Environmental Science
ISSN: 0974-7451

Environmental Science: An Indian Journal

Research | Vol 13 Iss 6

First Survey of Agricultural Pesticides Used for Crops in Ichkeul Lake-Bizerte Lagoon Watershed (Tunisia)

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Received: November 10, 2017; **Accepted:** December 08, 2017; **Published:** December 12, 2017

Abstract

Indiscriminate use of pesticides in the modern agricultural practices leads to the contamination of soils, surface and ground waters. The types of pesticides used in the agricultural watershed surrounding the complex Ichkeul Lake-Bizerte lagoon from Tunisia were identified and their quantity estimated. The survey of farmers and dealers of pesticides showed that the most commonly used active ingredients are iodosulfuron (2014 kg), mesosulfuron (1218 kg), 2.4D (4618 kg), glyphosate (2886 kg) and fenoxaprop (5300 kg) as herbicidal active ingredient; tebuconazole (9260 kg) and epoxiconazole (17168 kg) as a fungicide; and deltamethrin (341 kg), as insecticide. Herbicides are used twice a year (pre- and post-emergence), treatment with fungicides is a result of rust attacks, insecticides are applied against insects such as aphids, for example. The percentages of active ingredient were determined to establish a ranking according to the physical-chemical parameters of each active ingredient (solubility, DT50 and KOC). Next, a theoretical estimation of the amount of each active ingredient was determined. Crops agricultural basin of Ichkeul Lake and Bizerta lagoon are important users of herbicides, fungicides and insecticides while vegetable crops use large amounts of insecticides and herbicides.

***Keywords:** Mediterranean southern shore; Quantification; Agricultural practices; Active ingredient; Crops*

Introduction

The intensification of agricultural production worldwide is often accompanied by an excessive use of pesticides [1,2]. Cereal production, millennium source of human nutrition continues to expand in connection with population growth and development. According to FAO (2009) the total annual cereal production will have to increase by about 3 billion tons to meet global demand by 2050. The use of pesticides (herbicides, fungicides, insecticides etc.) allows secure returns reducing crop losses by weeds, fungi and insects [3]. However, their use may result in the presence of toxic residues in consumer products, the biosphere and the environment. Pesticides are detected in water flows because they dissolve easily. They join the aquatic environment through runoff or infiltration and bound to suspended matter in water and sediment [4]. In the

Mediterranean region, the use of pesticides in agricultural watersheds has intensified in recent decades. Pesticides used have diversified to meet the resistance problems. The consideration of health and environmental risks associated with the use of pesticides is an important issue but could affect food production [5]. In Tunisia, except for the impact of the protocol Stockholm on obsolete pesticides [6], very little public information is available on the use of pesticides. An estimate by the "Pesticide Action Network" has evaluated the quantities of pesticides imported in Tunisia in 3985 tons of pesticides in 2004 and 3632 tons in 2005. The Tunisian agriculture is user of pesticides, but the context does not favor a clear vision about the amounts used or an estimate of their impact on the environment and human health, despite the cereals is a source of contamination elsewhere in Italy and Turkey [7].

The system of Bizerte Lagoon and Ichkeul Lake is an ideal study site. First, the Ichkeul Lake is one of the few sites in the world registered on three international conventions [8]. Second, Ichkeul Lake and Bizerte lagoon receive an unknown amount of pollutants from their watershed, agricultural zones mainly grown cereals. These two ecosystems communicate with each other through oued Tinja. The exploitation of this important complex issues in terms of ecosystem services such as biodiversity conservation, supply of fishery products and aquaculture for human consumption. The complex is under the influence of large agricultural areas, mostly specialized in field crops (cereals and fodder) users of pesticides [9] (FIG. 1). Pesticide use depends on the farmer in the context of its production chain that includes products and seed suppliers, the specifications, regulations, etc. The farmer aims the optimal level of pesticide treatments in terms of its risk assessment.

