Herbicide-based Weed Management for Enhanced Cowpea (*Vigna unguiculata*) Performance in Ghana's Semi-deciduous Forest Zone

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ABSTRACT

Background: This study evaluated the effects of herbicides on weed control and cowpea (*Vigna unguiculata*) performance in the semi-deciduous forest agro-ecological zone of Ghana.

Methods: Field experiments were conducted at Nkwanta (Ashanti region) and Abodom (Eastern region) using a single-factor, randomized complete block design with ten treatments and three replications. Treatments included one post-emergence herbicide (Agil 100 EC) applied at 2, 4 and 6 weeks after sowing (WAS), two pre-emergence herbicides (Butachlor 50% EC and Alligator 400 EC) and hand weeding at 2, 4 and 6 WAS as the control.

Result: At Nkwanta, the tallest cowpea plants were recorded with 3.6 mL a.i/ha of Butachlor 50% EC, while at Abodom, 1.8 mL a.i/ha of Agil 100 EC produced the greatest plant height. Branching at Nkwanta was highest with Alligator 400 EC at 4 and 6 WAS, whereas Abodom showed consistent branching responses across all intervals with Agil 100 EC. The application of Alligator 400 EC at 2 WAS and higher concentrations of butachlor 50% EC improved the canopy cover in Nkwanta, while the use of Alligator 400 EC in Abodom had the highest canopy spread. In both locations, the use of Butachlor 50% EC recorded the highest flowering and podding. The highest pod length and pods per plant were observed with manual weeding at 2, 4 and 6 WAS at Nkwanta, while the use of Alligator 400 EC recorded the highest pod performance in Abodom. The findings revealed a significant difference in the efficacy of the herbicide. Butachlor 50% EC improved growth metrics at Nkwanta and Agil 100 EC was most effective at Abodom.

Key words: Agronomic performance, Cowpea, Herbicide weed management, Pre-emergence herbicides, Post-emergence herbicides, Weed control efficacy.

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is known as a very important crop and a lifeline for many families in sub-Saharan Africa. Cowpea provides food security, essential revenue for cultivators, provide sustainable farming systems, especially in the savannah regions of West Africa (Valenzuela and Smith, 2002; Manibharathi *et al.,* 2024). Cowpea is cultivated on approximately 12.8 million hectares of land, producing about 7.6 million tonnes each year globally, which 87% of the total production coming from Africa (Abate *et al*., 2012). The main African countries that produce cowpea on a large scale include Nigeria, Niger, Senegal, Ghana, Mali and Burkina Faso (Langyintuo *et al.,* 2003; FAO, 2019). Cowpea is the second most essential legume in Ghana after groundnut (Asare *et al.,* 2020). Cowpea is mostly cultivated in communities in the Guinea and Sudan savannah zones, serving as an important protein source and supporting the community livelihoods (Al-Hassan and Diao, 2007).

Cowpea contains 25% of protein, essential micronutrients and can fix atmospheric nitrogen back into the soil. This makes it an ideal crop to be included in the crop rotation system (Sichone and Mweetwa, 2018; Simunji *et al.,* 2019). Aside from these benefits, the production of cowpea in the tropics is challenging. Aggressive weed competition largely reduces the productivity from 12.7% to over 70% (Gupta *et al.,* 2016; Ugbe *et al.,* 2016). Weeds compete with the cowpea crop for nutrients, light, moisture and also their ability to harbor pests and diseases, which increases production cost (Marinov-Serafimov, 2015).

With high labour costs and difficult manual weeding for large farms, the use of chemical weed control has become increasingly unavoidable (Manisankar *et al.,* 2022; Nath *et al.,* 2024; Rani *et al.,* 2024). The application of

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herbicides is crucial to finding the right dose to ensure the effective control of the weed without affecting the cowpea crop performance and total yield (Nath *et al.,* 2024; Nesha *et al.,* 2026). Therefore, it's very important to evaluate how specific herbicides and their application rates affect weed control and the agronomic performance within the semi-deciduous forest agro-ecological zone of Ghana.

MATERIALS AND METHODS

Experimental sites

Field trials were carried out in the 2023 cropping season at two separate sites, Abodom (Birim North District, Eastern Region) and Nkwanta (Mampong Municipality, Ashanti Region), Ghana. Abodom lies between latitude 6°20′18″N and longitude 0°59′44″W, elevated at 156 m above sea level, within the semi-deciduous forest zone. This trial site experience bimodal rainfall pattern, major season (March to July) and minor season (August to October). Yearly rainfall ranges from 1500 to 2000 mm, the average daily temperature is 25.2°C and the mean relative humidity is 55-59%. Soils are mainly silty sand, appropriate for cowpea production (Issaka *et al.,* 2012; Asubonteng *et al.,* 2001).

