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PESTICIDES RISK ASSESSMENT BY PIRI FOR SURFACE WATER IN SUGAR CANE CULTIVATION IN BURKINA FASO

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One consequence of land use for industrial sugar cane production by the SN-SOSUCO society (Nouvelle Société Sucrière de la Comoé) in the South Western part of Burkina Faso is the application of different pesticides. In our continued work on evaluating the contamination risk of pesticides to water resources, this study aimed to assess the risk of surface water contamination during the season 2007-2008. The risk was evaluated using the Pesticide Impact Rating Index (PIRI) software developed by CSIRO Australia, with the assumption of three scenarios taking into account soil organic matter content and the presence of a buffer zone. The results show that of the 13 pesticides applied, 4 (acetochlor, metribuzin, MSMA, terbufos) had very high potential and 4 (glyphosate, pendimethalin, MCPA, diuron) had high potential to contaminate surface water under actual usage conditions. Likewise, chlorimuron-ethyl, carbofuran, trichlopyr and pichloram had medium potential and triadimefon had very low pollution potential. The risk of contamination is reduced by the organic carbon content of soil and the distance from the pesticides application area to surface water. Promotion of better agricultural practices and the planting of a buffer zone of trees are required in order to prevent surface water pollution in the area.

INTRODUCTION

Among the usage of pesticides, crop protection against pests is one of the largest uses in agriculture. However, besides the desired effects of pest control, non-target organisms, soil and water are contaminated by the applied pesticides with direct consequence on ecosystems (Ramade, 1992) resulting in high risks for human beings. Of the applied pesticides, less than 0.1% effectively reaches the target organisms (Pimentel, 1995) and, consequently, pesticide residues are frequently found in the environment at considerable distances from the original point of their application (Van de Werf, 1996; Sutherland et al., 2002; Siddique et al., 2003; Calvet et al., 2005).

Since the 1960s, many studies were focused on the determination of pesticide residues in water within intensive agricultural practice zones all over the world. These studies have revealed the presence of pesticides in groundwater (Van de Werf, 1996; Ali and Jain, 2001; Traore et al., 2006; ORP, 2011) as well as in surface water (Van de Werf, 1996; Ali and Jain, 2001; Tapsoba et al., 2008; ORP, 2011). Hence, many programs in developed countries have been set up to minimize the impact of diffuse pollution by pesticides (Margoum et al., 2003; ORP, 2011). In developing countries, the risks of pesticides usage on both environment and human health are still an all too common reality and are responsible for a large portion of environmental damages.

Previous studies in Burkina Faso showed the potential risk of water resources contamination by pesticides (Toe et al., 2000; Toe et al., 2002; Toe and Coulibaly, 2006; Gomgnimbou et al., 2009) and the risk for the users (Toe et al., 2000; Toe et al., 2002). Some studies have revealed pesticides contamination in both soils and waters (Toe et al., 2004; Savadogo et al., 2006; Tapsoba et al., 2008) within cotton growing areas.

In the south western part of Burkina Faso, sugar cane is intensively cultivated by SN-SOSUCO (Nouvelle Société Sucrière de la Comoé), on an area covering 3850 ha. SN-SOSUCO is a public-private partnership enterprise and Burkina Faso's largest private employer, with a workforce of over 3,000, including 800 permanent staff, 400 seasonal workers and more than 1,800 day workers. The total sugar cane production per year is about 300,000 tons of which 25,000 to 30,000 tons of the sugar are for domestic consumption (Hema, 2008). The sugar cane farming is a year-round activity. To supplement the annual rains, the cane is irrigated by an 18 x 18 irrigation system pivot front-mounted spray booms and micro-irrigation. Water is fed by gravity from the Comoé, Toussiana and Lobi dams. This intensive agriculture requires SN-SOSUCO to import fertilizers and pesticides for cultivation. These inputs are supplied to all the permanent and temporary farmers, with well schedule application patterns (MEE, 2001). During the 2006/2007 season, 55.2 metric tons of pesticides were used by this society for sugar cane cultivation (Ouattara, 2007), with one application for the whole season. The observation of agricultural practices in the field has shown that good agricultural practices were not followed, including monitoring and management of buffer zones. In 2001, some pesticides residue measurements showed the presence of atrazine in the piped water lines and also in the waters of surrounding lakes at concentrations of 0.39 and 0.72 μg/l respectively (MEE, 2001). In a previous study (Toe et al., 2012) it has been shown that pichloram, carbofuran, trichlopyr, monosodium methanarsonate (MSMA), and the chlorimuron-ethyl have high leaching potential for groundwater contamination.

