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Effect of weed management with glyphosate on growth and early yield of young cocoa (*Theobroma cacao* L.) in Ghana

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Weeds are a limitation to cocoa production, and herbicide use in cocoa cultivation is known to lower the cost of weed management and support better plant growth. As a result, glyphosate was recommended for use in cocoa cultivation following a two-year field trial at the Cocoa Research Institute of Ghana. Recent informal debates among scientists and farmers, however, point towards a disagreement regarding the effect of glyphosate on young cocoa. Consequently, an experiment was conducted from 2011 to 2013 at the Cocoa Research Institute of Ghana to re-evaluate the suitability of glyphosate (Isopropylamine) for weed management and its effects on growth and yield of young cocoa. Five rates of glyphosate viz: (i) 1,920 g active ingredient a.i. ha^{-1} using polyjet nozzle; (ii) 1,920 g a.i. ha^{-1} using very low volume (vlv) nozzle; (iii) 960 g a.i. ha^{-1} vlv; (iv) 720 g a.i. ha^{-1} vlv; (v) 480 g a.i. ha^{-1} vlv; and (vi) manual weeding were tested in a randomized complete block design with four replicates in the field. Effects of treatments on weeds, cocoa growth and yield were recorded for three years. In a gauze house study, cowpea and maize were used to determine residual effects of glyphosate. Emergence, survival and dry matter accumulation by these plants were recorded. Results from the gauze house study showed that glyphosate did not exhibit residual soil activity at these rates. Glyphosate at 960 g ha^{-1} significantly increased yield of three year old cocoa compared to the other rates and manual weeding. The 1,920 g ha^{-1} rates significantly reduced the initial yield of 3 year old cocoa compared to the other glyphosate rates. Cost analysis showed that glyphosate at 960 g a.i. ha^{-1} was Gh¢ 136.00 (11%) and Gh¢ 1,784.00 (61%) cheaper than the 1,920 g a.i. ha^{-1} rates and manual weeding respectively. It was therefore concluded that glyphosate can be applied at 960 g a.i. ha^{-1} (equivalent to 2.0 l ha^{-1} in 120 l of water) for effective weed management without significant adverse effects on growth and yield of young cocoa.

Key words: Weeds, glyphosate, cocoa, growth, bean yield and cost.

INTRODUCTION

Glyphosate is a broad-spectrum, post emergent, systemic and non-selective systemic weedicide (Tu et al., 2001). It has been hailed for its ability to kill annuals, perennials and woody plants while exhibiting favourable environmental attributes (Dale, 2006; Duke and Powles, 2008). Earlier studies suggested that glyphosate neither affected the nervous system nor inhibited cholinesterase activity (Calisle and Trevors, 1988). The tendency of glyphosate to inhibit the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), a key enzyme in the shikimate biosynthetic pathway necessary for the production of aromatic amino acids, auxin, phytoalexins, folic acid, lignin, plastoquinones and many other secondary products is core to its weed control properties (Tu et al., 2001; Dale, 2006; Gill et al., 2017). This disruption however, was only reported to occur in plants, fungi and bacteria, suggesting that the rates being used for weed control were not toxic to mammals, birds, fish, amphibians and insects (Franz et al., 1997; Williams et al., 2000). Its overuse however has affected other non-target organisms present in the soil biota (Gill et al., 2017).

Glyphosate translocation in plants occurs in the source-sink direction with up to 70% of absorbed glyphosate translocating out of the treated leaves to the root and shoot apices (Siehl, 1997; Dale, 2006). The translocation process is however, self-limiting and only occurs for up to 48-72 h after application (Dale, 2006). When glyphosate comes into contact with the soil, it is reported to undergo various chemical and physical changes which control its retention, transport and degradation (Duke et al., 2012; Gill et al., 2017).

