh}	15.3^{hi}
One handweeding at 2 wae	15.33^{efg}	15.83^{def}	2312^{ijk}	2969^{fgh}	8382^{ef}	9733^{abcd}	40.1^{cde}	30.5^{efg}
Two handweeding at 2 and 5 wae	18.11^{cd}	19.00^{bc}	3452de	3864^{abc}	9831^{abcd}	10438^{ab}	11.6^{i}	9.5^{ij}
Weed free check	20.78^{ab}	20.67^{ab}	3907^{ab}	4277^{a}	9566^{bcd}	10113^{abc}	0.0^{j}	0.0^{j}
Weedy check	7.67 ^{l}	10.63^{jk}	1134^{m}	2241^{jk}	5661^{i}	9043^{cde}	70.9 ^{a}	47.5^{bc}
LSD (%) L x WMP	2.456		422.0		1079.0		10.57	
CV(%)	10.0		9.3		7.4		19.6	

CV= coefficientof **v**ariation; LSD= least significant difference; wae= weeks after emergence;Means in coloumn and row of same parameter followed by the same letter(s) are not significantly different at 5% level of significance

Harvest index

The results revealed that the locations and weed management practices had a significant influence on the crop harvest index. The crop grown at Sirinka had significantly higher harvest index than at Jari. Significantly higher harvest index than the other weed management practices was found when the crop was kept weed free throughout the growing season (Table 7). This was followed by pendimethalin 1.0 kg ha^{-1} + handweeding at 5 wae, s-metolachlor 1.0 kg ha^{-1}+ hand weeding at 5 wae and two handweeding at 2 and 5 wae. Though these weed management practices did not show statistically significant differences among them but had significantly higher harvest index than the remaining weed management practices. The weedy check showed the minimum harvest index that did not vary significantly with s-metolachlor 1.0 kg ha^{-1}, pendimethalin 1.3 kg ha^{-1} and pendimethalin 1.6 kg ha^{-1}.

Yield Loss

The weeds under different weed management practices caused variable amount of grain yield loss in cowpea. The highest yield loss (70.8%) was recorded in weedy check at Jari which was statistically in parity with the loss registered with the application of pendimethalin 1.3 kg ha^{-1} and pendimethalin 1.6 kg ha^{-1}at the same location. All these weed management practices recorded a significant yield loss compared to other treatments. At Sirinka, the highest loss (47.5%) in yield due to weeds was also in weedy check but it did not show significant variation with the loss accrued from the application of s- metolachlor at all its rate, pendimethalin at 1.0 kg ha^{-1} and one handweeding at 2 wae at Jari, and s- metolachlor at 1.0 kg ha^{-1} and pendimethalin at 1.0 and 1.6 kg ha^{-1}. The application of s-metolachlor 1.0 kg ha^{-1} combined with one handweeding 5 wae resulted in the lowest yield loss which was statistically at par with two handweeding at 2 and 5 wae both at Jari and Sirinka, as well as s-metolachlor at 1.0 kg ha^{-1} and pendimethalin at 1.0 kg ha^{-1} both combined with one handweeding 5 wae at Sirinka. Moreover, it was observed that the yield loss due to s-metolachlor 1.0 kg ha^{-1} superimposed with one handweeding 5 wae at Jari and two handweedings at 2 and 5 wae at Sirinka were not significant compared to complete weed free at both the location (Table7). This observation is in agreement with work of [6]and [8] who

reported that the presence of weeds reduced yield by 82 %. On the other hand [7]; [48]and[49], found 12.7- 60.0%, 40 to 60% and 25 and 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 herbicide might have dissipated soon from the soil under the influence of environmental conditions prevailing during the crop season.

3.5. Partial Budget Analysis

The result of the partial budget analyses (Table 8) showed that the highest total variable input cost was accrued due to the two handweedings followed by pendimethalin at 1.0 kg ha^{-1} and and s –metolachlor at 1.0 kg ha^{-1} both combined with handweeding. This increased total variable cost was 4.2 and 13.4% higher than handweeding, respectively. On the other hand the highest gross benefit was obtained with the application of s-metolachlor at 1.0 kg ha^{-1}+ handweeding, followed by two handweedings at 2 and 5 wae and pendimethalin at 1.0 kg ha^{-1} + one handweeding. Owing to higher yield thereby gross benefit, these treatments resulted in higher net benefit of 42879 ETB, 41638 ETB and 37333ETB ha^{-1}, respectively.

