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Response of pepper (*Capsicum annuum* L.) to preemergence application of Oxadiargyl and pendimethalin

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ABSTRACT

Two field experiments were conducted in two agro-ecological zones of Ghana (Forest and Coastal Savannah) to assess the efficacy of preemergence herbicides Oxadiargyl and Pendimethalin on weed incidence, growth and yield of pepper. The experiment was factorial arranged in a randomized complete block design. The treatments were Oxadiargyl at 0.4, 0.5, 0.6 L/ha, Pendimethalin at 1.5, 2.0, 2.5 L/ha and hand weeding at intervals of 3, 6 and 9 weeks as control. Data was collected on weed type and abundance, number of days to weed emergence, type of re-emerging weeds and percentage weed cover. Data on plant height, number of branches per plant, yield and yield components of pepper plants were also collected. Results indicated that application of Pendimethalin led to a significantly ($p < 0.05$) longer number of days to weed emergence as compared to the application of Oxadiargyl which also delayed weed emergence significantly longer than hand weeding. Plant height was not affected by weed control method. The yield of pepper plants was significantly higher in plots where Pendimethalin (2.0 L/ha) was applied. Generally, the yield components of pepper plants have been positively affected by weed control treatments. However, application of Pendimethalin at 2.0 L/ha resulted in better weed control.

1. Introduction

Typically, the most popular vegetables grown by farmers in West Africa include chili peppers, onions, tomatoes, garden eggs, and okra [1]. The production of these vegetables is popular among small-scale farmers in Ghana probably because of growing demand both locally and internationally. Among these popular vegetables, chili is second in terms of production, with a cropland allocation of 13,700 ha and a crop value of GH¢ 919 million, in 2017 [2]. The benefit of cultivating pepper in Ghana is not limited to only economic reasons; it has enormous health benefits and plays a significant role in most foods eaten throughout the country. Pepper is an important component of many foods such as soups, stews, and sauces, adding flavour, colour, and pungency to many diets. It is also a source of micronutrients and vitamins in the Ghanaian diet. Nutritionally, all peppers are rich in vitamins A, C, and K, but red peppers have a relatively higher content [3]. Antioxidants, vitamins A and C in pepper are said to help prevent cell damage, cancer, and diseases related to aging, as well as supporting immune function.

The economic and health benefits of pepper production are enormous. However, weed infestation presents a major constraint to its cultivation. The availability of water in pepper fields usually promotes speedy and profuse weed growth, thus, the entire farm becomes heavily infested with weeds in no time. Farmers are usually overwhelmed by the weed problem and weed their fields late leading to yield losses or in some cases they abandon the farm. To reduce the weed menace, some agrochemical companies in Ghana have introduced a number of pre-emergence herbicides including Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L EC for weed control in vegetable production. Application of preemergence herbicides offers weed control from the early stages of the crop, giving the crop a head start and a competitive advantage [4]. Pendimethalin 500 g/L EC has been used for weed control in pepper and tomatoes. Oxadiargyl 400 g/L SC which is used for weed control in rice on the other hand has not been tried in pepper as a weed control herbicide in Ghana. There are variations in the response of crops, soil microorganisms, and weeds to herbicide application [5,6]. This work, therefore evaluated Oxadiargyl 400 g/L SC for weed control in pepper.

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2. Materials and methods

2.1. Experimental site

The first experiment was conducted at the University of Ghana (UG) farm at Legon. The area falls in the coastal savannah agro-ecological zone of Ghana with a mean annual rainfall between 600 and 800 mm per annum. The soil of the area is described as ''Adenta'' series and was classified by the Soil Research Institute, Ghana in 1999 [7] as Ferric Acrisol. The second experiment was carried out at the research farm of the Council for Scientific and Industrial Research (CSIR) - Plant Genetic Resources Research Institute (PGRRI), Bunso. Bunso is in the semi-deciduous forest agro-ecological zone with a mean annual rainfall of 1450 mm per annum. The soils of Bunso range from red clay loams of elevated ground to heavier alluvial soil near the Birim River [8]. The climatic conditions that pertained at the two experimental locations over the period are shown in Table 1 below.

