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Growth and Yield Response of Cowpea (*Vigna unguiculata* L. Walp.) to Integrated Use of Planting Pattern and Herbicide Mixtures in Wollo, Northern Ethiopia

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Abstract

To assess the integrated effect of planting pattern and low dose herbicide mixtures on weeds and growth, yield attributes and yields of cowpea, and to determine the economic feasibility of different weed management practices in cowpea, a field experiment was conducted at Sirinka Agricultural Research Center experimental sites at Jari and Sirinka in Northern Ethiopia during the 2014 main cropping season. There were 16 treatments comprising the combinations of two planting patterns (60 cm × 10 cm, 45 cm × 15 cm) and eight weed management practices (s-metolachlor 2.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 35 weeks after crop emergence (WAE), pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}, s-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}, hand weeding and hoeing 3 WAE and weedy check. The treatments were laid out in factorial combination in a randomized complete block design with three replications. The highest number of pods per plant, number of seeds per pod, and hundred seed weight were obtained from the combination of s-metolachlor at 1.0 kg ha^{-1}+hand weeding 5 WAE along with 60 cm × 10 cm at Sirinka. Higher (3092 kg ha^{-1}) grain yield was recorded at Sirinka than at Jari (2714 kg ha^{-1}). The highest (53460 ETB ha^{-1}) gross benefit was obtained from s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, followed by pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE (46737 ETB ha^{-1}). Therefore, managing the weeds with the application of 1.0 kg ha^{-1} of s- metolachlor+hand weeding and hoeing 5 WAE along with 60 cm × 10 cm proved to be the most feasible practice. Alternate herbicides for the control of X. strumarium infested fields in the study area needs to be explored.

Keywords: Broadleaved and grass weeds; Cowpea; Grain yield; Herbicide mixtures; Integrated management; Pendimethalin; s-metolachlor; *Vigna unguiculata*; Weed

Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the most important food grain legumes in the tropics, including Africa, which accounts for 64% of the world production [1]. West Africa represents the largest production zone with modest amounts emanating from the east African countries of Mozambique, Tanzania, Uganda and to some extent Ethiopia [1,2]. In addition to its importance in human food, cowpea is also useful for soil fertilization through symbiotic nitrogen fixation and can be a major animal feed due to the quality of its leaves [3].

It is cultivated around the world primarily for seed, but also as a vegetable (for leafy greens, green pods, fresh shelled green peas, and shelled dried peas), as cover crop and for fodder [4]. In most African countries, cowpea is either grown alone or intercropped with various cereal crops, such as leafy vegetables, maize, millet, sorghum, beans, pigeon peas, bananas and others [5,6]. Since, it is shade tolerant and compatible as an intercrop with cereal crops, it helps to prevent buildup of disease incidence, insect pests and weeds. Its variability of uses, nutritive content and storage qualities have made cowpea an integral part of the farming system in Africa [7].

Cowpea yield loss due to weed interference was described to reach up to 96%, which indicates the importance of weed management in this crop [8]. Chikoye [9] stated that the reduction in yield of cowpea depends on the weed species, weed density and weed dry biomass. Also, Blackshaw [10] stated that cowpea is sensitive to weed competition; for instance, 2 to 100 plants m^{-2} density of *Solanum nigrum* plant, decreased cowpea yield that ranged between 13 and 77%. Fennimore [11] also reported up to 40% yield loss in cowpea due to the competition with *S. nigrum*. Similarly, Wilson [12] found that for every 100 kg dry weight of weeds, cowpea yield was reduced by about 208 kg ha^{-1}. In Ethiopia, one timely, early weeding at 25 days after emergence resulted in 70% yield increase of common bean and up to 300% increase in cowpea compared to the no-weeding [13].

Different management practices should be employed to reduce yield loss due to weeds. Among those practices, integrated weed management (IWM) involves a combination of cultural, physical, chemical and biological methods for effective and efficient or economical weed control [14]. The principle of IWM should provide the foundation for developing optimum weed control systems and efficient use of improved varieties. Integrating herbicides with cultural methods is an option for better 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 also involves using an agronomical approach to minimize the

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overall impact of weeds and, indeed, maximize the benefits. The use of a single herbicide may result in shift of the weed flora in favour of the species that are not controlled, thus may increase the problem in the future.

Moreover, to manage mixed population of weeds and also to avoid herbicide resistance development by continuous use of a single herbicide, compatible mixtures can be employed to widen the spectrum of weed suppression. Herbicide combinations can give spectacularly good control at doses considerably below those normally applied in a single application. It may be additive or synergistic or prevent rapid detoxification of herbicides and are safer to crops than application of a single herbicide alone. The use of herbicide combinations is not new, but it has not received the attention and input that is necessary to fully understand and implement the practice. Therefore, there is a need for evaluation of a range of herbicides alone and as a tank mixture to have broad spectrum weed management [15].

The present study, therefore, is intended 1) To assess the integrated effect of planting pattern and low dose herbicide mixtures on weeds, nodulation, growth, yield attributes and yields of cowpea, and 2) to determine the economic feasibility of different weed management practices in cowpea.