Glyphosate is partly inactivated by being adsorbed onto soil particles (Al-Rajab et al., 2008) where it is degraded slowly, and partly by rapid degradation of the unbound form through microbial activity (Dick and Quinn, 1995; Tu et al., 2001; Pollegioni et al., 2011; Gill et al., 2017). As a result, glyphosate has low seepage into ground water systems, thus causing minimum contamination (Glass, 1987; de Jonge et al., 2001). It has not shown volatility which will make it an atmospheric pollutant (Duke and Powles, 2008). Because it is soluble in water, glyphosate is not known to accrue in food web (Lane et al., 2012).

The widespread use of glyphosate as a post-emergence weedicide is known to have contributed immensely to increases in the profitability of crop production (Fernandez et al., 2002; Qaim and Taxler, 2005; Sansom, 2012). Used within recommended rates, glyphosate has little or no effects on non-target organisms (Franz et al., 1997). However, excessive use of glyphosate is reported to have adverse effects on metabolic functions of both unicellular organisms (Austin et al., 1991; Zobiole et al., 2011; Shehata et al., 2013; Newman et al., 2016) and wide range of multicellular organisms such as algae (Oliveira et al., 2016), earthworms (Santadino et al., 2014), arthropods (Pérez et al., 2011), honey bees (Balbuena et al., 2015), snails (Druart et al., 2011), fish (Hued et al., 2012), frogs (Pérez -Iglesias et al., 2016, Mann and Bidwell, 1999), lizards (Schaumburg et al., 2016), birds (Oliveira et al., 2007), swine (Lee et al., 2009) and humans (Samsel and Seneff, 2013).

In crop production however, manual weed control during the establishment phase accounts for up to 23% of the total cost (Bonaparte and Toseafa, 1975). Unlike the manual weed control methods, weedicides such as paraquat and glyphosate were found to lower the cost of weed control and resulted in better cocoa growth (Osei-Bonsu et al., 1991; Oppong et al., 1995, 1999). Subsequent field studies in young coffee and cocoa led to similar conclusions (Oppong et al., 2006; Konlan et al. 2014). Both studies went further and reported no adverse effects of glyphosate at the recommended rate of 1.5-2.0 l ha^{-1} on the yield of young coffee and cocoa. In spite of these reports, there still remain concerns about adverse effects of glyphosate; with both farmers and scientist raising red flags regarding the effect of glyphosate on growth and pod production in young cocoa. Some authors have reported that drift during glyphosate application exert adverse effects on fruit and seed formation in other crops through the disruption of aromatic amino acid synthesis, necessary for fruit formation and retention (Magdal et al., 2012; Abella et al., 2013; Salem, 2013). It is possible therefore, that complains by farmers regarding the effect of glyphosate on the cocoa crop holds true. As a response, an experiment was initiated in 2011 using a post-emergent systemic weedicide containing glyphosate, present as 480 g l^{-1} (41.2% w/w) of the Isopropylamine salt for weed management in cocoa. The objectives were to investigate its efficacy as a weedicide, phyto-toxicity and possible effects (immediate and residual) on growth and yield of young cocoa.

MATERIALS AND METHODS

Gauze house study

A gauze house assessment was carried out to determine the residual effect of glyphosate on maize (*Zea mays*) and cowpea (*Vigna unguiculata*). Plastic pots with single drainage holes at the bottom were filled with 2.5 kg top soil each. Two seeds of maize and cowpea were sown separately per pot. The soils in the pots were then watered to field capacity before the application of treatments. Glyphosate was sprayed over these pots at a walking pace as would be done in field application. The control treatment received a spray of water from a clean knapsack. The treatments were arranged in a completely randomized design with 6 replicates. The emergent seedlings were counted at 1 week after sowing (WAS) and were then thinned to one per pot. Seedling survival, plant height and dry matter accumulated were measured at 6 WAS.

Field experiment

Experimental site and treatments

The field experiment was conducted at the Cocoa Research Institute of Ghana (latitude 6° 13' N, longitude 0° 22' W, altitude 222 masl). Treatments were laid out in randomized complete block

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design with 4 replicates. Plot size was 18 x 18 m with cocoa planted at 3 x 3 m. Different rates of glyphosate (i. 480, ii. 720, iii. 960, iv. 1,920 g a.i. ha^{-1} vlv, v. 1,920 g a.i. ha^{-1} polyjet) and vi. manual weeding with a cutlass were used as the treatments.