2.2. Experimental design

At each of the two experimental locations, a 346.32 m^2 plot was demarcated, ploughed and harrowed. The experimental design was factorial arranged in a randomized complete block design with seven treatments and four replications. The treatments were: Topstar ® (Oxadiargyl 400 g/L SC) at 0.4 L/ha (lower rate), 0.5 L/ha (Manufacturer's recommended rate), 0.6 L/ha (higher rate) and Chemostomp® (Pendimethalin 500 g/L EC) at 1.5 L/ha (lower rate), 2.0 L/ha (Manufacturer's recommended rate), 2.5 L/ha (higher rate). Hand weeding was maintained as the control treatment. The interplot and interblock distances were 0.5 m and 1 m respectively. Herbicide application was done using a knapsack sprayer with a flow rate of 1.01 L/min, a swath width of 1.3 m and a volume application rate of 250 L/ha. The pre-emergence herbicides were applied after the treatment plots were moistened to enhance their effectiveness. Topstar (Oxadiargyl 400 g/L) was applied two weeks before transplanting while Chemostomp (Pendimethalin 500 g/L) was applied two days before transplanting.

2.3. Plant material and agronomic practices

At each site, three rows of six plants of the Legon18 pepper cultivar were transplanted at six weeks after germination per 4.8 m × 1.8 m treatment plot at 80 cm × 60 cm spacing. A starter solution (6 g of 15-15-15 NP K/litre) was applied to the seedlings at a rate of 50 m1 per plant a week after planting. Compound fertilizer, NPK 15-15-15 was applied at 450 kg/ha three weeks after planting. At the flowering stage, sulphate of ammonia at 150 kg/ha was applied. Plants were irrigated as and when necessary, using a watering can fitted with a fine nozzle. Weeds on the farm were controlled according to the treatments stated above. Insect pests including leaf miners, ants, and caterpillars were managed with cydim super® (Dimethoate, 400 g) at 35 ml per 15 L of water at two weeks intervals. To prevent fungal infestation, prophylactic spraying of Dithane M 45 (Mancozeb, 800 g/kg) at two weeks intervals was done at 30 g per 15 L of water.

2.4. Data collection

Data was collected on the incidence of weeds before land preparation and after the application of herbicides. Before land preparation, the weed types and species at the two sites were identified and their population density was determined using a 50 cm × 50 cm quadrat. The number of days to weed emergence and weeds that re-emerged were recorded. Also, the percentage weed cover at three, six and nine weeks using 20 cm × 20 cm quadrat after herbicide application in each treatment plot was recorded. Data was collected from five non-border plants in each plot. The mean height, number of branches, fruit length, pedicel length, fruit diameter, number of seeds, fruit weight, and yield in tons/ha were recorded.

2.5. Data analysis

All data collected were subjected to analysis of variance (ANOVA) using the GENSTAT statistical package (12th Edition software). Where there were significant differences, means were separated using the Least Significant Differences (LSD) method at a 5 % level of significance.

3. Results

Prior to land preparation at the UG farm, Legon, the field was infested with nineteen weed species belonging to ten families (Table 2). The dominant weed families were; Poaceae, Fabaceae and

Table 2
Weed species identified on experimental sites at UG Research farm, Legon before application of Oxadiargyl (400 g/L) and Pendimethalin (500 g/L).

Weed type	Weed species	Weed population (%)	Family
Broadleaves	*Cassia obtusifolia*	7.00	Leguminaceae
	Celosia laxa	0.33	Amaranthaceae
	Cleome viscosa	3.00	Capparaceae
	Croton lobatus	0.33	Euphorbiaceae
	Heliotropium indicum	0.33	Boraginaceae
	Indigofera hirsuta	6.00	Fabaceae
	Mimosa pudica	0.33	Fabaceae
	Puplia lappaceae	0.33	Amaranthaceae
	Senna obtusifolia	10.00	Fabaceae
	Stachytarpheta cayennensis	5.00	Verbenaceae
	Tephrosia purpurea	5.00	Fabaceae
	Tridax procumbens	0.33	Asteraceae
Sedges	*Cyperus rotundus*	0.33	Cyperaceae
Grasses	*Brachiara laxa*	0.33	Poaceae
	Digitaria horizontalis	0.33	Poaceae
	Panicum laxum	0.33	Poaceae
	Panicum maximum	60.00	Poaceae
	Sorghum arudinaceum	0.33	Poaceae
	Sporobolus pyramidalis	0.33	Poaceae

Table 1
Rainfall and temperature figures at Mpehuasem, Legon and Bunso during the experiment.

