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Differential responses of two cowpea (*Virgina unguiculata* L.Walp.) genotypes to pre-emergence herbicides in the savannah woodland and rainforest agroclimatic regions of Sierra Leone

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Abstract

Field trials were conducted in savannah woodland (Njala) and rainforest (Serabu) agroclimatic regions of Sierra Leone during 2016 second cropping season to assess different preemergence herbicides techniques that is efficient, cost effective and environmentally safe in cowpea production. The experiment consisted of 20 treatments which included 2 cowpea genotypes (slipea 4 and slipea 5) and 10 different weed control techniques viz: butachlor 50% emulsifiable concentrate (EC), double force®, power force® applied as preemergence herbicides at 2, 4 and 6 L ha^{-1}, respectively and weedy check. The treatments were laid out in a strip-plot design arranged in a factorial system with three replications. The results of this study revealed that the application of power force® at 6 L ha^{-1} recorded the highest phytotoxic effect, lowest weed dry weight, number of pods per plant and grain yield, highest total variable cost, lowest gross and net returns. Furthermore, butachlor 50% EC at 2 L ha^{-1} closely followed by double force® at 6 L ha^{-1} resulted in maximum grain yield, gross and net returns compared to the rest of the other weed control techniques. Thus, it is concluded that butachlor 50% EC at 2 L ha^{-1} was more economical, profitable and beneficial than other control treatments in the production of cowpea genotypes in the savannah woodland and rainforest agroclimatic regions of Sierra Leone. Conclusively, the relationship between phytotoxicity and grain yield indicates that the higher the grain yield the lower the phytotoxic effects of the chemicals.

Keywords: Cowpea; Butachlor 50% EC; Double force®; Power force®; Partial budget; Agroclimatic regions

1. Introduction

Cowpea (*Vigna unguiculata* (L) Walp.) belonging to fabaceae family and genus *Vigna* is one of the widely cultivated annual herbaceous legume crop in the savannah region of West Africa [1, 2, 3]. According to [4] and [5] the world estimated annual production of cowpea is about 4.5 million tonnes from a land area of 12.6 million hectares and West Africa accounts for about 80% of the estimated total land area under cowpea cultivation.

Among African leafy vegetables, cowpea hold high potential in solving food insecurity menace and improving livelihoods in Sub-Saharan Africa [6]. It is the most significant multifunctional and integral components of subsistence cropping system grown extensively under tropical and sub-tropical areas of the world [7]. Cowpea leaves can be used as fresh green vegetables, fermented or sun-dried and are rich in vitamins, macro and micro minerals, flavonoids, antioxidants, ß-carotene, fatty acids, amino acids, carbohydrates and dietary [8, 9, 10, 11].

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Nevertheless, the sustainable production of cowpea in Sierra Leone is limited by weed infestation, insect attack and low soil fertility [12]. Among these limitations, weeds constitute the most important constraints that influence cowpea production in the tropics as they compete with crops, reduce their growth rate, quantity and quality of grain yield as well as increase the cost of production due to insects and plant disease control [13, 14, 15, 16]. According to [17], competition of weeds with crops is mainly for available nutrients, moisture, space and sunlight, thus causing a significant crop yield loss. Yield losses caused by weeds alone in cowpea production can range from 25% to 76% depending on the cultivar and environment [18, 19, 20, 21]. Weeds may also reduce crop yield by releasing allelopathic compounds into the environment [22] and by providing a conducive environment for pest and virus [23].

However, in Sierra Leone, resource poor cowpea farmers employ hand and hoe weeding for weed control, but this cultural method is time consuming, energy boring and overpriced. The use of chemical weed control in cowpea is limited due to scarcity of studies into the selectivity of herbicides for the crop [24, 25] and there are no registered herbicides for cowpea in Sierra Leone. Thus, one of the components of improved production technology is appropriate weed control, but weeds continue to render mayhem to the efforts geared towards increasing cowpea yield. Hence, the present study aimed at comparing different pre-emergence herbicides techniques in cowpea production, which should be efficient, cost effective and environmentally safe.

2. Material and methods

2.1. Description of trial locations

The field trials were conducted at Njala (N 08.12036^0, W 12.06727^0) in the Moyamba district (Savannah woodland agroclimatic region) and Serabu (N 07.85249^0, W 011.27757^0) Kenema district (Rainforest agroclimatic region) during the second cropping season (October 2016 to January 2017). The climatic conditions experienced in the study areas were two distinct seasons, rainy season (May-October) and dry season (November-April) not different from the rest of the country. Tables 1 and 2 shows the characteristics of the agroclimatic regions and physiochemical properties of the soil at the respective trial sites.

