International Journal of Agricultural Policy and Research Vol.4 (1), pp. 7-16, January 2016
Available online at http://www.journalissues.org/IJAPR/
http://dx.doi.org/10.15739/IJAPR.016.002

ISSN 2350-1561

Original Research Article

Biological efficiency of hexazinon on sugar cane weeds and its effects on soil agrochemical properties, in Burkina Faso

Received 17 December, 2015 Revised 6 January, 2016 Accepted 15 January, 2016 Published 22 January, 2016

Kambou Georges
and
Ouattara Boubakar

INERA FARAKOBA Research Laboratory, P. O. Box 403, Bobo – Dioulasso, Burkina Faso

*Corresponding Author Email: kambougeorges2000@yahoo.fr

Tel: +2267800 9103

A study of herbicidal activity of hexazinone 750 g/kg for reducing weeds such as *Vernonia cinerea* and *Cyperus* sp. and its secondary effects on soil agrochemical properties was carried out in the sugarcane fields at Bérégadougou in Burkina Faso. The biological efficacy of herbicides was evaluated by counting and weighing the dry biomass of weeds using a sampling square of 0.25 m² placed on four tufts diagonally on the 4 lines of the useful plot. The biological efficiency coefficients of hexazinone at 480 g/ha ranged from – 125.00 to 100.00%, while at high doses of 800, 960 and 1440 g/ha, it ranged from 37.33 to 100%. The soil nitrogen nitrate and available phosphorus contents were evaluated with a spectrophotometer. The available potassium contents in hexazinone treatments were not different from those of manual weeding during the maturity stage. On the opposite, those of nitrate nitrogen decreased by 24.97 to 37.40% compared to the manual weeding. All these factors provided hexazinone 1440 g/ha a yield surplus of 20.42% compared to the untreated control, an extractable sugar and sucrose contents equivalent to manual weeding. Hexazinone did not disturb at the studied doses, the dynamic evolution of soil agrochemical components.

Key words: Agrochemical properties, *Cyperus* sp, hexazinone, sugarcane, *vernonia cinerea*, weeds.

INTRODUCTION

Sugar cane (*Saccharum officinarum* L.) is a plant of the Poaceae family from which sugar is extracted from their stalks. It was only the major source of sugar until the early 19th century [Inra, 2007]. In terms of planted area, sugarcane has an annual worldwide production of more than 1.8 billion tons or 28% of the total mass produced in agriculture. The main source of sugar for man, sugarcane contains up to 16% sucrose and 96% of it can be extracted from industrial processing (Arzate, 2005). The increase in sugarcane production worldwide may be due to increased consumer needs, the agro-food development as well as ethanol and bio fuel production. Brazil, India and the European Union are the major producers of sugar in the world, as they contribute nearly half of global production. Sugarcane accounts for three quarters of world sugar production compared to sugar beet which accounts for a quarter (Courteau, 2005).

Sugar cane is mainly cultivated in tropical and subtropical areas, such as Burkina Faso, where its production is modern and play an important role in the national economy. In Burkina Faso, the area of waterfalls cultivated to sugar cane by the New Sugar Company of Comoé (SN-SOSUCO) is about 10,000 ha. SN-SOSUCO currently operates approximately 4000 ha and employs over 3800 people per year allowing the industry to supply approximately 300,000 tons of sugar cane per year. In addition to annual rainfall, the crop is irrigated by an irrigation system of pivot rampes and moving lateral systems (Industrial promotion services –West Africa, 2010).

However, production in Burkina Faso and around the world is facing enormous constraints. In addition to losses caused by diseases and insect pests, cultivation of sugar cane is faced with the challenge of weeds.

Weeds management is a major problem in sugarcane production (Chabalier et al., 2012). In a sugar cane plot, weeds can cause yield losses of 20 t/ha when they are not reduced in the three months following the cut (Bulletin de santé du végétal, 2014). Yield losses of about 40% due to natural weed populations have been recorded in experiments on sugarcane (Ibrahim, 2006). The weed competition reduced the number of stems per square meter by 32%, the height of the rod by 24%, the thickness of the stem by 15% and the number of rod nodes by 14% (Ibrahim, 2006). Weeds colonization must be below 30% especially for perennials, creepers and those that grow through the mulch for sugarcane cultivation (Bsv, 2014).

Weed control methods often practiced by SN-SOSUCO such as manual and mechanical weeding have limits. Indeed, the unavailability of local labor at a certain time of year for manual weeding accentuated by the destruction of soil structure due to mechanization have forced the company to increasingly turn to chemical control. Therefore chemical control appears as the most appropriate method of control in the short term for weeds control. Many studies have been done on hexazinone alone or in combination, use of cultivation methods (Judice et al., 2008) to control sugarcane weeds (Fadayomi, 1988; Rainbolt, 2007; Jones and Griffin, 2008), its sorption, leaching of the soil surface (Bicachos et al., 2010, Kodesov et al, 2011), The impact of hexazinone on microorganisms (Estok et al., 1989; Ngigi et al., 2011), and its toxicity on cold-blooded organisms (Mam et al., 2011) were studied. The role of microorganisms in hexazinone degradation (Mostafa and Helling, 2003), environmental pollution by hexazinone (Muendo et al., 2012, Liq et al., 2001), as well as some depollution measures by cultivation techniques by microbial bioreactors (Hunter and Shaner, 2012) under anaerobic conditions (Wang et al., 2009) were considered.

However, no study has been done on the impact of hexazinone on the production of nitrogen nitrate, available phosphorus, and available potassium resulting from microorganism's activity, responsible for soil fertility. Therefore, this study is aimed to study the activity of hexazinone for controlling common weeds in sugarcane field as well as its secondary effects on soil agrochemical properties.

