Research Article
Ecological Risk Assessment of Pesticide Residues in Water from Desert Locust Area in Burkina Faso

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Abstract: Locust control requires sometimes an important use of pesticides in infested area with concomitant environment contaminations. Using the Gas Chromatography (GC) technical, pesticide residues were determined in water samples collected from locust outbreak areas of Burkina Faso, West Africa. The risk quotient method coupled with probabilistic risk assessment model was used for ecological risk assessment of pesticide detected in water. For ten pesticides belonging to Organophosphates, Pyrethroid and Phenylpyrazole chemical class, only diazinon was detected in water samples from all sites with content ranging from 2.02 to 2.21 µg/L. The presence of pesticide residues seem to be linked to specific agropedoclimatic conditions of study area. Results of risk assessment show that diazinon level in water generates a risk for considered groups of aquatic organisms following this decreasing order: Aquatic invertebrates Crustacean Fish Algae. This risk is particularly important if only most sensible group of organisms is taken account or if probabilistic risk assessment is applied. The findings suggest that pesticides in locust control generate a potential hazard for aquatic organisms. Cautious or restrictive use of these agrochemicals in the Sahelian context is recommended. Moreover, Ecological risk assessment approach that we applied can provide more information for risk managers and decision makers.

Keywords: Burkina faso, ecological risk assessment, locust control, pesticide residues, water contamination

INTRODUCTION

Pesticides are used for yield improvement and devastators as Desert Locust control. To fight a locust outbreak, intensive and extensive uses of pesticides are commonly reported (Lecoq, 2004; Toé and Coulibally, 2007). However, pesticides use is sometimes concomitant with the occurrence and persistence of their residues in some environmental compartments (Ware and Whitacre, 2004). The presence of pesticides in surface water was well documented (Gomgnimbou *et al*., 2009; Tapsoba *et al*., 2008; Ouedraogo *et al*., 2012). It is estimated to less than 0.1% the amount of pesticides applied that reaches the target pests (Pimentel, 1995). In environment, the fate of pesticides is linked to their physicochemical properties, the properties of the soil and water systems, climate, biology and other factors (Singh, 2001). After spraying, they may move downward in the soil and either adheres to particles or dissolve, taken by plants, vaporize and enter the atmosphere, reach surface and underground water through runoff and leaching (Rao *et al*., 1983).

The environment pestilential contamination is of great concern for non target organisms. Indeed, the toxicity of pesticides to aquatic organisms is established (Khan and Law, 2005; Relyea and Hoverman, 2008; Verbruggen and Van den Brink, 2010). Some approaches combining monitoring and both toxicological and ecotoxicological data exploitation were used to assess pesticide residues in water as well as the subsequent risk to human and non-target organisms (Qu *et al*., 2011; Jin *et al*., 2011; Vryzas *et al*., 2011). Food and Agriculture Organization of United Nations (FAO) recommends health and environmental impacts assessment after locust control operation (Van der Valk and Everts, 2003). For this purpose, several studies were conducted (Peveling, 2001; Peveling and Sidibé, 2005; Toé and Coulibally, 2007; CERES-Locustox, 2008). However, to our knowledge, no pesticide residues determination after

Table 1: Environmental fate and ecotoxicological parameters of studied pesticides

Insecticides	CAS No.	Koc[1] (mL/g)	Gus score	$t_{1/2}$[2] (days)	BCF[3]
Chlorpyrifos-ethyl	2921-88-2	8151 (not mobile)	0.15	25.5	1374 (TC[4])
Chlorpyrifos-methyl	5598-13-0	4645 (not mobile)	0.16	21	1800 (TC[4])
Diazinon	333-41-5	643 (slightly mobile)	1.14	138	500 (TC[4])
Fenitrothion	122-14-5	332 (moderately mobile)	0.64	183	29 (LP[5])
Fipronil	120068-37-3	577 (slightly mobile)	2.67	Stable	321 (TC[4])
Malathion	121-75-5	217 (moderately mobile)	-1.28	98	103 (TC[4])
Pyridafenthion	119-12-0	7211 (slightly mobile)	0.18	46	-
Deltamethrin	52918-63-5	1.024×10^7 (not mobile)	-3.35	Stable	1400 (TC[4])
Fenvalerate	51630-58-1	5273 (not mobile)	0.45	115	1664 (TC[4])
Lambda-cyhalothrin	91465-08-6	157000 (not mobile)	-1.67	Stable	1950 (TC[4])

[1]Koc: Soil Organic Carbon-Water Partitioning Coefficient; [2]$t_{1/2}$: time of half live of pesticides (in water); [3]BCF: Bioconcentration factor; [4]TC: Threshold of concern; [5]LP: Low potential

pesticides use for locust control in water has been conducted in Burkina Faso.

