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Research Article

Efficacy of Sequential Applications of Pendimethalin 500 EC (Pendimight®) and Oxyfluofen 240 EC (Harris®) for Weed Control in Direct Seeded Onion (*Allium cepa* L.) in Sudan

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Abstract

A field study was carried out to evaluate the efficacy of pendimethalin 500 EC (trade name: Pendimight®) and oxyfluorfen 240 EC (trade name: Harris®) to control weeds in direct-seeded onion (*Allium cepa* L.). Pendimethalin and oxyfluorfen were applied solely at reduced rates (1.35 and 0.17 kg a.i. ha^{-1}), and at the recommended rates (1.8 and 0.25 kg a.i. ha^{-1}) as pre-and post-emergence herbicides, respectively. Both herbicides were also applied sequentially at the same doses. Ten weeks after sowing (WAS), the application of pendimethalin alone provided better weed control (62% - 65%) than oxyfluorfen alone (33% - 43%) when they were applied at the lower and recommended rates, respectively. Sequential applications of the two herbicides as pre-and post-emergence herbicides, outperformed applications of the two herbicides alone, and resulted in the best weed control (79% to 85%), lowest weed dry weight (18.35 to 35.60 $g.m^{-2}$), significantly increased plant height and the number of leaves per plant, and resulted in a ten-fold higher onion yield (24.64 to 26.37 t. ha^{-1}) compared with the Un-weeded control (2.27 t. ha^{-1}). There were no significant differences observed between the treatments on the emergence (%) of onion seeds and the survival of onion seedlings. Sequential applications of pendimethalin and oxyfluorfen is a promising techniques for weed control in direct-seeded onions in Sudan.

Introduction

Onion (*Allium cepa* L.) is the most important economic vegetable in Sudan, occupying about 33% of the total area under vegetables. Around 273,000 tons are produced each year, representing about 25% of the country's total vegetable production [1]. The production of the onion crop is challenged by several biotic constraints, especially weeds and diseases [2]. The crop cannot tolerate prolonged competition from weeds because of its initial slow growth rate after planting, its shallow fibrous roots, and its small above-ground canopy that does not provide competitive soil shading [3,4]. In one study, onion was compared with 27 crops for weed competition, and it was ranked as the least competitive crop [5], As a result, weeds cause substantial crop losses in onion crops if they are not removed, or if weeding is delayed [2]. Direct-seeded onion is considerably more sensitive to weed competition than bulbs or seedling-grown onion [6] Losses to weed competition in transplanted onion have been reported to be in the region of 50% [7], whereas losses of 100% have been reported in direct-seeded onion crops [8,9].

The use of herbicides is one of the options available to farmers to manage crop weed competition, especially at an early stage of the crop cycle. Several herbicides, including pendimethalin, oxadiazon, and oxyfluorfen, have been recommended for weed control in onion [10,11]. One issue is that a single pre-emergence or post-emergence application of herbicides may not adequately control weeds in onions [12,13]. Some studies have demonstrated the sequential application

of two or more herbicides may be the most effective option to control weeds because the post-emergence treatments strongly influenced subsequent weed flushes [14,15].

Saha, et al. [16] studied the fate of pendimethalin and oxyfluorfen in field soil and reported that both herbicides have a short-lived and mixed effect, that is, both stimulatory and inhibitory on soil biological and biochemical properties, and effects that are controlled by the dose, chemical, and time after application of herbicides. The positive effects on soil microbial biomass carbon, and fluorescein diacetate hydrolyzing activities were probably due to stimulated microbial growth. An increased ammonification process and a decreased nitrification process indicated a diversified microbial population in the soil, showing variable responses toward the application of herbicides. Both herbicides had a critical effect on dehydrogenase activity and the availability of phosphorous. The stimulative effect of pendimethalin was found higher than oxyfluorfen in the present study. Though the adverse effects of herbicides at the recommended rate and half the recommended rate disappeared within a few days or weeks, they had strong and prolonged effects at double the recommended rate. Though higher doses are not relevant for agriculture management practices, they may be useful for assessing the environmental risks associated with herbicides in the case of continuous applications.

