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Work Practices, Exposure Assessment and Geographical Analysis of Pesticide Applicators in Argentina

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1. Introduction

1.1 Argentina

Argentina is the second largest country of South America. In its central-eastern region, there is a plain extending over more than 50 million hectares, whose high fertility and productivity provide significant comparative advantages for agriculture production (Hall et al., 1992, as cited in Manuel-Navarrete et al., 2009). This activity is one of the main axes of Argentina's economy, particularly the production of cereals and oilseeds, the primary export of Argentina, placing it among the main grain-producing countries of the world (United States Department of Agriculture, 2010).

In the history of Argentina, agriculture has been a prime contributor to economic and social development. Among the factors that explain this process are the external economic environment, the political framework, domestic economic conditions and the behaviour of production and innovation. At the same time, it is important to analyse its impact both socially and environmentally.

Several evolutionary periods can be noticed in Argentinean agriculture: a birth and expansion period (from 1862 to 1929); an agricultural recession period (from 1929 to 1950); a mechanization and modernization period (from 1950 to 1989) and the productive specialization and agriculturalization period (from 1990) (Stratta Fernández & Ríos Carmenado, 2010).

In the latter two periods, from the mid-20th century, there was an important expansion of agricultural production, marked by technological transformations. Some highlights of this period are: a) the creation of INTA (National Institute for Agricultural Technology) in 1957;

b) the total mechanization of agricultural labour; c) the introduction of improved seeds; d) the use of agrochemical products and fertilizers; and e) the popularisation of soybean cultivation (Stratta Fernández & Ríos Carmenado, 2010). There was an increase of agricultural production of almost 30%, which led not only to an expansion of the agricultural surface (17%) but also to an increase in soil productivity (Obschatko, as cited by Stratta Fernández & Ríos Carmenado, 2010).

Worldwide, the so-called "Green Revolution", with the incorporation of new machinery, the massive use of agrochemical products and fertilizers, the use of improved seeds (known hybrids in corn, sorghum and sunflower and their development in other crops such as soybean) helped to double and even triple the yields of the most important grains. In Argentina, National Institute for Agricultural Technology developed and promoted a new method of organizing production and incorporating technological changes, by means of which, between 1965 and 1985, annual grain production rose from 14 to 80 million tons (Lódola, 2008, as cited in Stratta Fernández & Ríos Carmenado, 2010). The transformations during this period tripled the value of production, doubled soil productivity, and quadrupled labour force productivity (Stratta Fernández & Ríos Carmenado, 2010).

The outstanding increase of farming activity since 1990, known as "agriculturalization", occurred as a result of this production increase and adoption of new technology. It was characterized by an increasing and continuous change in land use, including converting large stretches of forests into farmlands, so that the country has one of the highest rates of deforestation in South America (0.8%/year) (FAO, 2001, as cited by Cabido & Zak, 2010). Agricultural crops also steadily replaced stockbreeding and dairy-farming (Stratta Fernández & Ríos Carmenado, 2010).

From 1996, an extensive agricultural model developed, based on glyphosate-resistant transgenic soybean farming, no-till and the intensive use of fertilizers and pesticides. Soybeans occupied 34,700 ha in 1970, but had reached more than 18 million ha by 2010 (Sistema Integrado de Información Agropecuaria. Ministerio de Agricultura, Ganadería, Pesca y Alimentos de la República Argentina, 2011). With this, the marketing of pesticides grew strongly, from 155 million pounds in 1995 (Cámara de Sanidad Agropecuaria y Fertilizantes, 2010) up to 600 million pounds in 2007 (Secretaria de Ambiente y Desarrollo Sustentable, 2009). The growth of the sector, the rising trend in commodity prices and the continuous encroachment of the agricultural frontier into marginal areas indicate that demand for pesticides will continue its upward trend in coming years (World Bank, 2006).

1.2 Study area - Córdoba province

Córdoba province is located in the central region of Argentina (from 29º 29′ 53″ to 35º 0′ 0″ Lat. S and 61º 26′ 40″ to 65º 46′ 46″ Long. W), with much of its surface in the central-eastern Pampas. It occupies 165.321 km^2 and has 3, 304,825 inhabitants, with a population density of 20 inhabitants per km^2 and a heterogeneous population distribution: 88.7% of it is urban and only 11.3% is rural (Instituto Nacional de Estadísticas y Censos, 2011a). This means that housing areas coexist with agricultural areas without clearly defined borders, increasing the risk of non-occupational exposure to pesticides in communities adjacent to agricultural fields.

Córdoba plays an important role in the agricultural history and transformation of Argentina because of its strong livestock and agriculture sector, accounting for 48.02% of the provincial area devoted to agricultural production. Córdoba provides 90% of the total production of soybeans for export (Dirección General de Estadísticas y Censos, 2009).

The extensive crops (soybean, maize, sorghum, peanut, wheat, and sunflower) area has expanded from 3,397,050 ha in 1994/95 to 6,810,500 ha in 2009/2010 (Sistema Integrado de Información Agropecuaria, 2011). As in other provinces of Argentina, the expansion of arable lands replacing stockbreeding and dairy farming has also invaded natural ecosystem areas. About 120,000 km2 of forest in Córdoba, in the early 20th century, had been reduced to 17,000 km2 of forest and 9,600 km2 of bush by 2004 (Cabido & Zak, 2010). Between 1970 and 2000, agricultural expansion in the northern departments of Córdoba caused the loss of 10,000 km2 of dry woodland converted to annual crops, mainly soybeans (Zak et al., 2004).
About 65% of extensive crops are soybeans (Ministerio de Agricultura, Ganadería y Alimentos de la Provincia de Córdoba, 2011), representing 30% of the area cultivated with this oilseed nationally. The Argentine Agricultural Census 2002 showed that, from 1988-2002, the greatest annual increase of the crop was in Córdoba (Dirección General de Estadísticas y Censos, 2002). As expected, pesticide use has accompanied this trend.