Table 1 Characteristics of the agroclimatic regions

Characteristics	**Agroclimatic regions**	
	Njala (Savannah woodland)	**Serabu (Rainforest)**
Dominant land form	Drainage depressions, undulating plains, low plateau, and hills	Plateau with undulating plains, rolling plains and hills
Altitude (m)	150-300	300-600
Mean temperature. (^{0}C)	28.2	28.6
Average length of growing period (days)	255 ± 10	314 ± 9
Dominant vegetation	Lophira Savannah, Savannah woodland, mixed tree Savannah upland grassland and forest re- growth.	Forest and forest re- growth

Source: [26]

Table 2 Physiochemical properties of soil at the trial locations.

Soil properties	**Trial locations**	
	Serabu (Rainforest)	**Njala (Savannah woodland)**
Soil physical properties		
Texture	Loamy sand	Sandy clay loam
Sand (%)	88	68
Silt (%)	7	8
Clay (%)	5	14

Soil chemical properties		
Organic carbon (%)	1.7	1.6
pH (1:2:5)	5.1	4.48
Available Nitrogen (mg/kg)	0.67	0.78
Available Phosphorus (mg/kg)	2.5	0.09
Exchangeable Potassium (mg/kg)	0.38	13.2

2.2. Experimental treatments and design

The field trials were laid out in a strip-plot design arranged in a factorial system with three replications. The trials were made up of factor A which entails two genotypes of cowpea (slipea 4 and slipea 5) and factor B comprised of 10 weed control techniques (weedy check, butachlor at 2, 4 and 6 L ha^{-1}, double force® at 2, 4 and 6 L ha^{-1}, power force® at 2, 4 and 6 L ha^{-1} and weedy check.

Table 3 Herbicides, recommended rate, active ingredient and time of application

Herbicide trade name	Recommended rate (L ha^{-1})	Active ingredients (g a.i. L^{-1})	Time of application
Double force®	4 L ha^{-1} in dilution with 200-250 L ha^{-1} of water	Diuron (350 g/l) + Paraquat dichloride (150g/l)	Pre-emergence
Power force®	4 L ha^{-1} in dilution with 200-250 L ha^{-1} of water	Atrazine (350 g/L) + of Paraquat dichloride (140 g/L)	Pre-emergence
Butachlor 50% EC	2.5-4 L ha^{-1} in dilution with 250-600 L ha^{-1} of water	NButoxy methyl 1-2-chloro-2, 6-Diethyl acetanilide	Pre-emergence

2.3. Experimental procedures

The essential materials for the field trials were two cowpea genotypes (slipea 4 and slipea 5) obtained from the Njala Agricultural Research Centre (NARC), Njala, Sierra Leone. A compound fertilizer (NPK 15:15:15), herbicides (double force®, power force® and butachlor 50% EC) and an insecticide (Chlorpyrifos 480 EC) were used and obtained from agrochemical stores in urban areas of Sierra Leone.

The trial sites were brushed, tilled and flattened to fine tilth with locally manufactured tools such as hoes, shovels, pickaxes and matchets. Each plot measured 3 m × 2 m (6 m^2) with a distance of 0.5 m among plots and 1 m between replications giving an experimental area of 42.5 m x 14.5 m (616.25 m^2) equivalent to approximately 0.06 ha. The genotypes were seeded at a spacing of 0.5 m x 0.2 m inter and intra-row spacings with two seeds per hill on 14th October 2016. The preemergence herbicides were applied at the rates of 2, 4 and 6 L ha^{-1} in a spray volume of water as a carrier at 200 L ha^{-1} with the aid of knapsack sprayer (15 L capacity) using flat-fan nozzle on specified plots. These herbicide's rates were calculated using this formular: $Q = R \times A/C$. Where, Q = Quantity, R = Rate of herbicide to be used, A = Area of Land or Plot, C = Concentration of the herbicide formulation. A composite fertilizer (NPK 15:15:15) was applied at 2 weeks after sowing (WAS) at the rate of 200 kg ha^{-1}. Chlorpyrifos insecticide was applied at flowering and after pod formation at a rate of 2 L ha $^{-1}$ to control insect pests' attack. Harvesting was done manually in piecemeal on a net plot of 4 m^2 at crop maturity, pods were sun dried for about 2 weeks after harvesting, threshing and winnowing was done subsequently to separate the seeds from the chaff.