Month	Monthly Rainfall (mm), UG Research Farm, Legon.	Temperature (°C) Mpehuasem, Legon		Month	Monthly Rainfall (mm), CSIR-PGRRI Research Farm, Bunso	Temperature (°C), Bunso	
		Min.	Max.			Min.	Max.
September	13.5	23.3	30.2	February	11.2	20.2	35.5
October	140.1	24.1	31.3	March	225.4	22.6	33.6
November	27.2	24.5	31.8	April	186.7	22.8	32.8
December	0.0	22.3	33.8	May	281.4	22.7	30.7
January	0.0	22.4	33.9	June	134.4	21.9	29.5

Source: Ghana Meteorological Agency, Mpehuasem, Legon and Koforidua

Amaranthaceae. Leguminaceae, Euphorbiaceae, Asteraceae, Capparaceae, Verbenaceae, Boraginaceae and Cyperaceae constituted the minor weed families identified in the field. Based on their gross morphology; broadleaved weeds dominated the weed types (63.2 %) in the experimental area, followed by grasses (31.6 %), and sedges (5.2 %). The dominant weed species recorded were *Panicum maximum* (60 %), *Senna obtusfolia* (10 %), and *Cassia obtusifolia* (7 %). There were fifteen pre-existing weed species belonging to eight families at the experimental site at the CSIR-PGRRI farm, Bunso (Table 3). Poaceae, Asteraceae, and Fabaceae were the dominant weed families with Verbenaceae, Boraginaceae, Amaranthaceae, Malvaceae, and Cyperaceae being the least. The weeds at the experimental site were categorized into broadleaved weeds (66.6 %), grasses (26.7 %), and sedges (6.7 %). The dominant weed species recorded at the site were *Chromolaena odorata* (50 %), *Panicum maximum* (30 %), and *Pueraria phaseoloides* (10 %).

Table 4 indicates that there were significant differences ($p < 0.05$) in the mean number of days to weed emergence after the application of preemergence herbicides at the UG farm and the CSIR-PGRRI farm. At the UG farm, Pendimethalin at 2.5 L/ha led to the longest number of days (57.5) to weed emergence, this was however not significantly different ($p > 0.05$) from the number of days (54.3) to weed emergence in fields treated with Pendimethalin at 2.0 L/ha (Table 4). At the CSIR-PGRRI farm, Pendimethalin at 2.5 L/ha resulted in the longest number of days (36.5) to weed emergence, however, the duration was not significantly ($p > 0.05$) different from Pendimethalin applied at 2.0 L/ha (Table 4). Plots on which weeds were managed manually with hand weeding had the shortest number of days to weed emergence in both experiments (Table 4).

The types of weeds that re-emerged in treatment plots three, six, and nine weeks after herbicide application were similar at the two experimental sites (Table 5). In the third week, seven weed species re-emerged on the hand weeded plots, and none on the herbicide-treated plots. The majority of re-emerged weeds were broadleaves, followed by grasses and sedges (Table 5). In the sixth week after herbicide application, there was no weed re-emergence on plots treated with Oxadiargyl (0.6 L/ha), Pendimethalin 1.5 L/ha, 2.0 L/ha and (2.5 L/ha). The other herbicide treated plots as well as hand weeded plots had some weed re-emergence including; *Cyperus rotundus and Gumphrena celiodes* which were among the dominant weeds (Table 5). By the ninth week after herbicide application, only *Cyperus rotundus* re-emerged on plots treated with Pendimethalin (2.5 L/ha), while on plots receiving other treatments, *Cyperus rotundus* was the dominant weed along with other re-emerging weeds (Table 5). At the CSIR-PGRRI farm, Bunso, similar weed species re-emerged on treatment plots three, six, and nine weeks after herbicide application. In the third week after application, Oxdiargyl at 0.4 L/ha and hand weeded plots had some weed growth with *Commelina erecta* being the common weed species (Table 6). There was no re-emergence of weeds on the other plots treated with herbicides. By the sixth week after application, weeds re-emerged on all herbicide-treated and hand-weeded plots (Table 6). The predominant weed species were; *Cyperus rotundus*, *Commelina erecta*, and *Mimosa pudica* (Table 6). All herbicide-treated plots again had weed re-emergence by the ninth week after herbicide application. The common weed species were; *Cyperus rotundus, Mimosa pudica, Phyllantus amarus, Commelina erecta, and Oldenlandia corymbosa* (Table 6).

