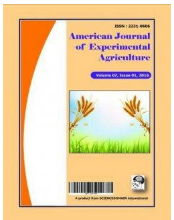

American Journal of Experimental Agriculture
7(5): 326-346, 2015, Article no.AJEA.2015.134
ISSN: 2231-0606

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

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Authors' contributions

This work was carried out in collaboration between all authors. Author GM is PhD student designed the study, performed the statistical analysis, wrote the protocol and write first draft of the manuscript. Co-authors JJS, LN and TT are advisors and giving relentless guidance, valuable comments on the dissertation manuscript and encouragement during the course of research work and prepared the final manuscript for publication. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2015/14513
Editor(s):
(1) Rusu Teodor, Department of Technical and Soil Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Romania.
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Reviewers:
(1) Anonymous, Brazil.
(2) Anonymous, Nigeria.
(3) Anonymous, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=919&id=2&aid=8425

Original Research Article

Received 1st October 2014
Accepted 26th January 2015
Published 12th March 2015

ABSTRACT

Cowpea [*Vigna unguiculata* (L.) Walp.] is usually infested and its yield is adversely affected 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 pre-emergence s-metolachlor and pendimethalin on weeds, and growth, yield components and

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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: 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} + handweeding at 5 WAE, one handweeding at 2 WAE, two handweeding at 2 and 5 WAE, weed free and weedy checks. The treatments were arranged in randomized complete block design with three replications. 78.6% of the weeds comprised in the experimental sites were the broadleaved. At 20 DAE, application of 2.0 kg ha^{-1}s-metolachlor 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 hand weeding were as effective as complete weed free treatment in reducing the broadleaved weeds and sedge density. The minimum weed dry weight was registered with the application 2.0 kg ha^{-1} of s-metolachlor in both locations; however, at 55 days and harvest, weeds accumulated significantly lower dry weight due to1.0 kg ha^{-1} s-metolachlor 1.0 kg ha^{-1} pendimethalin superimposed with hand weeding at both 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 treatment at Sirinka which was statistically equivalent with complete weed free and two hand weeding treatments at Jari and Sirinka experimental sites respectively. Due to weed infestation throughout the crop growth, the highest yield loss (70.8%) was recorded at Jari while it was 47.5% at Sirinka. The highest gross benefit was obtained with the application of 1.0 kg ha^{-1} of s-metolachlor superimposed with hand weeding followed by two hand-weeding at 2 and 5 WAE. Therefore, managing the weeds with the application of 1.0 kg ha^{-1} of s- metolachlor + hand weeding and hoeing 35 DAE proved to be the most profitable practice. However, under the condition of labour constraint and timely availability of the herbicide, pre emergence application of 2.0 kg ha^{-1} of s-metolachlor should be used to preclude the yield loss and to ensure maximum benefits.

Keywords: Broadleaved and grass weeds; economic analyses; herbicides; yield loss.

1. INTRODUCTION

Cowpea is 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].

A number of weed species are affecting the yield by competing with the crop from germination to harvest [6], and this yield loss in cowpea which ranged from 12.7% - 60.0% is due to weeds [7]. According to [8], 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]. Herbicide use would improve the lives of farmers by eliminating the need for back-breaking labour.

Significantly higher grain yield and net return of cowpea were obtained with pendimethalin applied pre-emergence at 0.75 kg ha^{-1}+ hand-weeding at 5 weeks after planting (WAP) compared to other treatments [6,12] 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 $ha^{-1}$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].

Integrating herbicides with cultural methods is an option for better weed control. Integrated weed management (IWM) does not preclude herbicide use, it includes their judicious use along with other agronomic methods that help crops compete with weeds and reduce weed seed production. IWM involves using an agronomical approach to minimize the overall impact of weeds and, indeed, maximize the benefits.

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 to assess the effect of s-metolachlor and pendimethalin on weeds, growth, yield components and yield of cowpea. It was also meant 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 experimental sites at Jari (11°21'N latitude and 39°38'E longitude; 1680 m. a. s. l. altitude) and Sirinka (11°45'00" N latitude; 39°36'36"E longitude; 1850 m. a .s .l. altitude) in northern Ethiopia during the 2013 main cropping season (July to October).The soil of the experimental fields was clay loam and clay with the pH of 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 mg kg^{-1} and 33.44 $cmol_C$ kg^{-1}. The total seasonal rainfall received during the crop season was 750.4 mm and 589.1 mm at Sirinka and Jari with mean maximum and minimum temperatures of 28.6 and 14.7°C, and 29.6 and15.8°C, respectively (Fig. 1).