MATERIALS AND METHODS

Materials

For this study, *Saccharum officinarum* L variety CO997, sensitive to weeds was used. The experimental design was a Randomized Latin Rectangle of eight treatments with four replicates. The size of an elementary plot was 11.11 m × 9 m (99.99 m^2), while the size of the useful plot was 10.11 m × 7.50 m (75.82 m^2). The treatments were, hexazinone 240, 480, 800, 960 and 1440 g/ha, Lumax (Mesotrione 125 g /l + Metolachlor 375 g/l +Terbutylazin 37,5g /l) (4 l/ha), untreated control and manual weeding,. The mineral fertilizers were applied at doses of 140 kg of nitrogen, 52 kg phosphorus and 145 kg of potassium followed by a fractional addition of 350 kg of urea, 242 kg of potassium chloride and 116 kg of triple super phosphate (TSP). Water needs were met by an irrigation system and rainwater. The maintenance work on the plots concerned mainly irrigation and weeding according to the protocol. Maintenance work consisted of irrigation depending on the frequency of rainfall and weeding (twice in the plots) according to the protocol.

Methods

After herbicides application, their phytotoxicity on sugarcane was evaluated at the different periods of observations by the visual rating scale of the European Union Bioassays Commission (C.E.B.) numbered from 0 to10. The weed flora analysis was done using identification keys described by Berhaut (1967), Akobundu and Agyakwa (1989), Terry (1985) and Johnson (1997). The biological efficiency of different treatments was studied using the method of counting and weighing the dry biomass of weeds [Likov and Tulikov, 1989)] using a 0.25m^2 quadrant at regular intervals in diagonal and in the same way, in each useful plot at 9, 17, 31, 63, 90, 121 and 169th days after application (DAA) of herbicides. The biological efficacy coefficients of herbicides in these observation periods were calculated using the formula [Vilitsky, 1989] as follows:

$$C = 100 - \frac{Bi \times 100}{Bx}$$

where C= coefficient of efficiency; Bi = number of weeds per m^2 or weight of the dry biomass (g / m^2) of each treatment on the 1st or 2nd or 3rd ... counting.; Bx = number of weeds per m^2 or weight of the dry biomass (g / m^2) of the untreated control on the 1st or 2nd or 3rd ... counting.

For the study of agrochemical soil properties, surface soil samples were collected at 0-20 cm soil depth, near the root system of the cane plants in the useful plots of two blocks, before applying the herbicide on the 65th and 120th day after herbicides application. The nitrate nitrogen extractions from the soil were evaluated with spectrocalorimeter according to the method of Greweling and Peech (1960), available phosphorus determination according to the method of Bray and Kurtz (1945) and available potassium by flame photometer. At the 121st day after herbicide application, the number of machining rods were counted per useful plot. During the harvest, the canes were cut and the yield estimated in tonnes/ha. The contents of extractable sugar and sucrose were determined using a refractometer RFM 340 and a universal polarimeter.

Table 1. Effects of Hexazinone at different rates on sugar cane weeds dry biomass (g/m^2).

Treatments	Sugar cane weeds dry biomass at periods of observations (days)													
	09		17		31		63		90		121		169	
	Without transf.	After $\sqrt{x+1}$	Without transf.	After $\sqrt{x+1}$	Without transf.	After $\sqrt{x+1}$	Without transf.	After $\sqrt{x+1}$	Without transf.	After $\sqrt{x+1}$	Without transf.	After $\sqrt{x+1}$	Without transf.	After $\sqrt{x+1}$
Untreated control	0.00	**1.00**^{a*}	0.00	**1.00**^{a}	0.08	**1.04**^{a}	3.87	**2.11**^{a}	7,50	**2.48**^{a}	13.89	**3.64**^{a}	23.25	**3.88**^{a}
Manual weeding	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00c**	9,43	**2.75**^{a}	0.39	**1.15d**	0.19	**1.08**^{c}
Lumax (4 l/ha)	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.53	**1.19**^{a}	3.65	**1.93**^{a}	2,85	**1.77**^{b}	4.27	**1.81**^{b}	0.92	**1.30**^{b}
Hexazinone (240g/ha)	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.08	**1.12**^{a}	0.00	**1.00**^{c}	3,00	**1.83**^{b}	1.38	**1.47**^{c}	0.57	**1.20**^{bc}
Hexazinone (480g/ha)	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.18	**1.07**^{a}	2.14	**1.52**^{b}	2,68	**1.73**^{b}	0.00	**1.00**^{d}	0.00	**1.00**^{c}
Hexazinone (800g/ha)	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00**^{c}	0,79	**1.26**^{bc}	0.00	**1.00**^{d}	0.04	**1.02**^{c}
Hexazinone (960g/ha)	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00**^{c}	0,00	**1.00**^{c}	0.00	**1.00**^{d}	0.09	**1.04**^{c}
Hexazinon (1440g/ha)	0.00	**1.00**^{a}	000	**1.00**^{a}	0.00	**1.00**^{a}	0.00	**1.00**^{c}	4,70	**1.86**^{b}	0.00	**1.00**^{d}	0.08	**1.03**^{c}
Mean	-		-		**1.05**		**1.32**		**1.83**		**1.51**		**1.45**	
CV (%)	-		-		**14.60**		**10.20**		**16.90**		**6.00**		**7.00**	
ETR (ddl =21)	-		-		**0.15**		**0.13**		**0.31**		**0.09**		**0.10**	
ETM (Sx)	-		-		**0.08**		**0.07**		**0.16**		**0.05**		**0.05**	

* Means following by the same letter within the column are not significantly different at 5% level of probability using NEWMAN –KEULS test.