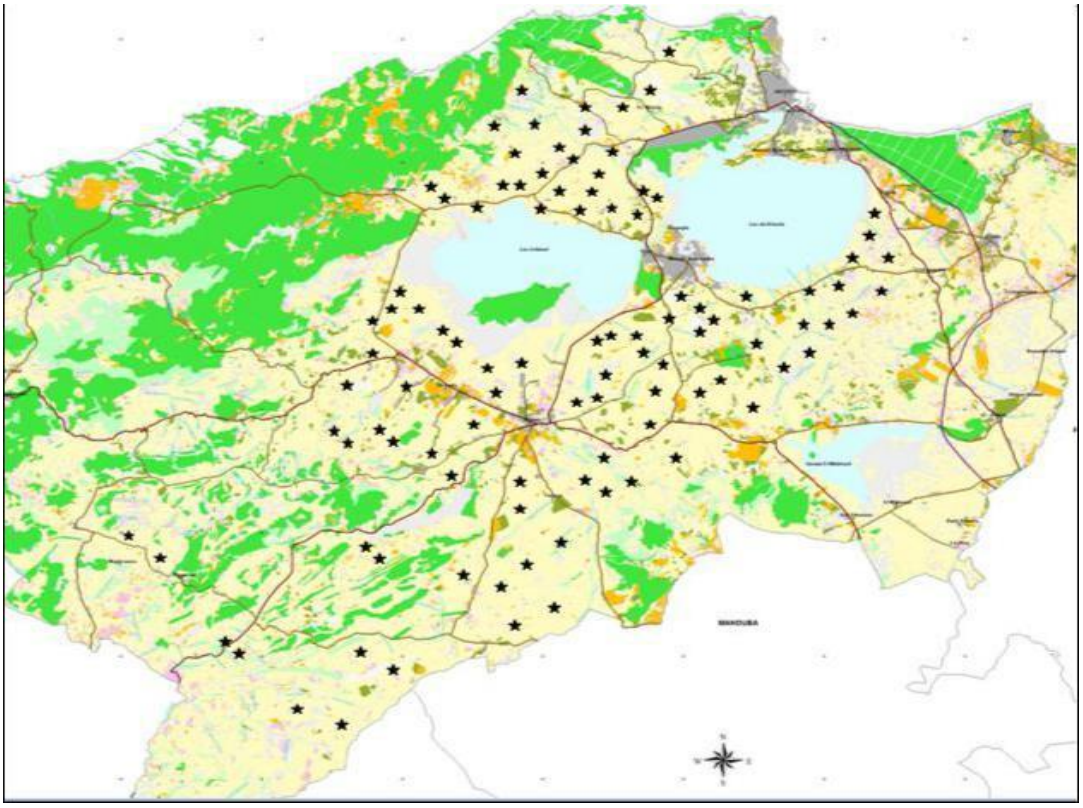

FIG. 1. **Land cover map of the region of Bizerte and approximate location of the land of surveyed farmers.**

Despite several ecotoxicological studies on the lagoon of Bizerte (10-12) and some data on metal pollution of Lake Ichkeul [8] also on several aquatic ecosystems of southern Mediterranean no study has been undertaken to estimate intakes of agricultural pesticides in the complex or in all southern Mediterranean. The objective of this study was therefore to define, for the catchment area of the complex Ichkeul Lake-Bizerte lagoon, agricultural practices in order to identify the most used pesticides and estimate their quantities. The collection of agricultural practices in areas surrounding the two lakes, has allowed to compare with agricultural practices in other countries and to highlight some problematic molecules likely to end up in the water and sediment of the complex.