From the aforementioned cases, the assessment of the surface water pollution in the area is required, both as a part of our previous study (Toe et al., 2012) and to set techniques and strategies for better management of the water resources in the area. The aim of this study was to evaluate the risk of the surface water contamination by pesticides used in the cultivated area of the SN-SOCUCO during the season 2007-2008. To achieve this goal, Pesticide Impact Rating Index (PIRI) software developed by CSIRO Australia (Kookana et al., 2005) were used.

MATERIAL AND METHODS

Description of the study area

The SN-SOSUCO cultivated area is located in the south western part of Burkina Faso, the Cascades Region, which lies between latitude 10°41' to 10°47' north and longitude 4°38' and 4°39' west (Figure 1). The climate is Sudanese Sahelian with an average annual rainfall and temperature from 1974 to 2004 of 1,100 mm and 27 °C, respectively (Millogo et al., 2004). Soil organic matter varied from 1.06% to 1.36% within the perimeter (Direction culture/SN-SOSUCO, 2008).

Soils from the study area are of three types: i) raw mineral soils with sandstone outcrops; ii) tropical ferruginous soils characterized by sandy and sandy clay structure; iii) and hydromorphic soils generally found in swampy areas, while sands are found around the lakes (Millogo et al., 2004).

The study area has two lakes: Lake Karfiguela and Lake Lemouroudougou located 70 and 100 m, respectively, from the cultivated area, as well as two small rivers, River Yannon and River Berega, located 30 m from the cultivated area, which join to form one river (Figure 1).