There were significant differences ($p < 0.05$) in the mean percentage weed cover of plots receiving herbicide and hand weeding control treatments at both sites (Table 7). By the third week after application of the treatments on the UG farm plots, all herbicide-treated plots were not covered by weeds, while plots with hand weeding control had (100 %) weed coverage. Similarly, the plots with hand weeding control on the PGRRI farm had significantly higher weed coverage (100 %) than any plot with herbicide treatment. Oxadiargyl application at a rate of 0.4 L/ha resulted in significantly higher weed coverage (6.5 %) than any other herbicide treatment (Table 7). At the sixth week after application of the treatments on the UG farm plots, weed cover on the hand-weeded plots was (52.5 %), but was not significantly different from weed cover (47.5 %) on plots with Oxadiargyl applied at 0.4 L/ha. Application of Pendimethalin at rates of 1.5, 2.0 and 2.5 L/ha respectively resulted in the lowest weed cover of (0.0 %). Similarly, on the PGRRI farm, all Pendimethalin rates of 1.5, 2.0 and 2.5 L/ha, respectively, resulted in significantly lower ($p < 0.05$) weed cover of (0.0 %) in comparison to the other herbicide treatments. Weed cover was significantly higher (70.5 %) with hand weeding treatment compared to all herbicide treatments (Table 7). At the ninth week after application of the treatments on the UG farm, the lowest percentage of weed cover (30.8 %) was recorded on plots treated with Pendimethalin at a rate of 2.5 L/ha. Hand weeding control resulted in the highest weed cover of (81 %), which was similar to (77 %) weed cover on plots treated with Oxadiargyl at 0.4 L/ha. At the PGRRI farm, hand weeding control treatment resulted in a significantly higher percentage weed cover (88 %) compared to all herbicide treatments except Oxadiargyl which was applied at 0.4 L/ha and a percentage weed cover of (83 %). Application of Pendimethalin at a rate of 2.5 L/ha resulted in the lowest percentage weed cover of (52 %), but was similar to percentage weed cover of (60.5 %) on plots treated with a Pendimethalin application of 1.5 L/ha and the percentage weed cover of (59.8 %) on plots treated with 2.0 l/ha (Table 7).

There was no significant difference ($p > 0.05$) in the height of pepper plants grown under the different weed control systems with Oxadiargyl and Pendimethalin at the UG farm, Legon, and the CSIR-PGRRI farm, Bunso, from the second to eighth week after transplanting (WAT). On the UG farm, by the 8th WAT, the tallest plants with a mean height of 52.8 cm were observed on plots treated with Pendimethalin at the rate of 2.5 L/ha. The shortest plants with an average height of 47.0 cm were recorded in plots treated with Oxadiargyl at 0.4 L/ha. At CSIR-PGRRI farm, Bunso, Pendimethalin applied at 2.5 L/ha had the tallest plants with an average height of 53.8 cm. The shortest plants, with a mean

Table 3
Weed species identified on experimental sites at CSIR-PGRRI farm, Bunso before application of Oxadiargyl (400 g/L) and Pendimethalin (500 g/L).

Weed type	Weed species	Weed population (%)	Family
Broadleaves	*Aspillia africana*	0.300	Asteraceae
	Chromolaena odorata	50.00	Asteraceae
	Heliotropium indicum	0.300	Boraginaceae
	Mimosa pudica	0.300	Fabaceae
	Pueraria phaseoloides	10.00	Fabaceae
	Puplia lappaceae	0.300	Amaranthaceae
	Sida acuta	3.00	Malvaceae
	Stachyterapheta cayennensis	0.300	Verbenaceae
	Tridax procumbens	4.00	Asteraceae
	Tephrosia purprea	0.300	Fabaceae
Sedges	*Cyperus rotundus*	0.300	Cyperaceae
Grasses	*Digitaria horizontalis*	0.300	Poaceae
	Panicum laxum	0.300	Poaceae
	Panicum maximum	30.00	Poaceae
	Sorghum arudinaceum	0.300	Poaceae

Table 4
Number of days to weed emergence after preemergence application of Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L EC herbicides in pepper.

Herbicides Rate		No. of Days to Weed Emergence	
	Rate (L/ha)	UG Research Farm	CSIR-PGRRI Farm
Oxadiargyl	0.4	29.3	21.8
Oxadiargyl	0.5	29.3	24.3
Oxadiargyl	0.6	31.8	27.8
Pendimethalin	1.5	49.0	33.0
Pendimethalin	2.0	54.3	35.3
Pendimethalin	2.5	57.5	36.5
Hand weeding	–	11.0	11.8
LSD ($p < 0.05$)		**3.2**	**2.3**

Table 5
Weed species re-emergence after application of pre-emergence herbicides in pepper plots at the UG farm, Legon.