There were four applications of treatments per year, with each application carried out when weeds were 30 cm tall or 70% ground cover. Other recommended cultural practices necessary for the management of pests and diseases in cocoa were routinely carried out. Data collected from the experimental plots included pre- and post-application weed composition, weekly assessment of weed kill, growth of young cocoa at quarterly intervals and initial yield of 3 year old cocoa trees. Weed kill assessment was done at weekly interval after every application. After four applications in each year, the average annual weed kill was determined by adding each week's assessment and dividing by the number of such weeks in the year. The data was subjected to analysis of variance and differences among treatment means determined by the least significant difference at 5% probability level. Percentage data were arcsine-transformed to fit the assumptions of ANOVA before analysis.

Cost of treatments

Cost components for use of glyphosate included the cost of the weedicide required per hectare for each rate and the cost of labour for application. These were determined as:

$$\text{Weedicide cost/ha} = \text{No. of litres of glyphosate} \times \text{cost/litre} \quad (1)$$

$$\text{Labour cost/ha} = \text{No. of mandays} \times \text{cost/manday} \quad (2)$$

Total cost per hectare per year was then determined as:

$$\text{Cost/ha/year} = (\text{weedicide cost} \times \text{applications/year}) + (\text{labour cost} \times \text{application/year}) \quad (3)$$

The cost for manual weed control comprised the cost of labour and was determined as:

$$\text{Cost of weeding/ha} = \text{No. of mandays} \times \text{cost/manday} \quad (4)$$

$$\text{Cost of weeding/ha/year} = \text{Cost/ha} \times \text{weeding frequency/year} \quad (5)$$

RESULTS

Gauze house study

Post-plant pre-emergence application of glyphosate had no significant ($p<0.05$) adverse residual effects on emergence, survival, growth and by matter accumulated by maize and cowpea plants (Table 1).

Field study

Effects of treatments on weed growth

There were significant treatment effects ($p<0.05$) on percentage weed kill at 2nd, 3rd and 4th weeks after application (WAA) of treatments in the 1st year (Table 2). Manual weeding with a cutlass achieved immediate weed suppression, but weed cover score only showed significant differences ($p<0.05$) between this treatment and the 1,920 g a.i. ha^{-1} (polyjet and vlv) during the 1st and 2nd WAA. The 1,920 g a.i. ha^{-1} vlv rate accounted for the highest weed kill at 8 and 9 weeks after the 1st and 2nd applications (Tables 2 and 3), and also from 3 to 6 weeks after the 3rd application, while the 480 g a.i. ha^{-1} vlv recorded the least weed kill a (Table 4).

The performance of glyphosate at the rate of 1,920 g a.i. ha^{-1} was not significantly ($p>0.05$) affected by the nozzle type (polyjet or vlv) at any time during the three years. There was no significant differences ($p>0.05$) in weed kill among the weedicide treatments after the 1st and 2nd applications. However, the 720 g a.i. ha^{-1} vlv achieved a higher weed kill than the 960 g a.i. ha^{-1} vlv after the 3rd application. Generally, the 720 and 960 g a.i. ha^{-1} vlv achieved higher weed kill after the 2nd and 3rd applications.

Weed species succession

Before treatment application, about 15 to 19 weed species were identified per experimental plot with *Aspillia africana, Justicea sp, Oplismenus burmannii* and *Synedrella nodiflora* constituting the major species (Table 5). The results showed that there was no drastic shift in the weed species composition after the 3 years of repeated application of the treatments. In isolated cases, *Ageratum conyzoides, Amaranthus* spp. and *Euphorbia heterophyla* emerged as species previously absent within the plots.