1.3 Ecological classification of Córdoba province

In 1987, Córdoba was classified into five homogeneous ecological areas (HEAs) (Figure 1) according to soil and climatic characteristics, land use and production activities. HEA I, the so-called "North-western Extensive Livestock Area" is characterized by grass cattle; HEA II, named the "Middle Agricultural and Livestock Area" has extensive crops and beef cattle. HEA III, the "Mid-eastern Dairy Area" is the main milk shed of the province, but also has extensive crops; HEA IV, the "South-eastern Agricultural Area", is based on agriculture and, finally, HEA V, the "South-eastern Agricultural and Livestock Area", has a large area devoted to extensive crops, with a significant participation of beef cattle (Centro Regional Córdoba INTA, 1987).
Becerra et al. (2007) characterized the HEAs through a family farmers study, showing large differences related to conditions of land ownership, capitalization levels, family work and social reproduction. However, no others aspects related to labour conditions were characterized. The high diversity of production systems historically has been reduced in

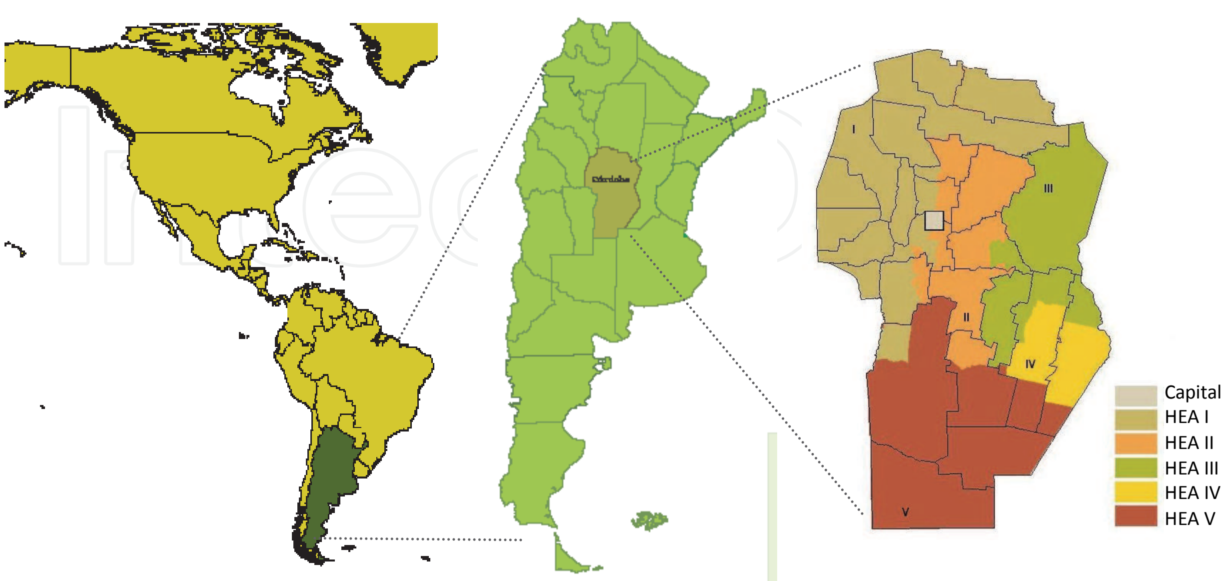


Fig. 1. Homogeneous ecological areas (HEAs) of Córdoba province

recent decades by a concentration process, expulsion of farmers and of the rural population Of 40,817 farms surveyed in 1988, there were 26,226 left in 2002, indicating a reduction of around 36%, coupled to an increase in the average size of farms (36%, from 343 ha to 467 ha in 2002) (Dirección General de Estadísticas y Censos, 2002). Both issues, the number and the size of farms, have become the emerging focus of studies on land use and access.
Even before 2001, changes had occurred: the agriculture area had grown, replacing regions devoted previously to meat and milk production (Da Veiga, 2005); nearly 90% of the increase corresponded to soybean cultivation (Martellotto et al., 2001) and cattle stock had decreased 19% between 2002 and 2009 (Calvo et al., 2009). The best lands were devoted to agriculture and the others to livestock.

1.4 Pesticides and human health

Pesticides have a strong environmental impact and produce adverse effects upon living beings, including humans, in whom acute exposure can lead to death or serious illness (WHO, 1990). The wide use of pesticides in agricultural and other settings results in continuing human exposure (Alavanja et al., 2004), shown by epidemiological studies to be associated with risks to health. Chronic exposure is most often a problem in occupational settings and can increase the risk of developmental and reproductive disorders, immune system diseases, endocrine disruption, impaired nervous-system function, and development of certain cancers (Bassil et al., 2007; Sanborn et al., 2007; WHO, 1990; Yañez et al., 2002).
The good management, use, and disposal of agrochemicals, particularly pesticides, thus becomes a global health and environmental issue in agricultural settings, particularly in developing countries, such as Argentina, where economies may be heavily dependent on agriculture (WHO, 2010).
In third world countries, pesticide poisoning is a major problem primarily due to precarious and unsafe pesticide application and handling practices. Furthermore, an enlightened and enforceable pesticide policy, legislation and regulation are scarce or absent. In Argentina, and particularly in Córdoba, legislation exists but enforcement is lacking. In effect, our previous research shows indicators of irregular or non inspection of the chemical use, at least in the studied topics of the local specific law (Lantieri et al., 2009).
Current concern in Argentina about the environmental impact and human health effects of pesticide use arises from an annual incidence of accidents/occupational diseases in agricultural activity of 94.8‰. This is one of the activities whose values were higher than the overall incidence rate for the entire national system of work risk, 56.6‰, with a mortality index of 195 fatalities per million workers covered, only surpassed by construction (229‰) (Superintendencia de Riesgo de Trabajo, 2009). It is worth pointing out that the number of acute pesticide poisonings is not a good indicator of the problem due to underreporting in rural areas (Henao et al., 1993).
In this country, and particularly in Córdoba province, despite its long agricultural history, occupational pesticide use and its health effects have not been studied in this sensitive population, until recent years.

1.5 Previous results

The only work to date is Lantieri et al. (2009), a population-based study of around 700 terrestrial pesticide applicators in Córdoba province, which assessed the current and past use of pesticides, as well as the technologies, personal protective equipment (PPE) employed, worker practices and different social and demographic characteristics. Briefly, the main results showed that 50 per cent of the workers reside less than 500 m from the nearest cultivated area, 60 per cent of them do not use personal protective equipment and more than half spray up to 5000 ha per year. This, along with other results, would indicate that there is a risk scenario for the study population, and warrants further evaluation, particularly for the occurrence of chronic health effects.