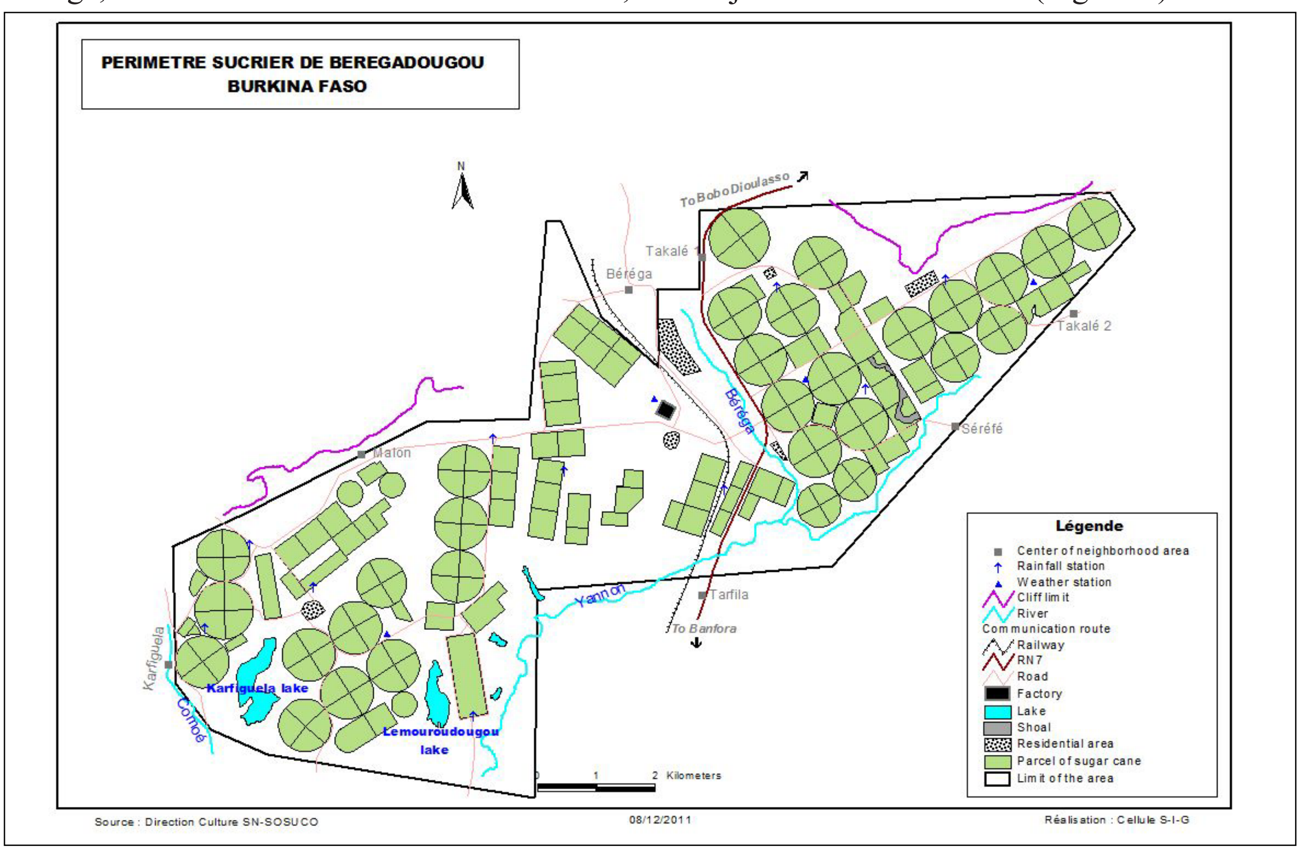

Figure 1. Map of the study area (Redrawn from Direction Culture/SN-SOSUCO, 2011).

Soil in the surroundings of Lake Karfiguela has mean organic carbon (OC) content of 1.24%, while the surrounding of Lake Lemouroudougou has 1.36% organic carbon content. The mean OC in soils near the rivers is equal to 1.06% (Table 1). The slope of the study area is estimated to 4% and yearly soil erosion to 5 t/(ha · year). The total amount of water used for irrigation during the study period was 396 mm and the cumulative rainfall from November 2007 to August 2008 was 800 mm (SN-SOSUCO, Irrigation service, 2008).

Table 1. Some PIRI input information of surface water in the area*

Surface water	Width of the water resource (m)	Distance to the application area (m)	Organic carbon content of soil in the neighborhood (%)
Lake Karfiguela	350	70	1.24
Lake Lemouroudougou	200	100	1.36
Rivers Yannon and Berega	5	30	1.06

* From Direction culture/SN-SOSUCO, 2008

Pesticide Impact Rating Index (PIRI)

The Pesticide Impact Rating Index (PIRI) is a software package developed by CSIRO with support from Land and Water Australia and other agencies. PIRI is a model to predict the potential for pesticides to move off-site and pollute adjacent waterways (CSIRO, 2001) based on quantitative risk management, and taking into account the selected pesticides chemical properties, application rates and frequency, climatic seasons and soil variables. PIRI's objective is to determine which among an array of pesticides has the greatest potential of contaminating the environment and the water pathway.

In this study, the evaluation and calculation of parameters needed for PIRI software are carried out according to the methods developed by Kookana et al., (2005). The concentration of pesticide in receiving waters (C_{SW}) is calculated, as suggested by OECD (1998), from the pesticide load moving into surface water adjacent to the field being treated. This needs consideration of the relative size of the water body as compared to the field being treated (*WI*) and the depth of water *H* (m) in it. *WI* is the water index defined as an approximate ratio of length of shoreline of the adjacent surface water to the perimeter of the field being treated (OECD, 1998).

Thus the predicted concentration (C_{SW} in kg m^{-3}) of pesticide in surface water with depth *H* (m), adjacent to treated area is:

$$C_{SW} = L \times T \times WI/H \quad (1)$$

where *L* is the mass of pesticide applied to the soil and *T* is the total surface transport factor for each pesticide, determined according to Kookana et al. (2005).

PIRI ranks pesticide in a following category : 'Very Low', 'Low', 'Moderate', 'High', 'Very High' and 'Extremely High'. These categories are based on a relative ranking of the pesticides for their potential for off-site migration against one another under a selected set of site, soil and environmental conditions. 'Very Low' and 'Low' categories indicate that the probability of off-site migration of pesticides is low and represents a scenario where one would not expect these compounds to be routinely detected in water. 'Moderate' risk implies that the compounds are likely to move off-site and be detected in waterways in close proximity to the site. The higher risk categories ('High', 'Very High', 'Extremely High') progressively show increased probability of the chemicals moving off-site and being detected in waterways. The divide between medium and high categories is 1.00, and the other categories limits are separated by a factor of 4.64 (corresponding to antilog of 0.667) (Kookana and Correll, 2008).

Pesticides used in the study area during the season 2007-2008 as listed in Table 2 are in the focus of the present study. The need parameters are obtained from the SN-SOSUCO society department in charge of the irrigation, and from Footprint (2008).