Analysis of variance (Dospiehov, 1985) was computed and means were analysed using Newman-Keuls test at 5% level using STAT -ITCF software. The correlations between the factors studied were computed using ORIGIN 3.0 software.

RESULTS

Phyto-toxicity of hexazinone on sugar cane

Visual observations made after the application of different doses of hexazinone showed good recovery and no phytotoxicity on sugarcanes.

Effects of hexazinone at different doses on sugar cane weeds dry biomass accumulation

The dynamics of dry biomass accumulation of weeds is characterized by an increase during all observations periods (Table 1). From the 9th to 31st day after application, there is no significant difference between the studied variables. On the 63rd day after application, the average effect of the herbicides (1.10 g/m^2) caused a reduction of 47.87% in dry biomass of weed compared to the control. Hexazinone at doses of 240, 800, 960 and 1440 g/ha do not differ statistically and resulted in reductions of 52.61% compared to the untreated control and 48.17% compared to the control product; Lumax (4 l/ha).

Hexazinone at 480 g/ha showed an average effect between the control product and at other doses of hexazinone. On the 90th day after application, the average effect of herbicides (1.57 g/m^2) caused a weed dry biomass reduction of 36.69% compared to the untreated control and 42.91% compared to manual weeding. The different doses of hexazinone caused a reduction of 25.00 to 59.68% compared to the untreated control. Hexazinone at 960 g/kg dose was more effective than at other rates, but did not differ from Lumax (4 l/ha) (Table 1).

On the 121st day after herbicide applications,

Table 2. Biological efficiency of Hexazinone different doses according to the weeds dry biomass (%)

Treatment	Weeds dry biomass (%) at periods of observations						
	09	17	31	63	90	121	169
Untreated control	-	-	-	-	-	-	-
Manual weeding	100.00	100.00	100.00	100.00	-25.73	97.19	99.18
Lumax (4 l/ha)	100.00	100.00	-56.25	05.68	62.00	69.26	96.04
Hexazinone (240g/ha)	100.00	100.00	100.00	100.00	60.00	90.06	97.55
Hexazinone (480g/ha)	100.00	100.00	-125.00	100.00	64.27	100.00	100.00
Hexazinone (800g/h)a	100.00	100.00	100.00	55.30	89.47	100.00	99.83
Hexazinone (960g/ha)	100.00	100.00	100.00	100.00	100.00	100.00	99.61
Hexazinone (1440g/ha)	100.00	100.00	100.00	100.00	37.33	100.00	99.65

The symbol (-) in front of the number, indicates an increase in weeds dry biomass.

the average effect of herbicides (1.21 g/m^2) was a weeds dry biomass reduction of 66.76% compared to the untreated control. At different doses, hexazinone resulted in a reduction of 59.62 to 72.53% compared to the untreated control and 18.78 to 44.75% compared to the control product (Lumax). On the 169th day after herbicides application, the mean effect of herbicides (1.32 g/m^2) reduced the weight of weeds dry biomass by 65.98% in comparison with the untreated control and 22.00% from manual weeding. The different doses of hexazinone were more effective than Lumax while there was no significant difference with manual weeding. Overall, the application of hexazinone caused a reduction in the weight of weed dry biomass (Table 1).

Efficiency coefficients of hexazinone at different doses based on dry biomass of weeds

The efficiency coefficient for manual weeding varied from -25.73 to 100% during the experiments with an average of 74.13% (Table 2). The efficiency coefficients of Lumax during the experiment ranged from -56.25 to 96.04% with a steady increase over time. These coefficients were above 60.00% from the 90th to 169th day after application with an average value of 35.35%.

The efficiency coefficients of hexazinone at 240 g/ha ranged from 0.00 to 100.00% with an average rate of 69.52%. The weed reduction rate of hexazinone at 480 g/ha ranged from – 125.00 to 100.00% with an average rate of 38.91%. The efficiency coefficients of hexazinone at 800 g/ha varied from 89.47 to 100% from the 31st to 169th days after application. During this time, the average rate was 97.86%. Overall, the coefficients of efficiency of hexazinone at 960 g/ha remained constant (100.00%) during the experiments from the 31st to 121st day after application of the herbicide. Its average rate is 99. 92%.

For hexazinone at 1440 g/ha, the coefficients varied from 37.33 to 100.00% during the study period. This treatment also resulted in significant coefficients with an average rate of 87.40%. In all observations, there was no weed dry biomass on the 9th and 17th days after application. Hexazinone at high doses showed the best rates of reduction in weed weight dry biomass.

Effects of hexazinone different doses on sugar cane weed flora

The inventory of the weed flora on the 90th day after herbicide application shows that *Vernonia cinerea* of the Asteraceae family and *Cyperus* sp. of the Cyperaceae family were the most abundant weeds in the experimental plot (Table 3). Treatments with Lumax (4 l/ha) and hexazinone at doses of 480, 800, 960 and 1440 g/ha resulted in a reduction of *V. cinerea* on different plots. *Cyperus* sp. (Cyperaceae) was absent with the application of Hexazinone at 960 and 1440 g/ha in the untreated control and manual weeding, respectively. However, this weed was present with the application of Lumax at 4 l/ha and Hexazinone at 240 g/ha. Herbicide applications reduced the total population of *Ageratum conyzoides* (Family Compositae) while Hexazinone at 240 g/ha reduced *Ipomoea involucrata* (Family: Convolvulaceae). They were absent the other treatments. The herbicidal activity of various doses of Hexazinone focused primarily on *V. cinerea* and *Cyperus* sp (Table 3).