Preliminary results showed that 40% of this sensitive population of pesticide applicators in Córdoba have had, sometimes/frequently, symptoms such as skin and eye irritation, nausea and vomiting, 35% had a medical consultation and 5.4% had been hospitalized as a result of pesticide use. Besides, unprotected workers showed differences in the frequency of symptoms such as eye irritation, headache, nervousness and depression. Many workers showed health effects related to pesticide exposure and many of the symptoms have a statistically significant association with the years of activity related to agrochemical use.

Furthermore, the exceptional increase of the cultivated area in Córdoba, particularly of glyphosate-resistant transgenic soybean, presents a particular agricultural panorama, on top of the pre-existing environmental differences defined by the homogeneous ecological areas (HEAs) classification. The adoption of new technological resources, direct sowing, complementary irrigation, use of transgenic seeds, fertilizer application and intensive pesticide usage, have given rise to new technological and economic scenarios in the HEAs (Ghida-Daza, 2009), from which we can hypothesize that new risk scenarios have also emerged in the province.

1.6 Objectives

The basic factors necessary to effectively study the association between pesticide exposure and health effects include determination of the population at risk; a valid determination of exposure; verification of diagnosis, symptom, or biological marker of a health effect among the populations being studied; methods to link individual exposure to health effects; and the ability to establish a temporal relationship between the exposure and the health effect (McCauley, 2006).

The purpose of this chapter is to provide a comprehensive characterization of terrestrial pesticide applicators in Córdoba province, with the emphasis on the assessment of occupational exposure. We provide two new methodological tools to estimate the workers' exposure level, analyze the stochastic behaviours of these measures, and supply the corresponding scales for assessing exposure risks in the regional agricultural scenarios.

2. Materials and methods

2.1 Study population and data collection

We conducted a population-based study in Córdoba province, Argentina. All the workers attending the mandatory courses provided by the Agriculture, Livestock and Food Ministry to obtain the applicator license, were asked to participate in the survey, from 2007 to 2010. After an explanation of the purpose of the study and prior informed consent, a self-administered questionnaire (adapted from Agricultural Health Study, Alavanja et al., 1996; Bonner & Alavanja, 2005) was used. Exposure determinants such as possible characteristics that influence exposure levels, (Steward, 1999) were covered. A checklist of 49 specific pesticides in use and of forbidden or restricted-use chemicals with common and trade names was included to enhance recall. Current and historical pesticide use and its frequency, as well as social and demographic data, tasks (mixing/applying pesticides; repairing sprayer equipment), crops and area/year sprayed, personal protective equipment (PPE) used and application methods, were included, as well as pesticide prescriptions, indicated by agricultural engineers. Workers' diagnosed diseases, frequency of medical consultations and hospitalization related to adverse health events occurring during occupational exposure, and finally, questions about health of the applicator's family were included in the form.

From 1122 completed forms, a consistency analysis for various responses was carried out, leaving a sample size of 880 applicators directly exposed to pesticides (mixing/applying pesticides) for future analysis. The procedures were submitted to a regional ethics committee and all data was encrypted for legal and confidentiality purposes.

2.2 Variables

2.2.1 Social and demographical variables

Social and demographic variables included age (constructed from birth date); education level (incomplete primary school, complete primary, incomplete secondary and complete secondary, technical or university studies); marital status (married or cohabiting, and unmarried, separated, divorced or widowed); origin (country, province and department of birth; current address including province and department).

2.2.2 Exposure determinants

Exposure determinants included: personal protective equipment (PPE) used: waterproof clothing, gas mask, chemically resistant (e.g. nitrile) gloves, face shields or goggles, hat or helmet and other protective clothing (boots, apron, waterproof pants). Years mixing/applying; hectares applied in the last year; period of the year in which the applicator works, taking into account two periods (lower temperature months, from April to August; higher temperature, from September to March); applicator household proximity in meters with respect to the nearest crop, and written pesticide prescription.

2.2.3 Protection level

In order to analyze associations between some of the variables and protection habits, we constructed a new measure called protection level (Table 1), based on Dosemeci et al. (2002) scores (see adapted version in Díaz & Stimolo, *in revision*), considering firstly, three levels of protection: unprotected (0% of protection); partially protected (20% to 70%) and protected (90%); and secondly, considering as Protected those workers with 90% protection and Unprotected, the rest of the applicators (0% to 70%).

2.2.4 Geographical classification variable

As mentioned above, the regions of the province were classified through homogeneous ecological areas (Centro Regional Córdoba INTA, 1987). The notation and names of these five areas are as follows: HEA I: Northwestern Extensive Livestock Area; HEA II: Middle Agricultural and Livestock Area; HEA III: Mid-eastern Dairy Area; HEA IV: Southeastern Agricultural Area, and HEA V: Southeastern Agricultural and Livestock Area.

Scores for combinations of PPE use	Protection Categories	% of protection	Combinations of Personal Protective Equipment Used
0	Unprotected	0	Never used PPE
1	Partially Protected	20	Face shields o goggles. Other protective clothing (boot, hat)
2		30	Gas mask. Waterproof clothing.
3		40	Chemically resistant gloves.
4		50	PPE 1 y 2.
5		60	PPE 1 y 3.
6		70	PPE 2 y 3.
7	Protected	90	PPE 1, 2 y 3.

Table 1. Description of categories of protection level

2.2.5 Applicator health variables

Six variables were collected for the assessment of worker health: Symptoms: Perception of acute and sub-acute manifestations - irritative symptoms (skin and eye irritation, nausea or vomiting, chest discomfort); fatigue tiredness; nervousness or depression; headache /dizziness; Occurrence of symptoms: Never / Rarely, Sometimes / Frequently; Medical consultations related to pesticide use effects: Yes / No; and Hospitalization linked to tasks with pesticides: Yes / No.

2.3 Epidemiology and exposure assessment

Historically, the major limitation of epidemiology of pesticide effects has been inadequate exposure assessment. More accurate quantification of exposure has been the hallmark of some of the more recent epidemiological studies, and the present work gives an insight into this issue including the development of methodological techniques to assess pesticide exposure. Two indexes were created that describe intensity level and accumulated exposure to pesticides, using specific characteristics of pesticide application and of some personal habits.