2.4. Data collected

2.4.1. Weed assessment

The weed flora present in the experimental fields were collected and recorded at 4 and 8 WAP by randomly throwing a 0.25 m^2 quadrat at three spots in each plot. The different weed species falling within the quadrat were scored, counted, identified and categorized to species levels and families at the herbarium unit of Njala University and with the aid of flora books [27]. The various species were harvested very close to the soil surface, air-dried and placed into paper bags separately per treatment. They are then oven dried at 65^0 C temperature to a constant weight and expressed in g m^{-2}.

Phytotoxicity (%) = Total seedlings injured/number of initial seeds used x 100.

Number of pods per plant: The number of pods per plant were counted and recorded from the total pods of the above-tagged plants at harvest.

Grain yield (kg ha^{-1}): The grain yield was measured after threshing the sun-dried plants harvested from each net plot and the yield expressed in kilogram per hectare. Data for grain yield in kg ha^{-1} were transformed by using the following formula applied by [28].

Grain yield (Kg ha^{-1}) = Grain yield (kg) from the net plot/Harvested area (m^2) x 10,000

Economic analysis of cowpea production

Partial field trial budget analysis of the various treatments in both locations were calculated according to [29] and [30] formulas.

- Gross revenue (GR) = Average grain yield in both locations x current market price of cowpea (SLL 12,000 kg^{-1})
- Total variable cost (TVC) = Sum of field cost (land preparation, cost of herbicides, cost of spraying, harvesting, threshing, winnowing and transportation etc.)
- Net return (NR) = Gross revenue – Total variable cost

2.4.2. Statistical analysis

Data collected were subjected to combined analysis of variance (ANOVA) across agroclimatic regions using the PROC Mixed procedure of SAS version 9.4 [31]. Replications were treated as a random effect while agroclimatic regions, weed control methods and cowpea genotypes and their interactions were considered as fixed effects in determining the expected mean square and appropriate F-test. Means were separated using LSMEANS statement of PROC Mixed code of SAS with option pdiff at $P \leq 0.05$. The statement calculates the difference between two means and the standard error of the difference (SED). Pearson's correlation coefficient between phytotoxicity and grain yield was computed using PRO CORR of SAS 9.4 [31].

3. Results

3.1. Probability of F-values

There were significant ($P < 0.0001$) effects of location (L), weed control techniques (W), and their interactions on number of pods, weed dry weight, yield and phytotoxicity of cowpea. Genotype had no significant effect on number of pods, weed dry weight, yield and phytotoxicity of cowpea neither locations. In addition, the three-way interactions between genotype x weed control techniques x locations recorded no significant effect on number of pods, weed dry weight, yield and phytotoxicity of cowpea.

Table 4 Probability of F-values of response of number of pods plant^{-1}, weed dry weight, phytotoxicity and grain yield of cowpea to genotypes, locations and weed control techniques at Njala and Serabu.

Effect	**Pods plant^{-1}**	**Weed dry weight (g m^{-2})**	**Grain yield (t ha^{-1})**	**Phytotoxicity (%)**
Genotype (G)	0.9127	0.6421	0.5188	0.3281
Weed control techniques (W)	<.0001	<.0001	<.0001	<.0001
Location (L)	<.0001	<.0001	<.0001	<.0001
G x W	0.5442	0.4616	0.9513	0.7703
G x L	0.9810	0.7942	0.7254	0.4029
W x L	<.0001	<.0001	<.0001	<.0001
G x W x L	0.4856	0.6488	0.8876	0.4179

3.2. Weed flora composition of cowpea

The two field trials were conducted under naturally occurring diverse weed population and had a spectrum of 19 weed species representing 11 dissimilar families (Table 5). Among those species, 10 were widespread in both locations during 2016 second cropping season. These experimental field locations had an almost uniform infestation of weed species and were mostly dominated by broadleaves (63.16%), grasses (26.32%) and sedges (10.52%). Additional analysis revealed that comparative composition of the broadleaf (72.7%), sedges (9.09%), and grasses (18.2%) were recorded in Njala, whereas 61.1%, 27.8% and 11.1% were respectively recorded for broadleaves, grasses and sedges in Serabu.

Table 5 Weed species composition observed during second cropping at Njala and Serabu in 2016.