On the 121st day after application, *Cyperus* sp. was the most abundant weed in number during the evaluation of the weed flora followed by *V. cinerea*, *Diodia scanden* (Rubiaceae), *A. conyzoides* of rubiaceae family (Table, 4). For *V. cinerea*, all doses of hexazinone and Lumax (4 l/ha) were effective against this weed. *Cyperus* sp was not present in plots treated with hexazinone at 480 and 1440 g/ha and manual weeding. The concentration of Lumax seems to have a low efficiency on this weed with a presence of 24 weeds per m^2. *Diodia scandens* was present in the untreated control, absent on the application of other treatments with a total reduction. This fact reflects the effectiveness of the treatments against this weed (Table 4).

Table 3. Effects of different rates of Hexazinone on sugar cane weeds flora on the 90th day after application (weeds/m^2)

Plant	Family	Untreated control	Manual weeding	Lumax 41 g/ha	Hexazinone 240 g/ha	Hexazinone 480 g/ha	Hexazinone 800 g/ha	Hexazinone 960 g/ha	Hexazinone 1440 g/ha
Vernonia cinerea	Asteraceae	14	6	-	4	-	-	-	-
Cyperus sp	Cyperaceae	-	-	7	16	6	4	-	-
Gomphrena amaranthaceae	Celocioideae	-	1	-	-	-	-	-	-
Oldenlandia herbacea	Rubiaceae	-	-	-	-	1	-		-
Chrozophora tinctonia	Euphorbiaceae	-	1	-	-	-	-	-	-
Ageratum conyzoides	Compositae	2	-	-		-	2	-	-
Cucumis melo	Cucurbitaceae	-	-	3	-	-	-	-	-
Ipomea involucrata	Convolvulaceae	2	-	-	-	-	-	-	-
Mean		**4.50**	**2.00**	**2.50**	**5.00**	**1.75**	**1.50**	**0.00**	**0.00**

Table 4. Effects of different rates of Hexazinone on sugar cane weeds flora on the 121st day after application (weeds/m^2)

Plant (Family)	Untreated control	Manual weeding	Lumax 4l g/ha	Hexazinone 240 g/ha	Hexazinone 480 g/ha	Hexazinone 800 g/ha	Hexazinone 960 g/ha	Hexazinone 1440 g/ha
Vernonia cinerea (Asteraceae)	13	1	-	-	-	-	-	-
Cyrpeus sp (Cyperaceae)	-	-	24	2	-	-	-	-
Pennisetum pedicellatum (Poaceae)	1	-	-	1	-	-	-	-
Diodia scandens (Rubiaceae)	4	-	-	-	-	-	-	-
Sida acuta (Malvaceae)	1	-	-	-	-	-	-	-
Phyllenthus amarus (Euphorbiaceae)	1	-	-	-	-	-	-	-
Ageratum conyzoides (Compositae)	-	5	-	5	-	-	-	-
Mean	**5.00**	**1.50**	**6.00**	**2.00**	**0.00**	**0.00**	**0.00**	**0.00**

Influence of different doses of Hexazinone on the dynamics of soil nitrate nitrogen content.

The dynamics of nitrate nitrogen content is characterized by two peaks. The first peak occurs at tillering compared to the period before herbicide applications and the second peak at complete maturity of sugar cane after a significant reduction in the flowering stage (Table 5). Before herbicide applications, statistical analyses showed no significant difference among plots in the nitrate-nitrogen content at 5% level of probability using Newman-Keuls test. The average content of the plots to be treated with herbicides (4.00 mg/kg) increased by 7.33% compared to the untreated control. The sample treated with 480 g/ha Hexazinone had the highest content among the plots, about 40.00% more than that treated with 240 g/ha Hexazinone (Table 5).

At tillering, significant differences were recorded among treatments. The average effect of herbicides (8.09 mg/kg) was an increase in soil nitrate nitrogen content by 28.41% compared to the untreated control and 44.46% more than manual weeding. Manual weeding and Lumax application at4 l/ha did not differ from the untreated control. Hexazinone application at 240 g/ha was not significantly different from the untreated control as well as at other doses with no significant differences among them at an excess of 33.33 to 44.44% nitrate nitrogen content, compared to the untreated control.

At the flowering stage, the analysis of variance showed that nitrate - nitrogen content did not show a significant difference among the treatments. On complete maturity of the sugar cane plant, the average effect of herbicides (7.24 mg/kg) decreased by 29.50% compared to the untreated control and 22.40% compared to manual weeding. There are no significant differences among manual weeding,

Table 5. Effects of different doses of Hexazinone on soil nitrate- nitrogen (N-NO_3) content (mg/kg)

Treatment	Soil nitrate nitrogen (N-NO_3) content (mg/kg)			
	Before application	**Tillering**	**Flowering**	**Maturity**
Untreated control	3.73^{ab}	6.30^{bc}	2.69^{a}	10.27^{a}
Manual weeding	4.20^{ab}	5.60^{c}	2.92^{a}	9.33^{a}
Lumax (4 l/ha)	3.73^{ab}	5.60^{c}	2.80^{a}	10.03^{a}
Hexazinone (240 g/ha)	3.50^{b}	7.23^{b}	2.57^{a}	6.77^{b}
Hexazinone (480 g/ha)	4.90^{a}	8.40^{a}	2.68^{a}	7.00^{b}
Hexazinone (800 g/ha)	4.43^{ab}	9.10^{a}	2.68^{a}	7.00^{b}
Hexazinone (960 g/ha)	3.73^{ab}	9.10^{a}	2.68^{a}	6.77^{b}
Hexazinone (1440 g/ha)	3.73^{ab}	9.10^{a}	2.57^{a}	5.84^{b}
Mean	**4.00**	**7.55**	**2.70**	**7.88**
CV (%)	8.50	5.50	6.60	8.60
ETR (ddl=7)	0.34	0.42	0.18	0.68
ETM (Sx)	0.24	0.30	0.13	0.48

