ISSN 1819-1894

Asian Journal of Agricultural Research

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

Asian Journal of Agricultural Research 10 (1): 56-64, 2016
ISSN 1819-1894 / DOI: 10.3923/ajar.2016.56.64

Crop and Weed Response to Diuron in the Rain Forest Zone of Ghana

[1]S. Konlan, [1]K. Opoku-Ameyaw, [1]F.K. Oppong, [2]J. Ackornoh and [1]R. Dorgbadji
[1]Cocoa Research Institute of Ghana, P.O. Box 8, New Tafo, Akim, Eastern Region, Ghana
[2]Makhteshim Agan, West Africa

Corresponding Author: S. Konlan, Cocoa Research Institute of Ghana, P.O. Box 8, New Tafo, Akim, Eastern Region, Ghana Tel: +233 (0) 243 314 068

ABSTRACT

A series of experiments were carried out to evaluate a residual herbicide containing 800 g kg^{-1} Diuron present as 3-(3,4-Dichlorophenyl)-1,1-dimethylurea water dispersible granules for weed management in 2012. The experiments assessed the effect of Diuron on selected annual weeds, cowpea and maize when applied pre and post-emergence. The rates of Diuron evaluated ranged from 0-2.0% for potted weeds and trays and 0-4% for phyto-toxicity and field tests. Data taken included damage caused to potted weeds and crops, crop emergence, leaf chlorophyll content, survival and dry matter accumulation of cowpea and maize at 6 weeks after application. The results show that 1% Diuron solution easily controlled the weed species present with the exception of *Rottboellia granularis* and *Commelina diffusa*. When applied pre-emergence, Diuron killed all the cowpea and maize plants that emerged within 2 and 3 weeks after sowing, respectively. With the exception of the 4% solution, early post-emergence application was found not to be lethal to cowpea and maize although rates above 2% affected both growth and dry matter accumulation of these crops. It was, therefore, recommended that Diuron at 1.0% solution (2 kg ha^{-1} in 200 L of water) be used for early post-emergence weed management in cowpea and maize in the forest zone of Ghana and places of similar agro-ecologies.

Key words: Diuron, post-emergence, weed kill, phyto-toxicity, residual

INTRODUCTION

Most crops need long periods during which competition with weeds is low to ensure maximum use of growth resources (Opoku-Ameyaw *et al*., 2012). Weed control is therefore, an important cultural practice since it accounts for a high proportion of the cost of cultivation of most crops (Zimdahl, 1988; Doll, 1994; Ellis-Jones *et al*., 1993; Akobundu, 1996). The elimination of weed competition at the early stages of crop growth is critical and can be achieved manually or with the use of herbicides. Manual weed control in most cases has been found to be too slow and more expensive than the use of herbicides (Ellis-Jones *et al*., 1993; Akobundu, 1996; Oppong *et al*., 1999; Osei-Bonsu *et al*., 1991). In addition, most herbicides known to the average Ghanaian farmer are non-selective and cannot easily be used after crop emergence. The use of selective active molecules such as Diuron which has residual properties has offered a relief to many agricultural production systems elsewhere, allowing for expansion as it greatly lowers labour requirements for weed control while ensuring none or little competition at the onset of crop growth. Elsewhere, Diuron is a common herbicide in a variety of agricultural systems ranging from fruit trees to cereals and legumes (Hess and Warren, 2002; Turner, 2003). Diuron has widespread use in non-agricultural applications, especially industrial and right of way where it is used in combination with other

herbicides to provide total vegetation control (USEPA., 2004; Adriana, 2009). As a broad-spectrum residual herbicide, Diuron is known for its effectiveness in pre and post-emergence control of both broadleaf and annual grassy weeds.