Growth and yield of cocoa

There were no significant differences ($p>0.05$) in growth (girth and height increase) of young cocoa trees attributable to treatment application (Table 6). The initial yield of the 3 year old cocoa was significantly higher ($p<0.05$) in the 480-960 g a.i. ha^{-1} glyphosate treated plots than in the 1,920 g a.i. ha^{-1} (polyjet and vlv) and the manually weeded plots (Figure 1). There was no significant difference ($p>0.05$) in cocoa yield between the manually weeded plots and plots treated with 1,920 g a.i. ha^{-1} glyphosate rate (polyjet and vlv).

Cost of treatments

Manual weeding resulted in the highest cost of weed control per hectare (Table 7). Labour cost for the application of all the glyphosate rates were the same. The amount of active ingredient required for each rate was the major factor establishing cost differences

Table 1. Residual effects of glyphosate on the emergence and growth of maize and cowpea.

Glyphosate rate (a.i. g ha^{-1})		Final emergence (%)	Survival at 6 weeks (%)	Height at 6 weeks (cm)	Dry matter per plant (g)	% Dry matter per plant
Response of maize	1,920 poly-jet	66.7 (55.0)	100 (88.2)	67.3	3.1	12.8 (21.0)
	1,920 vlv	62.5 (53.1)	100 (88.2)	69.0	2.8	12.9 (21.1)
	960 vlv	83.3 (66.2)	100 (88.2)	88.1	3.1	14.8 (22.6)
	720 vlv	62.5 (57.0)	100 (88.2)	64.7	2.3	13.9 (21.9)
	480 vlv	91.7 (75.6)	100 (88.2)	88.9	3.2	15.5 (23.2)
	Water only	62.5 (53.1)	100 (88.2)	71.0	3.9	15.1 (22.9)
	F-test	ns	-	ns	ns	ns
	% cv	21.6	-	15.9	24.8	10.6
Response of cowpea	1,920 poly-jet	87.5 (72.5)	100 (88.2)	78.6	3.2	17.9 (25.0)
	1,920 vlv	87.5 (72.5)	100 (88.2)	79.2	3.1	16.8 (24.2)
	960 vlv	91.7 (75.6)	100 (88.2)	85.5	3.0	17.3 (24.6)
	720 vlv	91.7 (75.6)	100 (88.2)	85.8	2.6	16.4 (23.9)
	480 vlv	91.7 (75.6)	100 (88.2)	82.8	2.5	17.2 (24.5)
	Water only	87.5 (76.2)	100 (88.2)	81.5	2.5	19.6 (26.3)
	F-test	ns	-	ns	ns	ns
	% cv	19.5	-	10.4	18.9	8.0

Values in parenthesis are arc sine transformations; a.i. g ha^{-1} (active ingredient in grams per hectare).

Table 2. Response of weeds to glyphosate rates and manual weeding 1-9 weeks after application of treatments in first year.

Glyphosate rate (a.i. g ha^{-1})	Weed kill (%)								
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks
1,920 poly-jet	58.2(49.7)	65.5(54.0)	67.8(55.4)	74.0(59.3)	72.2(58.2)	69.0(56.2)	67.2(55.1)	60.8(51.2)	45.0(42.1)
1,920 vlv	58.2(49.7)	70.0(56.8)	75.0(60.0)	83.2(65.8)	81.8(64.8)	78.2(62.2)	75.5(60.3)	67.5(55.2)	55.5(48.2)
960 vlv	48.0(43.9)	54.8(47.8)	58.5(49.9)	70.5(57.1)	67.8(55.4)	63.2(52.7)	59.0(50.2)	46.0(42.7)	33.5(35.4)
720 vlv	51.2(45.7)	55.0(47.9)	57.8(49.5)	59.8(50.7)	53.5(47.0)	49.8(44.9)	47.0(43.3)	44.5(41.8)	37.0(37.5)
480 vlv	47.5(43.6)	51.2(45.7)	52.8(46.6)	52.8(46.6)	46.8(43.2)	42.0(40.4)	37.8(37.9)	27.8(31.8)	21.3(27.5)
Manual control	100(88.2)	85.8(67.9)	78.8(62.6)	75.0(60.0)	67.5(55.2)	63.2(52.7)	60.5(51.1)	27.5(31.6)	6.8(15.1)
F-test	14.6	13.8	14.6	16.3	17.4	17.1	17.5	25.4	20.3
% cv	16.6	14.5	15.0	15.7	17.7	19.2	19.9	25.4	38.4

Values in parenthesis are arc sine transformations; a.i. g ha^{-1} (active ingredient in grams per hectare).