Table 6. Effects of different doses of Hexazinone on soil available phosphorus (P_2O_5) content (mg/kg)

Treatment	Soil available phosphorous (P_2O_5) content (mg/kg)			
	Before application	**Tillering**	**Flowering**	**Maturity**
Untreated control	11.14^{c}	11.35^{d}	46.55^{a}	62.00^{a}
Manual weeding	15.26^{b}	12.81^{b}	8.37^{d}	57.50^{ab}
Lumax (4 l/ha)	13.93^{b}	35.81^{a}	4.43^{e}	55.00^{ab}
Hexazinone (240 g/ha)	22.12^{a}	11.72^{bd}	28.81^{c}	64.00^{a}
Hexazinone (480 g/ha)	21.94^{a}	20.67^{b}	34.72^{b}	59.50^{ab}
Hexazinone (800 g/ha)	8.36^{c}	9.67^{d}	4.43^{e}	47.00^{ab}
Hexazinone (960 g/ha)	19.13^{a}	21.83^{b}	45.07^{a}	53.00^{ab}
Hexazinone (1440 g/ha)	10.43^{bc}	8.73^{d}	23.89^{c}	41.00^{b}
Mean	**15.29**	**16.49**	**24.54**	**54.88**
CV (%)	9.97	6.70	5.00	8.70
ETR (ddl=7)	1.49	1.11	1.23	4.79
ETM (Sx)	1.05	0.79	0.87	3.39

Lumax (4 l/ha) and untreated control. At different doses of Hexazinone there is also no significant difference. These doses caused a decrease in nitrate nitrogen content from 24.97 to 37.40% compared to manual weeding. However, these contents are higher in comparison to the period before herbicide applications.

Effects of Hexazinone different doses on the dynamics of soil available phosphorus content

The dynamics of available phosphorus content in the soil is not very clear from the phenological stage to another stage of sugar cane (Table 6). Before the application of herbicides, the average effect (15.89 mg/kg) on applied plots increased by 43.49% compared to the untreated control. The contents of the plots to be treated with Hexazinone at doses of 240, 480 and 960 g/ha are not significantly different. At 800 g/ha of Hexazinone, the effect was 8.36 mg/kg between the plots, 25.00% less than in the untreated control and 40.00% less than in the Lumax (4 l/ha) treated plot. Between the weeding plot and control, there was no significant difference. This was the same for Hexazinone at 1440 and 800 g/ha and the untreated control.

At the tillering stage, the average effect of herbicides on available phosphorus content (18 mg/kg) caused an increase of 58.59% more than in the untreated control but 59.44% lower than Lumax (4 l/ha) application treatment. At the different doses of Hexazinone (240, 800 and 1440 g/ha) there was no significant difference from the untreated control but decreased by 8.51% to 31.85% compared to manual weeding.

Hexazinone at doses of 480 and 960 g/ha resulted in excess in comparison with the manual weeding as well as the untreated control. The highest content is at Lumax (4 l/ha). At the flowering stage, the average effect of the treated plots (23.56 mg/kg) decreased available phosphorous content by 49.39% compared to the untreated

Table 7. Effects of Hexazinone different doses on soil available potassium (K_2O) content (mg/kg)

Treatment	Soil available potassium (K_2O) content (mg/kg)			
	Before application	Tillering	Flowering	Maturity
Untreated control	54.67^{ab}	62.04^{a}	83.87^{a}	70.50^{b}
Manual weeding	63.03^{a}	40.39^{c}	55.57^{b}	47.50^{c}
Lumax (4 l/ha)	23.64^{c}	67.77^{a}	49.27^{b}	52.50^{bc}
Hexazinone (240 g/ha)	55.15^{ab}	47.77^{b}	59.75^{b}	60.50^{bc}
Hexazinone (480 g/ha)	47.77^{b}	37.43^{c}	48.76^{b}	44.00^{c}
Hexazinone (800 g/ha)	53.68^{ab}	34.97^{c}	52.43^{b}	43.00^{c}
Hexazinone (960 g/ha)	55.15^{ab}	63.03^{a}	57.67^{b}	63.00^{bc}
Hexazinone (1440 g/ha)	58.61^{ab}	49.24^{b}	48.23^{b}	116.00^{a}
Mean	51.46	50.35	56.94	62.13
CV (%)	5.30	5.50	6.20	9.8
ETR (ddl=7)	2.74	2.78	3.52	6.11
ETM (Sx)	1.94	1.97	2.49	4.32

control and of 2.81% compared to manual weeding. Among the different doses of Hexazinone, the largest declines were observed in Hexazinone application at concentrations of 240, 800 and 1440 g/ha. Hexazinone at 960 g/ha was equivalent in content compared to the untreated control. At maturity, Hexazinone application at 480 g/ha resulted in a decrease of 25. 41% compared to the untreated control. At stage of, the average effect of herbicides (53.25 mg/kg) decreased by 14. 11% compared to the untreated control, and was not significant at 7.39% compared to manual weeding. Practically, there is no significant difference between the treatments and the untreated control except Hexazinone application at 1440 g/ha which led to a significant decrease of 33.87% compared to the untreated control (Table 6).

Effects of Hexazinone different doses on the dynamics of soil available potassium content

Before application, the effect of herbicides (49 mg/kg) decreased by 10.37 and 22.26% in comparison with untreated control and with manual weeding, respectively. Among the different doses of Hexazinone, there was no significant difference with the untreated control. The lowest content was on the plot treated with Lumax (4 l/ha).

At the tillering stage, the average effect of herbicides (50.00 mg/kg) caused a decrease of 19.35% compared to the untreated control and 23.79% increase than manual weeding. Since Lumax at 4 l/ha and Hexazinone 960 g/ha concentrations did not differ from the untreated control at high levels, available potassium in the other treatments was low, less than that of the untreated control. The lower levels were obtained at 480 and 800 g/ha Hexazinone which did not differ significantly from manual weeding (Table 7).