Herbicides	Rate (L/ha)	Weed species at 3 WAP	Weed species at 6 WAP	Weed species at 9 WAP
Oxdiargyl	0.4	Nil	*Cyperus rotundus, Talinum triangulare, Mimosa pudica, Panicum maximum, Echinachiloa colona, Gumphrena celiodes*	*Senna obtusfolia, Cyperus rotundus, Mimosa pudica, Talinum triangulare, Portulaca quadrifolia, Sporobolus pyramidalis, Echinachiloa colona, Panicum maximum, Gumphrena celiodes*
Oxdiargyl	0.5	Nil	*Cyperus rotundus, Panicum maximum, Echinachiloa colona, Gumphrena celosiodes, Cyperus rotundus, Echinachiloa colona*	*Senna obtusfolia, Cyperus rotundus, Panicum maximum, Echinachiloa colona, Gumphrena celosiodes*
Oxdiargyl	0.6	Nil	Nil	*Senna obtusfolia, Cyperus rotundus, Echinachiloa colona*
Pendimethalin	1.5	Nil	Nil	*Senna obtusfolia, Cyperus rotundus, Mimosa pudica, Echinachiloa colona*
Pendimethalin	2.0	Nil	Nil	*Senna obtusfolia, Cyperus rotundus*
Pendimethalin	2.5	Nil	Nil	*Cyperus rotundus*
Hand weeding	No herbicide	*Cyperus rotundus, Panicum maximum, Brachiaria lata, Croton lobatus, Spigelia anthelmia, Mimosa pudica, Thrianthema purtulacastrum*	*Cyperus rotundus, Mimosa pudica, Euphorbia heterophylla, Commelina benghalensis, Phyllanthus amarus, Gumphrena celiodes*	*Cyperus rotundus, Mimosa pudica, Talinum triangulare*

WAP = Weeks after planting.

Table 6
Weed species re-emergence after application of pre-emergence herbicides in pepper at the CSIR-PGRRI farm.

Herbicides	Rate (L/ha)	Weed species at 3 WAP	Weed species at 6 WAP	Weed species at 9 WAP
Oxdiargyl	0.4	*Commelina erecta*	*C.rotundus, D. horizontalis, M. pudica, C.eracta, E.colona*	*C. rotundus, M. pudica, P. quadrifolia, D. horizontalis, P. maximum, P. amarus, C. eracta, T. triangulare, Oldenlandia. Corymbosa,*
Oxdiargyl	0.5	Nil	*C. rotundus, P. maximum, C. eracta, M. pudica,*	*C. rotundus, E. colona, P. maximum, C. erecta, P. amarus, M. pudica, O. corymbosa*
Oxdiargyl	0.6	Nil	*C. rotundus, P. maximum, C. erecta*	*C. rotundus, C. erecta, P. amarus, M. pudica, O. corymbosa*
Pendimethalin	1.5	Nil	*C. erecta, C. rotundus, P. amarus*	*C. erecta, C. rotundus, P. amarus, M. pudica, S. acuta, O. corymbosa*
Pendimethalin	2.0	Nil	*Cyperus rotundus, Commelina erecta, Mimosa pudica*	*Oldenlandia corymbosa, Chromolaena odorata, Phyllantus amarus, Commelina erecta, Cyperus rotundus, Mimosa pudica*
Pendimethalin	2.5	Nil	*Cyperus rotundus, Commelina erecta, Mimosa pudica*	*Phyllanthus amarus, Commelina erecta, Cyperus rotundus, Chromolaena odorata*
Hand weeding	No herbicide	*Cyperus rotundus, Panicum maximum, Commelina eracta, Mimosa pudica, Cyperus rotundus*	*Cyperus rotundus, Mimosa pudica, Panicum maximum, Heliotropium indicum, Commelina eracta, Thrianthema purtulacastrum, Echinachiloa colona*	*Cyperus rotundus, Mimosa pudica, Euphorbia heterophylla, Commelina erecta, Talinum triangulare, Heliotropium indicum, Panicum maximum, Phyllantus amarus, Oldenlandia corymbosa*

WAP = Weeks after planting.

height of 47.8 cm, were recorded in Pendimethalin at 1.5 L/ha treated plots.