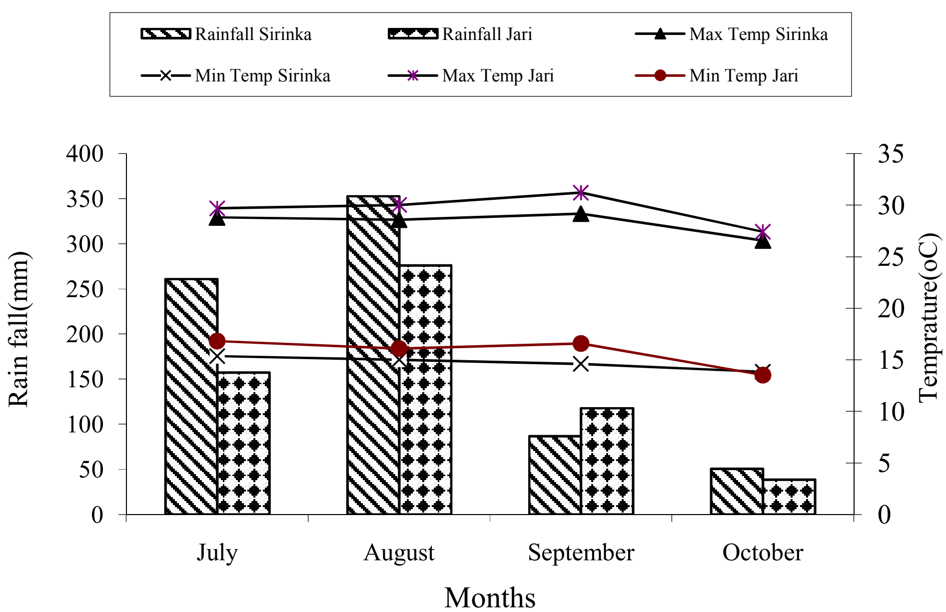

Fig. 1. Monthly mean maximum and minimum temperatures (°C) and total rainfall (mm) at Jari and Sirinka in 2013 main cropping season
Source: Sirinka Agricultural Research Center

2.2 Treatments and Experimental Design

The experiment of this study comprises 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 design with three replications.

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 inter- and intra- row spacing of 60 cm and 10 cm, onthe 8^{th}July and 13^{th} of July, 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. The pre-emergence herbicides were applied at the specific rates using Knapsack sprayer one day after planting using flat-fan nozzle. The spray volume was 450 l ha^{-1}. The outermost one row from each side and 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 flora present in the experimental fields were recorded during the experimental period. The weed density was recorded by throwing a quadrate (0.25 m×0.25 m) randomly at two places in each plot at about 15 days before the expected harvest time. The weed species found within the sample quadrat were identified, counted and expressed in m^{-2}. For the aboveground weed dry weight/ biomass, the weeds falling within the quadrate were cut near the soil surface immediately after taking observation on weed count and placed into paper bags separately treatment 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}.

Weed Index: It was measured from a particular treatment when compared with a weed free treatment and expressed as percentage of yield potential under weed free.

$$\text{Weed Index}= \frac{x-y}{x} X100$$

Where

x= Yield from weed free check; y= Yield from a particular treatment

Weed Control Efficiency (WCE): was calculated using the following formula

$$\text{WCE} = \frac{WDC - WDT}{WDC} \text{x}\ 100$$

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

Number of days to 50% flowering was recorded as number of days from emergence of cowpea to the date when first flower appeared on 50% of the plants in each plot, whereas days to maturity was recorded as the number of days from planting to the day when 90% of the plants reached physiological maturity, *i.e.* both pods and plants turned yellow (senescing) based on visual observation. Plant height (cm) was taken with a measuring tape 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 by harvesting ten plants in each plot at physiological maturity and their dried aboveground biomass was recorded and then as grain yield divided by the aboveground dry biomass. Treatment per plant dry weight of straw 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.