Morphological group	Botanical name	Family
Broadleaves	*Calopogonium mucunoides*	Fabaceae
	Combretum spp	Combretaceae
	Clerodendron scandens	Verbenaceae
	Croton hirtus	Euphorbiaceae
	Diodia scandens	Rubiaceae
	Euphorbia heterophylla	Euphorbiaceae
	Euphorbia hirta L.	Euphorbiaceae
	Mimosa pudica L.	Fabaceae
	Sida acuta	Malvaceae
	Spigelia anthelma	Loganiaceae
	Hyptis suaveolens	Lamiaceae
	Phylanthus amarus	Euphorbiaceae
Grasses	*Andropogum tectorum*	Poaceae
	Digitaria ciliaris	Poaceae
	Oxonoopus compressus	Poaceae
	Panicum maximum	Poaceae
	Elaeis guineensis	Arecaceae
Sedges	*Cyperus esculentus*	Cyperaceae
	Cyperus rotundus L.	Cyperaceae

3.3. Weed dry weight (g m^{-2})

The results of the analysis of variance using mixed model procedures of SAS revealed highly significant ($P < 0.0001$) effects of weed control techniques, location and their interactions on weed dry weight, whereas genotype and the three-way interactions among genotype x weed control techniques x location was not significant ($P > 0.6421$ and $P > 0.6488$, respectively). Similarly, genotype x weed control techniques ($P > 0.4616$) and genotype x location ($P > 0.7942$) did not show significant effects on weed dry weight of cowpea.

The minimum (1.17 g m^{-2}) weed dry weight recorded across locations were from power force® at 6 L ha^{-1} and double force® at 6 L ha^{-1}, which was statistically at par with the application of power force® at 4 L $ha^{-1.}$ The analysis of variance using mixed model procedures of SAS further showed that the maximum (16.69 g m^{-2}) weed dry weight obtained in weedy check was significantly ($P \leq 0.05$) higher than all the other weed control techniques (Table 6). Furthermore, we also observed that there was no significant difference ($P \geq 0.05$) in weed dry weight obtained from butachlor 50% EC at 4 L ha^{-1} and power force® at 2 L ha^{-1} across genotype and locations. In the case of cowpea genotypes, slipea 4 genotype with high fodder and grain yield recorded significantly ($P \leq 0.05$) lower weed dry weight compared with slipea 5 at both locations.

Table 6 Interactive effects of location, genotype and weed control techniques on total weed dry weight during second cropping season at Njala and Serabu in 2016.

Weed control techniques	Njala		Serabu		Mean
	Slipea 4	Slipea 5	Slipea 4	Slipea 5	
Butachlor 50% EC at 2 L ha^{-1}	1.00	3.67	13.00	20.00	9.42
Butachlor 50% EC at 4 L ha^{-1}	1.00	5.67	6.00	10.67	5.83
Butachlor 50% EC at 6 L ha^{-1}	3.00	1.00	4.67	11.33	5.00
Double force® at 2 L ha^{-1}	1.00	2.00	3.67	1.67	2.08
Double force® at 4 L ha^{-1}	1.00	1.00	4.00	3.33	2.33
Double force® at 6 L ha^{-1}	1.00	1.33	1.00	1.33	1.17
Power force® at 2 L ha^{-1}	2.67	2.67	10.00	6.33	5.42
Power force® at 4 L ha^{-1}	1.00	1.00	1.33	1.33	1.33
Power force® at 6 L ha^{-1}	1.00	1.00	1.00	2.33	1.17
Weedy check	5.67	6.11	33.33	21.67	16.69
Mean	1.83	2.54	7.80	8.00	
SED: Genotype (G)	0.69				
SED: Weed control techniques (W)	1.54				
SED: Location (L)	0.69				
G x W x S	3.09				

* SED = Standard error of difference of least square mean.

3.4. Phytotoxic effect (%)

Analysis of variance results on phytotoxicity exhibited highly significant ($P < 0.0001$) effects of weed control techniques, location and their interactions, while analyzing the effect of each herbicide between genotypes no significant ($P > 0.3281$) effect was observed (Table 4).

Table 7 Phytotoxic effects of butachlor 50% EC, power force® and double force® on cowpea genotype at Njala and Serabu during second cropping season in 2016.