Significant ($p < 0.05$) differences were observed in the mean number of branches of pepper plants under different treatments at the UG farm, Legon, and the CSIR-PGRRI farm, Bunso (Table 8). On the UG farm, plots treated with 2.0 L/ha Pendimethalin produced more branches (29.3) compared to plots treated with other rates of the two herbicides. However, the number of branches observed was not significantly different ($p > 0.05$) from that in hand-weeded plots (27.0) (Table 8). At the CSIR-PGRRI farm, Bunso, the number of branches on plants in plots treated with 2.0 L/ha Pendimethalin did not differ significantly ($p < 0.05$) from the number of plants in hand-weeded plots (64.8) and 0.6 L/ha (62.5) Oxadiargyl treated plots were significantly ($p < 0.05$) higher than plants in other treated plots (Table 8).

Table 7
Percentage weed cover in pepper plots as influenced by weed control with Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L EC.

Herbicides	Rate (L/ha)	Percentage weed cover					
		UG Research Farm			CSIR-PGRRI Farm		
		3	6	9	3	6	9
		WAH			WAH		
Oxadiargyl	0.4	0	47.5	77	6.5	64.5	83
Oxadiargyl	0.5	0	37.2	61.2	0	54.5	68.8
Oxadiargyl	0.6	0	28.5	53.8	0	41.5	65.2
Pendimethalin	1.5	0	0	36.5	0	0	60.5
Pendimethalin	2	0	0	34.5	0	0	59.8
Pendimethalin	2.5	0	0	30.8	0	0	52.0
Hand weeding	–	100	52.5	81	100	70.5	88.0
LSD ($p < 0.05$)		**2.3**	**11.9**	**11**	**2.5**	**5.6**	**12.1**

WAH= Weeks after application of herbicides.

Table 8
Mean number of branches at harvest of pepper as influenced by weed control with Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L EC.

Herbicides Rate	Rate (L/ha)	Mean Number of Branches	
		UG Research Farm	CSIR-PGRRI Farm
Oxadiargyl	0.4	24.5	53.8
Oxadiargyl	0.5	21.5	58.5
Oxadiargyl	0.6	25.8	62.5
Pendimethalin	1.5	23.0	61.8
Pendimethalin	2.0	29.3	69.8
Pendimethalin	2.5	23.8	59.8
Hand weeding	–	27.0	64.8
LSD ($p < 0.05$)		**3.4**	**7.5**

Significant ($p < 0.05$) differences in mean yield were observed between pepper plants in different treatment plots at the UG farm, Legon and the CSIR-PGRRI farm, Bunso (Table 9). At the UG farm, the treatment of pepper plants with Pendimethalin at 2.0 L/ha resulted in a considerably higher yield (6.01 t/ha) compared to that of plants in the other herbicide treated plots. The yield of plants in Pendimethalin at 2.0 L/ha treated plots was however not significantly ($p > 0.05$) different from that obtained in hand-weeded plots (5.76 t/ha). At the CSIR-PGRRI farm, plots treated with Pendimethalin applied at 2.0 L/ha gave the highest yield (23.05 t/ha) which was not significantly ($p < 0.05$) different from that obtained from plots treated with Oxadiargyl at 0.6 L/ha (21.04 t/ha) (Table 9). There were significant ($p < 0.05$) differences in mean fruit length, mean fruit diameter, mean fruit weight and the mean number of fruits per plant between treatments (Table 10). At the UG farm, hand-weeded plots had the longest mean fruit length of 7.13 cm, which was not significantly ($p < 0.05$) different from that observed in plots treated with Pendimethalin at 2.0 and 2.5 L/ha (Table 10). At the CSIR-PGRRI farm, plots of Oxadiargyl at 0.6 L/ha led to a significantly longer mean fruit length of 10.38 cm. This mean fruit length (10.38 cm) was not significantly ($p < 0.05$) different from that of (10.23 cm) observed in plots treated with Pendimethalin at 2.0 L/ha (Table 10). At the UG farm, fruits harvested from plots of Pendimethalin applied at 2.0 L/ha had a significantly wider mean diameter of 9.19 mm which was not significantly ($p < 0.05$) different from the diameter of fruits harvested from plots treated with Oxadiargyl applied at 0.5 and 0.6 L/ha and plots treated with Pendimethalin at 2.5 L/ha (Table 10). At the CSIR-PGRRI farm, there was no considerable difference in the diameter of harvested fruits among treatment plots. Plots treated with Pendimethalin at 2.5 L/ha gave the highest mean value of 12.32 mm while fruits from plants in plots of Oxadiargyl applied at 0.4 L/ha recorded the least mean value of 10.47 mm (Table 10). At the UG farm, fruits harvested from plots that received Pendimethalin at 2.0 L/ha recorded the highest fruit weight per plant of 192.4 g which was not significantly ($p < 0.05$) different from the weight of fruits (184.20 g) harvested per plant from hand-weeded plots (Table 10). Similarly, at the CSIR-PGRRI farm, fruits from plots of Pendimethalin applied at 2.0 L/ha had the highest fruit weight per plant of 737.6 g. This was however not significantly ($p < 0.05$) different from the weight of fruits per plant of 673.40 g harvested from plots treated with Oxadiargyl at 0.6 L/ha (Table 10). At the UG farm, fruits from plots treated with Pendimethalin at 2.0 L/ha had the highest number of fruits per plant of 65.25. This was not significantly ($p < 0.05$) different from the number of fruits per plant of 61.75 harvested from hand-weeded plots (Table 10). On the CSIR-PGRRI farm, plots applied Pendimethalin at 2.0 L/ha yielded the highest number of fruits per plant, 199.5. However, this was not significantly different ($p < 0.05$) from harvesting from plots with Oxadiargyl at 0.6 L/ha (192.00) and Pendimethalin at 2.5 l/ha 174.80 (Table 10).