2.3.1 Intensity level and cumulative exposure indexes

One of the main aims of this work is to contribute to the study of exposure to pesticides in our region. No measure has been proposed so far. We therefore created two indexes to describe applicator exposure. The Intensity Level of the pesticide Exposure (ILE) index measures instantaneous exposure intensity and has a Cronbach'α value (coefficient of reliability) equal to 0.95; the Cumulative Exposure Index (CEI) takes into account the average time of exposure, and incorporates the previous ILE information, with a similar reliability coefficient. Both indexes are based on the proposal of Dosemeci et al. (2002), carefully adapting the weighting scores procedure to our own context, using mainly local professional judgments. As mentioned, Diaz and Stimolo (*in revision*) show the selection of these scores for both indexes, although basically, these are weighted for the exposure indicators considered most important, such as the PPE information. The ILE and CEI are presented below:

$$ILE = (mix * PPE) + (\sum_{i=1}^{n} \frac{meth * PPE}{\# meth}) + (repair * PPE) + house\_dist$$

and

$$CEI = ILE + (\sum_{i=1}^{n} \log(1 + \frac{Ha / year}{55}),$$

respectively, with *mix* representing a dichotomic response about mixing pesticides, *meth* the category of the method used with a certain PPE, *repair* the binary variable for which success is the positive response, *house_dist* the score indicating the applicator household proximity to the nearest crop, and *55* the average of ha that is treated with a single load in the crop sprayer. Both measures were evaluated for all subjects in the sample.

Using Bootstrap and Monte Carlo Resampling methods, we identified the most suitable theoretical stochastic distribution for each measure, drawing m=30,000 random samples. Thus, density models were generated (Diaz & Stimolo, *in revision*), after an appropriate goodness-of-fit analysis, and the percentiles estimated for the future use of indexes and recommendations through confidence bands. This step allowed us to estimate the cut-off points or percentiles that define the scales of pesticide exposure for the applicators. The cut-off points served as reference points for classifying subjects into, firstly, one of three categories: low, medium and high exposure, and then, one of four modalities: low, medium, medium high and high exposure. A double-blind design using the researchers as participants was implemented to check both scales. Unity minus the cross-validation error rate was reported, which showed around 80% of agreement. The most suitable density models have a Gamma distribution.

2.4 Statistical analysis for association

We used a modelling approach to verify differences between ecological areas. Assuming counts or frequencies in each category of the variables as the outcome, we fitted Poisson and Gamma generalized models to estimate the parameters (effects). Association between two or three variables was inspected through log-linear models in order to estimate the odds ratio as association measures.

3. Results

3.1 Social and demographical characteristics

The population is largely composed of Argentinean white men. Only 0.7% is foreign born, from Bolivia and Chile. Nearly all the applicators reside in Córdoba (98.3%). Generally, they are not migrant workers: 89.9% were born in Córdoba and 64% still live in the same city, while the remainder still lives within the same province. Because there were only four female applicators (0.5%), these were excluded from data analysis. The applicators are young men (34.9 y, s.d. 11.04 y) and 80% of the population are under 45; 5.9% are under 21 and 4.5% over 55 years of age. Only 25.6% have completed secondary school, technical or university studies, with 11.8% being illiterate or with incomplete primary school. 63.5% of the workers are married or cohabiting (Table 2).

Table 3 shows that 72.5% of the applicators have personally mixed or applied pesticides up to 10 years. The principal crops sprayed by the applicators surveyed were soybean (95.3%), maize (81.9%), wheat (79.5%) and alfalfa (54.8%), with the average area/year worked in the last year, 7000 ha. It should be noted that 46.5% of workers live, with their family, 500 m or less from the nearest treated crop.

Social and demographical characteristics	Number	Valid (%)(1)
Age (years)		
Mean	34.9	
Standard Deviation	11.04	
Education		
Incomplete Primary	88	11.8
Complete primary	271	36.3
Incomplete Secondary	196	26.3
Complete secondary, technical or university studies	191	25.6
Missing	134	
Marital status		
Married or cohabiting	474	63.5
Unmarried, separated, divorced or widower	273	36.5
Missing	133	
Country of origin		
Argentina	869	98.8
Bolivia	5	0.6
Chile	1	0.1
Missing	5	
Change of residence birth		
No	543	64.0
Yes	306	36.0
Missing	31	

1. Percentage considering the total of the responses

Table 2. Social and demographic characteristics of pesticide applicators. Córdoba. Argentina. 2007 – 2010

3.2 Pesticides used

The most frequently used pesticides were herbicides; glyphosate for 98.5% of the responses, 2, 4-D – 2, 4 DB for 93.5% and atrazine for 92.2%. The insecticides most commonly handled were cypermethrin (95.7%), chlorpyrifos (82.1%), endosulfan (75.6%) and dimethoate (65.8%). The less used chemicals were fungicides, pyraclostrobin + epoxiconazole (Opera) for 37.8%, azoxystrobin + ciproconazole (Amistar) for 36.7% and carbendazim + epoxiconazole (Duett) for 34.3%. Applicators have used or still use either simultaneously or serially, an average of 12 chemical products (s.d. 5), some of them having used up to 25 pesticides (range 1 to 25) (Table 4).

Work characteristics	Number	Valid %(1)
Years personally mixed/applied pesticides		
≤ 1	119	14.2
2-5	299	34.8
6-10	201	23.4
11-20	162	18.9
21-30	56	6.5
>30	18	2.1
Missing	22	
Crops sprayed		
Soybean (**Glycine max** L.)	803	95.3
Maize (**Zea mays** L.)	690	81.9
Wheat (**Triticum aestivum** L.)	670	79.5
Alfalfa (**Medicago sativa** L.)	462	54.8
Sorghum (**Sorghum vulgare** Pers.)	388	46.0
Oat (**Avena sativa** L.)	290	34.4
Peanuts (**Arachis hypogaea** L.)	221	24.9
Sunflower (**Helianthus annus** L.)	185	21.9
Average area/year applied (ha)		
Up to 5000	408	55.8
5001 to 10000	113	15.5
10001 to 15000	87	11.8
15001 to 20000	83	11.4
20001 to 25000	24	3.3
> 20000	16	2.2
Missing	149	
Applicator home location wrt the nearest crop		
< 100 m	175	25.7
101 - 200 m	56	8.2
201 - 500 m	85	12.5
501 - 1000 m	89	13.1
1001 - 1500 m	13	1.9
> 1500	262	38.5
Missing	200	

1. Percentage considering the total of the responses
wrt: with respect to

Table 3. Work characteristics among pesticide applicators, Córdoba, Argentina. 2007-2010

Current use of forbidden or restricted-use pesticides was also surveyed and the results showed, surprisingly, that applicators continue to use heptachlor (3.3%), DDT (3.2%), malathion (2.2%), parathion (2.1%), aldicarb (1.0%) and aldrin (0.5%).