In this study, pesticide residues in water were assessed to obtain information on the status of residues in the locust area in Burkina Faso. This study was also designed to determine the risk for aquatic non target organisms linked to the presence of pesticide residues in water.

MATERIELS AND METHODS

Study area: Study was conducted in three administrative regions of the northern part of Burkina Faso, West Africa: "Région du Nord", "Région du Sahel" and "Région du Centre-Nord". This part of the country shares some frontiers with Mali and Niger, both countries also known for the recurrence of locust invasions. The study zone represents the predilection area for locust and over devastator as grasshoppers, bugs and cantharis in the country. Moreover, the area is known for its adverse climatic conditions. Soils are generally poor with organic matters content ranging from 0.5 to 0.8% (BUNASOLS, 1980). Water is a scarce resource in the study area. A retrospective survey was performed to identify the risk factors for environment associated with pesticides use for locust control. It was addressed to a convenient sample of subjects selected among locust control agents.

Pesticides analysis: Pesticides researched were those used for locust control in Burkina Faso. Table 1 records pesticides with their CAS number, their environmental fate and some ecotoxicological parameters. All pesticide standards and chemicals were purchased from Sigma (Sigma-Aldrich, Germany). Water samples (2.5 l) from dams were collected from 22th to 28th march 2010. Samples were taken from 10 different points randomly distributed, kept in sterile bottles and transported in laboratory at 4°C. Pesticide residues were extracted by liquid/liquid separation with dichloromethane (2×70 mL) in a separatory funnel. The organic phase was further extracted with hexane (70 mL). The extracts were cleaned by passage through silica gel column containing AgNO_3, H_2SO_4 and KOH. Pesticide residues were analyzed using Gas Chromatograph (GC) Aligent 6890 (Aligent Technology, USA), equipped with electron-capture

detector (μECD), nitrogen-phosphorus detector (NPD) and flame-photometric detector (FPD). A capillary Agilent HP-5 column of 30 m length, 0.32 mm i.d and 0.25 μm film thicknesses was used. The carrier gas was nitrogen. Analytical process was adapted to each group of pesticide searched. For pyrethroids, injector temperate was set at 240 and 310°C for the μECD detector, the oven temperature was programmed at 60°C initially (3 min hold) and then evolved successively to 150 (2 min), 200 (10 min) and 260°C (15 min). For organophosphates and fipronil, NPD and FPD detectors temperate was set at 310 and 200°C for the injector, the oven temperature was programmed at 40°C initially (0, 5 min hold) and evolved successively to 120 (1 min), 200 (10 min) and 250°C (3 min).

Ecological risk assessment:

Hazard characterization: From results of pesticide residues determination, the chemicals to which aquatic organisms could be exposed were identified. The selected Toxicological Reference Values (TRVs) which characterizes the hazard of compounds were purchased from FOOTPRINT PPDB (2014) database which was selected for its multiple advantages according to Vryzas *et al*. (2011).

Risk characterization:

Risk quotient method: The ecological risk assessment following the risk quotient (RQ) method was performed according to previous studies (Qu *et al*., 2011; Vryzas *et al*., 2009; Vryzas *et al*., 2011) with modifications.

The RQ as quantification of risk to specific species was first calculated using the following formula:

$$RQ_i = \text{exposure/toxicity} = MEC_i/TRV_i = MEC_i/(LC50 \text{ or } EC50 \text{ or } NOEC) \quad (1)$$

where,

MEC_i = The measured environmental concentration of pesticide i

TRV_i = The toxic reference value (LC50-half lethal concentration for the 50% of the population of the tested species or EC50-effect concentration for the 50% of the population of the tested species or NOEC-no observed effect concentration) of pesticide i

The RQ as overall ecosystem toxicity was afterward calculated according to the following formula:

$$RQ = MECi/PNEC \qquad (2)$$

where,
MECi = The measured environmental concentration of pesticide i
PNEC = The predicted no effect environmental concentration

PNEC values were calculated by dividing the long-term NOEC or lowest short-term LC (EC) 50 of the most sensitive species by an appropriate assessment factor (PNUMA/IPCS, 1999; Palma *et al*., 2004; Vryzas *et al*., 2009). Three trophic levels and in particular algae, aquatic invertebrates and fish were taken into consideration for the determination of the most sensitive species. In the cases where at least one short term assay at one trophic level was available, an assessment factor of 1000 was used. When data from one long term assay with either fish or zooplankton were available, an assessment factor of 100 was used. Assessment factors of 50 and 10 were used in cases of two and three existing long term assays, respectively (Vryzas *et al*., 2009).