Table 9
Yield of pepper as influenced by weed control with Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L EC.

Herbicides Rate	Rate (L/ha)	Yield (t/ha)	
		UG Research Farm	CSIR-PGRRI Farm
Oxadiargyl	0.4	2.96	15.58
Oxadiargyl	0.5	3.23	16.15
Oxadiargyl	0.6	4.61	21.04
Pendimethalin	1.5	3.36	17.30
Pendimethalin	2.0	6.01	23.05
Pendimethalin	2.5	3.49	19.13
Hand weeding	(No herbicide)	5.76	16.64
LSD ($p < 0.05$)		**0.83**	**3.68**

4. Discussion

Prior to land preparation, a total of nineteen and fifteen weed species were identified at the UG farm, Legon and the PGRRI farm, Bunso, respectively. The weeds were predominantly broadleaved weeds, followed by grasses and sedges. Pendimethalin at all rates, suppressed weed emergence more than Oxadiargyl which also, suppressed weed emergence more than hand weeding. Application of Pendimethalin resulted in the most effective weed control and longest time to weed emergence in pepper [9]. At both locations, application of pendimethalin at a rate of 2.5 L/ha resulted in the least weed cover and the longest number of days to weed emergence in pepper trials than the other treatments. The reason could be that Pendimethalin at a rate of 2.5 l/ha has a longer lasting effect in the soil, probably killing weed seeds and preventing them from germinating. But like all other herbicides, Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L are degradable over time. This is reflected in the general increase in weed population in pepper trials from week 6 in all herbicide-treated plots on the UG farm and the PGRRI farm. According to Ref. [10], pre-emergence herbicide treatments without additional hoeing could not ensure full-season weed control due to their short persistence. Chemostomp (Pendimethalin 500 g/L EC) effectively controlled both broadleaf weeds and grasses in chili pepper production up to about ten weeks after transplanting, requiring additional manual weed control [5]. The progressive loss of effectiveness of the Pendimethalin herbicide over time could be due to the volatile nature of the dinitroanaline herbicides [11,12]. Hand weeding control resulted in the least effective weed control and fewer days to weed emergence in all cases. Weeds such as *Cyperus rotundus*, *Talinum triangulare* and *Commelina erecta* were difficult to control with hand weeding because they have underground vegetative structures (rhizomes) that allow them to sprout easily under favourable conditions. Hand-weeding only affected the aerial parts, but other weeds also germinated because they reproduce vegetatively when in contact with the soil. Manual weed control could not suppress weed growth for long because there was no mechanism to prevent weed seed from germinating in the soil [13] as compared to pre-emergence herbicide weed

Table 10
Yield components of pepper as influenced by weed control with Oxadiargyl 400 g/L SC and Pendimethalin 500 g/L EC.