The pre-emergence application of Diuron allows weed seeds to germinate normally, but interferes with chlorophyll formation which then leads to starvation and death of the young plants (Ferrell *et al*., 2004; Hess and Warren, 2002). Diuron is often used in combination with other herbicides such as bromacil, hexazinone, paraquat, thiadiazuron, imazetapyr, monosodium, sodium chlorate, sodium metaborate and copper sulfate (USEPA., 2004). Diuron exhibits moderate to high persistence in soils with reported average field dissipation half-life of 90 days although such half-lives are typically highly variable (USEPA., 2004). Phytotoxic residues generally dissipate within a season through microbial degradation when applied at low rates. Photo-degradation is not considered a primary dissipation route but losses were found to be significant when Diuron remains on the soil surface for long periods (Hess and Warren, 2002). At higher application rates, residues may persist for more than a year (Kidd and James, 1991). Similar to most other pesticides, Diuron sorption is highly correlated with organic matter (Spurlock and Biggar, 1994). Other soil conditions that favour Diuron leaching include high soil permeability to water. Due to its persistence and mobility, the use of large volumes of Diuron is reported to lead to contamination of ground water sources (Troiano *et al*., 2001).

The introduction of Diuron into the Ghanaian farming systems therefore require a careful evaluation in the different agro-ecologies and soil conditions for the determination of minimum effective rates for control of weeds in order to address environmental concerns, lower the risk of crop loss through misapplication and meet farmer's objective of cost-effective and safe early weed control. For the control of annual weeds on arable lands, 2 kg ha^{-1} of Diuron or 1% solution (equivalent to 2 kg in 200 L of water) is the recommended rate elsewhere when weeds are 4-5 cm tall (Adriana, 2009; USEPA., 2004). The objective of this study was therefore to evaluate the efficacy of Diuron and determine minimum effective and crop-safe rates for weed control in the forest zone of Ghana.

MATERIALS AND METHODS

The experiment was conducted on the research station of the Cocoa Research Institute of Ghana (latitude 6°13'N, longitude 0°22'W, altitude 222 m above sea level). Diuron 80 WG, a residual herbicide containing 800 g kg^{-1} Diuron present as 3-(3,4-Dichlorophenyl)-1,1-dimethylurea water dispersible granules was tested for its efficacy and phyto-toxicity in a gauze house and field trials.

Potted weeds experiment: Weed species such as *Ageratum conyzoides*, *Commelina diffusa*, *Chromolaena odorata*, *Centrosema pubescens*, *Rottboellia granularis*, *Oplismenus burmannii* and *Synedrella nodiflora* which are weeds commonly found on arable lands were transplanted into plastic pots with drainage holes at the bottom and watered for three weeks. The heights of the weeds were taken and the pots arranged in a Randomised Complete Block Design (RCBD) with 6 replicates. Different concentrations of Diuron was applied to the pots and data collected on damage caused at weekly intervals using the scale 0-5 where 0-no damage, 1-slight chlorosis, 2-severe chlorosis, 3-moderately scorched, 4-severely scorched and 5-totally killed.

Tray experiment: Seed trays were filled with top soil from an arable land and the different rates of Diuron applied to the weeds that naturally emerged from the soil when they were about 30 cm

tall. The experimental design was RCBD with 6 replicates. Data collected included percentage weed kill and effectiveness of Diuron in controlling specific weed species.

Field experiment: The evaluation of different rates of Diuron in the field was carried out on uncultivated arable land from which top soil was collected for the tray experiment. The rates of the herbicides evaluated using poli-jet nozzle was the same as the gauze house phyto-toxicity test with manual weeding as control. The experiment was laid out in a randomised complete block design, replicated five times with each plot measuring 5.0 m^2. The treatments were applied when weeds on the land were about 30 cm tall and monitored over 8 weeks. Data collected in the field trial included pre and post-application weed composition and weekly assessment of weed kill (%).

Phyto-toxicity experiment: Cowpea and maize were used for the phyto-toxicity test on planted crops in a randomised complete block design with 6 replicates. There were 120 plastic pots with drainage holes at the bottom were filled with topsoil for each crop. The pots were divided into two groups of 60 pots, each for pre-emergence and post-emergence applications. For pre-emergence application, two seeds of each crop were sown per pot and watered after which the concentrations of the herbicide were immediately sprayed over them. The treatments were replicated six times. In the case of the post-emergence application, the herbicide was applied 1 Week After Sowing (WAS) when the maize and cowpea were at 3 and 2-leaf stages, respectively. Data collected on both crops included percentage emergence, plant survival, leaf chlorophyll content (measured with chlorophyll content meter-CL-01 by Hansatech Instruments Ltd) and total dry matter accumulated at 6 Weeks after Application (WAA).