The RQ was interpreted as follow: $RQ \geq 1$ indicates high risk, $0.1 \leq RQ < 1$ medium risk, $0.01 \leq RQ < 0.1$ low risk (Sanchez-Bayo *et al*., 2002).

Probabilistic risk assessment: In probabilistic risk assessment performed according to Qu *et al*. (2011), ecological risk is expressed as the degree of overlap between the distribution of environmental exposure concentrations and distribution of toxicity values. This method provides quantitative estimations of ecological risk based on relevant single-species toxicity data and exposure distributions (Solomon *et al*., 2007; Hela *et al*., 2005). The mean and the standard deviation of the ln-transformed data set of a number of toxicity end points (LC50 or EC50) of a specific pesticide were used to estimate the parameters those describe the distribution. From this distribution, in order to protect 95% of species, the hazardous concentration for 5% of the species (HC_5) in an ecosystem was calculated using the following model based on species sensitivity distributions (Aldenberg and Slob, 1993; Steen *et al*., 1999; Wang *et al*., 2008):

$$HC_5 = exp\ (Xm–KSm) \qquad (3)$$

where,
m = The number of test species
Xm = The mean of the ln-transformed effect levels (LC50 or EC50)
Sm = The standard deviation of the ln-transformed effect levels
K = The extrapolation constant obtained from Luttik and Aldenberg (1997) and the 50% confidence

level of under-estimation was used according to Hela *et al*. (2005)

Using HC_5 as toxicological reference value instead PNEC, the ecological risk posed by a certain pesticide to the ecosystem is defined by Ecological Risk Quotient (ERQ) calculated according to the Eq. (4). This new term is proposed by Qu *et al*., (2011) to identify the ecological risk of each pesticide over time:

$$ERQ = MEC/HC_5 = MEC/exp\ (Xm – KSm) \qquad (4)$$

where, ERQ is the ecological risk quotient and the other parameters as aforementioned defined.

RESULTS AND DISCUSSION

Pesticides residues in water samples: Ten locust control pesticides namely chlorpyrifos-ethyl, chlorpyrifos-methyl, diazinon, fenitrothion, fipronil, malathion, pyridafenthion, deltamethrin, fenvalerate and lambda-cyhalothrin were analyzed in water from locust area in Burkina Faso. Diazinon has been the unique pesticide detected in water samples and its presence was noticed in samples from all sites namely Arbinda (2.16 µg/L), Djibo (2.02 µg/L), Dori (2.13 µg/L) and Kaya (2.16 µg/L) (data not shown). In accordance with farmers survey results, these findings explain the recent use of pesticides in the study area. In a United States national surface water monitoring program, diazinon was detected in samples collected with maximum concentration of 2.38 µg/L (Carey and Kutz, 1985). The degradation of diazinon in aqueous medium is slow at neutral pH (Howard, 1991) with a $t_{1/2}$ of 138 days (FOOTPRINT PPDB, 2014). According to GUS and Koc values of Table 1, diazinon has a low leaching potential and a weak mobility (FOOTPRINT PPDB, 2014). However, it was reported the low adsorption of diazinon to soil particles and its high mobility in some soil types (U.S.EPA, 2000). The low organic matters content of soils in study area, from 0.5 to 0.8% (BUNASOLS, 1980), can justify at least in part the presence of the pesticide in water, since organic matter is a key parameter limiting pesticides mobility. Furthermore, in agreement with previous findings (Thiam, 1991; Toé *et al*., 2004), the survey reports an unsafe management of these chemicals testifying by attitudes as leaving empty packaging in nature, washing sprayers or protective equipments (Fig. 1) and bathing in surface waterholes.

Fig. 1: Washing of miscellaneous linen including personal protection equipments into dam. This picture taken at Arbinda shows a current practice of the inhabitant in the study area raising the contamination risk of water by pesticides from the personal protection equipments

Table 2: Selected toxicological reference values (µg/L) of diazinon for aquatic organisms

Fish *Oncorhynchus mykiss*		Aquatic invertebrate *Daphnia magna*		Crustacean *Americamysis bahia*	Algae Unknown species	
LC$_{50}$ 96 h	NOEC 21 d	EC$_{50}$ 48 h	NOEC 21 d	LC$_{50}$ 96 h	EC$_{50}$ 72 h	NOEC 96 h
3100	700	1	0.56	4.2	6400	10000

FOOTPRINT PPDB (2014)

Table 3: Ecological risk by trophic level of diazinon detected in water from four sites based on risk quotient calculation