Nkwanta lies between latitude 01°45′N and longitude 1°24′W and is elevated at 402 m above sea level, positioned in the forest-savannah transitional zone. The area experiences bimodal rainfall, with yearly rainfall of 1094-1200 mm, major rains in (March to July) and minor rains in (August to November), with a daily average temperature of 30°C. Soils are well-drained, pebbly, moderately fertile, with a pH 6.0-6.5 and good water-holding capacity. Common weeds include *Cyperus rotundus*, *Cynodon plectostachus* and *Panicum maximum*. Nearly 80% of land is under smallholder cultivation (Tachie-Menson *et al.,* 2021; Bolfrey-Arku *et al.,* 2006).

Experimental design and treatments

Design

A single-factor experiment was laid out in a randomized complete block design (RCBD) with three replications at each site. Ten treatments were evaluated, with each replication containing ten plots of 4 m × 3 m, separated by 1 m between plots and 2 m between blocks, giving a total of 30 plots per site (529.5 m^2).

Treatments

Two pre-emergence herbicides (Butachlor 50 EC and Alligator 400 EC) were applied at three rates each and one post-emergence herbicide (Agill 100 EC) at three rates, along with a manual weeding control (2, 4, 6 WAS). The treatments were:

- T1: Butachlor 50 EC, 1.8 ml a.i./ha.
- T2: Butachlor 50 EC, 3.15 ml a.i./ha.
- T3: Butachlor 50 EC, 3.6 ml a.i./ha.
- T4: Alligator 400 EC, 1.62 ml a.i./ha.
- T5: Alligator 400 EC, 1.98 ml a.i./ha.
- T6: Alligator 400 EC, 2.16 ml a.i./ha.
- T7: Agill 100 EC, 1.08 ml a.i/ha at 2, 4, 6 WAS.
- T8: Agill 100 EC, 1.44 ml a.i/ha at 2, 4, 6 WAS.
- T9: Agill 100 EC, 1.8 ml a.i/ha at 2, 4, 6 WAS.
- T10: Manual weeding at 2, 4, 6 WAS.

Planting material

Cowpea variety 'Zamzam' was obtained from the Crop Research Institute, CSIR, Fumesua, Kumasi, Ashanti Region, Ghana.

Land preparation and sowing

Field preparation involved clearing with cutlasses and leveling with hand hoes. Planting at Abodom was on 20 May 2023 and at Nkwanta on 17 June 2023. Each plot had five rows, 0.6 m between rows, 0.2 m within rows, with one seed per hole at 4 cm depth, totaling 100 seeds per plot. No fertilizers were applied. Tools included meter rules and tapes (layout and growth measurements), pegs and tags (identification), knapsack sprayers (herbicide application) and electronic scales (grain measurement).

Soil physiochemical properties of the experimental sites

The two experimental sites differed considerably in soil physicochemical properties (Table 1). Abodom recorded higher organic carbon, organic matter, total nitrogen and ECEC (1.48%, 2.95%, 0.16% and 12.54 mol/kg) compared to Nkwanta (0.32%, 0.64%, 0.04% and 3.02 mol/kg), indicating greater inherent fertility. Both sites were slightly acidic (pH 5.69 and 5.65), though Abodom's silty loam texture contrasted sharply with Nkwanta's sandy soil, likely influencing water retention, nutrient availability and the differential herbicide and cowpea growth responses observed across locations.

Cultural practices

Manual weed control

Weeds were controlled by cutlass and hand-picking at 14-day intervals. Predominant weeds were *Cyperus* spp.

Chemical weed control

Pre-emergence herbicides were applied before sowing and post-emergence herbicides were applied at 2, 4 and 6 WAS, according to treatment rates.

Pest and disease management

Insect pests were controlled using emetine benzote (1.5 L/ha) and Karate 2.5 EC (50 ml per knapsack, 20 knapsacks/ha). Fungal diseases were monitored and controlled with Redomil at 1.5 kg/ha. Regular scouting was employed to detect early infections.

Data collection

Seedling emergence

Emergence counts were conducted within two weeks of sowing and the percentage emergence was calculated.

Growth parameters

Plant height, number of branches and canopy spread were measured on five tagged plants per plot at 2, 4 and 6 WAP using meter rules and tapes.

Phenological traits

Days to 50% flowering and podding were recorded visually.

Yield components

At harvest, the number of plants, pods per plant, pod length, seeds per pod, thousand-grain weight and net grain yield were determined from the net plot. Pods were sun-dried before measurements and seed weights were obtained using electronic scales.

Statistical analysis

Data were subjected to ANOVA and treatment means were separated using least significant difference (LSD) at 5% probability level. Assumptions of normality and homogeneity of variance were checked before analysis.

RESULTS AND DISCUSSION

Effect of herbicide on growth parameters of cowpea

Plant height (cm)

At 14 days after sowing (DAS), herbicide application did not significantly influence cowpea plant height at Nkwanta ($p = 0.377$). The highest plant height was observed under

Table 1: Preliminary chemical and physical characteristics of soil at the study sites at 0-15 cm.