Materials and Methods

Description of the study area

The experiment was conducted at Jari experimental sites (11°21'N latitude and 39°38'E longitude; 1680 masl. altitude) at Sirinka Agricultural Research Center and Sirinka (11°45'00" N latitude; 39°36'36"E longitude; 1850 masl altitude) in northern Ethiopia during the 2014 main cropping season. The soil of the experimental fields was clay loam and clay, while the pH was 6.98 and 6.94 at Sirinka and Jari, respectively. At Sirinka, the organic carbon was 1.35%, total N was 0.07%, available P 13.7 mg kg^{-1} soil and CEC 56.47 cmolC kg^{-1}, while the respective values at Jari were 1.37%, 0.05%, 11.17 mg kg^{-1} soil and 47.44 cmolC kg^{-1}. The total rainfall received during the crop season was 795.4 and 649.1 mm at Sirinka and Jari with mean maximum and minimum temperatures of 27.0 and 14.2°C, and 30.1°C and 16.0°C, respectively (Figure 1). Soil sample analysis was done at the Sirinka Agricultural Research Center.

Experimental materials

The cowpea variety Asrat (ITS 92KD-279-3), released by Sirinka Agricultural Research Center/Amhara Region Agricultural Research Institute (SRARC/ARARI) in 2001, was used in these experiments. The variety is well adapted to moisture stress areas in the northeast Wollo and similar lowland areas. This variety is suitable for an altitudinal range of 1450-1850 masl and annual rainfall of 660-1025 mm. It is bushy and trailing type I. It attains physiological maturity in 95-100 days [16]. Description of herbicides (s-metolachlor and pendimethalin) used in the experiment has been presented in tabular form hereunder Table 1.

Treatments and experimental design

There were 16 treatment combinations comprising of two planting patterns (60 cm × 10 cm and 45 cm × 15 cm) and eight weed management practices (s-metolachlor at 2.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 weeks after crop emergence (WAE), pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}, s-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}, hand weeding and hoeing 3 WAE, and weedy check). The treatments were laid out in factorial combination in a randomized complete block design with three replications.

Experimental procedure and management

The experimental field was ploughed to get a fine seedbed using tractor and the plots were leveled manually. The gross plot size was 3.6 m × 2.4 m (8.64 m^2). The pathway between replications and plots were 1 and 0.5 m, respectively. The cowpea variety Asrat was planted on 21 and 22 July 2014 at Jari and Sirinka, respectively. Fertilizer (100 kg DAP; 18 kg N+46 kg P_2O_5 ha^{-1}) was applied to each plot uniformly at the sowing time. There were 6 and 8 rows per plot under 60 cm and 45 cm row spacing, respectively.

The herbicides were applied as per the treatment in the assigned plots as pre-emergence within one day after planting. Herbicide spray volume with water as carrier was 450 l ha^{-1}. Spraying was done with manually-operated knapsack sprayer (15 l capacity) using flat-fan nozzle. The outermost one row from one side and two rows from another side of in the plots having 60 cm inter row spacing, while two rows from each side of the plots having 45 cm inter row spacing were

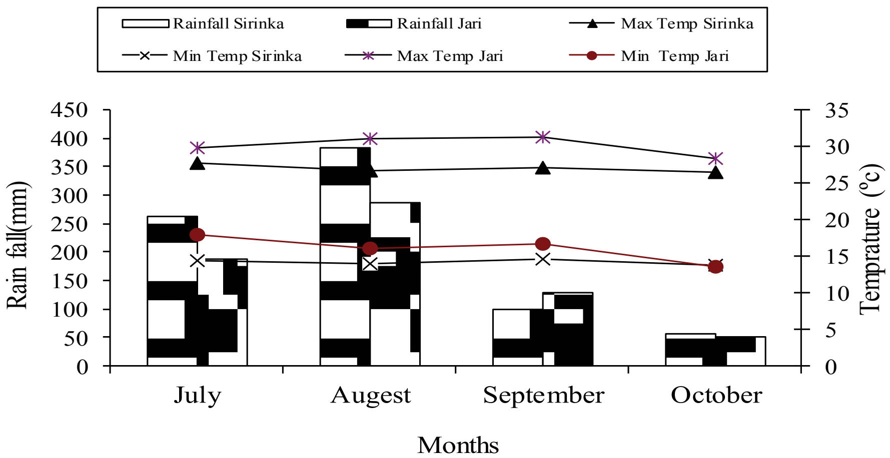

Figure 1: Monthly mean maximum and minimum temperatures (°C) and total rainfall (mm) at Jari and Sirinka in 2014 cropping season.

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

Table 1: Description of herbicides used in the integrated weed management in cowpea experiment at Jari and Sirinka in 2014.

considered as borders. From the end-point of each row, three plants in plots having 10 cm intra row spacing and two plants in 15 cm intra row spacing were considered as borders. Thus the net plot size was 1.8 m × 1.8 m (3.24 m^2). All the recommended practices, except the treatments, were followed to raise the crop. The crop was harvested on 29 October and 6 November 2014 at Sirinka and Jari, respectively. The harvested produce was sun-dried for 7-10 days and threshing and winnowing was done subsequently.