Table 3. Response of weeds to glyphosate rates and manual weeding 1-10 weeks after application of treatments in the second year.

Glyphosate rate (a.i. g ha^{-1})	Weed kill (%)									
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks
1,920 poly-jet	39.5(38.9)	51.5(45.9)	56.2(48.6)	65.0(53.7)	74.0(59.3)	80.8(64.0)	78.5(62.4)	77.0(61.3)	86.2(68.2)	88.2(69.9)
1,920 vlv	67.8(55.40)	75.0(60.0)	77.5(61.7)	80.0(63.4)	83.5(66.0)	90.5(72.1)	89.8(71.4)	89.0(70.6)	92.8(74.4)	93.5(75.2)
960 vlv	44.2(41.7)	50.0(45.0)	62.2(52.1)	72.0(58.1)	77.0(61.3)	87.5(69.3)	87.8(69.6)	86.2(68.2)	86.5(68.4)	87.8(69.6)
720 vlv	37.5(37.8)	52.5(46.4)	55.8(48.3)	66.5(54.6)	72.5(58.4)	82.0(64.9)	81.2(64.3)	79.8(63.3)	83.5(66.0)	84.5(66.8)
480 vlv	30.7(33.7)	35.2(36.4)	42.5(40.7)	46.8(43.2)	51.0(45.6)	57.5(49.3)	55.0(47.9)	52.5(46.4)	51.8(46.0)	53.0(46.7)
Manual control	96.5(79.2)	85.0(67.2)	78.0(62.0)	73.8(59.2)	70.5(57.1)	62.2(52.1)	60.8(51.2)	59.5(50.5)	58.5(49.9)	57.5(49.3)
F-test	15.8	16.3	12.7	12.6	11.4	15.1	15.6	15.2	17.7	20.0
% cv	19.9	18.6	13.6	12.4	10.5	13.0	13.7	13.6	15.4	17.3

Values in parenthesis are arc sine transformations, a.i. g ha^{-1} (active ingredient in grams per hectare).

Table 4. Response of weeds to glyphosate rates and manual weeding 1-6 weeks after application of treatments in the third year.

Glyphosate rate (a.i. g ha^{-1})	Weed kill (%)				
	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks
1,920 poly-jet	28.8 (32.5	62.5 (52.2)	79.0 (62.7)	89.8 (71.4)	93.2 (74.9)
1,920 vlv	18.5 (25.5)	77.0 (61.3)	91.0 (72.5)	97.0 (80.0)	98.8 (83.7)
960 vlv	22.0 (28.0)	39.5 (38.9)	55.5 (48.2)	70.0 (56.8)	78.0 (62.0)
720 vlv	35.8 (36.8)	77.2 (61.5)	89.0 (70.6)	92.0 (73.6)	94.5 (76.4)
480 vlv	18.2 (25.3)	20.2 (26.7)	34.5 (36.0)	39.0 (38.7)	45.2 (42.3)
Manual control	100.0 (88.2)	98.0 (81.9)	95.5 (77.8)	85.8 (67.9)	80.8 (64.0)
F-test	16.3	28.5	25.2	16.3	15.2
% cv	30.2	30.6	22.5	13.8	12.3

Values in parenthesis are arc sine transformations; ai g ha^{-1} (active ingredient in grams per hectare).

between rates of application in the glyphosate treatments. As a result, the cost of weed control per hectare per year using glyphosate increased with increasing dosage. Glyphosate at the rate of 1,920 g a.i. ha^{-1} (polyjet and vlv) had the highest weed control cost. Although there were differences in the cost of weed control among the 480, 720 and 960 g a.i. ha^{-1} glyphosate rates, these differences were marginal compared to the higher rates (1,920 g a.i. ha^{-1}) and manual weeding.