	Abodom	Nkwanta
% Organic carbon	1.48	0.32
% Organic matter	2.95	0.64
% Total nitrogen	0.16	0.04
% Base saturation	98.05	86.75
Exchangeable cations (mol/kg)		
Ca	9.59	1.92
Mg	2.34	0.64
K	0.57	0.05
Na	0.04	0.01
P	3.56	8.43
pH (1:2.5 H_2O)	5.69	5.65
Total exchangeable base (mg/kg)		
Acidity (H+Al)	0.25	0.40
Effective cation exchange capacity (ECEC)	12.54	3.02
% Sand	38.00	90.00
% Silt	58.00	6.00
% Clay	4.00	4.00
Soil texture class	Silty loam	Sand

Table 2: Effect of different rates of herbicides on cowpea plant height (cm).

Treatment	Nkwanta			Abodom		
	14 DAS	28 DAS	42 DAS	14 DAS	28 DAS	42 DAS
Butachlor 50% EC 1.8 mL	6.99[a]	14.90[a]	34.93[ab]	7.34[bcd]	16.55[abc]	45.24[cd]
Butachlor 50% EC 3.15 mL	6.96[a]	14.79[a]	29.15[b]	6.95[cd]	14.77[bc]	44.28[de]
Butachlor 50% EC 3.6 mL	7.63[a]	16.17[a]	39.08[a]	6.15[d]	12.21[c]	32.86[e]
Alligator 400 EC 1.62 mL	7.03[a]	15.09[a]	27.56[b]	9.48[abc]	20.55[ab]	48.75[cd]
Alligator 400 EC 1.98 mL	7.29[a]	15.23[a]	30.29[ab]	9.69[abc]	21.89[ab]	49.84[bcd]
Alligator 400 EC 2.16 mL	6.79[a]	14.90[a]	32.68[ab]	8.71[abcd]	18.62[abc]	52.88[abcd]
Agil 100 EC 1.08 mL	7.39[a]	15.95[a]	31.55[ab]	11.06[a]	23.93[a]	56.56[abc]
Agil 100 EC 1.44 mL	6.79[a]	14.79[a]	37.11[ab]	10.35[ab]	22.97[a]	54.67[abcd]
Agil 100 EC 1.8 mL	7.32[a]	15.58[a]	32.73[ab]	11.16[a]	24.05[a]	63.41[a]
Control (Manual weeding)	7.32[a]	16.07[a]	34.75[ab]	10.09[ab]	21.12[ab]	52.86[abcd]
HSD-value (0.05)	1.35	2.94	9.61	3.02	8.07	12.06
p-value	0.37	0.52	0.01	0.00	0.00	0.00
CV (%)	6.41	6.53	9.84	11.06	13.82	7.99

Values with the same letter are not significantly different at $p \leq 0.05$. DAS= Days after sowing, mls= Millilitres, a.i= Active ingredient, ha= Hectare.

3.6 mL a.i./ha of Butachlor 50% EC, while the lowest occurred with 1.44 mL a.i./ha of Agil 100 EC. In contrast, plant height at Abodom differed significantly among treatments at the same growth stage ($p<0.05$), with 1.8 mL a.i./ha of Agil 100 EC producing the tallest plants and 3.6 mL a.i./ha of Butachlor 50% EC the shortest, excluding the control (Table 2).

At 28 DAS, no significant variation in plant height was recorded among treatments at Nkwanta ($p=0.524$). Here, 3.6 mL a.i./ha of Butachlor 50% EC resulted in the greatest height, while 3.15 mL a.i./ha of the same herbicide gave the lowest. However, a highly significant treatment effect was observed at Abodom ($p<0.0003$), where 1.8 mL a.i./ha of Agil 100 EC produced the maximum plant height and 3.6 mL a.i./ha of Butachlor 50% EC the minimum.

By 42 DAS, plant height at Nkwanta differed significantly among herbicide treatments ($p<0.011$), with the tallest plants recorded under 3.6 mL a.i./ha of Butachlor 50% EC and the shortest under 1.62 mL a.i./ha of Alligator 400 EC. Similarly, a significant treatment effect was observed at Abodom (p = 9.28E), where 1.8 mL a.i./ha of Agil 100 EC consistently produced the greatest plant height, while 3.6 mL a.i./ha of Butachlor 50% EC resulted in the least (Table 2).

Number of branches

Herbicide active ingredient rates had no statistically significant effect on cowpea branching at 14, 28, or 42 DAS at Nkwanta ($p>0.05$) and a comparable lack of significance was observed at Abodom across all assessment periods (Table 3). Despite the absence of significant differences, treatment-related numerical trends were evident. At 14 DAS in Nkwanta, the weeded control recorded the highest branch number, while the lowest values occurred under 1.8 and 3.15 mL a.i./ha of Butachlor 50% EC. Conversely, at Abodom, 1.44 mL a.i./ha of Agil 100 EC produced the highest branch count, whereas the weeded control recorded the lowest. By 28 DAS, branching at Nkwanta peaked under 1.62 mL a.i./ha of Alligator 400 EC and declined most under 3.6 mL a.i./ha of Butachlor 50% EC. At Abodom, the highest and lowest values were associated with 1.8 mL a.i./ha of Agil 100 EC and 1.62 mL a.i./ha of Alligator 400 EC, respectively. At 42 DAS, the highest branch number at Nkwanta occurred under 2.16 mL a.i./ha of Alligator 400 EC, with the lowest recorded at 3.6 mL a.i./ha of the same herbicide. In Abodom, 1.44 mL a.i./ha of Agil 100 EC resulted in the highest branching, while 1.98 mL a.i./ha of Alligator 400 EC produced the lowest (Table 3).