Transplanting of seedlings and traditional manual weeding are the most popular ways to combat weeds in Sudan. However, they are time-consuming, labor-intensive, painstaking, and expensive [17]. It is estimated that about 40 – 60 % of production costs are spent on manual weeding. In addition to the high cost, labor availability is uncertain, making it difficult to ensure timely weeding, resulting in a greater loss of yield [18]. The use of herbicides is widely used in large-scale crop production, being more efficient, scaleable, cheaper, and labor-saving. In Sudan, the selected herbicides have been registered by the National Pest and Diseases Committee for weed control against many crops including onion. Globally, the effective use of pendimethalin and oxyfluorfen for weed control has been previously reported for weed control in vegetables in various studies, including in Indonesia for weed control in soybean [19] and in India to control weed in blackgram (*Vigna mungo* L.) [20] Therefore, this study tested a novel approach to use sequential applications of pendimethalin and oxyfluorfen for weed control in direct-seeded onion in Sudan.

Materials and methods

Experimental site

A field experiment was conducted at the Demonstration Farm (latitude 15°40' N and longitude 32°32' E), Faculty of Agricultural, University of Khartoum at Shambat, Sudan. The soil of the experiment site is a vertisol [21], which is alkaline (pH 7.8 to 8.0) and cracking, with a 50% clay content. The site is located in a tropical, semi-arid zone with an annual rainfall of 100-400 mm, peaking in August. The experimental site was infested by many weeds, including eleven species of broad-leafed weeds and six species of grasses. Among the broad-leafed weeds, *Amaranthus viridis* L, *Datura stramonium* L., and *Solanum dubium* Fresen were dominant. The dominant grassy weed species were *Cynodon dactylon* L. and *Eragrostis cilianensis* All.

Cultural practices

The experimental site was plowed, disc-harrowed, leveled, and ridged to a height of 70 cm. The experimental area was divided into 30 plots of 3x4 m^2 each. Each plot consisted of four ridges three meters long. Ridges were laid out in a north-south direction. Onion seeds of the cultivar Baftaim S (Agricultural Research Corporation, Republic of Sudan) were hand-sewn at a rate of three seeds per hole. The depth of sowing was 2.0 cm. Seeds were sown in three rows per ridge. Spacing was 20 cm between rows and 10 cm between holes. The trial site was irrigated to field capacity immediately after sowing and five days later to ensure optimum germination. The crop was then irrigated every 10-15 days thereafter, depending on weather conditions. The crop was thinned to one seedling per hole two weeks after sowing. Urea fertilizer (46% N) was applied at a rate of 110 kg ha^{-1} in split doses, five and eight weeks after sowing (WAS).

Treatments and design

The experiment consisted of ten treatments, as presented in Table 1

The selected herbicides were applied as aqueous sprays using a flat fan nozzle and a knapsack sprayer at a volume of 238 L ha^{-1}. The experiment was laid out in a Randomized Complete Blocks Design (RCBD) with three replications.

Weed data collection

The effects of the treatments on weed density and dry weight were assessed. Weeds inside a quadrant of 0.25m^2 were counted to determine weed density (number of weeds m^{-2}) at six and ten WAS. The control of the weeds was estimated as a percentage of the Un-weeded Control plots, using the following equation:

$$\text{Weed control}(\%) = \frac{\text{number of weeds in the un-weeded plots} - \text{number of weeds in the treated plots}}{\text{number of weeds in the un-weeded plots}} \times 100$$

In addition, weeds inside the 0.25m^2 area were cut at soil level using hand hoes, air-dried, oven-dried for 3 days at 80°C, then weighed to determine the weed dry weight.

Crop safety

To determine the effect of the pre-planting application of pendimethalin on onion seed emergence, seedlings in an area of 0.7 m^2 of the two central ridges, were counted in each plot. Seedling emergence (%) was then calculated. Similarly, the survival of onion seedlings was counted in an area of 0.7 m^2 of the two central ridges, two weeks after the post-emergence application of oxyfluorfen.