Data on weed community, weed density, weed dry biomass; crop phenology, growth, yield attributes and yield were subjected to analysis of variance using GenStat 15.0 computer software [15]. Fisher's protected Least Significant Difference (LSD) test at 5% level of significance was used to separate the differences among treatment means ($P < 0.05$) [16]. As the F-test of the error variances for the parameters of the two sites was homogeneous, combined analysis of data was used.

2.4 Partial Budget Analysis

The concepts used in the partial budget analysis were the mean grain yield under each treatment for both locations, the field price of the crop (sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation), the varied total costs including 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 [17].

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 broadleaved, while sedges were found at lesser extent. There was only one grass species present at Sirinka to a very limited extent. Hence this weed was merged with sedges for the purpose of describing the results. The parasitic weed broomrape (*O. cerenata*) was found 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 2.

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]

3.1.2 Weed density

3.1.2.1 Weed density at 20 days after crop emergence

Weed density showed a significant difference (P <0.01) due to various weed management practices. At 20 DAE, the application 2.0 kg ha^{-1}of s-metolachlor at Jari and Sirinka resulted in the existence of lowest broadleaved weed density. Furthermore, at Sirinka, no significant differences existed between s-metolachlor at 1.5 kg ha^{-1}, pendimethalin 1.0 kg ha^{-1} + handweeding at 35DAE, and pendimethalin at 1.0 kg ha^{-1}. The density of broadleaved weeds decreased with the increase in s- metolachlor application rates but significant difference was notobserved 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 hand-weeding at 2 WAE (or 14 DAE), two hand-weeding at 2 and 5 WAE (or 14 and 35 DAE) and pendimethalin at 1.3 kg ha^{-1} had 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 DAE, the sedge density at Jari was minimum for 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 (35 DAE).The 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 the application of 2.0 kg ha^{-1}s-metolachlor also 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 hand-weeding at 5 WAE (35 DAE).

The total weed density was lowest with the application of 2.0 kg ha^{-1}of s- metolachlor at Jari while at Sirinka, the lowest total weed density was obtained with s-metolachlor at 2.0 kg ha^{-1}, but it had no significant difference with s-metolachlor at 1.5 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1} + handweeding at 5WAE (35 DAE)and pendimethalin at 1.0 kg ha^{-1}.The increasing s-metolachlor application rates decreased the total weed density but there was no significant difference observed between 1.0 and 1.5 kg ha^{-1}treatments of s-metolachlor at Jari. In contrast, pendimethalin at 1.0 kg ha^{-1}resulted insignificant 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 also controlled which reduced inter specific competition. Further, this in turn might have provided greater opportunity to C. *benghalensis* to germinate in larger amount. At Sirinka the total weed density also decreased with the increase in s-metolachlor application rate, but at jari, there was no significant different 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 locations 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.

3.1.2.2 Weed density at 55 days after crop emergence

At 55 DAE, the density of broadleaved weeds was lowest due to the application of 1.0 kg ha^{-1}of pendimethalin superimposed with one hand-weeding at 5 WAE at Jari. However, it had no significant difference with s-metolachlor at 1.0 kg ha^{-1} treatment combined with one hand-weeding at 5 WAE and two hand-weeding at 2 and 5 WAE. The results also depicted that low rate of s-metolachlor and pendimethalin when combined with one hand-weeding were as effective as complete weed free treatment to reduce the broadleaved weed density. Alike what was 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 significantly differ weed density, but there observed a significant reduction in density over 1.0 kg ha^{-1}rate. In case of pendimethalin, the results remained inconsistent. Two hand-weeding proved significantly better than one hand-weeding in reducing the broadleaved weed density. This might partially be due to the late emerging *X. strumarium* which infested the plots after one hand-weeding was resorted. On the other hand, one hand-weeding was found to bring significant reduction in broadleaved weed density at all rates of pendimethalin treatments.

At Sirinka, the application of 1.0 kg ha^{-1}of s-metolachlor + one hand-weeding at 5 WAE gave the lowest weed density which was not significantly different with two hand-weeding. Both of these practices were found to be significantly better than other weed management practices. The application of higher rates (1.5 and 2.0 kgha^{-1}) of s-metolachlor gave significant reduction in density over its lower application rates while at higher rates (1.3 and 1.6 kgha^{-1}) of pendimethalin it significantly increased over the lower rates. Furthermore, 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 be applied herbicides due to positional selectivity.