Canopy spread (cm)

Canopy spread of cowpea at Nkwanta was not significantly influenced by herbicide active ingredient concentration at any sampling time (14, 28, or 42 DAS; $p>0.05$). In contrast, significant treatment effects were observed at Abodom across all measurement periods ($p<0.05$). At 14 and 28 DAS, plots treated with 1.8 mL a.i./ha of Agil 100 EC (applied at 2, 4 and 6 WAS) recorded the greatest canopy spread and differed significantly from those treated with 3.6 mL a.i./ha of Butachlor 50% EC. By 42 DAS, the widest canopy was associated with 2.16 mL a.i./ha of Alligator 400 EC, which was significantly higher than values obtained under butachlor 50% EC (3.6 mL a.i./ha), Agil 100 EC (1.8 mL a.i./ha) and the manually weeded control (Table 4).

Days to 50% flowering

The days to 50% flowering of cowpea further showed significant differences ($p<0.0002$) among the various herbicide active ingredient concentrations for the days to 50% flowering in Nkwanta with 3.6 mL a.i/ha of Butachlor 50% EC had recorded the maximum and 2.16 mL a.i/ha of Alligator 400 EC had recorded the minimum whiles there was no significant difference ($p= 0.4176$) among the various herbicide

Table 3: Number of branches of cowpea under different herbicide treatments.

Treatment	Nkwanta			Abodom		
	14 DAS	28 DAS	42 DAS	14 DAS	28 DAS	42 DAS
Butachlor 50% EC 1.8 mL	0.07[a]	2.47[a]	4.60[a]	0.80[a]	2.60[a]	4.93[a]
Butachlor 50% EC 3.15 mL	0.07[a]	2.53[a]	4.47[a]	0.93[a]	2.73[a]	4.67[a]
Butachlor 50% EC 3.6 mL	0.13[a]	1.93[a]	3.93[a]	1.00[a]	3.00[a]	5.07[a]
Alligator 400 EC 1.62 mL	2.33[a]	3.80[a]	5.93[a]	0.93[a]	2.47[a]	4.60[a]
Alligator 400 EC 1.98 mL	2.00[a]	3.53[a]	5.93[a]	1.00[a]	2.53[a]	4.40[a]
Alligator 400 EC 2.16 mL	2.13[a]	3.60[a]	6.07[a]	1.07[a]	2.87[a]	4.87[a]
Agil 100 EC 1.08 mL	2.13[a]	3.27[a]	5.80[a]	0.80[a]	2.53[a]	4.20[a]
Agil 100 EC 1.44 mL	1.07[a]	2.87[a]	4.80[a]	1.40[a]	3.00[a]	5.13[a]
Agil 100 EC 1.8 mL	1.67[a]	3.40[a]	5.40[a]	0.93[a]	3.13[a]	5.00[a]
Control (Manual weeding)	2.40[a]	3.33[a]	5.47[a]	0.73[a]	2.60[a]	4.53[a]
HSD-value (0.05)	2.95	2.15	2.24	1.14	1.25	1.65
p-value	0.02	0.12	0.03	0.72	0.47	0.43
CV (%)	27.5	23.7	14.5	22.3	15.2	11.7

Values with the same letter are not significantly different at $p \leq 0.05$. DAS= Days after sowing, mls= Millilitres, a.i= Active ingredient, ha= Hectare.

Table 4: Canopy spread (cm) of cowpea under different herbicide treatments.