Table 1: Application methods and doses of the selected herbicides.

Treatments			
Herbicide/names	**Time of application**	**Dose levels**	**Dose (kg a.i.ha^{-1})**
pendimethalin 500 EC (Pendimight®) + oxyfluorfen 250 EC (Harris®)	Pre + Post	RD + RD	1.8 + 0.25
pendimethalin 500 EC (Pendimight®) + oxyfluorfen 250 EC (Harris®)	Pre + Post	RD + LD	1.8 + 0.17
pendimethalin 500 EC (Pendimight®) + oxyfluorfen 250 EC (Harris®)	Pre + Post	LD + RD	1.35 + 0.25
pendimethalin 500 EC (Pendimight®) + oxyfluorfen 250 EC (Harris®)	Pre + Post	LD + LD	1.35 + 0.17
pendimethalin 500 EC (Pendimight®)	Pre	RD	1.8
pendimethalin 500 EC (Pendimight®)	Pre	LD	1.35
oxyfluorfen 250 EC (Harris®)	Post	RD	0.25
oxyfluorfen 250 EC (Harris®)	Post	LD	0.17
Hand-Weeded Control	-	-	-
Un-Weeded Control	-	-	-

Pre: Pre-Emergence; Post: Post-Emergence (one month after emergence); RD: Recommended Dose; LD: Lower Dose

Crop data collection

Crop data were collected from the two inner ridges in each plot six weeks after sowing and every two weeks thereafter. Five plants were randomly selected and data on plant height (cm) was recorded. Plant height was measured from the soil surface to the tip of the youngest fully expanded leaf. The number of leaves per plant was also determined. The crop was manually harvested after 105 days from sowing (DFS) as a green salad crop. This was done in an area of 0.7 m^2 of the two central ridges, and onion fresh weight (ton ha^{-1}) was determined. Ten plants were randomly selected and the mean bulb diameter (mm) was determined using a digital Vernier scale. Onion fresh yield reduction was assessed as a percentage from the hand-weeded control plots using the following equation.

$$\text{Onion fresh yield reduction \%} = \frac{\text{onion fresh yield in hand} - \text{weeded plots} - \text{onion fresh yield in the treated plots}}{\text{onion fresh yield in hand} - \text{weeded plots}} \text{x100}$$

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using Gen Stat for Windows 14th edition (Payne *et at*., 2012). Treatment means were compared using Duncan's Multiple Range Test. All variables except dry weight at 6 and 10 days after sowing had homogenous error variances and acceptable CV percentages. A square root transformation was applied to the variable weed dry weight at 6 and 10 weeks after sowing before ANOVA was applied to the data.

Results and discussion

Effect of the treatments on weed control

All weed control treatments were effective in reducing the weed population and weed dry weight compared with the Un-weeded Control treatment, irrespective of the herbicide used. A single pre-emergence application of pendimethalin at all doses provided weed control levels of 62% and 65% compared to only 33% and 43% weed control after a post-emergence oxyfluorfen application, suggesting that the early control of weeds is critical for onion seedlings to germinate, emerge and grow. Post-emergence application of oxyfluorfen one month post-emergence of onion seeds was too late to prevent damaging weed competition. These findings are similar to those of Mohmood, et al. [22], who found that the application of pendimethalin was initially effective in controlling weeds in garlic, but weeds appeared in abundance late in the season, and the level of weed control declined with time. Ghosheh [23] also found that a single herbicide application pre- or post-emergence was not enough to control weeds in onion satisfactorily. On the other hand, our results are in contrast with Abdalla & Babiker [7], who reported that a single pre-emergence application of pendimethalin controlled weeds effectively and resulted in the highest onion yield.