Table 8. Partial budget analysis of weed management practices in cowpea based on total variable cost during main cropping season 2013

Weed management practices	Total variable cost (ETB ha^{-1})	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1}) 10% down	Gross benefit (ETB ha^{-1})	Net Benefit (ha^{-1})
S-metolachlor 1.0 kg ha^{-1}	3935	2172.4	1955.2	29328	25393
S-metolachlor 1.5 kg ha^{-1}	4841	2612.1	2350.9	35264	30423
S-metolachlor 2.0 kg ha^{-1}	5283	2756.0	2480.4	37206	31923
Pendimethalin 1.0 kg ha^{-1}	5589	2477.5	2229.8	33447	27858
Pendimethalin 1.3 kg ha^{-1}	5339	2009.0	1808.1	27122	21783
Pendimethalin 1.6 kg ha^{-1}	5581	1918.6	1727.4	25911	20330
S-metolachlor 1.0 kg ha^{-1}+ hand weeding at 5 wae	6828	3682.0	3313.8	49707	42879
Pendimethalin 1.0 kg ha^{-1} + hand weeding at 5 wae	7430	3315.8	2984.2	44763	37333
One handweeding at 2 wae	5620	2640.5	2376.5	35648	35649
Two handweeding at 2 and 5 wae	7742	3658.4	3292.6	49380	41638
Weedy check	2642	1687.3	1518.6	22779	20137

Cost of s-metolachlor 417 Birr/ kg; cost of pendimethalin 620 Birr/kg; Spraying Birr 99/ ha; Cost of hand weeding and hoeing 2 wae 45 persons, 35 dae 16 persons @Birr 33 / person; Sale price of cowpea Birr 15/ kg; Field price of cowpea (sale price- variable input cost-harvesting, threshing and winnowing Birr 165/ 100 kg; packing and material cost Birr 4.0 per 100 kg, transportation Birr 5 per 100 kg ; ETB= 0.0498 USD

4. CONCLUSION

Cowpea [*Vigna unguiculata* (L.) Walp.] is usually infested by a number of weed species that compete with the crop from germination to harvest, affecting the crop yield adversely. In the experimental field 14 weed species were found out of which 78.6% were broadleaved. Weed density and dry matter accumulation were significantly reduced to a variable extent due to weed management practices. Application of preemergence s-metolachlor and pendimethalin alone failed to control *C.benghalensis* and *X. strumarium* while s-metolachlor was more effective in controlling *Cyperus* spp. than pendimethalin. Application of low dose of both s-metolachlor and pendimethalin each combined with one handweeding 5wae were most effective in reducing weed infestation. Crop phenology was significantly influenced by the location and weed management practices while plant height, final crop stand, seeds pod^{-1}, 100 grain weight and harvest index remained unaffected due to interaction. The location and weed management practices interaction also had significant effect on number of pods $plant^{-1}$, aboveground dry biomass and grain yield. Uninterrupted weed growth throughout the crop growth resulted in 70.8 and 47.5 % reduction in yield at Jari and Sirinka, respectively, which was reduced to 9.5% and 7.9% with the application of two handweedings and s-metolachlor at 1.0 kg ha^{-1}combined with handweeding. Partial budget analysis indicated that the highest gross benefit with the application of s-metolachlor at 1.0 kg ha^{-1} superimposed with one handweeding followed by two handweedings at 2 and 5 wae. The result of this experiment could be used as a tentative recommendation; however, herbicide combinations need to be further evaluated to preclude the weed shift in the area.

Authors' contributions

This work was carried out in collaboration between the authors. Author "A"is PhD student designed thestudy, performed the statistical analysis, wrote the protocol, and the first draft of themanuscript. Co-authors "B" are advisors and giving relentless guidance, valuable comments on the thesis manuscript, and encouragement during the course of my research

workandprepared the final manuscript forpublication. Authors read and approved the final manuscript.

Acknowledgments

Above all, I wish to thank Jesus Christ, my good Shepherd, Savior and Lord, "for everything that was made through Him, nothing was made without Him." John 1:3.I wish to express my deep, heartfelt gratitudeto myuncles Megabie Hadis Negussie Ayale, Haile Georgis Ayale and Sister Tsige Mekonnen for their help and encouragement during my undergraduate and post graduate study that paved the way for today's success.Last but not least, I would like to express my passionate thankfulness to my beloved wife Mekdes Dessie for her moral support andencouragement during the course of study.

Competing Interests

"Authors have declared that no competing interests exist."

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