DISCUSSION

Effective and timely weed control is critical to obtaining the potential yield in cocoa. The effectiveness of the 1,920 g a.i. ha^{-1} vlv rate during the early periods following treatments application was due to the higher concentration of the active ingredient which facilitated rapid weed kill. Its effectiveness however, declined with time since glyphosate is not known to exhibit residual activity at recommended rates (Franz et al., 1997). This was confirmed by the bioassay results

Table 5. Species composition of weeds in experimental plots before (August 2011) and after (October 2013) treatment applications.

Weed species	1,920 g a.i. ha^{-1} poly-jet		1,920 g a.i. ha^{-1} vlv		960 g a.i. ha^{-1} vlv		720 g a.i. ha^{-1} vlv		480 g a.i. ha^{-1} vlv		Manual weed control	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Paspalum spp.	2.2	*	4.5	*	6.0	*	3.5	*	2.3	*	1.8	0.5
Rottboellia granularis	3.0	6.3	2.3	4.1	1.6	3.5	1.0	2.7	1.5	1.8	10.8	3.8
Synedrella nodiflora	10.5	13.1	29.3	31.7	29.2	26.1	9.0	10.6	43.0	27.8	11.5	15.7
Justicea spp.	25.3	*	8.5	*	17.0	*	10.4	*	22.0	21.4	12.0	5.1
Oplismanus burmannii	17.0	*	10.1	*	5.8	*	32.5	*	11.0	*	22.3	8.3
Chromolaena odorata	4.3	*	2.1	*	4.9	*	2.8	*	4.3	1.7	7	1.7
Amaranthus spp.	10.0	15.7	*	7.5	0.5	8.7	*	16.4	*	11.7	*	7.8
Sapplings	10.2	11.5	2.6	8.1	4.5	7.3	8.3	10.4	12.3	11.3	22.3	*
Ageratum conyzoides	*	3.7	2.0	4.2	*	1.5	0.5	3.1	*	2.5	*	0.8
Commelina diffusa	4.4	*	3.8	*	4.0	2.1	1.0	*	2.1	3.8	1.3	2.7
Sedges	*	1.8	2.0	3.1	1.0	2.7	1.0	*	2.0	2.6	0.8	1.8
Centrosema pubescens	1.3	*	0.5	*	4.3	3.1	*	2.5	0.5	1.2	*	1.7
Desmodium spp.	1.5	*	4.2	*	6.5	*	2.6	3.4	2.0	6.7	10.3	*
Euphorbia heterophylla	*	6.7	*	5.1	*	6.0	*	2.7	*	1.5	*	*
Digitaria insularis	1.0	1.2	*	*	*	*	1.0	*	0.5	*	0.5	0.5
Spigia anthelmia	*	*	*	*	*	*	*	*	*	*	0.5	3.1
Momordica charantia	1.5	3.1	0.5	2.7	1.5	1.5	1.3	*	0.5	*	1.0	5.2
Lantana camara	*	*	5.0	1.7	5.0	*	0.5	*	0.5	*	10.0	*
Aspillia africana	31.5	10.5	49.0	7.8	24.0	5.1	8.5	0.5	7.2	1.7	*	1.2
Phyllanthus amarus	0.5	2.5	*	2.7	2.0	1.2	*	1.5	0.5	2.8	2.0	*
Richardia spp.	50.0	*	0.5	*	*	*	*	*	*	*	1.0	0.8
Chloris batata	*	*	*	*	1.0	*	*	*	*	*	3.0	2.7
Setaria barbata	*	*	*	*	*	*	1.0	*	*	*	0.5	*
Sida acuta	*	*	*	*	*	*	1.0	*	*	*	0.5	*
Panicum maximum	*	*	*	*	*	*	1.0	*	*	*	*	*

Note: *weed species absent.

which indicated the absence of residual effects of the weedicide on emergence and subsequent growth of cereals and legumes, similar to findings of Konlan et al. (2014).