At the flowering stage, the average content (52.69 mg/kg) of the plots which received herbicides decreased by 62.82% compared to the control and 5.18% compared to manual weeding. Statistically, there is no difference between herbicides and manual weeding. The different doses of Hexazinone led to a decrease of 28.76 to 42.49% compared to the untreated control.

At the complete maturity stage of sugar cane, the average effect of herbicides (63.17 mg/kg) decreased by 10.40% compared to the untreated control. Hexazinone at 1440 g/ha concentration, and the other herbicide treatments do not differ with manual weeding. Hexazinone 1440 g/ha led to an increase of 64.54% available potassium compared to the untreated control and of 2.44 times of manual weeding (Table 7).

Effects of different doses of Hexazinone on Sugar cane yield and yield components

As shown by the statistical analyses, Hexazinone at different doses affected sugar cane yield and its components (Table 8). According to machining rods criteria, on the 121st day after application, the average effect of herbicides (848.50 machining canes/ useful plot) increased by 11% machining rods compared to the untreated control. The largest increase in machining rods was obtained with Hexazinone at 1440 g/ha concentration with a gain of 17.83% compared to the untreated control. There is no significant difference between other concentrations of hexazinone and the untreated control (Figure 1).

For the yield criteria, the average effect of herbicides (68.79 tons/ha), an increase of 10.28% was recorded in comparison with the untreated control. Hexazinone (1440 g/ha) led to a yield surplus of 20.42% compared to the untreated control. For the extractable sugar and sucrose content criteria, there were no significant differences between them.

Table 8. Effects of different doses of Hexazinone on yield components and sugar cane yield

Treatment	Machining canes (number/useful plot)	Yield (t/ha)	Untreated control (%)	Quantity of extractible sugar (t/ha)	Sucrose content (%)
Untreated control	764.25[b]	62.38[b]	-	7.24[a]	12.74[a]
Manuel weeding	850.75[ab]	67.43[b]	108.10	8.14[a]	13.23[a]
Lumax (41 g/ha)	805.25[ab]	68.86[b]	110.39	8.40[a]	13.25[a]
Hexazinone (240 g/ha)	819.25[ab]	65.31[b]	104.70	7.98[a]	13.10[a]
Hexazinone (480 g/ha)	850.00[ab]	66.80[b]	107.09	7.98[a]	13.11[a]
Hexazinone (800 g/ha)	856.00[ab]	68.29[b]	109.47	8.30[a]	13.13[a]
Hexazinone (960 g/ha)	860.25[ab]	68.35[b]	109.57	8.29[a]	13.27[a]
Hexazinone (1440 g/ha)	900.05[a]	75.12[a]	120.42	9.66[a]	13.83[a]
Mean	838.28	67.91		8.25	13.21
CV (%)	5.70	4.10		12.60	3.90
ETR (ddl=21)	47.53	2.75		1.04	0.51
ETM (Sx)	23.77	1.38		0.52	0.26

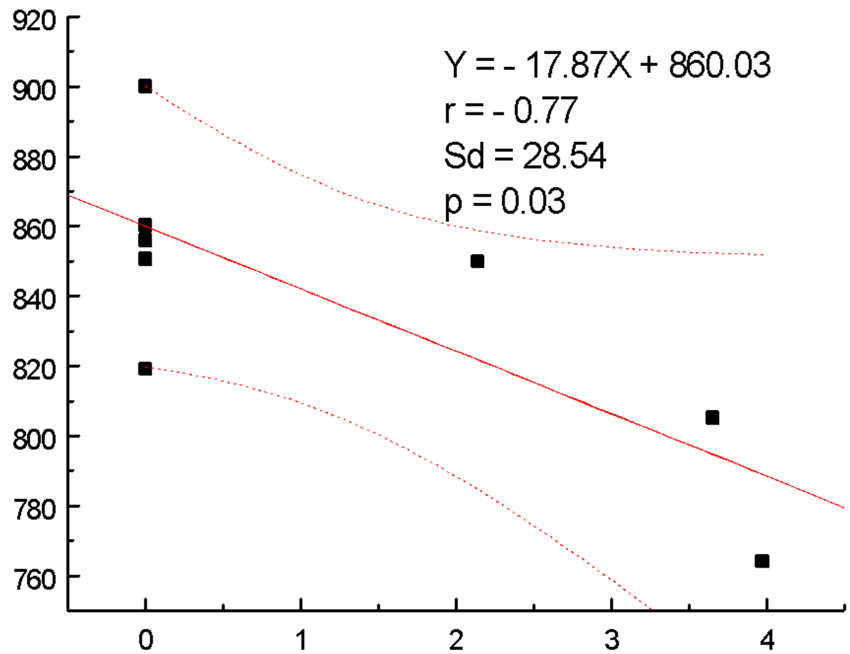

Figure 1. Correlation between weed dry biomass weeds on the 63rd day after application and the number of machining canes

DISCUSSION

Herbicidal activity was determined by active ingredients application at different doses. Indeed, the correlation between weeds dry biomass on the 63rd day and the number of machining rods at the 121st day after herbicides application were expressed by the following regression equation:

$$Y = -17.87X + 860.03$$

with correlation coefficient $r = -0.77$ (probability $p = 0.03$).