Hypothesis and scenarios

To run the software, we set up hypothesis and scenarios as follows: the outputs from PIRI have realistic bounds, which are guided by existing data as described in the material section above and references therein. In order to set up better environmental management plan, we assume two others situations, which are likely to occur. Hence, in total, three scenarios are considered in this study.

Scenario 1 is the actual situation of the area with mean organic carbon content of the soil equal to 1%, without any buffer zone. In Scenario 2, a buffer zone between the treated area and the adjacent surface water is introduced, while the organic carbon content of soil remaining the same, i.e. 1%. The third scenario is the worst case one, likely to occur sometimes within a longer timeframe, with no buffering zone, and mean organic carbon content of soil equal to 0.1%. In fact, according to some survey undertake in the area, the organic carbon content of the soil is already decreasing with the present usage condition.

Table 2. Pesticides used by the SN-SOSUCO during the season 2007–2008 and their application rate.

Pesticide formulation	Usage	Active ingredient (a.i.)	Concentration a.i. (g/L or g/kg)	Application rate of a.i. (kg or L/ha)
EXTREME PLUS WP	Herbicide	Metribuzin / chlorimuron-ethyl	643 / 107	0.76 / 0.13
PARAGON 500 EC	Herbicide	Pendimethalin	500	2.01
VOLCANO acetochlor 900 EC	Herbicide	Acetochlor	900	3.54
DINO 800 W	Herbicide	Diuron	800	1.24
KALACH 360 SL	Herbicide	Glyphosate	360	2.83
VOLCANO MCPA 400 SL	Herbicide	MCPA[a]	400	0.61
MASTER 720 SL	Herbicide	MSMA[b]	720	2.03
TRICLON 480 EC	Herbicide	Trichlopyr	480	0.91
BROWSER	Herbicide	Pichloram	240	0.33
DIAFURAN 10 G	Insecticide	Carbofuran	100	0.03
COSMOPOL 15 G	Insecticide	Terbufos	150	5.00
BAYLETON 250 EC	Fungicide	Triadimefon	250	0.05

[a]4-Chloro-2-methylphenoxyacetic acid
[b]Monosodium methanarsonate

RESULTS AND DISCUSSION

The results of the pesticide risk assessment for surface water within the SN-SOSUCO area are given in Tables 3-5.

As shown in Table 3, acetochlor, used in all the cultivated area with mean quantity of 3.54 L active ingredient/ha, have very high risk for both River Berega and River Yannon. Even in case of the scenario 2, with a planned buffer zone, the potential risk for this pesticide to contaminated theses adjacent rivers is high as indicated by the PIRI impact rating. In Table 4 and 5, this pesticide, acetochlor has also very high potential for contamination of Lake Lemouroudougou and Lake Karfiguela, respectively, in the actual land use condition by the SN-SOSUCO (Scenario 1), and

Table 3. PIRI risk rating for pesticides used by the SN-SOSUCO during the season 2007–2008 for rivers Berega and Yannon vs scenarios.

Pesticides	PIRI risk rating		
	Scenario 1	Scenario 2	Scenario 3
Acetochlor	Very high	High	Extremely high
Metribuzin	Very high	Medium	Very high
MSMA	Very high	Medium	Very high
Terbufos	Very high	Medium	Very high
Glyphosate	High	Medium	High
Pendimethalin	High	Low	High
MCPA	High	Low	High
Diuron	High	Low	High
Chlorimuron-ethyl	Medium	Very low	High
Carbofuran	Medium	Very low	Medium
Triclopyr	Medium	Very low	Medium
Picloram	Medium	Very low	Medium
Triadimefon	Very low	Very low	Very low

Table 4. PIRI risk rating for pesticides used by the SN-SOSUCO during the season 2007–2008 for Lake Lemouroudougou vs scenarios.

Pesticides	PIRI risk rating		
	Scenario 1	Scenario 2	Scenario 3
Acetochlor	Very high	Very low	Extremely high
Metribuzin	Very high	Low	Very high
MSMA	Very high	Low	Very high
Terbufos	Very high	Very low	Very high
Glyphosate	High	Low	High
Pendimethalin	High	Low	High
MCPA	High	Very low	High
Diuron	High	Very low	High
Chlorimuron-ethyl	Medium	Very low	High
Carbofuran	Medium	Very low	Medium
Triclopyr	Medium	Very low	Medium
Picloram	Medium	Very low	Medium
Triadimefon	Very low	Very low	Very low

Table 5. PIRI impact rating for pesticides used by the SN-SOSUCO during the season 2007–2008 for Lake Karfiguela vs scenarios.