Sites	MEC (µg/L)	Fish TRVs (µg/L)	RQ	Aquatic invertebrates TRVs (µg/L)	RQ	Algae TRVs (µg/L)	RQ	Crustacean TRVs (µg/L)	RQ
Arbinda	2.16	700	0.0031	0.56	3.8571	10, 000	2.16×10^{-4}	4.2	0.5143
Djibo	2.02	700	0.0029	0.56	3.6071	10, 000	2.02×10^{-4}	4.2	0.4810
Dori	2.13	700	0.0030	0.56	3.8036	10, 000	2.13×10^{-4}	4.2	0.5071
Kaya	2.16	700	0.0031	0.56	3.8571	10, 000	2.16×10^{-4}	4.2	0.5143

Table 4: Ecological risk of diazinon detected in water from four sites based on risk quotient calculation

Sites	MEC (µg/L)	PNEC (µg/L)	Assess factor	RQ[1]	HC$_5$	ERQ[2]
Arbinda	2.16	0.056	10	38.57	0.018	120.00
Djibo	2.02	0.056	10	36.07	0.018	112.22
Dori	2.13	0.056	10	38.04	0.018	118.33
Kaya	2.16	0.056	10	38.57	0.018	120.00

[1]RQ calculated with PNEC; [2]ERQ calculated with HC$_5$

Ecological risk assessment: Ecological risk assessment of pesticides will provide valid and clear information, which is useful for risk management and environmental decision-making. Table 2 represents the selected Toxicological Reference Values (TRVs) of diazinon for aquatic organisms. These TRVs characterizes the hazard of the compound toward fish, aquatic invertebrate, crustacean and algae. The risk quotients were calculated by dividing the environmental concentrations by the toxicant values in Table 2 using Eq. (1). If available, NOEC is used but LC50 is used for the lack of NOEC. Overall, according to diazinon RQs values of Table 3, the risk can be classified in this decreasing order: Aquatic invertebrates   Crustacean   Fish   Algae. As is to be expected, the insecticide diazinon generated highly risk for animals than plants. Our results coincide with those of Hela *et al*. (2005) and Vryzas *et al*. (2009) who were found that insecticides were more toxic to zooplankton and fish. Furthermore, these findings suggest that diazinon poses higher risk to lower organisms (aquatic invertebrates and crustaceans) and lower risk to higher animals (fish). This observation accords with the biological rule that lower creatures are more vulnerable to the chemicals in general. Thus, for an ecological protection objective in the locust control context, lower organism must be chosen as sentinel organisms for risk assessment (Qu *et al*., 2011). To take account the risk at global ecologic level, the RQs were calculated by dividing the environmental concentrations by the PNEC. NOEC (0.56 µg/L) of aquatic invertebrates as most sensitive species is used to calculate PNEC with an assessment factor of 10. According to results of Table 4, the RQs ranging from 36.07 to 38.57 in the four sites, indicating an unacceptable risk for aquatic ecosystem. Vryzas *et al*. (2009) had detected diazinon in water at median and extreme concentrations of 0.027 µg/L and 0.179

µg/L, respectively. The corresponding RQs were 9 and 60 for, respectively median and extreme concentrations.

According to Hela *et al*. (2005), the ecological risk characterization using the RQ method is conservative and has high uncertainty. For this reason, Qu *et al*. (2011) considers that risk assessment according to this deterministic method does not quantify well the ecological risk and therefore purpose probabilistic method. The HC$_5$ value at the 50% confidence level obtained by this latest method was 0.018 µg/L. HC$_5$ was calculated using Eq. (3) and parameters namely Xm = 4.56 µg/L, Sm = 4.48 µg/L, m = 4 and K = 1.92. The derived ERQs were ranged from 112.22 to 120. This indicates that environmental concentration of diazinon in locust outbreak area in Burkina Faso exceeds highly the HC$_5$ value. Thus, diazinon poses a non acceptable ecological risk.

Overall, the results from all methods indicate an unacceptable risk associated with diazinon presence in water. During operational use of pesticides in locust control, incidents on aquatic organisms including toad, frog and other animal death were reported by farmers. These reported incidents corroborate the findings of environmental contamination from residue analyses and the risk suggested by ecological risk assessment.

CONCLUSION

Pesticides use for locust control in Burkina Faso has led to water contamination by diazinon. This contamination justifies the relatively recent use of this chemical and could be explained by their low rate of degradation linked to the specific soil and climatic conditions of the Sahelian region. Integrating risk quotient and probabilistic risk assessment method was used to characterize ecological risk generated by diazinon. The results indicate an unacceptable risk for representative organisms. The locust control is

therefore an activity generating high-risk for the Sahelian fragile ecosystems. To minimize this risk and other real impacts identified in our study, cautious or even restrictive use of pesticides in the Sahelian context is recommended. Likewise, other studies including environmental monitoring must be conducted to obtain more relevant and specific data in order to ensure the safe use of agrochemicals in Sahelian conditions of Burkina Faso.

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