Data analysis: Data on percent weed kill, final emergence of maize and cowpea and plant survival were subjected to angular transformations before analysis. A statistical analysis of data was done using ANOVA and differences between treatment means determined by the LSD at 5% probability level.

RESULTS

Effect on potted weeds: *Ageratum conyzoides*, *Synedrella nodiflora*, *Setaria barbata*, *Oplismenus burmanii* and *Chromolaena odorata* were most susceptible to the herbicide and were totally killed by the 1, 1.5 and 2% rates (Table 1) at 3 Weeks After Application (WAA). Apart from the higher rates, *Ageratum conyzoides* and *Synedrella nodiflora* were totally killed by 0.5% Diuron solution (Table 1). *Commelina diffusa* was totally killed by the 1.5 and 2% rates while *Rottboellia granularis* was only moderately scorched (Table 1). At 4 WAA, 1% or higher concentration totally killed all

Table 1: Damage caused to potted weed species at 3, 4 and 5 weeks after application of various concentrations of Diuron

	Week 3 (%)					Week 4 (%)					Week 5 (%)				
Weed species	0	0.5	1.0	1.5	2.0	0	0.5	1.0	1.5	2.0	0	0.5	1.0	1.5	2.0
Ageratum conyzoides	0	5	5	5	5	0	5	5	5	5	0	5	5	5	5
Centrosema pubescens	0	4	5	5	5	0	5	5	5	5	0	5	5	5	5
Setaria barbata	0	4	5	5	5	0	4	5	5	5	0	5	5	5	5
Oplismenus burmannii	0	4	5	5	5	0	4	5	5	5	0	5	5	5	5
Commelina diffusa	0	2	4	5	5	0	3	4	5	5	0	4	5	5	5
Rottboellia granularis	0	2	2	2	2	0	2	3	4	5	0	4	5	5	5
Synedrella nodiflora	0	5	5	5	5	0	5	5	5	5	0	5	5	5	5
Chromolaena odorata	0	3	5	5	5	0	3	5	5	5	0	4	5	5	5

0: No damage, 1: Slight chlorosis, 2: Severe chlorosis, 3: Moderate scorching, 4: Severe scorching, 5: Totally killed

Table 2: Percentage of weed kill at various times after post-emergence application of Diuron to weeds in trays

Diuron concentration (%)	Weed kill (%) WAA 1	2	3	4	5	6	7	8
0.0 (control)	0.0	0.0	0.0	0.0	0.0	12.5 (21.6)	12.5 (21.6)	12.5 (21.6)
0.5	37.5 (38.4)	70.0 (57.1)	75.0 (60.3))	75.0 (60.3))	75.0 (60.3))	57.5 (49.9)	60.0 (51.1)	55.0 (48.2)
1.0	65.0 (54.1)	91.2 (74.1)	91.2 (74.1))	91.2 (74.1))	87.5 (70.2))	95.0 (77.8)	80.5 (64.5)	62.5 (52.8)
1.5	70.0 (57.1)	92.5 (75.2)	93.8 (76.4))	96.2 (80.9))	98.8 (86.0))	96.2 (80.9)	82.5 (66.1)	67.5 (55.9)
2.0	62.5 (52.8)	93.8 (76.4)	98.8 (86.0))	100.0	97.5 (83.0))	95.0 (77.8)	77.5 (62.4)	65.0 (54.1)
$LSD_{0.05}$	16.8	8.5	8.7	8.0	16.3	22.3	25.1	36.1
CV (%)	23.2	8.0	7.9	7.3	14.8	20.3	23.5	40.0

Values in parenthesis are angular transformations, WAA: Week after application, LSD: Least significant difference

Table 3: Percentage weed kill at various times after post-emergence application of Diuron to weeds in experimental plots