Methodology

Site description

The study land belongs to two bioclimatic zones. The humid Mediterranean and the Mediterranean sub-humid. The average annual rainfall in the area varies from 450 mm to 650 mm per year. The complex lake and lagoon is fed by several oueds. The freshwater input from the watershed of Ichkeul Lake is 0.15 m^3/km^2, while it is 0.06 m^3/km^2, the lagoon is lower and flatter, so it receives less than runoff (ANPE 2005). Ichkeul Lake is the terminus of a major river system. It drains a catchment area of approximately 2080 km^2 surface. The lowest slopes surround the complex. Moving away from these ecosystems increases the slope, drainage water and oueds eventually drain into the lake and the lagoon (RCAD, 2007). The salinity of the lake depends on the hydrology of the complex; however, it is around 4 gL^{-1} in winter (fresh water) and it goes to 35 gL^{-1} in summer due to evaporation and influence marine water from the lagoon. A database compiled by the Regional Commissioner for Agricultural Development (RCAD), to better understand the characteristics of the two watersheds. The analysis of land use in the watershed show that cereals and fodder crops occupy the biggest agricultural land (Cereals 77 620 ha and fodder 46470 ha). The fruit trees (18, 465 ha), located in the upper parts, is marginally as the market garden areas and legumes (5230 ha and 11 770 ha respectively).

Sampling strategy

Contact with farmers was taken through the RCAD and their representatives at the level of delegations called extension territorial cells (ETC). Data were also collected from dealers of pesticides and finally among farmers. ETC visited were those belonging to the watershed of Ichkeul Lake and Bizerte Lagoon. Dealers of pesticides in the Bizerte region consist of one large supplier of crop protection products located in Mateur which sells its products to farmers who have land around Lake Ichkeul and resellers located in Bizerte town, clientele of these resellers are rather the farmers who have land around the Bizerte Lagoon. During the visits, the questions focused on the nature and amounts of pesticides sold. Each investigated farmer has land all belonging to the watershed of the lake and the lagoon. A representative sample of the overall population of holdings with about 100 individuals was questioned (FIG. 1). A list of farmers has been provided by the RCAD and the choice was established in relation to the location of the nearest land to the lake and the lagoon and oueds that feed the complex. The interview was semi-directive. It begins about the problems faced by farmers in general and on pesticides used as treatment to diseases and weeds in cereal and forage crops. The speech was always friendly. The minimal information included three criteria: crop type, pesticides, area of cultivated field (See the questionnaire in Appendix 1).

Between April 2011 and March 2012, 100 farmers, 4 engineers (ETC) and engineers from the office of public lands (OPL) were questioned. OPL owns 4102 hectares, located in the delegations of Mateur and Ghezella, including 3524 ha of crops. Rainfall during this season was measured with an average of 600 mm between September 2011 and March 2012. A logical approach was adopted for calculating the total quantities of the active ingredients used in the lake and lagoon watershed.

Overall calculation method: Percentages of use of the active ingredients corresponding to pesticides (trade name) were determined by dividing the number of farmers using this active ingredient with the total number of surveyed farmers (*100). After a classification established according to the physical-chemical parameters of each active ingredient an estimate of the amount of each active ingredient used in the agricultural basin surrounding the complex Ichkeul Lake-Bizerte Lagoon, was determined. This amount (Q substance) corresponds to the product of cultivated area (ha) by the percentage of use of the pesticide (%) by the content of the active substance in the pesticide.

Calculation method per farmer: For each farmer, the percentage of the areas used for cereals and fodder crops was determined. Then, the amounts of pesticides used were calculated by multiplying the area by the determination of the most used herbicides by the farmer.

Results

Use of pesticides in the complex Ichkeul Lake-Bizerte Lagoon

According to the farmers and engineers RCAD field crops (cereals and fodder) occupy the largest percentage of cultivated fields. They are major users of herbicides, fungicides and insecticides; the main active ingredients are listed in TABLE 1.