Treatment	Nkwanta			Abodom		
	14 DAS	28 DAS	42 DAS	14 DAS	28 DAS	42 DAS
Butachlor 50% EC 1.8 mL	11.15^{a}	23.21^{a}	50.40^{a}	16.57^{bc}	35.05^{bc}	66.57^{cd}
Butachlor 50% EC 3.15 mL	10.86^{a}	22.53^{a}	50.71^{a}	18.69^{abc}	38.20^{abc}	68.68^{bcd}
Butachlor 50% EC 3.6 mL	11.17^{a}	23.45^{a}	52.71^{a}	15.26^{c}	31.17^{c}	58.33^{d}
Alligator 400 EC 1.62 mL	10.21^{a}	21.21^{a}	45.42^{a}	22.29^{a}	44.64^{a}	72.37^{bc}
Alligator 400 EC 1.98 mL	10.73^{a}	22.05^{a}	49.60^{a}	22.44^{a}	42.40^{ab}	71.00^{bc}
Alligator 400 EC 2.16 mL	11.23^{a}	23.29^{a}	48.29^{a}	19.84^{abc}	41.07^{ab}	87.91^{a}
Agil 100 EC 1.08 mL	11.07^{a}	21.59^{a}	51.36^{a}	21.57^{a}	41.41^{ab}	78.61^{ab}
Agil 100 EC 1.44 mL	10.73^{a}	21.64^{a}	50.31^{a}	20.27^{ab}	40.52^{ab}	68.87^{bcd}
Agil 100 EC 1.8 mL	10.95^{a}	23.33^{a}	50.27^{a}	22.03^{a}	42.75^{a}	69.93^{bcd}
Control (Manual weeding)	10.67^{a}	22.27^{a}	49.74^{a}	22.45^{a}	41.45^{ab}	69.31^{bcd}
HSD-value (0.05)	2.12	5.83	16.56	4.7	7.59	11.61
p-value	0.55	0.42	0.76	0.00	0.00	0.00
CV (%)	6.55	8.7	11.13	7.9	6.47	5.51

Values with the same letter are not significantly different at $p \leq 0.05$. DAS= Days after sowing, mls= Millilitres, a.i= Active ingredient, ha= Hectare.

Table 5: Days to 50% flowering of cowpea.

Treatment	Nkwanta	Abodom
Butachlor 50% EC 1.8 mL	40.33^{ab}	38.67^{a}
Butachlor 50% EC 3.15 mL	42.00^{a}	41.00^{a}
Butachlor 50% EC 3.6 mL	42.33^{a}	40.67^{a}
Alligator 400 EC 1.62 mL	35.33^{abc}	36.33^{a}
Alligator 400 EC 1.98 mL	38.33^{abc}	39.33^{a}
Alligator 400 EC 2.16 mL	32.67^{c}	40.00^{a}
Agil 100 EC 1.08 mL	33.67^{bc}	38.67^{a}
Agil 100 EC 1.44 mL	34.67^{bc}	38.00^{a}
Agil 100 EC 1.8 mL	34.00^{bc}	38.67^{a}
Control (Manual weeding)	34.67^{bc}	36.00^{a}
HSD-value (0.05)	7.10	8.48
p-value	0.00	0.42
CV (%)	6.56	7.46

Values with the same letter are not significantly different at $p \leq 0.05$. DAS= Days after sowing, mls= Millilitres, a.i= Active ingredient, ha= Hectare.

active ingredient concentrations for the days to 50% flowering in Abodom at the rate of 3.15 mL a.i/ha of Butachlor 50% EC had recorded the maximum and weeding at (2, 4 and 6 WAS) as control had recorded the minimum (Table 5).

Days to 50% podding

The results from (Table 6) for the days to 50% podding of cowpea indicated significant differences (p<1.77E-06) among the various concentrations of herbicide active ingredient in Abodom with the rate of 1.8 mL a.i/ha of Butachlor 50% EC had recorded the maximum and weeding at (2, 4 and 6 WAS) as control had recorded the minimum whiles there were no significant differences (p>0.2004) for the days to 50% podding of cowpea in Nkwanta with the rate of 3.6 mL a.i/ha of Butachlor 50% EC had recorded the maximum and 1.08 mL a.i/ha of Agil 100 EC (2, 4 and 6 WAS) had recorded the minimum.

Yield and yield-related parameters

Effect of herbicide application on cowpea yield and yield components

At Nkwanta, cowpea yield and its associated components were not significantly influenced (p>0.05) by the different herbicide active ingredient rates applied. Pod length, number of pods per plant, seeds per pod, thousand-seed weight and grain yield remained statistically comparable across treatments. Nonetheless, numerical variations were observed. The longest pods occurred under the weeding treatment, whereas the shortest pods were recorded at 3.15 mL a.i./ha of Butachlor 50% EC. The highest number of pods per plant was obtained at 1.08 mL a.i./ha of Agil 100 EC, while the lowest was observed at 3.6 mL a.i./ha of Butachlor 50% EC. Seeds per pod peaked at 1.8 mL a.i./ha of Butachlor 50% EC and declined at 3.15 mL a.i./ha of the same herbicide. Thousand-seed weight was greatest at 3.15 mL a.i./ha of Butachlor 50% EC and lowest at 1.44 mL a.i./ha of Agil 100 EC. Grain yield was numerically highest at 1.62 mL a.i./ha of Alligator 400 EC and lowest at 3.6 mL a.i./ha of Butachlor 50% EC (Table 7).