Diuron concentration (%)	Weed kill (%) WAA 1	2	3	4	5	6	7	8
Manual	100.0 (88.2)	100.0 (88.2)	73.0 (59.1)	59.0 (50.6)	37.0 (36.8)	31.0 (32.4)	24.0 (25.8)	16.6 (20.5)
1.0	41.0 (39.8)	74.6 (60.3)	84.6 (67.0)	84.0 (67.0)	84.6 (67.0)	87.6 (69.5)	87.6 (69.5)	87.6 (69.5)
2.0	38.2 (38.1)	67.6 (56.6)	76.2 (62.7)	76.8 (63.4)	76.8 (63.4)	76.8 (63.4)	76.8 (63.4)	76.8 (63.4)
3.0	40.4 (39.2)	74.6 (62.0)	89.0 (74.4)	89.4 (72.8)	89.4 (72.8)	89.4 (72.8)	89.4 (72.8)	89.4 (72.8)
4.0	42.0 (40.4)	80.2 (64.6)	92.0 (74.8)	92.6 (75.4)	92.6 (75.4)	92.6 (75.4)	92.6 (75.4)	92.6 (75.4)
$LSD_{0.05}$	7.1	16.2	13.0	13.9	16.4	15.4	16.4	15.2
CV (%)	10.8	18.2	14.3	15.7	19.3	18.5	19.9	18.7

Values in parentheses are angular transformations, WAA: Week after application, LSD: Least significant difference

weed species except *Rottboellia granularis* and *Commelina diffusa* which suffered severe to moderate scorching. It took 5 weeks for the 1% Diuron rate to achieve total week kill (Table 1).

Effect on tray weeds: Weeds that emerged in the tray before herbicide application were *Ageratum conyzoides*, *Centrosema pubescens*, *Commelina diffusa*, *Chromolaena odorata*, *Desmodium* spp., *Euphorbia heterophylla*, *Justicea* spp., *Oplismenus burmanii*, *Momordica charantia*, *Cyathula prostrata*, *Panicum maximum*, *Phyllanthus amarus*, *Rottboellia granularis*, *Setaria barbata* and *Synedrella nodiflora*. At 1 WAA, rates of 1% or higher gave over 60% weed kill which was significantly different ($p<0.05$) from that of the 0.5% solution (Table 2). The weed kill by the higher rates increased to over 90% by the second week and persisted up to the sixth week. Percentage of weed kill in trays treated with 2% solution peaked at 4 WAT while those of trays treated with 1.5 and 1% solution peaked at 5 and 6 WAA, respectively. There were however, no significant differences ($p>0.05$) in weed kill (%) among the 1, 1.5 and 2% rates throughout the 8 weeks of monitoring. Application of 0.5% solution to weeds in the trays resulted in 70 and 75% weed kill 2 and 3 WAA, respectively. Weed re-growth started earlier in trays treated with rates of 1.5% or higher.

Effect on weeds in the field: Apart from the first 2 WAA, Diuron killed the weeds better than manual weeding during the 8 weeks of monitoring (Table 3). Significant differences ($p<0.05$) were observed between percentage of weed kill at 3 and 4 WAA for the 3 and 4% rates, respectively. From 5-8 WAA, all the herbicide rates performed significantly better ($p<0.05$) than the manual control. No significant differences in performance were observed between the various concentrations of Diuron from 5-8 WAA. The percentage weed kill by the herbicide peaked at 4 WAA for 2-4% and 6 WAA for 1% solutions. All the rates of Diuron evaluated in the field achieved 75% weed control (Table 3), similar to the observation made in the gauze house tray experiment (Table 2).

Table 4: Effectiveness of different concentrations of Diuron in controlling weed species in trays

	Diuron concentration (%)				
Weed species	0 (manual)	0.5	1.0	1.5	2.0
Ageratum conyzoides	*	E	E	E	E
Centrosema pubescens	NE	NE	E	E	E
Commelina diffusa	NE	NE	NE	NE	NE
Chromolaena odorata	NE	E	E	E	E
Desmodium spp.	NE	*	E	E	*
Euphorbia heterophylla	NE	E	*	New*	New*
Justicea spp.	NE	NE	NE	E	E
Momordica charantia	NE	E	E	E	E
Cyathula prostrata	*	E	*	New*	*
Oplismenus burmannii	NE	E	E	*	E
Panicum maximum	NE	*	E	E	E
Phyllanthus amarus	*	*	*	E	New*
Rottboellia granularis	NE	E	E	E	E
Setaria barbata	NE	*	E	*	E
Solanum torvum	*	*	*	E	E
Synedrella nodiflora	NE	E	E	E	E