Data collection and analyses

Weeds data: Weed aboveground dry biomass (g): For aboveground weed dry biomass, the weeds falling within the quadrate were cut near the soil surface immediately after recording data on weed count and placed into paper bags separately treatment-wise. The samples were sun-dried for 3-4 days and thereafter were placed into an oven at 65°C temperatures till a constant weight and, subsequently, their dry weight was measured. The dry weight was expressed in g m^{-2}.

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

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

Where,

WDC=Weed dry weight in weedy check, WDT=Weed dry weight in a particular treatment.

Crop data:

***Plant height (cm)*:** It was taken with a ruler from 10 randomly taken and pre tagged plants in each net plot area from the base to the apex of the main stem at physiological maturity.

Number of pods per plant: It was taken from the total pods of the above tagged plants at harvest.

Number of per pod: The total number of seeds from the above pods was taken and counted to average the number of seeds pod^{-1}.

***Hundred seed weight (g)*:** Out of seeds from the above pods, 100 seeds were counted and their weight was recorded at 10.5% moisture content for hundred seed weight.

***Aboveground biomass (g)*:** This parameter was determined by harvesting ten plants in each plot at physiological maturity and their dried aboveground biomass was recorded. Treatment-wise 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.

***Grain yield (kg ha^{-1})*:** The grain yield was measured after threshing the sun-dried plants harvested from each net plot and the yield was adjusted at 10.5% seed moisture content. The grain weight obtained in ten plants was added to the final yield.

***Harvest index (%)*:** This parameter was calculated by dividing the grain yield by the aboveground biomass yield and multiplied by 100.

Data analyses: Data on weed density, weed dry biomass, growth, yield attributes and yield were subjected to analysis of variance (ANOVA) using GenStat 15.0 computer software [17]. Fisher's protected least significant difference (LSD) test at $p \leq 0.05$ was used to separate differences among treatment means [18]. As the F-test of the error variances for most parameters of the two sites was homogeneous, combined analysis of data was used.

Partial budget analysis

The concepts used in the partial budget analysis were the mean grain yield of each treatment in both locations, the field price of cowpea (sale price (ETB 15 kg^{-1}) minus the costs of harvesting, threshing and winnowing (ETB 165/100 kg) bagging (ETB 4.0 per 100 kg) and transportation (ETB 5 per 100 kg), the gross field benefit (GFB) per hectare (the product of field price and the mean yield for each treatment), the field price of s-metolachlor ETB 417 kg^{-1}, cost of pendimethalin ETB 620 kg^{-1} (the herbicide cost plus the cost of transportation from the point of sale to the farm), the total costs that varied (TCV) included the sum of field cost of herbicide and its application (spraying ETB 99 ha^{-1}). The net benefit (NB) was calculated as the difference between the GFB and the TCV. All costs and benefits were calculated on hectare basis in Ethiopian Birr (ETB). Actual yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. It was assumed that there was optimum plant population density, timely labor availability and better management (e.g., weed control, better security) under experimental conditions [19,20].

Results and Discussion

Weed parameters

Weed dry biomass: The minimum (30.4 g m^{-2}) weed dry weight recorded at Sirinka from s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE was statistically at par with the application of s-metolachlor at 2.0 kg ha^{-1}, pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1} and hand weeding and hoeing at 3 WAE at Sirinka and s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE at Jari. Hand weeding and herbicide significantly encouraged vigorous cowpea growth.

In line with the current research result, Ahmad [21] reported that pre-emergence application of pendimethalin at 1.25 and 1.50 kg ha^{-1}+hand weeding were equally and even much more effective in reducing dry weight of weeds than other treatments. The better weed suppression due to herbicide mixtures may be due to effective suppression of both types of weeds. Also, the low weed density observed in herbicides treated plots could be attributed to effective weed control of the herbicides and their ability to manage weeds beyond the critical period of cowpea growth. Also, the adequate weed cover by cowpea vine led to smothering effect of the weeds judging from the low weed population and low weed dry weight, which invariably led to increase in weed smothering efficiency [22]. They also found lower weed dry matter and higher weed control efficiency with herbicides+hand weeding than other treatments included in their experiment.

Sharma [23] also concluded that dry weight of weeds was significantly reduced in herbicide-treated plots of common bean. In pigeon pea, effective weed control has been reported with integrated use of pendimethalin and hand weeding [24]. However, lower performance of intra-group herbicides might be due to lower doses than their recommended doses, which needs to be investigated at recommended doses of individual herbicides in mixture [25].

The location and weed management practices interaction further showed that the maximum (472.4 g m^{-2}) weed dry weight obtained in weedy check at Jari was significantly higher than all the other interactions (Table 3). These results are consistent with the findings of Arif and Marwat [26,27] who reported more weed dry biomass in weedy check than pre-emergence herbicides (s-metolachlor and pendimethalin) application in canola (*Brassica napus* L.) for weed management.