The sequential application of the two herbicides at all doses caused weed control of 98% to 100% at six weeks after sowing (WAS), and 79% to 85% weed control at ten WAS, compared to zero weed control in the Un-weeded control (Table 2; Figure 1). Interestingly, even at ten WAS, sequential application of herbicides caused the lowest weed dry weight (18.35 to 35.60 g.m^{-2}), which is eight times less than the weed dry weight of the Un-weeded control (166.27 to 313.30 g.m^2) (Table 2). This reflected the efficacy of the sequential application of pendimethalin as a pre-emergence herbicide on grasses, and oxyfluorfen as a post-emergence herbicide on broadleaf weeds, which allowed the onion plants to grow without weed competition throughout the season. These results are in line with the findings of Gandolkar, et al. [24], who concluded that sequential applications of mixed herbicides controlled weeds better than single or standard applications of a single herbicide. In other studies, sequential applications of pre-and post-emergence herbicides provided the most consistency for weed control because the post-emergence treatments controlled weed escapes, and second flushes of weeds [14].

Results of the herbicide treatments on the onion crop

No significant differences were observed in the emergence of onion seeds when applied with pendimethalin as a pre-emergence herbicide compared to other treatments (Table 3), whereas the application of oxyfluorfen can cause phytotoxic reactions, including cell membrane disruption, leading to rapid leaf desiccation and, subsequently, plant death. Interestingly, in our case, the application of oxyfluorfen as a

Table 2: Results of herbicide treatments on weed control (%) and weed dry weight (g.m^{-2}) in direct-seeded onion.

Treatment	Herbicide rate (Kg a.i.ha^{-1})	Weeds Control %		Weeds Dry Weight (g.m^{-2})	
		6 WAS	10 WAS	6 WAS	10 WAS
pendimethalin (RD) + oxyfluorfen (RD)	1.8 + 0.25	98 a d	85 b	0.10 d	18.53 d
pendimethalin (RD) + oxyfluorfen (LD)	1.8 + 0.17	99 a d	82 b	0.43 d	32.00 cd
pendimethalin (LD) + oxyfluorfen (RD)	1.35 + 0.25	100 a d	83 b	0.00 d	23.20 d
pendimethalin (LD) + oxyfluorfen (LD)	1.35 + 0.17	99 a d	79 b	0.90 d	35.60 cd
pendimethalin (RD)	1.8	87 b c	65 bc	21.03 bc	234.30 ab
pendimethalin (LD)	1.35	86 bc c	62 bc	31.70 b	134.60 bc
oxyfluorfen (RD)	0.25	80 c b	43 cd	22.20 bc	287.07 a
oxyfluorfen (LD)	0.17	86 bc c	33 d	9.00 cd	157.17 b
Hand-Weeded Control	-	100 a d	100 a	0.00 d	0.00 d
Un-weeded Control	-	0.00 d a	0.00 e	166.27 a	313.30 a
Mean Square	-	2771.04***	2714.4***	47.3513***	42915***
CV%	-	4.1	22	24.5	22.9
Mean ± se	-	83.9 ± 3.5	63.3 ± 13.9	24.9 ± 0.8	124 ± 2.2

*: significant at $p \leq 0.05$; **: significant at $p \leq 0.01$; ***: significant at $p \leq 0.001$; ns: non-significant; RD: Recommended Dose; LD: Lower Dose; se: Standard Error.

Figure 1: Effect of (A) sequential application of pendimethalin and oxyfluorfen and (B) the Un-weeded Control in direct seeded onion at ten weeks after sowing (WAS).

Table 3: Effect of herbicide treatments on emergence (%) of onion seeds.