TABLE 1. **The list of active ingredients used in the watershed Ichkeul Lake-Bizerte Lagoon Lake.**

Types of pesticides	Active ingredients	Commercial names
Herbicides	Iodosulfuron	Puma, Amilcar
	Fenoxaprop	Puma
	Mesosulfuron	Amilcar
	2, 4D	Sansac, Factor, Dialene super, Mustang
	Glyphosate	Kalach
	Diclofop	Ilexan super, Dopler,
	Tribenuron	Granstar
Fungicides	Tebuconazole	Horizon
	Epoxiconazole	Opus, Ogam, Soprano, RexDuo, Spike
	Flusilazole	Punch
	Cyproconazole	Amistar, Altosuper
	Dimoxystrobine	Swing gold
	azoxystrobine	Amistar
Insecticides	Deltaméthrine	Decis

Herbicides are used for weed control to remove the interspecific competition in the space between wheat, barley and fodder and other weeds. Treatments are usually done twice a year, in autumn (October) and spring (March). Fungicides are used twice a year (April and May) as a preventive treatment. They are also used as a curative treatment of the "rust" whenever there is disease. Rust is a widespread disease caused by mold. Insecticides are used whenever there is disease. A total of at least two applications of herbicides, fungicides and two sprays of insecticidal were applied.

The pesticides are sprayed by airplane for large agricultural areas and tractors on small areas. It should be noted that farmers still use the indicated dosage recorded by resellers that is indicated in catalogs and on bottles of pesticides. It is therefore impossible to establish the variety of doses in this way. In the interview, it was difficult to discuss beyond this general indication. That poses problems for estimating volumes at the dilution of the product and quantity per area at the spreading. These two parameters produce high imprecision on real spillage. Farmers indicated that there were failures and resistors, which are cases when they ask for technical assistance, especially to the AER engineers and sometimes to resellers and are additional treatments. The amounts of active substances applied in the watershed are estimated at 44.7 t/year (TABLE 2). These values correspond approximately to 0.5% of pesticide imports in Tunisia. They are herbicide active compounds (17.9t), fungicides (26.4t) and insecticides (0.4t kg).

TABLE 2. **Estimated amount of the main active ingredients used in agricultural areas according to farmers survey.**

Active ingredients (Commercial names)	**Area cereals and fodder crops processed**	**Dosage of pesticide**	**Active ingredient quantity**	**Minimum number of application per year**	**Amount of active ingredient used**	**Amount of active ingredient sold**
Unit	**Ha processed**	**L ha^{-1} or g ha^{-1}**	**g L^{-1} or g kg^{-1}**		**Kg**	**Kg**
Iodosulfuron (Puma)	41410	1 L/ha	8 g/L		662	192
Iodosulfuron (Amilcar)	61480	330 g/ha	30 g/Kg		1352	1013
Iodosulfuron (Total)				**2**	**2014**	**1205**
Fenoxaprop (Puma)	41410	1 L/ha	64 g/L	**2**	**5300**	**1536**
2, 4D	8016	0.8 L/ha	360 g/L	**2**	**4618**	**2400**
Mesosulfuron (Amilcar)	61480	330 g/ha	30 g/Kg	**2**	**1218**	**1013**
Glyphosate	8016	1 L/ha	360 g/L	**2**	**4772**	**2160**
Tebuconazole (Horizon)	18520	1 L/ha	250 g/L	**2**	**9260**	**3750**
Epoxiconazole (Opus)	18520	0.8 L/ha	125 g/L		3704	2340
Epoxiconazole (Rex	21136	0.5 L/ha	187 g/L		3952	2280
Duo)	25082	1 L/ha	125 g/L	**2**	6270	1950
Epoxiconazole (Soprano)	18520	0.7 L/ha	125 g/L		3242	780
Epoxiconazole (Ogam)					**17168**	**7350**
Epoxiconazole (Total)						
Deltamethrine (Decis)	91049	0.25 L/ha	15 g/L	**1**	**341**	**300**

Estimation of amount of pesticides sold

Visits to the supplier and resellers have determined the nature and amounts of pesticides sold in the study area (TABLES 2 and 3). The amounts of active ingredients sold during the year 2012 were calculated based on the percentage of active ingredient present in pesticides. The balance sheet shows a consumption of 28 tons/year of active substances. The larger

quantities sold are those of the iodosulfurone (1205 kg), the mésosulfurone (1013 kg), the 2, 4-D (2400 kg), glyphosate (2160 kg) and fenoxaprop (1536 kg) as herbicidal active substances; tebuconazole (3750 kg) and epoxiconazole (7350 kg) as a fungicide and deltamethrin (300 kg) active substances insecticides.