Late emerging weed *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 treatment failed to control *C. benghalensis*. However, when the low dose of herbicides was superimposed with hand-weeding 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* which might have contributed to higher weed density was more persistent at Jari than at Sirinka.

The sedges population was lowest in pendimethalin at 1.0 kg ha^{-1}+ one hand-weeding at 5 WAE at Jari which did not significantly differ with s-metolachlor at 1.0 kg ha^{-1} combined with one hand-weeding at 5 WAE, s- metolachlor at 2.0 kg ha^{-1}and two hand-weeding 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 hand-weeding. 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 hand-weeding, however, it had no significant difference with s-metolachlor at 1.0 kg ha^{-1}+ one hand-weeding and two hand-weeding at 2 and 5 WAE at Jari. At Sirinka, the application of 1.0 kg ha^{-1}of s-metolachlor at + one hand weeding registered the minimum total weed density which was significantly lower than other weed management practices. Though, at Jari there was no significant difference in total weed density found between pendimethalin at 1.0 kg ha^{-1}+ one hand weeding , s-metolachlor at 1.0 kg ha^{-1}+ one hand weeding and complete weed free, but at Sirinka, significant a variation was observed between these treatments (Table 2). In total weed density, the trend due to s-metolachlor and pendimethalin application was similar to that of broadleaved weeds and sedges at both sites.

3.1.2.3 Weed density at harvest

The broadleaved weed density at crop harvest obtained due to application of 1.0 kg ha^{-1}of s-metolachlor + hand weeding at 5 WAE, 1.0 kg ha^{-1} of pendimethalin + hand weeding at 5 WAE, 2.0 kg ha^{-1}of s-metolachlor and two hand weeding 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 but no significant difference was found with one hand weeding at 2 WAE. The effect of weed management practices on sedges density was similar to broadleaved weeds at Jari; however, the application of 1.5 kg ha^{-1}s- metolachlor at was also in statistical parity.

The application of s–metolachlor alone, 1.0 kg ha^{-1}of pendimethalin, low dose of these herbicides combined with hand weeding and hand weeding treatments were statistically at par with each other and complete weed free except s-metolachlor and pendimethalin each at 1.0 kg ha^{-1}at Sirinka. All these weed management practices significantly reduced sedge density over other treatments. The density of both broadleaved weeds and sedges were lower at crop harvest than at 55 DAE. 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}+ hand weeding at 5 WAE, pendimethalin at 1.0 kg ha^{-1} + hand weeding at 5 WAE, s-metolachlor at 2.0 kg ha^{-1} and two hand weeding at 2 and 5 WAE over other weed management practices at Jari whereas, one hand weeding had also similar effect at Sirinka experimental site. All these practices were statistically equivalent with complete weed free in the practice of reducing total weed density (Table 3). Hand weeding uprooted the emerged weeds which were in turn suppressed by the crop canopy that brings about 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. The application of herbicide or hand weeding, however, caused mortality of weeds causing lower weed density at harvest. [19,20,9] have also reported a maximum weed density in weedy check and weed control methods like application of herbicides and hand weeding and hoeing significantly deceased weed density over weedy check.

Table 2. Weed community recorded in cowpea, at the experimental sites of Jari and Sirinka in main cropping season of 2013

Weed species	Family	Life form (category)
Amaranthus spinosus L.	Amaranthaceae	Annual (broadleaved)
Amaranthus hybridus L.	Amaranthaceae	Annual (broadleaved)
Bidens pilosa L.	Asteraceae	Annual (broadleaved)
Commelina benghalensis L.	Commelinaceae	Annual (broadleaved)
Cyperus esculentus L.	Cyperaceae	Annual (sedge)
C. rotundus L.	Cyperaceae	Perennial (sedge)
Datura stramonium L.	Solanaceae	Annual (broadleaved)
Galinsoga parviflora Cav.	Asteraceae	Annual (broadleaved)
Orobanche crenata Forsk.	Orobanchaceae	Annual (broadleaved)
Oxalis latifolia Kunth.	Oxalidaceae	Annual (broadleaved)
Seteria verticillata (L.) Beauv.	Poaceae	Annual (grass)
Solanum nigrum L.	Solanaceae	Annual (broadleaved)
Tagetes minuta L.	Asteraceae	Annual (broadleaved)
Xanthium strumarium L.	Asteraceae	Annual (broadleaved)