E: Effective, NE: Not effective, *Weed species not present in tray, New*-weed present only as re-growth, Control water

Table 5: Weed species present in experimental plots before and eight weeks after post-emergence application Diuron

	Diuron concentration									
	1.0%		2.0%		3.0%		4.0%		Manual weeding	
Weed species	Before	After	Before	After	Before	After	Before	After	Before	After
Panicum maximum	1	1	1	1	1	1	1	1	1	1
Centrosema pubescens	1	1	1	1	1	1	1	1	1	1
Chromolaena odorata	1	1	1	1	1	1	1	1	1	1
Synedrella nodiflora	1	1	1	*	1	*	1	*	1	*
Commelina diffusa	1	1	1	1	1	1	1	1	1	1
Justicea spp.	1	1	1	1	1	1	1	1	1	1
Acalypha ciliata	1	1	1	1	*	1	1	1	*	1
Solanum torvum	1	*	1	*	1	*	1	*	*	*
Cyathula postrata	*	1	1	*	1	*	1	*	1	*
Saplings	1	1	1	1	1	1	1	1	1	1
Flemingia	*	1	*	*	1	*	*	*	*	*
Oplismenus burmannii	1	1	*	1	1	1	*	*	1	*
Momordica charantia	1	1	1	1	1	*	1	1	1	1
Rottboellia granularis	1	1	1	1	1	*	*	*	1	*
Euphorbia hirta	*	*	*	*	*	*	1	*	*	*
Ageratum conyziodes	1	*	*	*	*	*	*	*	*	*
Amaranthus spp.	*	*	*	*	1	*	*	*	*	*
Paspalum spp.	*	1	*	*	*	*	*	*	1	*
Climbers	*	1	*	1	*	1	*	1	*	1
Fluerya spp.	*	1	*	*	*	*	*	*	*	*1*
Sedges	*	1	*	*	*	*	*	*	*	*
Talinum triangulare	*	1	*	*	*	*	*	*	*	*

1: Weed species present, *Weed species absent

Effectiveness against specific weed species: The spectrum of susceptible weed species in the trays increased with increasing herbicide concentration (Table 4). *Commelina diffusa* and *Justicea* spp. were however unaffected by even the 2% concentration during the 8 weeks of observation. Weed species such as *Euphorbia heterophylla* and *Phyllanthus amarus* which were not among the initial weed flora were observed in the subsequent re-growth after application of 1.5 and 2% solutions (Table 4). In the field, an assessment of the weed flora at the beginning of treatment application identified between 12 and 14 different weed species per plot (Table 5). Weed species successfully controlled by 8 WAA included *Solanum torvum* and *Ageratum conyzoides* (1% Diuron), *Chromolaena odorata*, *Solanum torvum*, *Cyathula prostrata* (2% Diuron),

Chromolaena odorata, *Solanum torvum*, *Cyathula prostrata*, *Flemingia*, *Momordica charantia*, *Rottboellia granularis* and *Amaranthus* spp. (3% Diuron), *Chromolaena odorata*, *Solanum torvum*, *Cyathula prostrata*, *Flemingia*, *Momordica charantia*, *Rottboellia granularis* and *Amaranthus* spp., *Ephorbia hirta* (4% Diuron). The manual weeding controlled *Chromolaena odorata*, *Cyathula prostrata*, *R. granularis* and *Paspalum* spp. (Table 5). Generally, the number of weed species controlled during the period of monitoring increased with herbicide concentration. The number of weed species killed by the manual method was higher than those killed by 1 and 2% Diuron solutions during the period. Weed re-growth however, started earlier in the manually weeded plots. New weed species emerging after application of Diuron included *Paspalum* spp., *Talinum triangulare*, Sedges and climbers (1% Diuron), *Oplismenus burmanii* (2% Diuron) and *Acalypha ciliata* (3% Diuron).