Pesticides	PIRI risk rating		
	Scenario 1	Scenario 2	Scenario 3
Acetochlor	Very high	Medium	Extremely high
Metribuzin	Very high	Medium	Very high
MSMA	Very high	Medium	Very high
Terbufos	Very high	Very low	Very high
Glyphosate	High	Medium	High
Pendimethalin	High	Medium	High
MCPA	High	Very low	High
Diuron	High	Low	High
Chlorimuron-ethyl	Medium	Very low	High
Carbofuran	Medium	Very low	Medium
Triclopyr	Medium	Very low	Medium
Picloram	Medium	Very low	Medium
Triadimefon	Very low	Very low	Very low

extremely high potential in Scenario 3. However, if a buffer zone is arranged as assumed in Scenario 2, the risk is very low and medium for Lake Lemouroudougou and Lake Karfiguela, respectively. The difference between the risk for rivers and lakes, a higher risk for the rivers than the lakes, could be attributable to the distance between the surface water and the cultivated area, as it was noted that buffer zone width has a large impact on risk (Trainer and Volker, 2008). Additionally, there is also a risk related to the high quantity of acetochlor used in the area (10,685 L), since its mobility is low (Koc = 156 L/kg) and it has a short persistence time in soil (DT50 = 14 days) (Footprint, 2008).

Very high PIRI ratings were shown for the applied pesticides metribuzin, MSMA and terbufos for all the water resources in Scenarios 1 and 3. The plan of a buffer zone, will significantly contribute to the decrease of the impact rating from very high to medium for the rivers and Lake Karfiguela. The PIRI risk rating for terbufos become very low for both Lakes Karfiguela and Lemouroudougou, while MSMA and metribuzin have low risk rating for Lake Lemouroudougou. As previously pointed out, the difference between PIRI risk impact ratings for the two lakes could be attributable to the distance between the lake and the nearest border of the cultivated areas. The plan of buffer area by planting trees will contribute to reduce the impact, mainly if the trees contributes to maintain soil organic carbon content. The risk rating is also linked to the quantity of pesticides used. Indeed, as shown in Table 2, terbufos is not highly mobile, but is widely used in the area, up to 5.00 kg/ha, hence his very high risk rating in Scenarios 1 and 3.

Glyphosate, pendimethalin, MCPA and diuron have high risk rating in the actual condition of usage, Scenario 1. Hence, the importance of planning buffer zone to reduce the impact (scenario 2). Diuron and glyphosate have been often detected in surface water resources in France (ORP, 2011). Atrazine and diuron have been also detected in surface water in USA (USEPA, 2010), showing that these pesticides had potential risk in surface water contamination.

This study, and many others (Holvoet et al., 2007; Calvet et al., 2005) have shown the importance of organic carbon content in soil, and the management of buffer zone between the cultivated area and the surface water. Scenario 3 clearly shows that the organic carbon content in soil is very important in controlling pesticides transfer from his application point to surface water. In accordance with our findings, Margoum et al. (2003) reported that pesticides transfer through drift to receiving surface water, is reduced as the distance between the surface water body and the application point is increased. The key factors susceptible to reducing or increasing the threat of the products to the surface water seem to be the soil organic carbon content, and a planning of buffer zone.

CONCLUSION

Results from PIRI impact rating find in this study show that of the 13 pesticides applied by SN-SOSUCO during the season 2007-2008, 4 had very high potential to contaminate surface water bodies in the area, and 4 had high rating impact risk in the current usage condition. These depend mainly on the quantity of each pesticide used, the distance between the pesticide application point and surface water as well as the presence of a buffer zone. The setup of a buffer zone would have a positive impact in reducing the contamination risk of pesticide to surface water. In addition, good agricultural practice is a key point to minimize the transfer of the pesticides to surface water. Hence, it is recommended to proceed to the inclusion of a buffer zone, by planting trees as suggested in Scenario 2 in this study. The usage of acetochlor has to be well controlled, if this pesticide cannot be substitute by another one. Analysis of pesticide residues in surface water in the area is being considered in order to set up sustainable environmental management system. However, better agricultural practices have to be set up, such as choosing the best dose and application period, controlling toxic substance impacts, combined with non-chemical practices.

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