Treatment	Herbicide dose Kg a.i.ha^{-1}	Emergence of onion seeds (%)
pendimethalin (RD) + oxyfluorfen (RD)	1.8 + 0.25	87.0 a
pendimethalin (RD) + oxyfluorfen (LD)	1.8 + 0.17	84.0 a
pendimethalin (LD) + oxyfluorfen (RD)	1.35 + 0.25	83.0 a
pendimethalin (LD) + oxyfluorfen (LD)	1.35 + 0.17	85.0 a
pendimethalin (RD)	1.8	86.0a
pendimethalin (LD)	1.35	83.0 a
oxyfluorfen (RD)	0.25	82.0 a
oxyfluorfen (LD)	0.17	81.0 a
Hand-Weeded Control	-	84.0 a
Un-weeded Control	-	83.0 a
Mean Square	-	8.756 ns
CV%	-	2.4
Mean ± se	-	83.9 + 2.1

*: significant at $p \leq 0.05$; **: significant at $p \leq 0.01$; ***: significant at $p \leq 0.001$; ns: Non-Significant; RD: Recommended Dose; LD: Lower Dose; se: Standard Error

post-emergence herbicide caused no phytotoxicity symptoms on onion seedlings (visual observation) if the application was made after the crop had passed the two-leaf growth stage. These results are in agreement with the findings of Mohmood, et al. [22], who reported that before the two-leaf stage, onion appears to be very susceptible to post-emergence herbicides because the plant has yet to form a protective leaf cuticle. Herrmann, et al. [25] also demonstrated that post-emergence broadleaf herbicides cannot be applied safely until onion plants have reached the two-leaf stage.

Determination of an appropriate herbicide dose rate is important in achieving adequate weed control and reducing crop phytotoxicity (Harding, et al., 2012). Herbicide rates depend on several factors, including weed seed bank size, presence or absence of residue, and soil properties (Blackshaw, et al., 2006, Chauhan and Abugho, 2012, Zhang, et al., 2000). Previous studies in several crops under different environmental conditions found substantial variations in weed control with different herbicide rates (Zhang, et al., 2000).

No significant differences in onion plant height were observed between treatments except at 12 WAS (Table 4). This may have been due to the high competition between weeds and onion plants for sunlight and nutrition, particularly in the Un-weeded Control plots, which led to the etiolated growth of the onion plants.

At the end of the season (10 and 12 WAS), treatments using the sequential application of herbicides, and the hand-wed control resulted in the most leaves per plant, compared to the single herbicide applications and the Un-weeded Control (Table 4). These results are similar to those of Malik, et al. [14] and Himaja, et al. [15], who found that the sequential applications of herbicides were more effective than the applications of single herbicides on mung bean (*Vigna radiata* L.).

The sequential application of the tested herbicides consistently caused the greatest bulb diameter (32.43-36.77 mm), the highest onion fresh yield (24.64 to 26.37 t. ha^{-1}), and the least reduction of onion fresh yield (5-13%) compared to other treatments, except the Hand-weeded control (Table 5.) This reflects to continuous control of weeds provided by the sequential application to control weeds from the beginning of the season, with the pre-emergence application of pendimethalin against grasses, followed one month later with the post-emergence application of oxyfluorfen against broadleafed weeds. This treatment ensured the best control of weeds, resulting in healthy onion plants, with high crop yields at the end of the season. These results are in agreement with Kathepuri, et al. [26], who found that yield reductions in onion were directly related to weed density, weed dry weight, and intensity of weed interference throughout the crop growth period.

Conclusion

The application of either pendimethalin or oxyfluorfen alone was not enough to control weeds satisfactorily in direct-seeded onion, whereas the sequential application of the same herbicides resulted in good weed control and enhanced the growth parameters of onion. Therefore, the sequential application technique can be used effectively and safely in controlling weeds in direct-seeded onion Sudan. A large-scale study should be undertaken to test this treatment combination in the various onion-growing areas in Sudan.

Table 4: Effect of herbicide treatments on plant height (cm) and number of leaves per plant.