Herbicides		Yield (t/ha)							
	Rate	UG Research Farm				PGRRI Research Farm			
	(L/ha)	F. L (cm)	F.D (mm)	T.F·W (g)	N·F	F. L (cm)	F.D (mm)	T.F·W (g)	N·F
Oxadiargyl	0.4	4.65	7.52	94.8	47.25	9.55	10.47	498.7	154.8
Oxadiargyl	0.5	4.96	8.74	103.5	48.75	9.73	10.54	516.7	157.8
Oxadiargyl	0.6	5.67	8.59	147.6	56.75	10.38	11.17	673.4	192
Pendimethalin	1.5	5.35	7.71	107.6	51.75	9.70	11.25	553.6	157.2
Pendimethalin	2.0	6.32	9.19	192.4	65.25	10.23	11.41	737.6	199.5
Pendimethalin	2.5	6.24	8.54	111.7	51.25	9.85	12.32	612.3	174.8
Hand weeding	(No herbicide)	7.13	8.24	184.2	61.75	9.80	11.34	532.6	153.2
LSD ($P < 0.05$)		1.22	0.83	26.4	5.67	0.52	NS	117.8	27.3

F. L = Fruit length, F. D = Fruit diameter, Total Fruit Weight, Number of fruits.

control. The herbicides used in each case controlled the weeds more efficiently than manual weeding. Oxadiargyl treatment significantly reduced most annual weeds and increased growth and yield of onions [14,15]. According to Ref. [16], Oxadiargyl is a pre-emergence herbicide that is effective against grasses, broadleaf weeds and annual sedges and acts on germination when the new shoots come into contact with treated soil particles. Similar observations were made by Refs. [17,18].

Pepper height increased steadily from the second to eighth week after transplanting in all treated plots on both the UG and PGRRI research farms. No significant difference was observed between treatments in the second, fourth and sixth weeks after transplanting pepper plants [5]. There was no significant difference between the treatments, probably because the herbicides applied at different rates had no phytotoxic effect on pepper growth. The use of Pendimethalin resulted in taller plants with more leaves and branches in cowpea for two consecutive seasons [19]. The greater number of branches produced in plots with an application of Pendimethalin at 2.0 L/ha at both locations is possibly due to its ability to reduce weed infestation and its non-phytotoxic effect on pepper plants. Pre-emergence application of Pendimethalin at 1.5 L ha-1 or 2.0 L ha-1 at 3 DAP + manual weeding at 30 DAP increased plant height, number of leaves per plant and number of branches per plant by reducing weed populations and weed dry matter in cowpea fields [20]. Weeds compete with crops for space and other resources such as nutrients, water and air. Reduction in weed population after herbicide application plausibly reduced weed competition and allowed pepper plants to absorb needed plant resources for higher yields. According to Refs. [5,21,22,23], pepper plants in plots treated with Pendimethalin at a rate of 2.0 L/ha and 2.5 L/ha gave the highest yields, because the applied herbicides were effective fighting weeds at these rates. On the UG farm, the second highest yield was from pepper plants on plots treated with Oxadiargyl at a rate of 0.6 L/ha. This is probably because it was effective in controlling the weed population in pepper plots. However, there are differences in the effects of different herbicides and the rates used. Higher concentrations of Oxadiargyl have a phytotoxic effect on weeds, but can also have negative effects on pepper plants. Nevertheless, in this experiment the negative effect, if any, was not sufficient to kill pepper plants, but it probably resulted in a yield reduction in plots treated with Oxadiargyl 0.6 L/ha compared to the yield increase in pepper on plots treated with pendimethalin at 2.0 L/ha. Similar observations were made by Ref.[24] who found that seed germination and early growth of sunflower and maize plants were significantly affected by increased Oxadiargyl concentrations.

Weed control treatments had a major impact on the yield components of pepper plants as there were differences in most yield components studied. Among the treatments, application of Pendimethalin at a rate of 2.0 L/ha resulted in the highest increase in fruit diameter, total fruit weight and number of fruits per plant on the UG farm and total fruit weight and number of fruits in the study on the CSIR PGRRI farm. The effective weed control and non-phytotoxic effect of pendimethalin at 2.0 L/ha may have contributed to the increase in pepper yield components. This is consistent with the findings of [5].

5. Conclusion

The application of Pendimethalin was more effective in increasing the number of days to weed emergence than the application of Oxadiargyl and hand weeding. Pendimethalin applied at the rate of 2.0 L/ha resulted in higher pepper yields at both locations of the study while Oxadiargyl applied at the rate of 0.4 L/ha resulted in the lowest yield. Therefore, to obtain better pepper fruit yield in terms of quantity, the recommended rate of herbicides should be used to achieve effective reduction of weed populations and prevent adverse phytotoxic effects on plants.

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Declaration of competing interest

The authors declare that they have no conflict of interest regarding the publication of this study.

Data availability

Data will be made available on request.

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