Table 3. 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 in 2013 main cropping season

Weed management practices	Weed density (M^{-2})											
	20 DAE						55DAE					
	Broadleaved		Sedges		Total		Broadleaved		Sedges		Total	
	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor at 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 at1.5 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 at 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 at1.0 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 at1.3 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 at 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 at 1.0 kg ha^{-1}+ hand weeding 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 at 1.0 kg ha^{-1}+ hand weeding 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 hand weeding 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}
Hand weeding at 2 and 5WAE	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= coefficient of 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

3.1.3 Weed dry matter weight

The influence of weed management practices at all the growth stages, in both the locations, on the weed dry matter weight was highly significant.

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 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 significantly decreased, while the results were inconsistent with the application of pendimethalin at 20 and 55 DAEat both locations. 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 accumulated significantly the lowest dry weight which might be due to the cumulative effect of herbicide and hand weeding (Table 3). [21] also obtained lower dry weight of weeds with 1.0 kg ha^{-1} of butachlor at 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 hand weeding as compared to one hand weeding 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 55 DAE. 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. [22] also 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, [23] found that 1.5 kg ha^{-1} of this herbicide is 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). [9,24] 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 1.0 kg ha^{-1} of pendimethalin + hand weeding at 5 WAE at both locations accumulated significantly the lowest dry weight due to the cumulative effect of herbicide and hand weeding (Table 3). At the time of crop harvest similar effect of weed management practices was observed (Table 3). [21] also obtained lower dry weight of weeds with 1.0 kg $ha^{-1}$of butachlor in combination with cultural practices, which was equivalent with weed free check. [9] and [24] also concluded that dry weight of weeds was significantly reduced in herbicide treated plots. The result of this study was in agreement with earlier works by [25,26] 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].

Hand weeding controlled the emerged weeds and those weeds which would emerged later that 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 the time harvest, the weed dry weight accumulation with the increasing rates of s-metolachlor application significantly decreased at Jari, but no significant difference was obtained between the treatment of 1.5 and 2.0 kg ha^{-1} of s-metolachlor at Sirinka. 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 Jari, whilethe difference existed between these rates at Sirinkawas not significant. Moreover, the treatment with 1.0 kg ha^{-1}pendimethalin had weed dry weight statistically in parity with s-metolachlor rates at Sirinka (Table 3). The occurrence of significantly higher weed dry weight with increased pendimethalin application at Jari might be owing to the presence of the severe infestation with *X. strumarium.* On the other hand, at Sirinka, 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 Jari whereas there was no significant difference observed at Sirinka. The contrasting results might be due to the extent to which the weed species and or the density differed at both locations. 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 Sirinka, 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 activeness of a herbicide (Table 3). At Jari experimental site, *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 bringing about lower dry weight. These results are in agreement with the findings of [19,28] 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 Growth Yield Attributes and Yield

3.2.1. Crop phenology and growth

3.2.1.1 Days to 50% flowering

Days to 50% flowering was significantly influenced by location, weed management practices and their interaction. It was observed that at Sirinka the application of s-metolachlor at 1.0 kg ha^{-1}+ hand weeding 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 hand weeding at 5 WAE at the same location which was statistically at par with the application of s-metolachlor at 1 kg ha^{-1}+ hand weeding at five WAE at Jari. The 50% flowering was delayed when weeds grown uninterrupted at both 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 1.0 kg $ha^{-1}$of s-metolachlor or 1.0 kg ha^{-1} of pendimethalin each combined with one hand weeding at 5WAEleads to enhanced 50% flowering at both locations. This is consistent with the finding of [31], who stated that treating plots with chemical and supplementing with hand weeding at intervals helped to reduce the number of days to flowering and maturity.