It was also recognized that there was no significant difference in weed dry weight obtained in weedy check at Sirinka with s-metolachlor at 2.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1} and hand weeding at 3 WAE at Jari, and s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1} and s-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1} at Sirinka. The moderate increase in weed dry weight could be attributed to frequent reoccurrence and persistent characteristics of weeds. Furthermore, like weed density, the weed dry biomass was also lower at Sirinka than at Jari. Herbicide molecules tend to bind with soil clay and organic matter particles, and thus become unavailable for weed killing purposes.

The lower weed dry matter accumulation may be attributed to lower weed density at Sirinka than at Jari (Table 2). The lowest (29.8 g m^{-2}) weed dry weight was recorded with 60 cm × 10 cm planting pattern when treated with s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, which was statistically at parity with pendimethalin at 1.0 kg ha^{-1}+hand weeding at 5 WAE, s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1} under both the planting patterns. Jafari [28] stated that pre-emergence herbicides reduced the weed density and dry weight significantly as compared to weedy check in common bean. Similarly, Masoumeh [29] found application of pendimethalin 0.5 kg ha^{-1}+hand weeding 30 days after sowing though was comparable with other treatments, but gave lower weed dry weight after weed-free check in soybean.

The highest (327.5 g m^{-2}) weed dry weight was found in weedy check under 45 cm × 15 cm planting pattern, followed by 60 cm × 10 cm planting pattern and both these interactions resulted in higher increase in weed dry weight than all the other planting pattern and weed management practices interactions (Table 2). A high weed density recorded in the weedy plots invariably resulted in high weed dry weight that could be attributed to low ground cover of cowpea vines.

This could be attributed to faster and better canopy cover of the crop under narrow spacing resulting in better suppression of weeds than in wide spacing. Reduction in weed dry biomass due to narrow rows has been reported by Adigun and Joseph [30,31]. This current result is consistent with the findings of other others in lentil [21,32,33].

Weed control efficiency: The data on weed control efficiency indicated that all the treatments in general gave more than 53% weed control efficiency over the weedy check. The maximum (91.6%) weed control efficiency was observed in s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing at 5 WAE under 60 cm × 10 cm planting pattern, which was statistically at par with the interaction of same weed management practice and 45 cm × 15 cm planting pattern as well as the interaction of combined application of metolachlor and pendimethalin each at 1.0 kg ha^{-1} under 60 cm × 10 cm planting pattern (Table 3).

The current finding is in agreement with the investigation of Shinde [34] who reported that integration of pendimethalin with hand weeding 40 days after sowing is known to provide high weed control efficiency in pigeon pea. Priya [35] also found the lowest weed dry matter and higher weed control efficiency with herbicides+hand weeding in soybean. A similar trend was also reported by Jafari [28] in common bean, where pre-emergence herbicides application gave high weed control efficiency by reducing the weed density and dry weight significantly as compared to the weedy check. Sylvestre [36] also reported that unweeded check showed lower weed control efficiency than the rest of pre-emergence herbicide treatments in soybean, while the lowest weed control efficiency was obtained in s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1} and s-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1} in planting pattern of 60 cm × 10 cm, respectively (Table 3).

A similar trend was also reported by Jafari [28] in common bean, where pre-emergence herbicides gave high weed control efficiency by reducing the weed density and dry weight significantly as compared to weedy check.

Initially, the weed flora may be suppressed because the toxic effect of herbicide normally appears immediately after application when their concentration in soil is highest. Later on, microorganisms take part in degradation process and herbicide concentration and its toxic

	Location (L)		Planting Pattern (P)	
	Jari	Sirinka	S1	S2
Weed management practices (W)				
S-metolachlor at 2.0 kg ha^{-1}	100.6^{d-g}	72.1^{e-h}	88.0^{def}	84.7^{def}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	50.4^{gh}	30.4^{h}	29.8^{g}	50.9^{fg}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	100.7^{d-g}	53.8^{fgh}	81.8^{d-g}	72.7^{efg}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	115.2^{cde}	77.2^{e-h}	62.0^{fg}	130.4^{bcd}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	162.9^{bc}	107.8^{def}	152.6^{bc}	118.0^{cde}
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	202.0^{b}	110.0^{cde}	183.9^{b}	128.1^{cd}
Hand weeding and hoeing 3 WAE	109.3^{cde}	73.6^{e-h}	91.8^{def}	91.0^{def}
Weedy check	472.4^{a}	136.9^{cd}	281.8^{a}	327.5^{a}
LSD (5%) L *x* W/ P *x* W			54.31	
CV (%)			38.1	

Means followed by the same letters are not significantly different at 5% level of significance, LSD=least significant difference, CV=Coefficient of variation, DAE=days after crop emergence, S1=60 cm × 10 cm; S2=45 cm × 15 cm

Table 2: Interaction effect of location with weed management practices and planting pattern with weed management practices on total weed dry biomass (g m^{-2}) at harvest in 2014 cropping season.