The performance of the lower rates of glyphosate treatments compared to the manual weeding with regard to weed control confirm earlier reports that weedicides ensure better weed control than manual weeding in cocoa (Osei-Bonsu et al., 1991; Oppong et al., 1995; 1999; Konlan et al., 2014). These rates were even more effective when applied to young and fresh weed re-growth, suggesting the importance of proper timing of weedicide application for good results (Wendy et al., 2001).

Table 6. Growth response of young cocoa to glyphosate rates and manual weeding 1-12 months after transplanting and application of treatments.

Glyphosate rate (a.i. g ha^{-1})		3 months	6 months	9 months	12 months
Girth (mm)	1,920 polyjet	4.7	8.1	12.8	15.2
	1,920 vlv	3.7	6.3	9.9	12.9
	960 vlv	4.3	7.0	10.4	14.4
	720 vlv	4.2	6.6	9.7	13.0
	480 vlv	4.4	7.7	11.6	14.7
	Manual control	4.3	6.8	9.2	12.7
	F-test	Ns	Ns	ns	ns
	% cv	23.6	17.1	17.8	14.8
Height (cm)	1,920 polyjet	16.1	26.4	52.1	73.6
	1,920 vlv	10.7	18.6	43.7	63.3
	960 vlv	14.8	23.1	46.0	67.4
	720 vlv	14.6	22.4	58.3	67.3
	480 vlv	16.7	24.5	51.4	76.2
	Manual control	17.9	22.7	46.2	62.8
	F-test	Ns	Ns	ns	ns
	% cv	32.5	29.3	28.6	21.4

Note: a.i. g ha^{-1} (active ingredient in grams per hectare).

Table 7. Cost of weed control as affected by glyphosate rates and labour requirements.

Rate (a.i g ha^{-1})	Litres/ha/spray	Weedicide cost/ha/spray (US$)	Labour cost/ ha/spray (US$)	Total cost/ ha/trt (US$)	Total cost/ ha/year (US$)
1,920 polyjet	4.0	13.60	48.00	61.60	246.40
1,920 vlv	4.0	13.60	48.00	61.60	246.40
960 vlv	3.0	6.80	48.00	54.80	219.20
720 vlv	1.5	5.10	48.00	53.00	212.40
480 vlv	1.0	3.40	48.00	51.40	205.60
Manual	-	-	96.00	96.00	576.00
Cost of 1 manday = US$8.00					
Cost of 1 litre of Sidasate = US$3.40					
No. of mandasy for weedicide application/ha = 6					
No. of weedicide applications/year = 4					
No. of mandays for manual weeding = 12					
No of manual weeding operations/year = 6					
Exchange rate: US$1 = Gh¢5.0.					

The unexpected higher weed kill by the 720 g a.i. ha^{-1} vlv compared to the 960 g a.i. ha^{-1} vlv was probably due to the presence of perennial weeds in the latter plots (Konlan et al., 2014). Because of the non-selective nature of glyphosate, weed species composition after three years was generally representative of what it was at the onset of treatments application. Except in the case of glyphosate resistance, the application of glyphosate is therefore not expected to lead to a buildup of specific weed species at the expense of others as a result of selective killing.

The absence of differences in stem diameter, which is better indicator of plant growth (Glending, 1966) and height increases suggests that growth of the young cocoa was not adversely affected by the application of glyphosate. In spite of similar morphological growth records, yields obtained from the 480-960 g a.i. ha^{-1} vlv treated plots were higher than yields from the 1,920 g a.i. ha^{-1} (polyjet and vlv) and manually weeded plots, where yields were similar.