3.2.1.2 Days to 90% physiological maturity

The effect of location, treatments and their interaction had a significant effect on 90% physiological maturity of the crop. The result within location treatments did not reveal significant difference in days to physiological maturity, however, at Sirinka; it was significantly delayed under all the treatments compared to what was found at Jari. The delayed maturity by about 10 days at Sirinka (Table 4) could be due the differences in amount and distribution of rain fall, temperature and elevation. The result was in contrast to 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 maturity.

3.2.1.3. 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.

The plants at Jari experimental site had significantly higher height by 12.3% than that of 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 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] found 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

3.2.3.1. 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 by 8.1% at Sirinka than at Jari. The weed density as well as weed dry weight was higher 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 of s-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WAE (120756 plants ha^{-1}) which was statistically in parity with weed free check, pendimethalin 1.0 kg ha^{-1}+ hand weeding at 5 WAE and two hand weeding at 2 and 5 WAE.

Comparatively higher survival of the plants observed under these weed management practices could be due to better weed control. The significantly lower plant stand under weedy check might be due to severe competition for growth resources particularly for space and light that suppressed crop plants the extent that the crop plants could not survive.

3.2.3.2. 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}obtained with the application of s-metolachlor at 1.0 kg ha^{-1} + one hand weeding at 5 WAE at Jari which was statistically similar to the weed free check at both locations (Table 7). 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 Jari and Sirinka as well as with the treatment of 1.0 kg ha^{-1} of s-metolachlor + one hand weeding at 5 WAE at Sirinka. Two hand weedings at 2 and 5 WAE when interacted with the location did not show significant difference but proved 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 [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 1.0 kgha^{-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 3) in these treatments at Jari. 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 [34].

These results are in line with [35] who observed an increased number of pods plant^{-1} where weed population was reduced by management techniques. Similarly, [36,37] stated that the number of pods produced per plant or maintained to final harvest depends on a number of environmental and management practices.

3.2.3.3. Number of seeds per pod

The number of seeds pod^{-1} had a significant effect due to locations, and at Sirinka, the pods had 10.4% higher number of seeds compared to Jari. Despite a difference of 2.7 seeds pod^{-1} the weed management practices did not show any significant difference (Table 5). However, in agreement with the findings of [30], this study also indicated lowest number of seeds pod^{-1}in weedy check.

3.2.3.4. 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 7.6%) 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 comparable 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, they utilized available resources to their maximum benefit leading to 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. The lowest 100 grain weight was observed in weedy check. However, it was equivalent with one hand weeding at 2 WAE and 1.5 kg ha^{-1}of s-metolachlor (Table 6). This is consistent with [38] who stated that cowpea plants in unwedded plots gave the lowest 100 seed weight. However, [39 and 40] reported that there was no significant difference found in grain weight due to weed management practices in common bean.

3.2.3.5 Grain yield

Cowpea grain yield was significantly (P<0.01) influenced by the 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 hand weeding at Sirinka. Further, the interaction effect showed that the yield obtained with complete weed free treatment at Jari and two hand weeding at Sirinka had no significant difference with the application of1.0 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 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 1.5 and 2.0 kg ha^{-1} of s-metolachlor application at both locations (Table 7). But these treatments depicted 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 Jari and Sirinka.

The interaction effect of location with 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 Jari. In contrast, at Sirinka, results were inconsistent and no significant difference existed among the rates. At Jari, 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 Sirinka. However, at both the locations, two hand weeding proved significantly better than one hand weeding (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 1.3 and 1.6 kg ha^{-1} of pendimethalin at Jari, and 1.0 and 1.6 kg ha^{-1} of pendimethalin as well as 1.0 kg ha^{-1} of s-metolachlor 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 1.0 kg ha^{-1} of s- metolachlor, 1.3 and 1.6 kg ha^{-1} of pendimethalin while it was statistically equivalent 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 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 [6,43,44,38] 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 [45,46].

3.2.3.6. Aboveground dry biomass yield

The highest aboveground dry biomass yield (10797 kg ha^{-1}) was obtained in 1 kg ha^{-1}of s-metolachlor + one hand weeding at 5 WAE treated plots at Jari which was statistically at par with two hand weeding s 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 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 hand weeding s 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. While comparing the individual treatments in general, the aboveground dry biomass yield was higher at Sirinka than Jari. 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.