Weed control techniques	Njala		Serabu		Mean
	Slipea 4	Slipea 5	Slipea 4	Slipea 5	
Butachlor 50% EC at 2 L ha^{-1}	10.56	11.11	32.22	21.11	18.75
Butachlor 50% EC at 4 L ha^{-1}	8.33	8.33	31.11	33.33	20.28
Butachlor 50% EC at 6 L ha^{-1}	20.56	8.33	41.67	37.22	26.94
Double force® at 2 L ha^{-1}	12.22	17.22	28.33	24.44	20.56
Double force® at 4 L ha^{-1}	20.00	22.22	41.67	34.44	29.58
Double force® at 6 L ha^{-1}	14.44	22.78	60.00	47.22	36.11
Power force® at 2 L ha^{-1}	76.11	76.11	80.56	92.78	81.39
Power force® at 4 L ha^{-1}	92.22	91.67	97.78	97.22	94.72
Power force® at 6 L ha^{-1}	98.33	94.44	100.00	97.22	97.50
Weedy check	14.44	12.78	17.78	17.78	15.69
Mean	36.72	36.50	53.11	50.28	
SED: Genotype (G)	1.09				
SED: Weed control techniques (W)	2.46				
SED: Site (S)	1.09				
G x W x S	4.91				

* SED = Standard error of difference of least square mean.

The interaction between herbicides for each genotype showed that power force® applied at 2, 4 and 6 L ha^{-1}, respectively provided 81.39%, 94.72% and 97.50% increase of crop injury (death) for both genotypes across locations, hence caused the highest levels of Phyto intoxication when compared to the weedy check plot (15.69%). Comparing the genotypes for each weed control technique, at 14 days after planting, it was confirmed that weedy check was the least affected. At 2 WAP, slipea 4 cowpea genotype (53.11% and 36.72%) in Serabu and Njala, respectively was most sensible to the application of power force®, which causes the death of most plants in both locations. Whereas those treated with double force® at 6 L ha^{-1} caused very strong phytotoxical symptoms, affecting the development and triggered 36.11% plant death. Among the herbicides applied, our results discovered that butachlor 50% EC at 2 L ha^{-1} was significantly ($P \leq 0.05$) less phytotoxic to both genotypes across locations (Table 7).

3.5. Number of pods per plant

Across location and weed control techniques, the highest number of pods was significantly ($P <.000$) recorded from double force® at 4 L ha^{-1} (23.63 plant^{-1}) and was statistically at parity with double force® at 2 L ha^{-1} (22.92 plant^{-1}). Furthermore, though butachlor 50% EC at 4 L ha^{-1} (21.58 plant^{-1}) and double force® at 6 L ha^{-1} (21.33 plant^{-1}) were statistically similar, they significantly ($P \leq 0.05$) had higher number of pods than the other weed control techniques (Table 8). However, plots treated with Power force® at 2, 4 and 6 L ha^{-1} significantly ($P \leq 0.05$) recorded the lowest number of pods per plant in this study. Genotype and its interaction with weed control technique and locations did not show significant ($P > 0.05$) effects on number of pods per plant. However, slipea 5 genotype recorded higher number of pods per plant than slipea 4 across locations. The increased number of pods per plant at Njala may be attributed to the differences in the physiochemical properties of soil at the trial sites (Table 2).

Table 8 Interactive effect of genotype, weed control techniques and location on number of pods during second cropping season at Njala and Serabu in 2016.

Weed control techniques	Njala		Serabu		Mean
	Slipea 4	**Slipea 5**	**Slipea 4**	**Slipea 5**	
Butachlor 50% EC at 2 L ha^{-1}	27.67	34.33	8.00	12.67	20.67
Butachlor 50% EC at 4 L ha^{-1}	33.00	35.00	10.67	7.67	21.58
Butachlor 50% EC at 6 L ha^{-1}	33.67	29.33	8.00	6.67	19.42
Double force® at 2 L ha^{-1}	30.67	44.00	9.67	7.33	22.92
Double force® at 4 L ha^{-1}	38.00	31.33	10.33	15.00	23.67
Double force® at 6 L ha^{-1}	36.67	34.00	6.67	8.00	21.33
Power force® at 2 L ha^{-1}	20.00	11.33	5.00	2.00	9.58
Power force® at 4 L ha^{-1}	1.00	1.00	1.33	1.00	1.08
Power force® at 6 L ha^{-1}	1.00	1.00	1.00	1.00	1.00
Weedy check	30.33	32.22	6.00	6.33	18.72
Mean	25.20	25.36	6.67	6.77	
SED: Genotype (G)	0.82				
SED: Weed control techniques (W)	1.84				
SED: Location (L)	0.82				
G x W x L	3.67				

* SED = Standard error of difference of least square mean.