Effects on cowpea and maize

Leaf chlorophyll: Pre-emergence application of 1-4% Diuron solution significantly reduced ($p<0.05$) leaf chlorophyll content of cowpea seedlings compared to the control (Table 6). There were no significant differences ($p<0.05$) in leaf chlorophyll contents of emerged cowpea and maize before herbicide application (Table 7). However, at 1 and 2 weeks after post-emergence application, the control recorded significantly higher ($p<0.05$) leaf chlorophyll content than the cowpea treated with Diuron. Post-emergence application of 2% or higher Diuron solution also significantly reduced ($p<0.05$) leaf chlorophyll compared to application of the 1% solution. No significant differences were detected from 3-6 WAA as surviving plants recovered from the effect of Diuron. Throughout the period of observation, leaf chlorophyll content of the control maize and the 1% Diuron concentration were similar and significantly higher ($p<0.05$) than those of the 4% solution which recorded the least leaf chlorophyll content. Generally, the 2 and 3% rates recorded lower chlorophyll content than the control and 1% solution at 1 and 3 WAA. As in the case of cowpea, maize leaf chlorophyll content generally improved with time as plants recovered from the effect of the herbicide (Table 7).

Table 6: Effect of pre-emergence application of Diuron on cowpea and maize leaf chlorophyll content

	Cowpea (μ mol cm^{-2})		Maize (μ mol cm^{-2})	
Diuron concentration (%)	1 WAS	2 WAS	1 WAS	2 WAS
0.0 (control)	12.9	14.7	11.0	12.0
1.0	3.4	*	2.1	4.6
2.0	6.0	*	2.2	1.7
3.0	2.4	*	2.0	*
4.0	1.6	*	2.4	*
$LSD_{0.05}$	2.2	-	6.7	5.2
CV (%)	30.2	-	35.2	19.7

*Test plants totally killed, WAS: Weeks after sowing, LSD: Least significant difference

Table 7: Effect of post-emergence application of Diuron on leaf chlorophyll content of cowpea and maize seedlings

	Cowpea leaf chlorophyll (μ mol cm^{-2})				Maize leaf chlorophyll (μ mol cm^{-2})			
Diuron concentration (%)	Before application	1 WAA	3 WAA	6 WAA	Before application	1 WAA	3 WAA	6 WAA
0.0 (control)	14.1	13.7	14.5	20.5	8.5	10.3	8.0	6.2
1.0	10.1	10.3	19.9	21.9	11.0	11.1	10.8	6.6
2.0	14.7	6.3	15.9	20.8	9.2	6.9	7.4	6.4
3.0	13.0	4.4	16.3	23.4	9.6	6.9	5.5	6.5
4.0	13.9	5.0	*	*	11.2	4.6	2.7	2.6
$LSD_{0.05}$	ns	4.0	2.7	3.2	ns	2.2	3.1	3.6
CV (%)	16.9	41.3	13.7	20.4	19.8	22.6	97.1	54.8

*Test plants totally killed, WAA: Weeks after application, ns: No significant difference at 5%, LSD: Least significant difference

Table 8: Effect of pre-emergence application of Diuron on emergence, survival and dry matter accumulation of cowpea and maize at 6 WAS

Diuron concentration (%)	Final emergence (%) at 1 WAS		Plant survival (%) at 6 WAS		Dry matter (g plant^{-1}) at 6 WAS	
	Cowpea	Maize	Cowpea	Maize	Cowpea	Maize
0.0 (control)	91.7 (73.3)	100 (83.2)	83.3 (65.9)	100 (83.2)	5.9	8.8
1.0	91.7 (73.3)	83.3 (65.9)	0	0	*	*
2.0	83.3 (65.9)	83.3 (65.9)	0	0	*	*
3.0	100 (83.2)	100 (83.2)	0	0	*	*
4.0	91.7 (73.3)	83.3 (65.9)	0	0	*	*
$LSD_{0.05}$	ns	ns	-	-	-	-
CV (%)	25.8	23.7	-	-	-	-

Values in parenthesis are angular transformations, *Test plants totally killed, WAS: Weeks after sowing, ns: No significant difference

Table 9: Effect of post-emergence application of Diuron on survival and dry matter accumulation of cowpea and maize