Pesticides	Number	Valid % (1)
Herbicides		
Glyphosate	858	98.5
2,4 D - 2,4 DB	810	93.5
Atrazine	799	92.2
Metsulfuron	706	82.3
Dicamba	587	69.4
Acetochlor	524	60.9
Metolachlor	440	51.8
Picloram	392	46.0
Insecticides		
Cypermethrin	829	95.7
Chlorpyrifos	705	82.1
Endosulfan	638	75.6
Dimethoate	526	65.8
Deltamethrin	516	60.8
Chlorimuron	223	40.8
Methamidophos	208	26.6
Fungicides		
Pyraclostrobin + Epoxiconazole (Opera*)	299	37.8
Azoxystrobin + Ciproconazole (Amistar*)	241	36.7
Carbendazim + Epoxiconazole (Duett*)	272	34.3
Carbendazim	277	33.0
Thiram	163	19.5
Propiconazole + Difenoconazole (Taspa*)	153	19.4
Carboxin	134	16.0
Tebuconazole	90	10.7
Trifloxistrobin + Propiconazole (Poseidon*)	80	10.1
Propiconazole (Tilt*)	80	10.1
Mancozeb	52	6.3

1. Percentage considering the total of the responses.
*Trade name. The citation of trade names in this publication is not to be construed as endorsement or as approval

Table 4. Pesticides most frequently used by applicators. Córdoba, Argentina, 2007 – 2010.

3.3 Technology and personal protection

Crop sprayers with activated charcoal filter were used by 71.9% of the applicators. Backpacks were used by 36.03%. Mixing/applying with a written pesticide prescription by an agricultural engineer is less than 40% in the whole province. In Córdoba province, by law Nº 9164, chemical or biological products of agricultural use must be prescribed by an agricultural engineer.

The analysis of use of single PPE components showed that "resistant gloves" were the most used (68.9%), followed by "gas mask" (51%), "face shields or goggles" (47.4%), "other clothing" (boots, apron, waterproof pants) (36.1%), "waterproof clothing" (30.1%) and "hat or helmet" (30.1%). Forty-four percent of workers use fabric gloves but, since we do not consider this to be effective, we do not include it in the protection level estimation. Our results indicated that 67.3% of the applicators work unprotected or partially protected (0 to 70%) and only 32.7% of them mix/apply protected 90%. We consider only the latter group of workers to be effectively protected. Finally, we found that 44.5% of the applicators live 500 m or less from the nearest treated crop.

"Protected" type Relative Risks (RR) versus "unprotected" were 0.93 (not significant) and 0.84 ($p<0.05$) in the months of lower and higher temperatures, respectively. Protection level was not associated with education ($p=0.223$). The number of hectares sprayed/year was inversely associated ($p=0.036$) with the correct use of PPE, and directly with written pesticide prescription by an agricultural engineer ($p=0.042$). Also, being married or cohabiting (RR=0.648, $p=0.025$), using a crop sprayer with activated charcoal filter ($p<0.01$), and mixing/applying under written pesticide prescription (signed by an agricultural engineer, RR=0.385, $p<0.01$) were found to be protective factors, with significant effects relative to protective behaviour.

The results in general matched those obtained by Lantieri et al. (2009). The population most exposed is young, has had several years in this activity (average up to 10 y), does not use PPE appropriately and, generally, has no suitable safety machines for this job. Moreover, in terms of the geographical areas defined by the HEAs, statistical differences between the areas were identified basically for technological variables.

3.4 Geographical analysis

Similar means of applicators' ages (34.8 y, s.d. 11.1) were found between ecological areas, except for HEA I and HEA IV, which showed significant differences, with 5.3% and 25.6% respectively, in the category of workers over 45 years old. It should be noted that the average percentage of workers over 45 is low in all the areas (19.7%). This may suggest that there is an early withdrawal from this work due to the probable deleterious effects on applicator health. As mentioned above, average years mixing/applying is also similar between areas (40% of the population mixing/applying 6 years or more); nevertheless a significant difference ($p<0.05$) was observed in the highest category (working more than 20 years) between HEA I and HEA IV (4.8% and 14.9% respectively), indicating that the applicators who have been exposed most years to pesticides belong to the South-eastern Agricultural area.

Significant differences were observed in education level between areas. In fact, HEA I had no illiterate applicators or with incomplete primary school, while in the other areas, this education level is around 10% except in HEA IV (5.6%), with a maximum of 13% in HEA III. Except for HEA I, all the areas showed a high percentage of workers in the incomplete primary school category, matching the previous report by Lantieri et al. (2009). Those authors had already noted the importance of this information, pointing out that these applicators constitute a vulnerable population group for risk assessment, in which it is necessary to implement prevention strategies. HEAI showed the highest percentage of workers with 90% protection (52.4%) and the lowest percentage of applicators with complete secondary, technical or graduate studies (11.1%). There was a weak association between protection level and areas; a tendency was found (33.8%, $p=0.101$) only between HEA I and HEA II. Only 37.3% of workers were found to be 90% protected in HEA IV, but this area had the highest percentage of applicators with complete secondary, technical or graduate studies (42.3%). Again, this matches Lantieri et al. (2009), who reported that a higher level of general education was not associated with higher PPE use. Also, we observed that workers with a lower level of education were more efficiently protected than applicators with a high level ($p<0.05$). Similar results were also noted by other authors (MacFarlane et al., 2008).

Around 45% of the workers use a self-propelled crop sprayer with an activated charcoal filter, and 55.1% a trailed crop sprayer. No significant differences among areas were detected in the use of crop sprayers. It should be noted however, that use of the self-propelled crop sprayer with activated charcoal filter is most frequent in HEA I (63.6%), followed by HEA V (48.6%) and HEA IV (47.1%). The lowest use of the self-propelled crop sprayer with activated charcoal filter (40.1%) and the highest use of the trailed crop sprayer with activated charcoal filter (13.6%) are in HEA II. This area also had the second lowest use of 90% protection level in the province. However, it is in this region that the highest use of written pesticide prescription by an agricultural engineer (43.4%) was found. Córdoba province has Law Nº 9164 regulating the use of chemical or biological products for agricultural tasks, which requires that products must be prescribed by an agricultural engineer.

Average crop surface treated was 7400 ha, showing significant differences between HEA III (10200 ha) and HEA IV (6050 ha).