3.2.3.7. 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 Sirinka had significantly higher harvest index than at Jari. 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 7). 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. 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 significantly vary 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 (Tables 2 and 3) might have decreased root/shoot ratio [46], increased vegetative growth duration (Table 4) 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.

3.2.3.8. 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 Jari. 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 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 rate, 1.0 kg ha^{-1} pendimethalin and one hand weeding at 2 WAE at Jari, 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 5WAE 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 5WAE at Sirinka. Moreover, it was observed that the yield loss due to s-metolachlor 1.0 kg ha^{-1} superimposed with one hand weeding 5WAE at Jari and two hand weeding at 2 and 5 WAE at Sirinka were not significant as compared to complete weed free at both locations (Table 7). This observation is consistent with the work of [6,8] who reported that the presence of weeds reduced yield (by 82%).

Table 4. Effect of weed management practices in cowpea on weed density (m^{-2}) at harvest and on weed dry biomass ($g\ m^{-2}$) at different growth stages of crop at Jari and Sirinka in 2013 main cropping season

Weed management practices	Weed density at harvest (m^{-2})						Weed dry biomass weight ($g\ m^{-2}$)					
	Broadleaved		Sedges		Total		20 DAE		55 DAE		At harvest	
	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor at 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 at1.5 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 at 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 at1.0 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 at1.3 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 at 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 at 1.0 kg ha^{-1}+hand weedingat 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 at 1.0 kg ha^{-1}+hand weedingat 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 hand weeding 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}
Hand weeding at 2 and 5WAE	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= coefficient of **v**ariation, LSD= least significant difference, DAE= days after 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*

Table 5. Interaction effect of location and weed management practices on days to flowering and physiological maturity of cowpea in 2013 main 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 at 1.5 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
S-metolachlor at 2.0 kg ha^{-1}	59.0^{e}	57.3^{f}	83.0^{e}	92.0^{b}
Pendimethalin at 1.0 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
Pendimethalin at 1.3 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
Pendimethalin at 1.6 kg ha^{-1}	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
S-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	56.7^{g}	55.0^{h}	83.0^{e}	92.0^{b}
Pendimethalin at 1.0 kg ha^{-1} + hand weeding at 5 WAE	57.7^{f}	56.3^{g}	83.0^{e}	92.0^{b}
One hand weeding at 2 WAE	61.0^{d}	62.0^{c}	85.0^{c}	94.0^{a}
Two hand weeding 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= coefficient of variation, 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

Table 6. Effect of location and weed management practices on plant height (cm) of cowpea in 2013 main cropping season

Treatments	Plant height (cm)
Location	
Jari	68.07^{a}
Sirinka	60.60^{b}
LSD (5%)	3.82
Weed management practices	
S-metolachlor at 1.0 kg ha^{-1}	64.04
S-metolachlor at1.5 kg ha^{-1}	65.53
S-metolachlor at 2.0 kg ha^{-1}	61.49
Pendimethalin at1.0 kg ha^{-1}	66.52
Pendimethalin at1.3 kg ha^{-1}	68.20
Pendimethalin at 1.6 kg ha^{-1}	62.51
S-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WAE	62.87
Pendimethalin at 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= coefficient of variation, 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

On the other hand, [7,47,48] found that there existed 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.

3.3 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 and1.0 kg ha^{-1} of s–metolachlor both superimposed with hand weeding, respectively at both sites (Table 9). On the other hand highest gross as well as net benefits were obtained with the application of 1.0 kg $ha^{-1}$of s-metolachlor at + hand weeding , followed by two hand weeding at 2 and 5 WAE and 1.0 kg $ha^{-1}$of pendimethalin +hand weeding.