In contrast, at Abodom, herbicide treatments significantly affected pod length and grain yield. Pod length was highest under the weeding treatment and lowest at 3.6 mL a.i./ha of Butachlor 50% EC. Grain yield reached its maximum at 1.62 mL a.i./ha of Alligator 400 EC and 1.8 mL a.i./ha of Agil 100 EC. However, pods per plant, seeds per pod and thousand-seed weight did not differ significantly among treatments. Despite this, the highest number of pods per plant was observed at 1.62 mL a.i./ha of Alligator 400 EC, while the lowest occurred at 1.8 mL a.i./ha of Agil

100 EC. Seeds per pod were highest at 2.16 mL a.i./ha of Alligator 400 EC, with the lowest values recorded at 1.8 and 3.6 mL a.i./ha of butachlor 50% EC (Table 7).

Effects of herbicide regimes on vegetative growth

Plant height

Cowpea height showed a strong site × herbicide interaction, revealing itself in radically different responses at Nkwanta and Abodom. At Nkwanta, variation in herbicide rate did not affect the early vegetative development, with differences that are statistically significant appearing only at later stages of growth. On the other hand, cowpea maintained at Abodom recorded vigorous and sustained response to treatment during the entire period of growth, implying that plant growth at this site was more sensitive to weed management practices under prevailing environmental conditions.

These different reactions match up with the ways the herbicides work and how picky they are. Butachlor is a pre-emergence chloroacetanilide that mostly keeps sprouting weeds in check, but can put some pressure on the crop when used at higher doses. Pendimethalin (Alligator 400 EC) also interferes with the growth of roots and shoots of weeds at the initial stage of their emergence. In contrast, Agil 100 EC (propaquizafop), a selective post-emergence herbicide for the control of grasses, is safe to broadleaved crops such as cowpea. This, therefore, means that the superior plant height recorded under the Agil treatments at Abodom could be attributed to adequate post-emergence grass control, which reduced competition for light, water and nutrients under high weed pressure conditions. A similar trend has, however, been reported across all agroecological conditions. Cruz *et al.* (2020) noted that the integrated herbicide program, which controlled grasses, resulted in greater height of cowpea, while Yadav *et al.* (2017) noted better vegetative growth from the application of pendimethalin, supported by subsequent control of weeds. Selective herbicides and hoe weeding have also been found to increase the height of cowpea as compared to unweeded plots by Kumar *et al.* (2025), though responses were seasonal. Such a relatively lower response at Nkwanta can be attributed to site limitations comprising lower rainfall, higher temperatures and well-drained pebbly soils that reduce weed competition, plus less dynamic benefit from capture resources facilitated by herbicide intervention (Guuroh *et al.,* 2025). This interpretation is an inspiration from Kusi *et al.* (2025), who found strong genotype × environment interaction effects on growth performance across locations in Ghana.

Branching

Branching exhibited very low sensitivity to the herbicide treatments at both locations, with only slight numerical differences among regimes. This clearly shows that in the Zamzam cowpea variety, branching is relatively less responsive to moderate contrasts of weed management compared to such attributes as plant height or canopy expansion and more so, largely dependent on inherent genetic controls and general resource status (Ibrahim, 2013; Wang *et al.,* 2006).

These results fall in line with earlier reports that stated, when interference from weeds is properly controlled, differences in weed control strategies have a negligible effect on branch and leaf production (Ali *et al.,* 2015; Felix *et al.,* 2019). Works of literature available further go ahead to note that the flexibility of branching in cowpea is prompted by plant population density and nutrient availability rather than minor variations among equally effective options for weed management (Satodiya *et al.,* 2015; Helmy *et al.,* 2015).

Canopy spread

Responses in canopy spread varied markedly between sites. At Nkwanta, canopy development was largely unaffected by the herbicide regimes, while at Abodom, distinct and consistent treatment effects were evident throughout the crop growth cycle. Notably, applications of Agil 100 EC and the higher doses of Alligator 400 EC repeatedly resulted in broader canopy expansion, whereas increased rates of Butachlor were linked to comparatively restricted canopy growth. It demonstrates the importance of effective grass weed control in places like Abodom, where conditions favor the quick establishment of weeds. Propaquizafop-based herbicides selectively control grassy weeds, allowing for encouraging canopy closure, which will later suppress other secondary weeds by their shading effect (Attri *et al.,* 2022; Bhullar *et al.,* 2015). Better canopy spread improves light capture and radiation use efficiency supports more biomass production. Results that were comparable have been recorded from the cowpea production systems where all pre-emergence herbicides were based on pendimethalin and the timeliness of supplementary control measures enhanced canopy development more than when applied singly or with late hand-weeding (Nath *et al.,* 2024). It was due to different

Table 6: Days to 50% podding of cowpea.

Treatment	Nkwanta	Abodom
Butachlor 50% EC 1.8 mL	49.00[a]	49.67[a]
Butachlor 50% EC 3.15 mL	47.67[a]	49.33[a]
Butachlor 50% EC 3.6 mL	50.00[a]	48.67[ab]
Alligator 400 EC 1.62 mL	42.00[a]	42.67[c]
Alligator 400 EC 1.98 mL	46.33[a]	40.67[c]
Alligator 400 EC 2.16 mL	43.67[a]	41.67[c]
Agil 100 EC 1.08 mL	41.33[a]	43.67[bc]
Agil 100 EC 1.44 mL	43.00[a]	42.33[c]
Agil 100 EC 1.8 mL	45.67[a]	41.33[c]
Control (Manual weeding)	42.67[a]	41.00[c]
HSD-value (0.05)	12.16	5.14
p-value	0.20	0.00
CV (%)	9.17	3.97

Values with the same letter are not significantly different at $p \leq 0.05$. DAS= Days after sowing, mls= Millilitres, a.i= Active ingredient, ha= Hectare.