	Planting Pattern (P)	
	S1	S2
Weed management practices (W)		
S-metolachlor at 2.0 kg ha^{-1}	75.9^{cd}	80.7^{bc}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	91.6^{a}	87.1^{ab}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	74.9^{cd}	81.3^{bc}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	82.2^{abc}	70.0^{d}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	53.3^{e}	74.3^{cd}
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	54.2^{e}	73.1^{cd}
Hand weeding and hoeing at 3 WAE	74.5^{cd}	78.6^{bcd}
Weedy check	0.0^{f}	0.0^{f}
LSD (5%) (P *x* W)	9.6	
CV (%)	12.7	

Means followed by the same letters are not significantly different from each other at 5% level of significance, LSD=least significant difference, CV=Coefficient of variation, DAE=days after crop emergence, S1=60 cm × 10 cm; S2=45 cm × 15 cm.

Table 3: Interaction effect of planting pattern with weed management practices on weed control efficiency (%) in cowpea at harvest in 2014 cropping season.

effect decreases [37]. This could be one of the reasons for lower weed control efficiency with the application of s-metolachlor at 2.0 kg ha^{-1} than s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE. S-metolachlor dissipation may be due to photo-degradation losses occurring since its application [38]. Chauhan [39] found decrease in bioavailability of s-metolachlor with the increase in days after sowing and it was 45% of the original amount applied 33 days after sowing. However, the lower dose of s-metolachlor initially suppressed the weed competition, which was further enhanced by integrating hand weeding at 5 WAE that kept the crop weed free during critical periods of 5 WAE, which offered prolonged and efficient weed control. Mondal and Warade [40,41] also observed similar results in onion.

Crop parameters

Growth parameters

***Plant height*:** Application of herbicides alone or in combination as well as hand weeding resulted in significantly taller (86.0 cm to 98.0 cm) plant height than in the weedy check (Table 4). The current results are also in agreement with findings of Jafari [28] who stated that pre-emergence herbicides increased plant height in common bean significantly as compared to the weedy check. Similarly, plant height was also remarkably increased in wheat by all weed management methods compared to the weedy check [42].

Yield components, yield and harvest index:

***Number of pods per plant*:** The highest (31.8 plant^{-1}) number of pods was recorded from s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE at Sirinka, which was significantly higher than that was obtained with different management practices at Jari and s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1} and hand weeding at 3 WAE at Sirinka (Table 5). The current result is in agreement with this findings of Priya and Abouziena [35,43] who reported the highest number of pods per plant with single herbicide and two hand weeding was at par with herbicide supplemented with hand weeding in peanut (*Arachis hypogaea* L.) and soybean, respectively. This can be ascribed to the fact that the effective management of weeds led to the favourable environment for growth and photosynthetic activity of the crop resulting in improvement in the number of per pods. Ayaz [44] stated that the number of pods produced per plant or maintained to final harvest depends on a number of environmental and management practices. Mirshekari [45] also showed that the presence of weeds is a prominent factor in reducing the number of pods in cowpea plant. Further, Dadari [46] reported that competition between weeds and crop starts right from germination of the crop up to harvest affecting both growth and yield parameters adversely.

The weedy check plots had the lowest number of pods per plant at both locations. At Sirinka, all the weed management practices had significantly higher number of pods per plant than the weedy check. However, it did not differ significantly with the combined application of s-metolachlor and pendimethalin and hand weeding and hoeing 5 WAE at Jari. In line with this result, Paudel [47] revealed that the average number of pods per plant was affected by different treatments of pre-emergence herbicides against weeds in cowpea and the treatments showed a significant difference from the uncontrolled plots. This result is in agreement with that of Jafari [28] who stated that pre-emergence herbicides increased the number of pods per plant significantly as compared to the weedy check in common bean. It was also found that, under all weed management practices at Sirinka, the number of pods per plant was significantly higher than at Jari.

The results obtained in this experiment also agree with the findings of Mousavi [48] who reported that the effect of s-metolachlor on cowpea pods per plant was significant. Also, Sylvestre [36] has documented earlier the role of yield contributing factors that enhanced yield on account of herbicidal control of weeds.