Treatments	*herbicide dose (kg a.i. ha^{-1})*	Plant height (cm)				Number of leave per plant			
		6 WAS	8 WAS	10 WAS	12 WAS	6 WAS	8WAS	10 WAS	12 WAS
Pendimethalin (RD) + oxyfluorfen (RD)	1.8 + 0.25	28.93 a	37.57 a	55.33 a	66.47 c	4.40 cde	5.77 a	7.93 d	10.40 c
Pendimethalin (RD) + oxyfluorfen (LD)	1.8 + 0.17	27.13 a	34.33 a	54.93 a	63.07 bc	4.33 cde	5.40 a	7.80 d	9.00 c
Pendimethalin (LD) + oxyfluorfen (RD)	1.35 + 0.25	29.57 a	35.27 a	54.33 a	62.80 bc	4.60 de	5.93 a	7.73 d	9.47 c
Pendimethalin (LD) + oxyfluorfen (LD)	1.35 + 0.17	29.57 a	36.10 a	53.60 a	67.00 c	4.80 e	5.90 a	8.06 d	8.93 c
Pendimethalin (RD)	1.8	27.87 a	32.73 a	54.47 a	62.20 bc	4.40 cde	5.63 a	6.33 c	7.00 ab
Pendimethalin (LD)	1.35	26.37 a	30.57 a	52.13 a	59.73 bc	3.87 abc	5.27 a	6.00 bc	7.20 b
oxyfluorfen (RD)	0.25	26.30 a	31.20 a	53.33 a	64.00 bc	3.53 ab	5.17 a	5.27 ab	5.93 ab
oxyfluorfen (LD)	0.17	24.47 a	30.23 a	54.60 a	57.87 b	4.06 bcd	4.83 a	5.73 bc	6.00 ab
Hand Weeded Control	-	29.57 a	36.20 a	55.20 a	63.00 bc	4.87 e	5.83 a	8.06 d	9.47 c
Un-Weeded Control	-	28.97 a	35.17 a	50.47 a	51.20 a	3.27 a	4.60 a	4.66 a	5.47 a
Mean square	-	8.87 ns	20.14 ns	38.77 ns	78.8**	0.9***	1.9 ns	21.2***	9.4***
CV% Mean ± se	-	10 27.9 ± 2.8	12.7 33.1 ± 4.4	8.7 54.1 ± 4.8	6.8 61.6 ± 4.2	8.5 4.3 ± 0.4	10.8 5.5 ± 0.6	7.3 6.8 ± 0.5	10.9 7.9 ± 0.9

*: significant at $p < 0.05$; **: significant at $p < 0.01$; ***: significant at $p < 0.001$; ns: non-significant; RD: Recommended Dose; LD: Lower Dose; se: standard error.

Table 5: Effect of herbicide treatments on onion bulb diameter (mm), onion fresh yield (t ha^{-1}), and onion fresh yield reduction (%).

Treatments	Herbicide dose (Kg a.i.ha^{-1})	Bulb diameter (mm)	Onion fresh yield (t.ha^{-1})	Onion fresh yield reduction (%)
Pendimethalin (RD) + oxyfluorfen (RD)	1.8 + 0.25	36.77 c	26.37 c	5 a
pendimethalin (RD) + oxyfluorfen (LD)	1.8 + 0.17	32.43 c	25.04 c	10 a
pendimethalin (LD) + oxyfluorfen (RD)	1.35 + 0.25	33.63 c	24.34 c	13 a
pendimethalin (LD) + oxyfluorfen (LD)	1.35 + 0.17	33.60 c	24. 64 c	11 a
pendimethalin (RD)	1.8	18.10 b	7.60 b	72 b
pendimethalin (LD)	1.35	21.30 b	7.57 b	073 b
oxyfluorfen (RD)	0.25	16.87 b	5.70 ab	79 bc
oxyfluorfen (LD)	0.17	15.63 ab	5.40 ab	80 bc
Hand-Weeded Control	-	39.93 c	27.84 c	00 a
Un-weeded Control	-	9.00 a	2.27 a	91c
Mean Square	-	343.7***	340.3***	4373.5***
CV%	-	15.9	13.3	16.5
Mean ± se	-	25.8 ± 4.1	15.7 ± 2.1	43.8 ± 7.3

*: Significant at $p \leq 0.05$; **: Significant at $p \leq 0.01$; ***: Significant at $p \leq 0.001$; ns: Non-Significant; RD: Recommended Dose; LD: Lower Dose; se: Standard Error.

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