Diuron concentration (%)	Plant survival (%) at 6 WAS		Dry matter (g plant^{-1}) at 6 WAS	
	Cowpea	Maize	Cowpea	Maize
0.0 (control)	100 (88.2)	100 (88.2)	5.7	8.3
1.0	100 (88.2)	100 (88.2)	5.8	8.3
2.0	80.8 (64.5)	83.3 (65.9)	3.2	7.8
3.0	66.7 (54.8)	66.7 (54.8)	3.4	6.8
4.0	0.0	25.0 (30.0)	*	2.8
$LSD_{0.05}$	35.9	25.7	ns	2.9
CV (%)	43.1	36.1	17.5	36.0

Values in parenthesis are angular transformations, *Test plants totally killed, WAS: Weeks after sowing, ns: No significant difference

Final emergence, survival and dry matter accumulation: Although pre-emergence application of Diuron did not significantly ($p<0.05$) affect the final emergence of cowpea and maize, application of all rates of the herbicide resulted in the death of both crops 2 and 3 weeks respectively, after emergence (Table 8). With the exception of the 4% solution, post-emergence application of Diuron did not completely kill cowpea although it significantly ($p<0.05$) affected the number of plants that survived and their dry matter accumulation (Table 9). The effect of the 1% Diuron solution on plant survival and dry matter accumulation did not differ significantly ($p<0.05$) from the control. It was however, observed that, increase in herbicide concentration resulted in a corresponding increase in plant mortality (Table 9). Similar to cowpea, post-emergence application of Diuron significantly influenced ($p<0.05$) maize survival and dry matter accumulation (Table 9). Application of higher rates of Diuron increasingly affected the parameters monitored negatively with no significant differences ($p<0.05$) observed between the control and 1% solution. Maize dry matter accumulation was significantly reduced ($p<0.05$) only when the 4% solution was applied (Table 9).

DISCUSSION

Application of Diuron was found to be effective for the control of common broad leaves and grasses in both the gauze house and field experiments. With the exception of *Rottboellia granularis* and *Commelina diffusa*, concentrations of 1% solution of Diuron (equivalent to 2 kg ha^{-1} in 200 L of water) achieved 75% weed kill in both gauze house and field experiments during the eight weeks of monitoring and was therefore able to bring weed population and competition below economic injury levels (Adriana, 2009; USEPA., 2004). While the inability of lower concentrations of Diuron to control *Commelina* spp. was probably due to the succulent nature of the weed, *R. granularis* at the time of application was tall and probably too mature for effective disruption of its photochemistry. With regard to crop response to Diuron application, death of all the cowpea and

maize plants that emerged after pre-emergence application of Diuron was as a result of the herbicide's ability to attack young germinating plants and interfere with their chlorophyll synthesizing system, thereby starving them to death, confirming its non-suitability for use as a post-plant pre-emergence herbicide in field crops production (Hess and Warren, 2002; Ferrel *et al*., 2004).

The known interference of Diuron with chlorophyll synthesizing systems of crops (Ferrell *et al*., 2004; Hess and Warren, 2002) did not lead to lethal starvation of cowpea and maize plants even at higher rates when applied post-emergence. Application of up to 4% concentration however showed lethal effects in cowpea. Also, post-emergence application of 2-3% solutions adversely affected growth and dry matter accumulation of both crops. The observations made with regard to the performance of Diuron in the control of weed species in the gauze house and field as well as its effects on field crops were consistent with earlier reports (Adriana, 2009; Ferrel *et al*., 2004; USEPA., 2004) and support the current recommended rate of 2 kg ha^{-1} elsewhere. The current study however showed that Diuron at this rate can be used to control weeds that are as tall as 30-35 cm, contradicting the findings of Adriana (2009) which suggested that application is effective when weeds are 4-5 cm tall. This however may depend on the soil, climate and weed species mix. The rapid total weed kill recorded under higher rates probably provided an opportunity for weed seeds in the soil to germinate as soil was exposed to more light, leading to faster weed regeneration in those plots. The fact that weed re-growth was made up of mainly broad-leaved species (*Commelina diffusa* and *Oplismenus burmanii*) may be suggesting that Diuron was more effective in interfering with the photochemistry of emerging grass species.