Table 7: Effect of herbicides on cowpea yield and yield parameters.

Treatment	Nkwanta					Abodom				
	PL	PP	SP	TSW	GY	PL	PP	SP	TSW	GY
Butachlor 50% EC 1.8 mL	13.43^{a}	15.40^{a}	11.40^{a}	178.73^{a}	520.60^{a}	16.19^{ab}	20.53^{a}	13.60^{a}	189.40^{a}	1017.59^{abc}
Butachlor 50% EC 3.15 mL	12.70^{a}	14.43^{a}	10.80^{a}	187.57^{a}	467.45^{a}	16.13^{ab}	20.93^{a}	12.27^{ab}	184.13^{a}	969.68^{bc}
Butachlor 50% EC 3.6 mL	13.45^{a}	13.70^{a}	11.27^{a}	171.80^{a}	406.25^{a}	15.14^{b}	20.47^{a}	11.13^{b}	184.10^{a}	968.84^{bc}
Alligator 400 EC 1.62 mL	13.28^{a}	16.17^{a}	11.20^{a}	177.23^{a}	683.70^{a}	17.23^{a}	21.97^{a}	13.13^{ab}	193.57^{a}	1124.63^{a}
Alligator 400 EC 1.98 mL	12.84^{a}	15.37^{a}	11.00^{a}	169.40^{a}	532.36^{a}	16.24^{ab}	21.13^{a}	12.60^{ab}	192.03^{a}	978.33^{bc}
Alligator 400 EC 2.16 mL	13.01^{a}	14.67^{a}	11.27^{a}	170.17^{a}	520.46^{a}	16.74^{ab}	20.73^{a}	13.67^{a}	189.20^{a}	997.45^{abc}
Agil 100 EC 1.08 mL	13.27^{a}	16.27^{a}	11.13^{a}	182.90^{a}	643.38^{a}	16.10^{ab}	20.40^{a}	13.00^{ab}	186.70^{a}	1020.93^{abc}
Agil 100 EC 1.44 mL	13.10^{a}	14.98^{a}	10.87^{a}	167.77^{a}	429.91^{a}	16.32^{ab}	21.83^{a}	13.47^{ab}	192.57^{a}	1059.12^{abc}
Agil 100 EC 1.8 mL	13.38^{a}	15.65^{a}	11.20^{a}	172.53^{a}	569.54^{a}	17.03^{a}	19.37^{a}	13.33^{ab}	189.70^{a}	940.83^{c}
Control (Manual weeding)	13.53^{a}	16.02^{a}	11.07^{a}	180.27^{a}	503.01^{a}	16.51^{ab}	20.43^{a}	12.93^{ab}	184.57^{a}	988.19^{abc}
HSD-value (0.05)	2.35	5.60	2.54	28.12	620.50	1.80	3.13	2.46	18.88	137.99
p-value	0.92	0.42	0.99	0.22	0.78	0.03	0.21	0.06	0.59	0.00
CV (%)	6.02	12.24	7.71	5.45	18.80	3.72	5.10	6.47	3.39	4.61

Values with the same letter are not significantly different at $p \leq 0.05$. DAS= Days after sowing, mls= Milliliters, a.i= Active ingredient, ha = Hectare, PL= Pod length, PP= Pods per plant, SP= Seeds per pod, TSW= Thousand seeds weight, GY= Grain yield. 1.8 mL Buta 50% EC= 1.8 mL a.i/ha of butachlor 50% EC, 3.15 mL buta 50% EC= 3.15 mL a.i/ha of butachlor 50% EC, 3.6 mL buta 50% EC= 3.6 mL a.i/ha of butachlor 50% EC, 1.62 mL Alli 400 EC= 1.62 mL a.i/ha of alligator 400 EC, 1.98 mL Alli 400 EC = 1.98 mL a.i/ha of alligator 400 EC, 2.16 mL Alli 400 EC= 2.16 mL a.i/ha of alligator 400 EC, 1.08 mL agil 100 EC= 1.08 mL a.i/ha of agil 100 EC 2, 4 and 6 WAS), 1.44 mL agil 100 EC= 1.44 mL a.i/ha of agil 100 EC (2, 4 and 6 WAS), 1.8 mL agil 100 EC= 1.8 mL a.i/ha of agil 100 EC (2, 4 and 6 WAS).

environmental and soil characteristics. Rainfall was somewhat better at Abodom, with silty sandy soils probably encouraging more vigorous competition from weeds, thus increasing the importance of early chemical input for maximum canopy expansion (Dieleman *et al.,* 2000; Anorvey *et al.,* 2018). There is a relatively drier transitional climate at Nkwanta, accompanied by a different species composition of weeds-herbs may not be so competitive here; hence, less apparent influence of herbicide treatment on canopy development (Anorvey *et al.,* 2018).