The increasing area cultivated in recent years (Secretaría de Agricultura, Ganadería y Alimentos, 2010) and the number of ha sprayed by applicators suggest an increased risk of pesticide exposure. The present geographical analysis, based on homogeneous ecological areas, adds to the knowledge of the risk scenario faced by the study population and highlights the need to study these more deeply.

Overall, these results match those already reported by Lantieri et al. (2009). The population most exposed is young, has several years in this activity (average greater than 10 y), does not use PPE appropriately and, generally, has no suitable safe machines for this job. The present work also identified statistical differences between the geographical areas defined by the HEAs, basically in technological variables.

3.5 Exposure assessment

This work provides two indexes, ILE and CEI, describing the exposure of the applicator population, proposes statistical techniques to study their stochastic behaviors and, after intensive simulation steps, supplies percentile tables for recommendation and general uses. The following paragraphs describe the main findings.

The percentile (theoretical) estimates for ILE were: p25=1.72, p70=4.83 and p99=14.07, corresponding to 21%, 51.7% and 27.3% for Low, Medium and High risk levels, respectively. The CEI estimates were: p25=20.42, p75=103.12 and p99=433.30, corresponding to 24.8%, 50.6% and 24.6% for Low, Medium and High cumulative risk levels, respectively. Appendix I, with table A, shows more details of percentiles.

In order to throw light on the middle category, we defined the scales containing four categories for both indexes. The percentile estimates followed the same tendency: ILE and CEI values were p25=1.72 and 20.42 (Low), p50=3.21 and 55.63 (Medium), p75=4.83 y 103.12 (Medium High) and p99=14.07 and 433.30 (High), respectively. Again, table B in the Appendix I gives more details.

The cut-off points were used to identify how many applicators of our sample are classified in each category. Table 5 shows the results for the classification of individuals by means of the two measures (ILE and CEI), when a) three and b) four category scales were used for the exposure risk. Figure 2 shows a comparison between both measures with the categories of each. It should be noted that the cumulative exposure is already detected in individuals from the first category, which is reflected by the estimates that are statistically higher than those obtained for the ILE.

a) Three categories scale

Index	Category	Percentage	Index	Category	Percentage
ILE	Low	21.0	CEI	Low	24.80
	Medium	51.70		Medium	50.60
	High	27.30		High	24.60

b) Four categories scale

Index	Category	Percentage	Index	Category	Percentage
ILE	Low	21.1	CEI	Low	24.8
	Medium	28.0		Medium	27.5
	Medium High	23.6		Medium High	23.1
	High	27.3		High	24.6

Table 5. Percentage of classification of the exposure risk of the subjects belonging to study population, using the ILE and CEI measures.

3.6 Applicator health

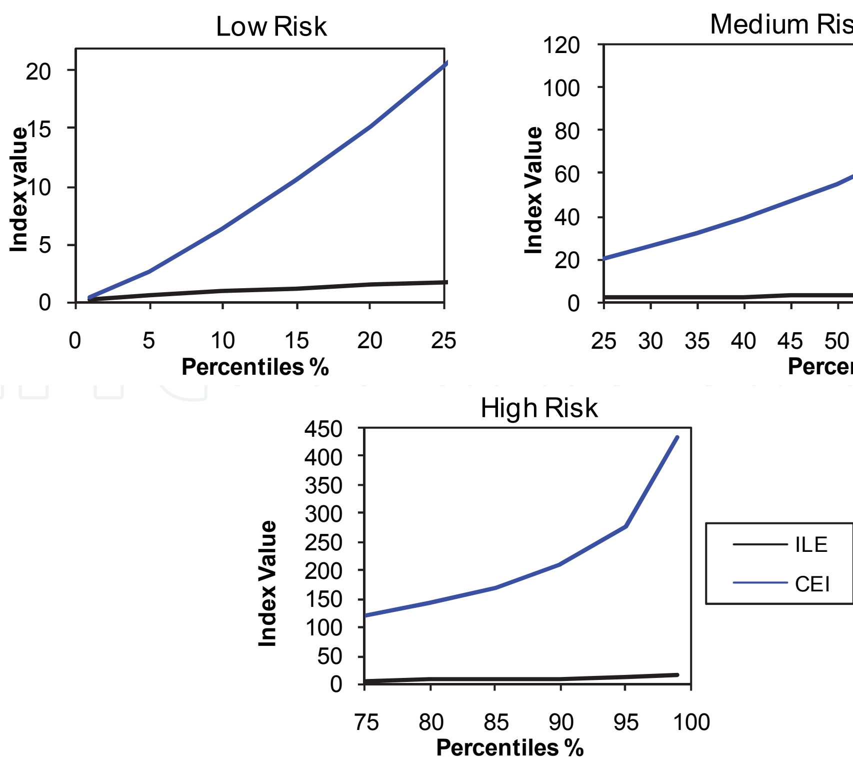
The study population shows a high prevalence of symptoms. Applicators reported suffering, sometimes or frequently, irritative manifestations (skin and eye irritation, nausea or vomiting, chest discomfort) 47.4%, excessive fatigue tiredness 35.5%, headache 40.4%, and nervousness or depression 27.6%. At least one medical consultation and hospitalization related to occupational pesticide exposure was recorded in 35.6% and 5.4%, respectively, of workers surveyed (Table 6).

By bivariate analysis, some of these health outcomes were associated to social and demographic characteristics as well as work practices. Headache was associated to age ($p<0.05$), with more frequency in the age group of 34 to 44. Seniority in application was associated to all the symptoms studied ($p<0.05$) and to greater frequency in medical consultation ($p<0.05$).

Improper use of PPE was associated to headache and irritative symptoms ($p<0.05$), showing an increasing trend among those suffering nervousness or depression but this does not reach statistical significance.

Medical consultation was associated to seniority in application (<0.05) and is more frequent among young adults (34 to 44 years), who also suffer headache. We also found an association with marital status, with an increase among those who are married or cohabiting ($p<0.05$), and with education level ($p<0.05$). Moreover and paradoxically, medical consultation related to pesticide use has been higher among the workers who are Protected (90%).

In this population, proximity of the applicator household to the nearest treated crop was associated neither with prevalence of symptoms nor with the frequency of medical consultation or hospitalizations.