CONCLUSION

The post-emergence application of 1% Diuron solution (2 kg ha^{-1} in 200 L of water) was found to be effective in controlling most broad leaves and grasses. Since this rate did not affect the survival and growth of cowpea and maize when applied early post-emergence, it was concluded that Diuron could be applied at a rate of 1.0% (2 kg ha^{-1} in 200 L of water) only for early post-emergence weed management in cowpea and maize.

ACKNOWLEDGMENTS

The authors will like to acknowledge the contributions of the entire technical staff and field assistants of the Agronomy Division of the Cocoa Research Institute of Ghana. Special mention to Godwin K. Addo, Ruth Agyeiwaa Ofori and Robert Sarkodie for their dedication and attention to detail.

REFERENCES

Adriana, M., 2009. Environmental fate of diuron. Environmental Monitoring Branch Department of Pesticide Regulation 1001 Street Sacramento, CA 95812-4015.

Akobundu, O., 1996. Principles and prospects for integrated weed management in developing countries. Proc. of the Second Int. Weed Control Congress, June 25-28, 1996, Copenhagen, pp: 591-600.

Doll, J.D., 1994. Dynamics and Complexity of Weed Competition. In: Weed Management for Developing Countries, Labrada, R., J.C. Caseley and C. Parker (Eds.). FAO, Rome, Italy, pp: 29-34.

Ellis-Jones, J., S. Twomlow, T. Willcocks, C. Riches, H. Dhliwayo and M. Mudhara, 1993. Conservation Tillage/Weed Control Systems for Communal Farming Areas in Semi-Arid Zimbabwe. In: Brighton Crop Protection Conference 1993: Weeds, BCPC (Ed.). Vol. 3, British Crop Protection Council, Alton Hampshire, UK., ISBN-13: 978-0948404702, pp: 1161-1166.

Ferrell, M.A., S.D. Miller and T.D. Whitson, 2004. Basic guide to weeds and herbicides. Cooperative Extension Service, MP18, College of Agriculture, Department of Plant Sciences, The University of Wyoming.

Hess, D. and F. Warren, 2002. The herbicide handbook of the weed. Sci. Soc. Am., 8: 159-161.

Kidd, H. and D.R. James, 1991. The Agrochemicals Handbook. 3rd Edn., Royal Society of Chemistry Information Services, Cambridge, UK.

Opoku-Ameyaw, K., F.K. Oppong and S. Konlan, 2012. Final report on the evaluation of sidalsate for weed control in cocoa. Cocoa Research Institute of Ghana, Ghana.

Oppong, F.K., K. Osei-Bonsu and F.M. Amoah, 1999. The efficacy of low volume application of roundup (glyphostate) on weed suppression in some plantation crops in Ghana. J. Sci. Ghana Assoc., 2: 40-48.

Osei-Bonsu, K., F.K. Oppong and F. M. Amoah, 1991. Appraisal of methods of weed control in cocoa establishment. Proceedings of the 17th Biennial Conference of the Ghana Science Association, August 4-8, 1991, University of Science and Technology, Kumasi.

Spurlock, F.C. and J. W. Biggar, 1994. Thermodynamics of organic chemical partition in soils. 2. Nonlinear partition of substituted phenylureas from aqueous solution. Environ. Sci. Technol., 28: 996-1002.

Troiano, J., D. Weaver, J. Marade, F. Spurlock, M. Pepple, C. Nordmark and D. Bartkowiak, 2001. Summary of well water sampling in california to detect pesticide residues resulting from nonpoint-source applications. J. Environ. Qual., 30: 448-459.

Turner, L., 2003. Diuron analysis of risks to endangered and threatened salmon and steelhead. PhD. Thesis, US EPA Publication 540/9-85-006.

USEPA., 2004. Environmental risk assessment for the reregistration of diuron. U.S. Environmental Protection Agency, USA.

Zimdahl, R.L., 1988. The Concept and Application of the Critical Weed-Free Period. CRC Press Inc., Florida, USA., ISBN: 08-493-68162, pp: 145-155.