***Number of seeds per pod*:** Application of s-metolachlor at 1.0 kg ha^{-1} supplemented with hand weeding and hoeing at 5 WAE resulted in significantly higher (14.3 pod^{-1}) number of seeds than the other weed management practices except the application of pendimethalin at 1.0 kg ha^{-1} supplemented with hand weeding and hoeing at 5 WAE (Table 6). Further, the latter treatment had no significant difference from the combined application of s-metolachlor and pendimethalin each at 1.0 kg ha^{-1}. The results also revealed that the weedy check plots produced significantly lower number of seeds per pod than the other treatments. The lower weed density and dry weight might have contributed to the significant increase in number of seeds per pod over the weedy check as suggested by Prakash [49] that number of seeds per pods in fieldpea increased with decrease in weeds density. This result agrees with the findings of Tenaw and Sharma [50,51] who reported that the number of seeds per pod was significantly reduced with the increased weed infestation and significantly increased with the weed-free period in common bean. In agreement with this observation, Jafari [28] also stated that pre-emergence herbicides increased the number of seeds per pod significantly as compared to the weedy check. Similarly, Muhammad [52] recorded a maximum number of seed per pod in

	Plant height (cm)
Weed management practices	
S-metolachlor at 2.0 kg ha^{-1}	87.7^{b}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	96.9^{a}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	87.2^{b}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	98.0^{a}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	86.0^{b}
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	87.6^{b}
Hand weeding and hoeing 3 WAE	88.2^{b}
Weedy check	71.1^{c}
LSD (5%)	8.4
CV (%)	11.7

CV=Coefficient of variation, DAE=Days after crop emergence, LSD=Least significant difference, Means followed by the same letters are not significantly different from each other at 5% level of significance.

Table 4: Main effect of weed management practices on plant height of cowpea in 2014 cropping season.

	Location (L)	
	Jari	Sirinka
Weed management practices (W)		
S-metolachlor at 2.0 kg ha^{-1}	17.8^{ef}	28.3^{ab}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	22.9^{cd}	31.8^{a}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	21.3^{de}	30.3^{ab}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	16.7^{e-g}	27.9^{ab}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	15.7^{fg}	26.1^{b-d}
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	16.2^{fg}	27.3^{a-c}
Hand weeding and hoeing 3 WAE	16.8^{e-g}	26.0^{b-d}
Weedy check	12.5^{g}	12.2^{g}
LSD (5%) (L *x* W)	4.9	
CV (%)	19.4	

CV=coefficient of variation, DAE=days after crop emergence, LSD=least significant difference, Means followed by the same letters are not significantly different from each other at 5% level of significance.

Table 5: Interaction effect of location with weed management practices on number of pods per plant in cowpea in 2014 cropping season.

Factors	Number of seeds pod^{-1}	Hundred seed weight (g)
Location:		
Jari	11.94^{a}	12.4^{b}
Sirinka	11.16^{b}	12.7^{a}
LSD (5%)	0.73	0.20
Weed management practices:		
S-metolachlor at 2.0 kg ha^{-1}	11.5^{c}	12.8^{bc}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	14.4^{a}	14.0^{a}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	13.1^{ab}	13.1^{b}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	11.7^{bc}	12.6^{cd}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	11.0^{c}	12.3^{d}
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	10.9^{c}	12.5^{cd}
Hand weeding and hoeing 3 WAE	10.9^{c}	12.5^{cd}
Weedy check	8.9^{d}	10.6^{e}
LSD (5%)	1.5	0.4
CV (%)	15.5	3.9

CV=Coefficient of variation, DAE=Days after crop emergence, LSD=Least significant difference, Means followed by the same letters are not significantly different from each other at 5% level of significance.

Table 6: Main effect of location and weed management practices on number of seeds per pod and hundred seed weight of cowpea in 2014 cropping season.

fieldpea with application of s-metolachlor, while the minimum number of seed per pod was obtained in the weedy check plots. Also, the size of pods increased with application of s-metolachlor and hence resulted in maximum number of seeds per pod and vice versa.

***Hundred seed weight*:** Hundred seed weight at Sirinka was 2.4% higher than the hundred seed weight at Jari. The highest (14.0 g) 100 seeds weight was recorded with the application of s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, which was significantly higher (6.4 - 24.3%) than the other treatments (Table 6). The application of the pre-emergence herbicides s-metolachlor and pendimethalin had been found to increase 100 seed weight of canola plant [26,27,53]. It was also found that pendimethalin at 1.0 kg ha^{-1} supplemented with hand weeding and hoeing 5 WAE had no significant difference from s-metolachlor at 2.0 kg ha^{-1}. On the other hand, the weedy check plots had significantly the lowest 100 seed weight of all the other treatments. This result is in line with Mohammadi [54] who found that the increased duration of weed interference in chickpea is associated with reduced dry matter to seed production, which results in yield reduction, in particular hundred seed weight per plant. Similarly, Sana [55] recorded the lowest 100 seed weight from the untreated weedy plots of chickpea. These results are in agreement with those of Yadav, Singh and Mohammadi [25,56,57] who found that the increased duration of weed interference in chickpea is associated with reduced dry matter to seed production which results in yield reduction in particular, hundred seed weight plant^{-1}.

***Aboveground dry biomass yield*:** The highest (10157 kg ha^{-1}) total dry biomass yield was obtained from s-metolachlor 2.0 kg ha^{-1} treated plots, which were not significantly different from dry aboveground biomass yield obtained with s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, hand weeding and hoeing 21 days after crop emergence, pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, and s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1} weed management practices (Table 7). Mizan [58] also reported that the increased dry matter weight of the crop was highly governed by the length of weed-free period. However, high production of total dry matter might not necessarily be of great value when the grain comprises a part of the plant. Aboveground dry biomass showed a significant variation across locations where significantly higher biomass was recorded at Sirinka than at Jari.