3.6. Grain yield (kg ha^{-1})

Results of the analysis of variance using proc mixed procedures of SAS showed highly significant ($P < 0.0001$) effects of weed control techniques, location and their interactions on grain yield, while genotype was not significant ($P > 0.5188$). The slipea 4 cowpea genotype attained the highest yield, while slipea 5 genotype had the least yield across locations and weed control techniques (Table 9). The diversity across genotype and weed control techniques exhibited that mean grain yield for individual location ranges from 4870 kg ha^{-1} to 5030 kg ha^{-1} at Njala and 1310 kg ha^{-1} to 1360 g ha^{-1} at

Serabu. The result indicates that available nitrogen (mg/kg) was 0.11 mg/kg greater at Njala than that of Serabu (Table 2) and rainfall was relatively higher in Serabu which might have caused flower abortion or destruction of pods (data not shown).

For weed control techniques, butachlor 50% EC at 2 L ha^{-1} (4220 kg ha^{-1}) was the best and had the highest grain yield followed by double force® at 6 L ha^{-1} (4140 kg ha^{-1}) implying some gain in grain yield has been achieved, while power force® at 2 L ha^{-1}, 4 L ha^{-1} and 6 L ha^{-1} attained the lowest grain yield 1690 kg ha^{-1}, 1260 kg ha^{-1} and 1000 kg ha^{-1}, respectively than weedy check treatment across both locations. The above results could be due to the little or no phototoxic effect of butachlor 50% EC at 2 L ha^{-1} and double force® at 6 L ha^{-1} herbicides on cowpea genotypes. In addition, the effectiveness of double force® at 6 L ha^{-1} in the control of weeds decreased weed rivalry with the crop and led to better utilization of mineral nutrients, moisture and light, and better crop growth associated to the other treatments.

Table 9 Interactive effect of genotypes, weed control techniques and locations on grain yield of cowpea during second cropping season at Njala and Serabu in 2016.

	Njala		**Serabu**		
Weed control techniques	**Slipea 4**	**Slipea 5**	**Slipea 4**	**Slipea 5**	**Mean**
Butachlor 50% EC at 2 L ha^{-1}	7.03	7.07	1.36	1.41	4220
Butachlor 50% EC at 4 L ha^{-1}	6.26	6.83	1.67	1.39	4040
Butachlor 50% EC at 6 L ha^{-1}	6.02	6.11	1.57	1.41	3780
Double force® at 2 L ha^{-1}	6.34	5.94	1.51	1.67	3870
Double force® at 4 L ha^{-1}	6.64	5.69	1.61	1.64	3900
Double force® at 6 L ha^{-1}	7.58	5.96	1.55	1.47	4140
Power force® at 2 L ha^{-1}	2.17	2.49	1.09	1.00	1690
Power force® at 4 L ha^{-1}	1.28	1.63	1.14	1.00	1260
Power force® at 6 L ha^{-1}	1.00	1.00	1.00	1.00	1000
Weedy check	6.02	5.96	1.07	1.08	3540
Mean	5030	4870	1360	1310	
SED: Genotype (G)	0.12				
SED: Weed control techniques (W)	0.26				
SED: Site (S)	0.12				
G x W x S	0.52				

* SED = Standard error of difference of least square mean.

3.7. Phytotoxicity and grain yield relationship

Grain yield was significant, weak and negatively correlated to phytotoxicity (P = <.0001, r = -0.66175), which shows that as cowpea grain yield increases, the lower the percentage of phytotoxicity. This indicates that, the higher the grain yield the lower the phytotoxic effects of the chemicals (Figure 1). The higher grain yield obtained from the butachlor 50% EC at 2 L ha^{-1} and double force® at 6 L ha^{-1} could be attributed to the significantly lower percentage of phytotoxicity. Even though Butachlor 50% EC 4 L ha^{-1} treatment plots had significantly lower percentage of phytotoxicity, grain yields were significantly lower when compared to double force® at 6 L ha^{-1}. This may have caused the weak strength of association between grain yield and phytotoxicity.

Partial budget analysis of different preemergence herbicides at various rates in the production of cowpea at Njala and Serabu is presented in Table 10. Butachlor 50% EC at 6 L ha^{-1}, double force® at 6 L ha^{-1} and power force® at 6 L ha^{-1} recorded the highest total variable cost (SLL 4,420,000.00), followed by Butachlor 50% EC at 4 L ha^{-1}, double force® at 4 L ha^{-1} and power force® at 4 L ha^{-1} (SLL 3,970,000.00) respectively, compared with the other weed control techniques applied in this study. Whereas the lowest total variable cost was observed under weedy check (SLL 2,270,000.00) compared with the other treatments in both locations.