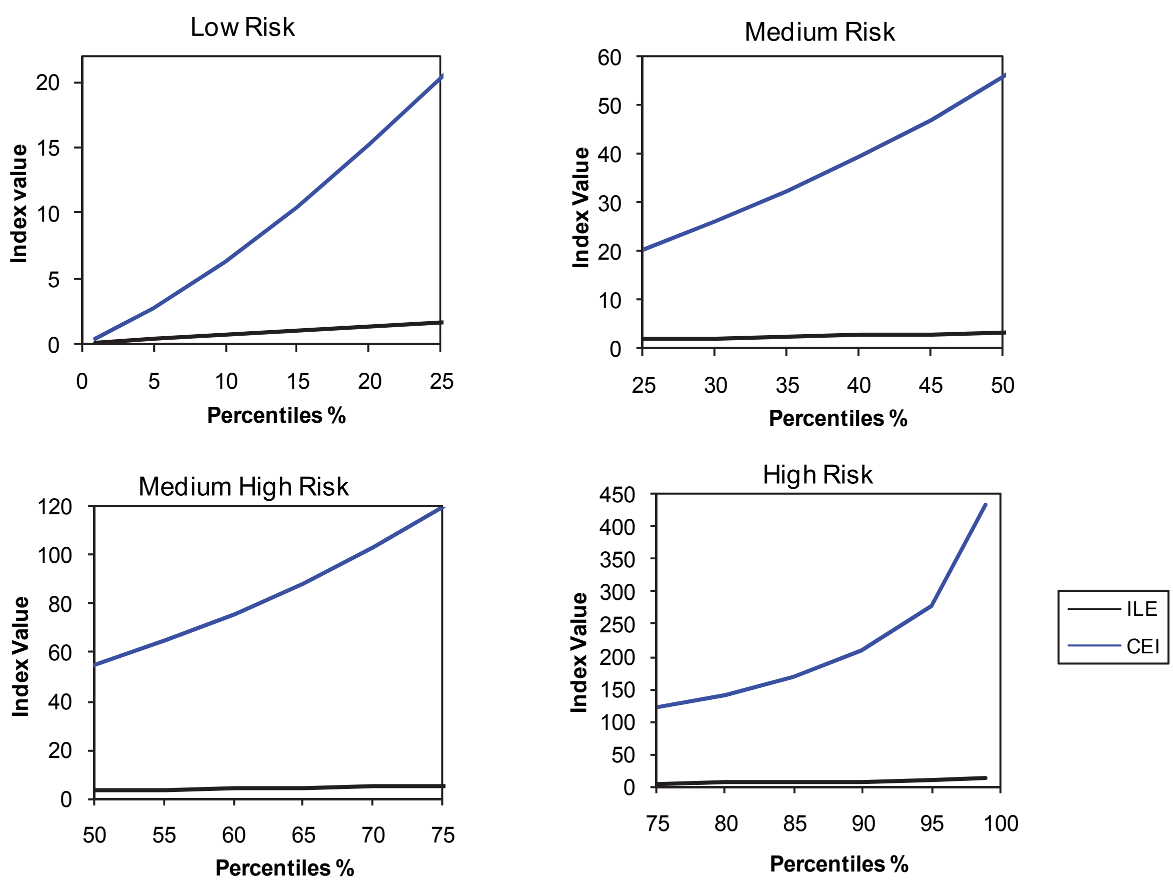


Fig. 2. Comparison between ILE and CEI behaviours, for each category: a) three category scale; b) four category scale

Symptoms	Never / Rarely[1]	Sometimes / Frequently[1]	Number
Fatigue tiredness	64.5	35.5	719
Headache	59.6	40.4	722
Nervousness or depression	72.4	27.6	648
Irritative manifestations	52.6	47.4	658
Health assistance	Never	Once or more times	Number
Hospitalization	94.6	5.4	742
Medical consultation	64.4	35.6	801

1. Percentage considering the total of the responses.

Table 6. Prevalence of symptoms, medical consultation and hospitalisation, related to occupational exposure among pesticide applicators. Córdoba, Argentina, 2007-2010.

In the exposure index (ILE and CEI), an association was found between adverse health outcomes and the highest exposure level of each index. Medical consultation at least once, for reasons related to occupational pesticide use, was associated with the highest exposure level of ILE ($p<0.05$). Using the CEI, almost all the health symptoms studied (irritative symptoms, fatigue tiredness, nervousness or depression, sometimes or frequently), as well as medical consultation at least once, were associated with the "high" category of cumulative exposure ($p<0.05$).

4. Discussion

We proposed two measures for the assessment of pesticide exposure risk. These performed well in terms of their probabilistic behaviour, which enables them to be used to draw up the percentile tables for use as a reference or recommendation and to construct two qualitative scales of exposure risk. These scales are worth testing and validating for other contexts in the future, as they are based on two robust and reliable formulations (ILE and CEI).

The main characteristics of the population most exposed is young, has several years in this activity (40% of the population have been mixing/applying for at least 6 years), does not protect itself appropriately and, generally, does not use suitable, safe machines for this job, matching previous results of Lantieri et al. (2009).

The study of pesticide applicators within HEAs highlights differences in basic characteristics of this population, such as their average age, instruction level and length of occupational exposure to pesticides. In HEA I, an area of recent agricultural development, the applicators are younger than in other areas and only 11% reached secondary school. In HEA IV, a traditional agricultural area in the province, applicators are older and at least 42% finished their high school. In terms of age and education, Lantieri et al., (2009) reported a negative statistical association in Córdoba province: on average, older pesticide applicators are those with a lower education level. The data indicate the unequal access to education between the areas of terrestrial applicators, and are valuable tools for the planning of preventive public health actions.

It is noticeable that in the newer agricultural areas, workers adopted safer labor practices in terms of the use of PPE. We did not find other statistical differences between areas in the technological variables studied; a trend to the use of more modern sprayer technology and the use of crop sprayers with activated charcoal filters, were described in traditional agricultural areas, reaching the highest proportion in the south east of the province (HEA IV). The low rate of PPE utilization found was not related to workers' educational level or to the years personally mixing/applying pesticides. Similar results were reported by other authors, (García et al., 2002; Macfarlane et al., 2008; Schenker et al., 2002), who found that education level, professional training, risk perception, environmental safety conditions and socio-cultural background, are some of the factors associated with self-protective behavior.

The increasing cultivated area in recent years (Secretaria de Agricultura, Ganadería y Alimentos, 2010) and the number of ha sprayed by applicators suggest an increased risk of pesticide exposure. Our geographical analysis, based on homogeneous ecological areas, adds to the knowledge of the risk scenario faced by the study population and highlights the need to deepen research.