***Grain yield*:** The grain yield (3092 kg ha^{-1}) obtained at Sirinka was significantly higher by 13.9% than that at Jari. Among different weed management practices, application of s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE gave significantly higher (3960 kg ha^{-1}) grain yield than the other treatments. This was followed by the application of pendimethalin at 1.0 kg ha^{-1} superimposed with hand weeding and hoeing at 5 WAE, which was also significantly higher than all the remaining treatments. Arif and Marwat [26,27] also reported significantly higher grain yield of canola with pre-emergence s-metolachlor and pendimethalin application.

Reduced crop-weed competition due to effective weed management with various treatments resulted in better growth, development and photosynthetic activity of the crop. Thus, the higher yield in these treatments might be attributed to the better weed management, which made better utilization of the resources, like nutrients, solar radiation, water and space by the crop that produced higher grain yield than the untreated control. In line with this, Rao and Begum [59,60] also reported higher yield due to effective management of weeds in early stage, which reduced weed growth and increased the growth and yield of black gram. Suppression of weed competition was further enhanced by integrating pre-emergence herbicides with hand weeding at 5 WAE that kept the crop weed-free during critical period, which offered prolonged and efficient weed control.

Grafton [61] opined better translocation of photosynthates under lesser competition among plants and this could be one of the reasons for obtaining higher yields. Townley [62] stated that good weed management is critical to obtain higher yield from fieldpea. Askew [63] reported that managing weeds and lesser competition within the plant community could result in utilization of the available resources efficiently, which, in turn, is reflected in higher grain yield. Morad [64] observed that yield of broad bean increased in plots treated with pre-emergence herbicides due higher pods per plant, seed number per pod and hundred seed weight.

Hand weeding and hoeing 3 WAE also proved significantly better than the mixture of s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}, and s-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}. This may be attributed to lower dry matter accumulation by weeds and decrease in their population, which, in turn, increased the yield attributes and ultimately increased the grain yield [65].

On the other hand, significantly lower yield was obtained in the weedy check than in the other treatments. Weed management practices significantly encouraged vigorous cowpea growth with minimal weed competition with cowpea. Thus, the cowpea grain yield obtained in the weedy check was 40.2 to 64.0% lower than the grain yield from other weed management practices as a result of intense weed competition (Table 7). This yield loss depends upon the density and species of weeds, duration of infestation and completing ability of the crop plants with weeds. These results are in line with the findings of Ahmad, Stork, Sangakkora and Tanveer [21,33,65,66] who reported 20 to 50% losses in grain yield if the weed management practices are not properly followed.

Similarly, Mohamed [32] reported that pre-emergence herbicides provided excellent suppression of weeds and the yield was significantly increased over weedy check. Weeds can severely affect the performance of the cowpea bean and the yield loss was 60 to 66% due to weed interference [67]. Prakash [49] found that long season crop-weed competition reduced the fieldpea yield by 44.6 to 55.6%. Similarly, several authors reported that weedy check plots gave the lowest yield in chickpea [25,57,68]. Blackshaw [10] stated that the weeds reduce more than 75% of yield in cowpea crop. However, the contradictory reports on the extent of yield losses due to weeds might be due to the variation in environmental conditions, soil types, the crop varietal characters and the extent of weed interferences at the locations.

***Harvest index*:** Significantly higher (31.9%) harvest index was recorded at Sirinka than at Jari. The result indicated that there was significant variation on harvest index among the weed management treatments evaluated at both locations. S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE gave the highest (40.0%) harvest index of all treatments, while the lowest (20.5%) harvest index was recorded from weedy check plots (Table 7). Increase in shoot weight with increasing weed interference might have increased the vegetative growth duration and decreased root/shoot ratio resulting in reduced harvest index. Soltani [69] reported that the harvest index of cowpea increases with increasing seed production. This result is in line with that obtained by Mousavi [48] who reported that the application of s-metolachlor herbicide application on cowpea increased harvest index.

Partial budget analysis

The result of the partial budget analysis and the data used for the partial budget analysis is given in a tabular form Table 8. The partial budget analysis was performed as described by CIMMYT (1988) where the variable costs that vary included the cost of inputs (herbicide) as well as the cost involved in their application.