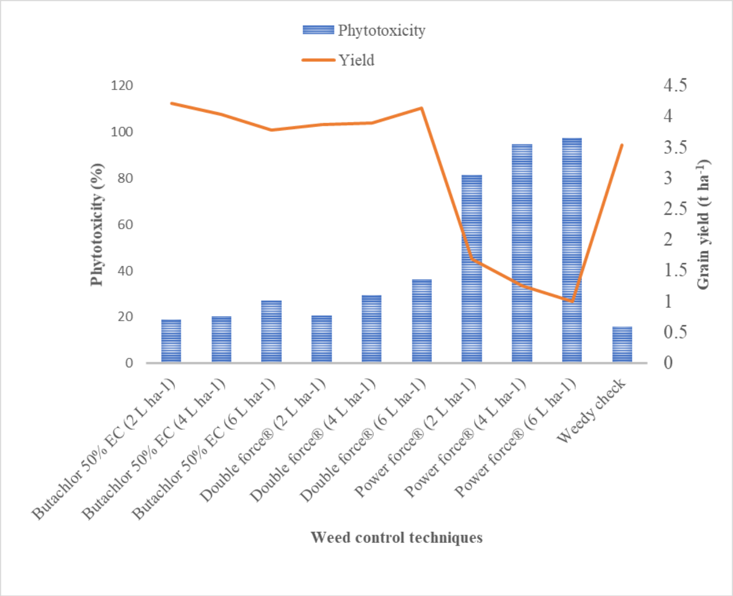

Figure 1 Relationship between phytotoxicity and grain yield as affected by weed control techniques.

Partial field budget analysis

Despite the high total variable cost of herbicides, butachlor 50% EC at 2 L ha^{-1} resulted in the highest gross return (SLL 50,640,000.00) followed by double force® at 6 L ha^{-1} (SLL 49,680,000.00), while power force® at 6 L ha^{-1} (SLL 12,000,000.00) recorded the lowest gross return compared to the rest of the treatments. Similarly, the highest net return was observed under butachlor 50% EC at 2 L ha^{-1} (SLL 47,120,000.00) followed by double force® at 6 L ha^{-1} (SLL 45,260,000.00), and lowest net return was recorded under power force® at 6 L ha^{-1} (SLL 7,580,000.00) compared with weedy check treatment.

Table 10 Partial budget analysis of weed control techniques on cowpea genotypes at Njala and Serabu during second cropping season in 2016

Herbicide	**Rates (L ha^{-1})**	**Grain yield (kg ha^{-1})**	**Total variable cost (SLL ha^{-1})**	**Gross return (SLL ha^{-1})**	**Net return (SLL ha^{-1})**
Butachlor 50% EC	2	4220	3,520,000.00	50,640,000.00	47,120,000.00
	4	4040	3,970,000.00	48,480,000.00	44,510,000.00
	6	3780	4,420,000.00	45,360,000.00	40,940,000.00
Double force®	2	3870	3,520,000.00	46,440,000.00	42,920,000.00
	4	3900	3,970,000.00	46,800,000.00	42,830,000.00
	6	4140	4,420,000.00	49,680,000.00	45,260,000.00
Power force®	2	1690	3,520,000.00	20,280,000.00	-3,499,720.00
	4	1260	3,970,000.00	15,120,000.00	11,150,000.00
	6	1000	4,420,000.00	12,000,000.00	7,580,000.00
Weedy check		3540	2,270,000.00	42,480,000.00	40,210,000.00

*Current marketing price of cowpea = SLL 12,000.00/kg

4. Discussion

Naturally occurring weed flora of the study locations indicated 19 different weed species belonging to 11 families. Broadleaf was the most prevalent group accompanied by grasses and sedges. The disparities in the weed composition may be attributed to differences in agroecological conditions, management practices and weed seed bank composition between the study locations. These results further buttressed the observations of [32], [33] and [34] who reported that relative weed community in aerobic rice is generally dominated by broadleaf weeds followed by sedges and grasses. Similar observations have been reported by]35] in their studies of weed control in tomato.

Though weed dry weight was reduced by the application of power force® at 6 L ha^{-1} and double force® at 6 L ha^{-1} treatments, vigorous cowpea growth and yield was not significantly encouraged due to high phytotoxicities. The current research result was in line with [36] who reported lower weed dry matter and higher weed control efficiency with herbicides used. In addition, [37] similarly stated that pre-emergence herbicides reduced the weed dry weight significantly as compared to weedy check in common bean. The higher weed biomass observed in the weedy check could be attributed to uncontrolled weeds measure on weed growth [38]. These results are consistent with the findings of [39] who testified more weed dry biomass in weedy check than pre-emergence herbicides application in *Brassica napus* L. for weed management. Slipea 4 cowpea genotype significantly recorded lower weed dry weight compared with slipea 5, which was in agreement with the findings of [36] that 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.