This reflects the beginning of damage caused by weeds on sugar cane and herbicide efficacy (Figure 1). Hexazinone belongs to triazine family. It acts by contact as well as it is easily absorbed by the roots and foliage where it inhibits photosynthesis. Hexazinone, in aqueous solution, can be decomposed by soil microorganisms. Translocation to the shoot is mainly through the xylem and rain or irrigation is needed before it becomes active (Acta, 2006). The present study showed that the different doses of Hexazinone had no phytotoxic effect on sugar cane. The application of Diuron + Hexazinone (1170 + 330 g/ha), Deafendin + Hexazinone (192.5 + 247.5 g/ha) showed phytotoxic effects on cane ratoon in 20 and 60 days, but this effect was gradually reduced. This is due to the fact that sugar cane has some enzymes that are able to degrade the herbicide molecules in the plant and to reduce their toxicity (Azania et al., 2005a; b).

In this study, the activity of Hexazinone showed persistent action for over five months. The biological coefficients of Hexazinone efficiency according to the weeds dry biomass showed different weed biomass rates from low to high rates. This is probably due to the presence of mulch. This means that the straw has herbicide retention effect thus compromising its effectiveness on weeds. According to Monquero et al., (2009), the amount of straw at 15 ton/ha reduced the effectiveness of herbicides and at 20 t/ha, their efficiency becomes zero. However, the weak presence of weeds throughout this experimentation was marked by a total absence until one month after treatment due to many factors, in particular the remaining mulch.

Mechanical control of weeds may reduce the degree of *Cyperus rotondus* infestation during the dry season, the extirpation of tubers during tillage promotes their drying in the sun. Manual weeding during this experiment was efficient, thus confirming this aspect. Herbicide treatments lead to increased sugar cane yields, similar to those of plots that received several manual weeding. The lack of difference between manual weeding and Hexazinone applications at machining canes criteria is linked to this fact (Ibrahim, 2006). The application of Diuron + Hexazinone is more effective at 91%, 14 days after application on sugar canes lines without straw (Chabalier et al., 2012). The leaching process is the main form of non-volatile molecules transport and solubility in water (Monquero et al., 2008). This implies that the application of herbicides tend to be leached under the influence of rainfall or artificial irrigation carried out on the plot with more pronounced effects in moderately low soil organic matter content.

The mulch reduces the direct impact of rainfall on the soil, slows runoff water, acts as a filter to remove suspended particles in water, improves infiltration and thereby reduces erosion (Braunack and Ainslie, 2001; Neycheong et al., 2003). This implies that the applied molecules remain in the soil and are not washed out immediately thus influencing nutrient contents of the soil and their absorption by the sugar cane or by weeds. Nitrate nitrogen, assimilable phosphorous and available potassium contents have many variations depending on the level of weeds or herbicide efficacy. The low contents at the phenological stage are due either to their absorption by weeds or the sugar cane. For example, during tillering, Lumax application may cause characteristic low nitrate nitrogen content (Table 5) while a low content for the untreated control is due to absorption by weeds. The nitrate nitrogen, assimilable phosphorous, available potassium contents increases during the period before application thus demonstrating a good restoration of biological activity in the soil. All these factors have led to the obtaining of machinable rods equivalent to manual weeding, Lumax and the control by Hexazinone treatments applied at different rates, demonstrating once again their selectivity on sugar cane.

Conclusion

Terrier 750 WG, which is the commercial name of Hexazinone showed no phytotoxicity on sugar cane at the studied different doses. Despite mulching, when applied at high doses, hexazinone showed high coefficients of efficiency in reducing dry weeds biomass, thereby ensuring good assimilation of mineral nutrients. The biological efficiency coefficients of hexazinone at 480 g/ha varied from -125.00 to 100.00%. At a higher rate of 1440 g/ha, Hexazinone efficiency ranged from 37.33 to 100%. It would be interesting to combine Hexazinone with other compatible molecules such as Diuron to fight against *Cyperus* spp. and to reduce the amount of Hexazinone applied. Hexazinone is a selective molecule of sugar cane and we recommend, besides other toxicological factors, it's pre-extension at 480 g/ha for approval by the Sahelian Pesticides Committee (SPC).

ACKNOWLEDGEMENTS

The authors acknowledge Farm–Ag International for providing financial backing and continuous encouragement. The authors also wish to acknowledge the editors for their helpful comments on the final version of the manuscript.

Competing interests

The authors declare that they have no competing interests

REFERENCES

Akobundu OI, Agyakwa CW (1989). West Africa Weed Guide. IITA.Ibadan, 522 pp.

Arzate A (2005). Extraction et Raffinage du Sucre de Canne. ACER, 40 p.

Association de coordination technique agricole (2006). Index Phytosanitaire. Marne Tours, 824pp.

Azania AAPM, Rolim CAM, Casagrande JC, Lavorenti AA , Azania NA (2005a).Herbicide Selectivity. I – Use of Additional Check Methods in Sugarcane Experiments. Planta Daninha, 23 (4): 661-667.

Azania AAPM, Rolim CAM, Casagrande JC, Lavorenti AA, Azania NA (2005b). Herbicide selectivity. II – Herbicide Application at Initial and Late and Post-emergence of Sugarcane in the rainy season. Planta Daninha, 23 (4):669-675.