However, for ease of calculation in place of field price of the crop, the cost incurred for harvesting, threshing, winnowing, packing and transportation was added to the variable input cost. The yield difference per hectare recorded from the different treatments accounted for the variation observed in value of gross benefit in both locations. The partial budget analysis indicated that the highest (ETB 53460 ha^{-1}) gross benefit was obtained from s-metolachlor at 1.0 kg ha^{-1}+ hand

Factors	Grain yield (kg ha^{-1})	Above ground biomass yield (kg ha^{-1})	Harvest index (%)
Location			
Jari	2714^{b}	8873^{b}	30.8^{b}
Sirinka	3092^{a}	9683^{a}	31.9^{a}
LSD (5%)	116.7	350.1	1.2
Weed management practices			
S-metolachlor at 2.0 kg ha^{-1}	3169^{c}	10157^{a}	31.9^{c}
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	3960^{a}	10099^{a}	40.0^{a}
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	3462^{b}	9655^{ab}	36.4^{b}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	3039^{c}	9473^{ab}	32.5^{c}
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	2683^{d}	8678^{c}	31.3^{c}
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	2383^{e}	9052^{bc}	26.8^{d}
Hand weeding and hoeing 3 WAE	3106^{c}	10063^{a}	31.4^{c}
Weedy check	1424^{f}	7043^{d}	20.5^{e}
LSD (5%)	233.5	700.2	2.5
CV (%)	9.9	9.2	9.8

CV=coefficient of variation, DAE=days after crop emergence, LSD=least significant difference, Means followed by the same letters in a column are not significantly different from each other at 5% level of significance.

Table 7: Main effect of location and weed management practices on grain yield, aboveground dry biomass, and harvest index of cowpea in 2014 cropping season.

	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1}) 10% down	Total variable cost (ETB ha^{-1})	Gross return (ETB ha^{-1})	Net return (ETB ha^{-1})
Weed management practices					
S-metolachlor at 2.0 kg ha^{-1}	3169	2852	5687	42782	37095
S-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	3960	3564	6984	53460	46476
Pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE	3462	3116	6440	46737	40297
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	3039	2735	5695	41027	35332
S-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 0.75 kg ha^{-1}	2683	2415	5006	36221	31215
S-metolachlor at 0.75 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}	2383	2145	4606	32171	27564
Hand weeding and hoeing 3 WAE	3106	2795	6144	41931	35787
Weedy check	1424	1282	2136	19224	17088

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

Table 8: Results of partial budget analysis of weed management practices in cowpea at Sirinka and Jari in 2014 cropping season.

weeding and hoeing 5 WAE, followed by gross benefit (ETB 46737 ha^{-1}) obtained from treatment with pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, while the lowest price was recorded from the weedy check plots. Singh [70] also reported a high economic return with butachlor+one hand weeding in rice, while Gupta [71] observed that the use of butachlor took equivalent to 186 hrs, while two-hand weeding took 604 hrs ha^{-1} in rice.

In agreement with the present result, most studies showed that applying herbicide or herbicide plus manual weeding was more economical than manual or hand weeding alone [72]. The result of this experiment indicated that the use of herbicide though reduced the cost of production, the poor management of weeds resulted in significantly low yield compared to the combinations of s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing at 35 days after emergence and pendimethalin at 1.0 kg ha^{-1}+hand weeding and hoeing at 35 days after emergence. Therefore, managing weeds with the application of s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE proved to be the most profitable practice in weed management for sustainable cowpea production in northen Ethiopia and elsewhere cowpea is cultivated.

Summary and Conclusions

The weed density and dry weight at harvest was considerably due to treatments with the application of both s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with hand weeding and hoeing at 5 WAE at Sirinka, and s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE at Jari. However, the performance of both planting patterns was similar under s-metolachlor and pendimethalin each at 1.0 kg ha^{-1} supplemented with hand weeding and hoeing at 5 WAE. The highest weed control efficiency was obtained with the combination of s-metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, and 60 cm × 10 cm spacing was statistically at parity with s-metolachlor at 1.0 kg ha^{-1}+pendimethalin at 1.0 kg ha^{-1}, and s- metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing 5 WAE, respectively, under 60 cm × 10 cm and 45 cm × 15 cm plant spacing.

Plant height was significantly influenced by weed management practices. Number of pods per plant was significantly influence by location and weed management practices, whereby at Sirinka all weed management practices resulted in significantly higher pods per plant than the weedy check. On the other hand, at Jari weedy check had no significant difference from treatment with herbicide mixtures and hand weeding. Location and weed management practices significantly affected the number of grains per pod and 100 seed weight. Application of low dose herbicides supplemented with hand weeding resulted in higher number of seeds per pod and hundred seed weight than that of the control plots. Weedy check had significantly lower seed weight and number of seeds per pod than the other treatments.

Aboveground dry biomass weight and grain yield and harvest index were significantly higher at Sirinka than at Jari. Application of s-metolachlor at 1.0 kg ha-1+hand weeding and hoeing 5 WAE gave significantly higher grain yield and harvest index than other treatments, while it did not significantly differ from treatment with pendimethalin at 1.0 kg ha^{-1} supplemented with hand weeding for the aboveground dry biomass yield.

From the result of the study, it can be concluded that managing the weeds with the application of s- metolachlor at 1.0 kg ha^{-1}+hand weeding and hoeing at 5 WAE along with 60 cm × 10 cm planting pattern proved to be the most profitable practice. Based upon availability, alternatively pendimethalin could also be used in supplement with hand weeding at 5 WAE. Further, to prevent the weed shift, these two herbicides (s-metolachlor and pendimethalin) 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.

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