Phenological responses: Flowering and podding

The herbicide treatments induced generally slight and location-specific effects on cowpea phenological development. Flowering time varied slightly between treatments at Nkwanta, with higher rates of Butachlor application delaying the onset of flowering, most likely due to initial herbicide stress or changes in early crop-weed dynamics. This, therefore, indicated a strong phenological plasticity under specific environmental conditions prevailing at the site since flowering at Abodom was not responsive to the applied herbicide regimes (Quee *et al.,* 2021). Patterns seen for podding further emphasize the role of local factors in guiding herbicide effects. Podding time at Nkwanta stayed mostly the same among treatments, while clear differences showed at Abodom. Some butachlor uses delayed pod start when compared to manual weeding. Delays might be associated with slower crop recovery or short-term effects of herbicides under high humidity conditions with high weed pressure. Such trends corroborate earlier studies that asserted that pre-emergence herbicides, especially when applied at higher rates, may instigate minor delays in the development of crops (Quee *et al.,* 2021; Ezebuiro *et al.,* 2021). Normally, these shifts are limited and do not necessarily result in yield penalties (Cruz *et al.,* 2020; Arshad *et al.,* 2025). In a related situation, found that hoe weeding usually encourages an earlier start of flowering and pod formation compared to chemical control of weeds (Dennis *et al.,* 2024).

Overall, the mild and localized phenological reactions observed in the current experiment confirm the high tolerance of the Zamzam cowpea variety. But under agro-ecosystems which are characterized by a short growing period or high risk of terminal drought, even small delays in developmental stages might be agronomically meaningful and warrant more detailed analysis (Quee *et al.,* 2021).

Effects on yield and yield components

Grain yield and its contributing characters were highly site-specific and treatment effects were more pronounced at Abodom than at Nkwanta. No significant differences in any yield component or overall grain yield were observed at Nkwanta, suggesting that the effectiveness of the weed control treatments evaluated was similar at this site.

In contrast, the effects of treatments at Abodom were highly significant, especially for pod length and grain yield. Alligator 400 EC and Agil 100 EC at intermediate application rates contributed to maximum grain yields, while higher rates of Butachlor were associated with lesser performance. The lack of consistent differences among individual yield components indicated that the yield responses observed resulted mainly from a general improvement in plant growth and vigor rather than from isolated reproductive attributes (Ebone *et al*., 2020; Dias *et al*., 2011).

The results line up with earlier studies showing that Butachlor's effectiveness really depends on how much you use and what the environment's like. Just dumping more doesn't always mean you'll get better yields (Chongdar *et al*., 2016). Other research from West Africa and South Asia found that cowpea yields improved with pendimethalin-based pre-emergence herbicides, especially when farmers combined them with good agronomic practices (Ibrahim, 2013). In this study, moderate doses of Alligator 400 EC kept yield numbers high, while hand weeding made pods longer but didn't always boost the grain yield. That fits with what Dennis *et al*. (2024) found, which showed that carefully managed herbicide use can match or even beat hand weeding, plus it saves a lot of labor.

CONCLUSION

This study shows that chemical weed control really shapes how cowpea plants grow, develop and yield, but the results depend a lot on which herbicide you use, how much you apply and the local environment. At the Nkwanta site, spraying Butachlor 50% EC before the plants emerged (at 3.6 mL a.i./ha) led to strong, tall plants. But at Abodom, the best plant height and canopy came from using Agil 100 EC (1.8 mL a.i./ha) after the plants were up. No matter the treatment or location, branching didn't respond much to the herbicides, which indicates that genetics drives this trait more than weed management practices.

Grain yield and yield components played out differently depending on the site. In Nkwanta, changing the type or amount of herbicide barely touched the yield, so performance stayed steady across treatments. But in Abodom, yields improved when Alligator 400 EC at 1.62 mL a.i./ha or Agil 100 EC at 1.8 mL a.i./ha were applied. Clearly, knocking back grass weeds matters more in spots with heavier weed pressure. Increasing herbicide doses higher, especially with Butachlor, didn't boost yields much and sometimes even slowed down the plants' move into reproductive stages.

Altogether, the results showed that using moderate amounts of herbicide works better than going heavy and post-emergence, grass-targeting sprays really help when weeds are thick. The big influence of location on how treatments work just shows that blanket herbicide advice doesn't cut it; farmers need weed control plans that fit their specific fields. Further research such as how long herbicide residues stick around, the best timing for applications and how different cowpea varieties react to these chemicals. Results will help build more sustainable and productive cowpea farming systems.

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Conflict of interest

All authors declare that they have no conflict of interest.

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