This result contradicts earlier reports by Oppong et al. (2006) and Konlan et al. (2014), which indicated no

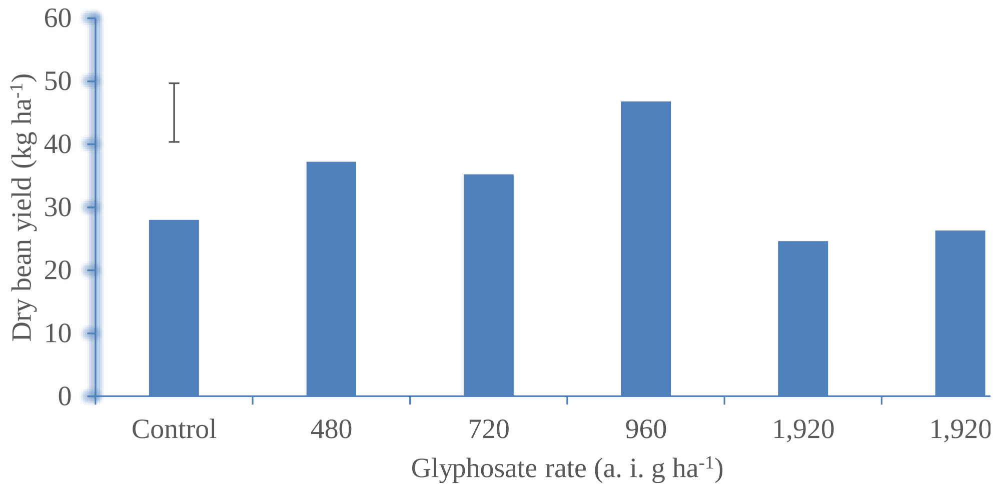

Figure 1. Dry bean yield (kg ha^{-1}) of 3 year old cocoa as affected by glyphosate rates and manual weeding. Note: a.i. g ha^{-1} (active ingredient in grams per hectare), Control (manual weeding).

significant differences in initial yield of young cocoa following glyphosate use for weed control. This may be the result of different field conditions under which the tests were carried out. The lower yields observed in the manually weeded plots and also in the plots treated with the highest glyphosate rates could probably be due to higher weed competition from residual weeds in the manually weeded plots, and strong drift effect after application of the 1,920 g a.i. ha^{-1} glyphosate rates (polyjet and vlv) respectively. The possible disruption of aromatic amino acid synthesis due to the strong drift of glyphosate might have contributed to lower yields since amino acids are known to play a vital role in fruit set and retention (Magda et al., 2012; Salem, 2013).

The cost of manual weed control, which is best recommended for young cocoa, was more than double the cost of the highest glyphosate rate. Dry bean yield (kg ha^{-1}) of young cocoa following manual weed control was comparable to those obtained from the 1,920 g a.i. ha^{-1} glyphosate (polyjet and vlv) treated plots. Lower glyphosate rates (480, 720 and 960 g a.i. ha^{-1}) which were very effective in killing weeds provided cheaper weed control options and increased dry bean yield, thus potentially increasing revenue and net benefits. These lower rates would also exert relatively less adverse effects on soil fauna and also lead to lower drift concentration which has been shown to affect fruit set and retention (Magdal et al., 2012; Abella et al., 2013; Salem et al., 2013). This probably explains why dry bean yields from plots treated with these lower rates were higher.

Conclusion

The yield of three-year-old cocoa in plots that have been treated with glyphosate at rate of 1,920 g a.i. ha^{-1} (polyjet and vlv) for weed control were comparable to those in manually weeded plots. The application of glyphosate at a rate of 960 g a.i. ha^{-1} vlv was cheaper, effectively kept weed growth below economic injury level without immediate or residual adverse effects on the growth of cocoa and consequently, caused improvement in yield above the farmers' practice of manual weed control and other glyphosate rates. It was therefore, concluded that glyphosate can be applied at a rate 960 g a.i. ha^{-1} vlv (equivalent to 2.0 L glyphosate ha^{-1} in 120 l of water) for effective weed control during the establishment phase of cocoa.

Adverse effects of glyphosate on growth and/or yield of young cocoa may however, result from improper application of this rate, effects of strong drift or both. It is therefore not advisable to carry out glyphosate application in windy conditions, as well as during transitioning into flower and fruit production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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