Berhaut J (1967). Flora of Senegal. Claire Edition

Africa,Dakar, 485pp.
Bicachos TT, Langenbach T, Rodrigues RR, Correia FV, Hagler AN, Matallom B , Luchini LC (2010). Herbicide distribution in soils of a riparian forest and neighboring sugar cane field. Geoderma,158(3/4): 392-397.
Braunack M, Ainslie H (2001).Trash blanket and soil physical properties. Mackay experience. In: proceedings of the Austratlian Society of sugar cane tehnoclogist, 213 rd Mackay Queensland , pp.154 -160.
Bray HR, Kurtz LJ (1945). Total available Determination organic form of P in soil. Soil Sci., 59:39-45.Crossref
Bulletin de Santé du Végétal (2014). Evolution des adventices sur les parcelles de références. [on line] (01 04 2014). Available. http://www.reunion.chambagri.fr/bsv/spip.php?article29.
Chabalier M, Marion D, Martin J, Arhiman E, Lambert A, Esther JJ , Chiroleu F (2012). Essais de désherbage d'une repousse de canne à sucre après une coupe manuelle à La Réunion [on ligne]. Available : http://www.canne-progres.com/publications/pdf/congres/AG123.pdf
Courteau A (2005). La canne à sucre et l'environnement à la reunion: revue bibliographique. Université de France-comté. Rapport de stage de Maîtrise, 53 p.
Dospiehov BA (1985). Field Experimentation Methods.Kolos, Moscow,416pp.
Estok D, Freedman B, Boyle D (1989). Effects of the herbicides 2,4 D, Glyphosate, Hexazinone and triclopyr on the growth of three species of ectomycorrhizal fungi. Bulletin of Environmental Contamination and Toxicology, 42 (6): 835-839.Crossref
Fadayomi O (1988). Weed control in sugar cane with hexazinone alone and in combinaison with diuron. J Agric. Sci., 111 (2): 333-337.Crossref
Greweling I, Peech M (1960). Chemicals soils tests. Cornels Univers .Bull., 30: 23-24p.
Hunter W, Shaner D (2012). Removing Hexazinone from ground water with microbial bioreactors. Current Microbiol., 64 (5): 405-411.Crossref
Ibrahim AAS (2006). Weed competition and control inn sugar cane. Weed Research, 24 (4):227-231.Crossref
Industrial Promotion Services (West Africa) (2010). Sn – Sosuco (2010) [on ligne]. Available :http:// www.ips-wa.org/fr/businesses/agribusiness/sn-sosuco.html.
Institut National de la Recherche Agronomique (2007). la canne à sucre. (Octobre 2007) [on line]. available : http:// www.transfaire.antilles.inra.fr/squelettes/images/depliant_canne.pdf.
Johnson DE (1997). Les adventices en riziculture en Afrique de l'Ouest. *Weed of rice in West Africa.* United Kingdom, Imprint Design, Hong Kong, 312pp.
Jones CA, Griffin J(2008). Residual red Morningglory (*Ipomea coccinea*) control with foliar and soil apllied herbicides. Weed Technology, 22(3): 402-407.Crossref
Judice WE, Griffin JL, Jones CA, Etheredge Jr LM, Salassi ME (2008). Weed control and economics using reduced tillage programs in sugar cane. Weed Technol., 20 (2): 37-47.
Kodesov AR, Kocarek M, Kodes V, Drabek O, Kozak J , Hejtmanky AK (2011). Pesticide adsorption in realation to soil properties and soil type distribution in regional scale. J. Hazard. Mater., 186 (1): 540-550. Crossref
Likov A, Tulikov AM (1985). Weed Science practical Handbook Based on Pedology. Agropromizdat, Moscow, 207 pp.
Liq X, Hwang EC, Guo F (2001). Occurrence of herbicides and their degradates in Hawaïi's ground water. Bulletin of Environmental Contamination and Toxicol., 66 (5): 653-659.
Mam M, Domingues I, Oliveira R, Jonsson CM, Nogueira AJA (2011). Toxicity of the sugar cane herbicides ametryn and hexazinone in Zebrafish (Danio rerio) early-life stages. Ecotoxicologia,58. [on line]. available : (www.Alice.cnptia.embrapa.br/bitstream/doc/919736/1/2011RA 105.pdf)
Monquero PA, Amaral LR, Binha DP, Silva AC, Silva PV(2008). Potential leaching of herbicides in the soil under different rainfall simulations. Planta Daninha, 26 (2): 403-409.Crossref
Monquero PA, Amaral LR, Silva AC, Binha DP and Silva PV (2009). Herbicide efficacy through different amounts of sugar cane straw on controlling *Ipomoea grandifolia*. Bragantia,68(2). [on line]. available :
Mostafa FIY, Helling C S(2003). Isolation and 16S DNA chracterization of soil microorganisms from tropical soils capable of utilizing the herbicides Hexazinone and Tebuthueron. J. Envron. Sci. and Health, 38 (6):789-797.
Muendo B, Lalah J , Getenga Z (2012). Behavior of pesticide residues in agricultural soil and adjacent river Kuywa sediment and water samples from Nzoia sugar cane belt in Kenya. Environmentalist, 32 (4): 433-444.Crossref
Neycheong LR, Ahkoon PD, Keekwong KE, (2003). Effets de la pluviométrie et des pratiques culturales sur le ruissellement et l'érosion dans la canne à sucre. Revue agricole et sucrière de l'île Maurice, 82:72-77.
Ngigi A, Getenga Z, Boga H, Ndalut P (2014). Isolation and identification of hexazinone degrating Bacterium from sugar cane cultivated soil in Kenya. Bulletin of Environmental Contamination and Toxicol., 92 (3): 364-368.Crossref
Rainbolt CR (2007). Fall panicum (*Panicum dichotmiflorum*) control and crop safety with hexazinone and diuron combinations in Florida sugar cane. Sugar Cane Technol., 26: 380-383.
Terry PJ (1985), Quelques adventices banals des cultures de l'Afrique occidentale et la lutte contre celles-ci. Some common crop weeds of West Africa and their control. Australie, Inkatapress, Melbourne,132 pp.
Vilitsky IN (1989). Technologies of Herbicides Use. L. Agropromizdat, 176pp.
Wang H, Xu S, Tan C and Wang X (2009). Anaerobic biodegradation of Hexazinone in four sediments. J. Hazard. Mater., 164 (2/3): 806-811.Crossref