Table 7. 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 Jari and Sirinka in 2013 main cropping season

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 at 1.0 kg ha^{-1}	92978^{d}	12.03	12.39^{bc}	0.24^{de}
S-metolachlor at 1.5 kg ha^{-1}	96065^{cd}	13.08	11.80^{cd}	0.30^{c}
S-metolachlor at 2.0 kg ha^{-1}	105324^{bc}	12.74	12.64^{ab}	0.29^{c}
Pendimethalin at 1.0 kg ha^{-1}	95293^{cd}	12.85	12.24^{bc}	0.27^{cd}
Pendimethalin at 1.3 kg ha^{-1}	93750^{cd}	12.56	12.66^{ab}	0.24^{de}
Pendimethalin at 1.6 kg ha^{-1}	101466^{cd}	11.36	12.32^{bc}	0.25^{de}
S-metolachlor at 1.0 kg ha^{-1} + hand weeding at 5 WAE	120756^{a}	13.40	12.68^{ab}	0.35^{b}
Pendimethalin at 1.0 kg ha^{-1} + hand weeding at 5 WAE	117284^{a}	13.60	12.55^{ab}	0.37^{b}
One hand weeding at 2 WAE	90664^{d}	12.72	12.05^{bcd}	0.29^{c}
Two hand weeding 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 variation; 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

Table 8. 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 (%) in cowpea in 2013 main cropping season

Weed management practices	Number of pods plant^{-1}		Grain yield (kg ha^{-1})		Aboveground dry biomass yield (kg ha^{-1})		Yield loss (%)	
	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor at 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 at1.5 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 at 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 at1.0 kg ha^{-1}	10.67^{ijk}	14.53^{fgh}	2373^{ijk}	2582^{hij}	8957^{de}	9136^{cde}	39.2^{cde}	39.6^{cde}
Pendimethalin at1.3 kg ha^{-1}	8.00^{l}	12.83^{hij}	1322^{m}	2696^{ghi}	6157^{hi}	9763^{abcd}	66.1^{a}	36.9^{def}
Pendimethalin at 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 at 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 at 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 hand weeding at 2 WAE	15.33^{efg}	15.83^{def}	2312^{ijk}	2969^{fgh}	8382^{ef}	9733^{abcd}	40.1^{cde}	30.5^{efg}
Two hand weeding at 2 and 5 WAE	18.11^{cd}	19.00^{bc}	3452^{de}	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= coefficient of variation; 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

Table 9. Partial budget analysis of weed management practices in cowpea based on total variable cost in 2013 main cropping season

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 at 1.0 kg ha^{-1}	3935	2172.4	1955.2	29328	25393
S-metolachlor at1.5 kg ha^{-1}	4841	2612.1	2350.9	35264	30423
S-metolachlor at 2.0 kg ha^{-1}	5283	2756.0	2480.4	37206	31923
Pendimethalin at1.0 kg ha^{-1}	5589	2477.5	2229.8	33447	27858
Pendimethalin at1.3 kg ha^{-1}	5339	2009.0	1808.1	27122	21783
Pendimethalin at 1.6 kg ha^{-1}	5581	1918.6	1727.4	25911	20330
S-metolachlor at 1.0 kg ha^{-1}+hand weeding at 5 WAE	6828	3682.0	3313.8	49707	42879
Pendimethalin at 1.0 kg ha^{-1}+hand weeding at 5 WAE	7430	3315.8	2984.2	44763	37333
One hand weeding at 2 WAE	5620	2640.5	2376.5	35648	35649
Two hand weeding 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

It can be inferred from this study that the treatment of 1.0 kg ha^{-1} of s-metolachlor supplemented with one hand weeding at 5 DAE is the most profitable treatment with an alternate weed management option i.e. 1.0 kg ha^{-1} of pendimethalin supplemented with one hand weeding 35 DAE. Therefore, managing the weeds with the application of 1.0 kg ha^{-1} of s-metolachlor + hand weeding and hoeing at 35 DAE proved to be the most profitable practice. However, under the condition of labour constraint and timely availability of the herbicide, pre emergence application 2.0 kg ha^{-1} of s-metolachlor should be used to preclude the yield loss and ensure maximum benefits. For broad-spectrum and effective weed control, the herbicide mixture should also be tested. Further, to prevent the weed shift, these two herbicides should be used as herbicide rotation. In future, there is a need to explore the effectiveness of various combinations of these two herbicides for cost effective and broad spectrum weed control in cowpea production.

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 would like to express my passionate thankfulness to my beloved wife Mekdes Dessie for her moral and sensible support and inspiration during the course of my study. I wish to express my deep, heartfelt gratitude to my Mother Tureya Musa for her help, pray and motivation during my under and post graduate study that paved the way for today's success. Last but not least, I am grateful to Bezawit Mewa for funding my paper expenses.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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