TABLE 3. **Quantities of pesticides sold per year in the concerned delegations (L: Litre, kg).**

Types of pesticides	**Trade name**	**Annual sales products**	**Active ingredients**	**Kg**
Herbicides	Puma	24000 L	Fenoxaprop 6.4%	1536
			Iodosulfuron 0.8%	192
			Mefenpyr 2.4%	576
	Amilcar	135000 L	Mesosulfuron 0.75%	1013
			Iodosulfuron 0.75%	1013
			Mefenpyr 2.25%	3087
	Glyphosate	6000 L	Glyphosate 36%	2160
	Mustang	8000 L	2, 4D 30% Florasulam 0.6%	2400 36
Total				**12013**
Fungicides	Soprano Ogam	15000 L 6000 L	Epoxiconazole 13% Epoxiconazole 13% Kresoxim 13%	1950 780 780
	Rex Duo	12000 L	Epoxiconazole 19%	2280
			Thiophanate 31%	3720
	Horizon	15000 L	Tebuconazole 25%	3750
	Opus	18000 L	Epoxiconazole 13%	2340
Total				**15600**
Insecticides	Decis	3000 L	Deltamethrine 10%	300
Total of all pesticides				**27913**

Estimation of pesticides used by farmers

The field survey covers an area of 113 390 hectares of field crops (cereals and fodder). The quantities of pesticides used in the catchment area of the Bizerte Lagoon and Ichkeul Lake for large cereal and forage crops were determined as active ingredients from herbicide (17, 9 t) fungicides (26, 4 t) and insecticides (0, 4 t) corresponding to a total of 44, 7 t active ingredients for 113, 390 hectares of crops. Thus, farmers would use 0.4 kg of active ingredient per hectare per year at minimum.

Comparing sold pesticides and used pesticides

The differences between the reported amounts of active ingredients sold by dealers and those reported used by farmers were not important for most substances. Thus, the active ingredients such as iodosulfurone (1205/2014 kg), mésosulfurone (1013/1218 kg), 2, 4-D (2400/4618 kg), glyphosate (2160/4772 kg) and deltamethrin (341/300 kg) correspond to that determined by the survey of farmers. However, differences in favor of that used appeared larger for fenoxaprop (1536/5300 kg), epoxiconazole (7350/17168 kg) and tebuconazole (3750/9260 kg) suggesting that farmers used other product suppliers such as phytosanitary separate supplier in the governorate of Bizerte including the AER, which intervenes in cases of resistance for providing new active ingredient.

The results of this survey indicated that currently commercial formulas Amilcar and Puma are the two most widely used herbicides in the end alternations to avoid resistance problems, although two of the three active principles are the same in both products. Glyphosate and other herbicides are spread in minority volumes but may represent significant amounts of active substances because of concentrations. Amilcar and Puma seem particularly advised by dealers, especially that treatment costs are not comparable. The statistics on the exploitation indicate that 38% of farmers use two fungicides with same active ingredients epoxiconazole and tebuconazole (Opus, Ogham, Soprano, RexDuo, Spike, Horizon), 62% use a very wide range.

Discussion

The potential transfer of phytosanitary products and the possibility of active ingredients detection can be assessed from several physical-chemical properties (TABLE 4) that characterize each active substance such as carbon partition coefficient organic/water solubility and half-life [10-13]. Organic carbon partition coefficient/water gives an indication of the ability of the molecule to be adsorbed or desorbed on organic matter: The strongly adsorbed pesticides are normally retained over-ground (less leachable). In this case, the quantities of leached pesticides will depend on the quantity of eroded and transported sediments [14]. Molecules with low Koc will be left with the highest concentrations in the aqueous phase of the runoff [15-20]. The half-life is the time it takes for a substance to lose half its biocidal activity.