The results presented in Table 7 clearly demonstrated that phytotoxic effect on cowpea increased linearly with the concentrations of butachlor 50% EC, power force® and double force®. The current result showed that chemo toxic effects of various herbicides when applied at different rates had variable effects on cowpea production by alternating their ecology [40]. The magnitude of the toxic effects of herbicides, however, depends primarily on the type and dose of compounds, duration of exposure, species and age of plants, and other environmental factors [41]. Our result corroborates with [42] who reported that Diuron was highly adsorbed in the soil profile and available for plant uptake during the growth season, thus a more phototoxic effect to the test plant was found.

The current results in Table 8 agrees with the findings of [43] and [44] who reported the highest number of pods per plant with single herbicide in peanut (*Arachis hypogaea* L.) and soybean, respectively. This can be attributed to the fact that effective weed management may lead to appropriate environment for growth and photosynthetic activity of the crop resulting to enhancement in the number of pods per plant. The lowest number of pods per plant recorded from power force® at 4 L ha^{-1} and 6 L ha^{-1} respectively, was not as a result of the presence of weeds, but due to the toxic effect of herbicide. However, [45] showed that the incidence of weeds is a prominent factor in reducing the number of pods in cowpea plant. Hereafter, [46] had reported that weeding suppressed or minimized the growth, development and competitive capacity of weeds thereby enhancing optimum pod yield. Additionally, [47] reported that chemical weeding at 2-3 leaf stage resulted highest value of number of pods plant^{-1}.

There are a number of reports on influence of herbicides on yield parameters and crop yield. In this regard, the grain yield of cowpea genotypes showed a substantial level of disparity due to differential genetic makeup of the crops or influence of the location since yield is quantitatively hereditary [48, 38] and [35]. However, [49] likewise found that genetic effects and ecological factors affected agronomic performance of cowpea genotypes. Thus, slipea 4 cowpea genotype was a spreading type with more fruit bearing branches, and hence higher fodder and grain yield [50]. Furthermore, differences in grain yield may be due to inconsistencies in soil fertility and rainfall in the two locations. The changes in genotype performance across different locations reduce the relationship between genotypes and their corresponding phenotypes [51, 52]. The poor yield by power force® at 2 L ha^{-1}, 4 L ha^{-1} and 6 L ha^{-1} may be attributed to the phytotoxic effects of this herbicide [53]. Furthermore, [54] similarly reported that application of Pendimethalin @ 0.75 kg a.i./ha as pre-emergence gave broad spectrum control of weeds and resulted in higher cowpea seed yield. Likewise, [55] also concluded that the highest seed yield of cowpea was recorded from plots that received chemical weeding.

Chemical weed control proved the most practical in recent years due to lower cost and effectiveness at lower dose gives economic return in controlling weeds. The current results shown in Table 10 indicated that the use of herbicide is more gainful in the production of cowpea than other weed control techniques, thus butachlor 50% EC at 2 L ha^{-1} and double force® at 6 L ha^{-1} resulted in the highest gross return. This result is similar to the findings of [56] who reported that herbicides for weed control in cowpea can result in highly effective control, lower production costs, optimum and highest net returns compared with the other methods of weed control treatments.

5. Conclusion

From this study, it can be concluded that power force® at 6 L ha^{-1} recorded the highest phytotoxic effect, lowest weed dry weight, decreased number of pods per plant and grain yield, highest total variable cost, lowest gross and net returns. Furthermore, butachlor 50% EC at 2 L ha^{-1} closely followed by double force® at 6 L ha^{-1} resulted in the highest grain yield, gross return and net returns compared to the rest of the other weed control techniques in both locations. However, butachlor 50% EC at 6 L ha^{-1}, double force® at 6 L ha^{-1} and power force® at 6 L ha^{-1} were more expensive and resulted in the highest cost of cowpea production than all the herbicide treatments and weedy check. Thus, butachlor 50% EC at 2 L ha^{-1} followed by double force® at 6 L ha^{-1} were more economical, profitable and beneficial than other control treatments in the production of cowpea in the savannah woodland and rainforest agroclimatic regions of Sierra Leone. The relationship between phytotoxicity and grain yield indicates that the higher the grain yield the lower the phytotoxic effects of the chemicals.

Compliance with ethical standards

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Disclosure of conflict of interest

Dan David. Queea, Philip Jimia. Kamanda, Musa Decius. Saffa, and Johnny Ernest Norman have respectively declared no conflict of interest.

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