TABLE 4. **Physical-chemical properties of some active ingredients.**

Active ingredient	**Koc**	**Solubility of water**	**DT50**
	ML g^{-1}	**mg l^{-1}**	**Day**
Herbicides			
Fenoxaprop	9490	0.9	1
Iodosulfuron	97.7	25000	181
Mefenpyr	634	20	135
Mesosulfuron	3	483	48
Glyphosate	1435	10500	12
2, 4D	88.4	23180	29
Fongicides			
Epoxiconazole	1073	7.1	119.8
Tebuconazole	769	36	365
Insecticides			
Deltamethrine	10240000	0.0002	65

The different active ingredients used in the studied watershed (TABLE 1) are currently used in European countries. From the results of TABLE 2 the most widely used pesticides in the agricultural basin of the Bizerte Lagoon and Ichkeul Lake were mostly herbicides and fungicides. Farmers used 0.4 kg of active ingredient per hectare. This quantity is small compared to 3 kg-4 kg of active ingredient per hectare used in France and the United States [2] and 13 kg of active ingredient per hectare used in Thailand on watershed cultures of exports [1]. A study by the French Ministry of Agriculture (Agreste 2014 [21]) indicates that for the crop year 2011, wheats receive an average of 2 per year treating of herbicides and fungicides that while insecticides are on average from 0.25 to 0.5 times a year, this result confirms our results.

Schreinemachers and Tipraqsa [2] indicate that an intensification of agricultural production by 1% would mean an increase in pesticide use by 1.8%. The authors also indicate that the reduction in the use of insecticides would be offset by an increase in the use of herbicides and fungicides, which seems to be the case in Tunisia. According Schreinemachers and Tipraqsa [2], the use of pesticides per hectare of cultivated land dependent on income countries. The use of 0.2 kg of active ingredient per hectare places Tunisia in the range of low-income countries, much lower than 13 kg per hectare of active substances used in Thailand [2]. From the perspective of the molecules used, the first census conducted in the watershed of Ichkeul Lake and Bizerte Lagoon, shows use of fungicides, herbicides and insecticides "new generation". These pesticides have replaced the old generation pesticides, organochlorine pesticides, very persistent in the environment and still present today in the sediments of the lagoon of Bizerte and probably in sediments Ichkeul. These molecules are authorized for use in France.

Current herbicides can cause new ecological disturbances in the complex Ichkeul Lake-Bizerte Lagoon. Thus, Glyphosate and 2, 4-D were found in over 20% of French surface water, so it is likely that these molecules are found in the sediments of Ichkeul Lake and Bizerte Lagoon with their metabolites, particularly aminomethylphosphonic acid (AMPA) (whose solubility and half-life time are higher than the parent compound, which was found in nearly 50% of French water surfaces). Regarding fungicides, tebuconazole presents a concern to the extent that its half-life time is high (in some cases up to 620 days) and that its mobility in flood proved [22]. Although its animal toxicity is low, this fungicide affects bacterial populations and the smooth functioning of the ecosystem.

Conclusion

The census of agriculture from farmers Basin complex Ichkeul Lake-Bizerte Lagoon, with a majority of field crops, shows a massive use of fungicides, herbicides and insecticides. However, it is necessary to ensure their presence in the dosages in different environmental matrices and understand their effects and their futures. To supplement our knowledge about the use of pesticides in the complex Ichkeul Lake-Bizerte Lagoon, a survey identifying the pesticides used in vegetable crops and pulses is needed. Finally, the contents of the main substances in the watershed should be monitored, especially during episodes of runoff to limit the effects on the environment.

Conflict of Interest

The authors declare no completing financial interest.

Acknowledgement

The authors would like to thank Mr. Kaabi Taher, senior engineer at the Regional Commission for Agricultural Development of Bizerte, for logistical and educational support.

Annex 1

Survey questionnaire for farmers:

Is there's a problem of insect or fungus in recent years?

How do you eliminate the weeds?

What are the pesticides you use?

Do you alternate the selection of pesticides each year?

How many times you spray your fields and as she time of year?

What is the amount of pesticide you use?

Pesticide use practices:

How do you spray the fields with pesticides by air with tractors?

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