The primary goal of exposure estimation in epidemiology is to correctly rank individuals with regard to exposure level in the study population (Alavanja et al., 2004). Percentile tables for both indexes were estimated here in order to identify which population group falls into the high exposure category as well as to describe some characteristics of risk levels. The frequency distribution of each measure illustrates the empirical behaviour. Indexes were generated by adapting and using published literature and evidence of our researchers. They seem to be intuitive and simple to interpret. However, some aspects related to the possible intra-subject and inter-subject variability should be considered here.

Between subjects, within the agricultural population and temporally, exposure to specific pesticides will vary highly depending on the type of agriculture (livestock versus arable production), type of crop (vegetables, fruits, flowers), type of application method (knapsack, boom sprayer, etc.), controls installed (cabin versus no cabin), and use of personal protective devices. It is known that, given all these possible variations in determinants of agricultural exposure (and pesticides in particular), it is difficult to accurately assess the intensity, duration, and frequency of exposures (Kromhout & Heederik, 2005). Our study includes all those variables because the population is, in fact, made up of pesticide applicators in crops (mainly soybean, followed by corn). Thus, in this case, characteristics such as agriculture type or crop type would not contribute variability when estimating the level of exposure. The remaining variables already mentioned, like type of application method, controls installed and use of personal protective equipment, are covered by the index formulas.

In addition to exposure determinants, there are variations between workers and within the same worker over a day. Dermal exposure is the main route of pesticide exposure and is highly relevant in the agricultural environment, followed by the inhalable route in workers handling chemicals outdoors. Kromhout & Heederik (2005) reported that, for agricultural re-entry workers exposed to pesticides, no between-worker differences in dermal exposure were observed. One argument to explain this could be that the tasks are similar among workers, and also that everyone is exposed to the omnipresent source of exposure (dislodgeable foliar residues). However, daily within-worker concentrations varied within an average 10- to 40-fold range (Kromhout & Heederik, 2005). For this reason, estimates of these authors will be taken into account when analyzing the results of exposure levels, based on the indexes that we developed. Empirical evidence obtained in this work showed that aspects of applicator behaviour must be taken into account in order to understand this daily variability.

One important point is that a large amount of daily work (amount ha/day), coupled with a small capacity of the machine available, causes more stops for pesticides handling, and thus makes the tendency to exposure over time more likely. In other words, applicators in our population might be appropriately protected at the time of application, but not when preparing the stock for each load. Besides, when the number of hectares is increased, time is even more restricted, and so it would not be surprising to see workers begin to perform their tasks faster and be more negligent of their protection. Finally, index values could come from people who are beginner applicators, and hence more cautious and fearful in the use of agrochemicals.

An assessment of exposures in occupational and environmental epidemiology also needs to cover the etiologically pertinent time periods. In retrospective studies, these periods lie by definition in the past of the study subjects. Ideally, the basic parameter to be estimated is the exposure intensity as a function of time. Exposure durations, average intensities, cumulated exposures, peak exposures and any other important parameters would be generated from this (Teschke et al., 2002). In our work, CEI incorporates the time by using the usual quantity of hectares that the applicator works as a surrogate variable. This proxy variable seems suitable for representing temporal information as cumulative exposure, since it is reported by the applicator considering only what is usual in his work every day.

From a public health perspective and for epidemiological purposes, estimates of actual dermal exposure and possible uptake would be a requirement to safeguard the working population from the negative health effects of dermal exposure to chemicals (Vermeulen et al., 2002). It is not possible to estimate exposure for a local situation solely on the generic exposure scenario involved. Additional measurements of dermal exposure and concomitant collection of detailed descriptive information will be necessary to evaluate potential dermal exposure (Kromhouti et al., 2004). Therefore, the present work performed a detailed and exhaustive characterization of the population of pesticide applicators.

Knowledge of ambient toxins depends on the agents and working processes used. Most epidemiological studies assessing health and environment risks have focused on the assessment of single exposures without addressing the effects of mixtures (Samet and Speizer, 1993). The synergistic effect of mixtures on the etiology of disease is of increasing concern for public health. Since there is an element of methodological uncertainty associated with determining the components of a mixture, measurements of the components most relevant to disease outcome may not be achieved (Leaderer et al., 1993). Like the present work, a few studies have dealt with multiple exposures but they had cross-sectional designs or used surrogates for exposure measurements. We believe this is a key point that must be addressed in the future in order to deepen both the design of epidemiological studies and the proper analysis of the information that is collected.

Even with the many complexities in estimating exposures, some studies have suggested that pesticides experts, industrial hygienists and crop-growing experts can identify the most important determinants of external exposures (Dosemeci et al., 2002). Our indexes were defined following this approach. As these measures constitute the first version for quantifying exposure risk in our context, we are aware that various methodological issues should be addressed before they are employed as a reference for monitoring exposure, mainly for human health uses. Therefore, we are in process of developing a series of validation studies to evaluate the effects of each exposure variable in the adapted Dosemeci algorithm, making some possible changes in the weighting procedure and then in the index formulations. Throughout these validation studies, we will monitor the most commonly used exposure scenarios observed in our population and compare the algorithm-based intensity estimates with the results for the monitoring data for that particular scenario. The scenarios could be the different homogenous ecological areas in the province. As a consequence, further refinement of the individual exposure score (value) will be carried out by using its predictive value obtained from, for example, a regression modeling based on the exposure variables used in our algorithm and index expressions and the actual monitoring results for the given exposure scenario.

Epidemiological and health-risk assessment of potential health hazards is difficult. Our work offers a first outline about the health of a clearly susceptible population of workers. Estimating the health effects of occupational exposure to para-occupational pesticide exposure cannot be measured exclusively by traditional indicators of mortality and morbidity. The statistics on acute pesticide poisoning do not reflect the magnitude of the problem, with evident under-reporting, particularly in rural areas (Henao et al., 1993), where farm workers suffer the most severe effects, creating a greater burden of health problems (Arcury et al., 2001). The high prevalence of reported symptoms associated with pesticide exposure, as well as the medical consultation and hospital discharge rates related to their occupational exposure to pesticides, are indicators of high occupational exposure.

The association between non-proper use of PPE and headache and irritative symptoms, and between seniority in the application task and all the symptoms studied and greater frequency in medical consultation are indicators of the negative impact on the health of our workers. These issues and the hospital discharge rate reported here, fifteen times higher than that calculated for males between 15 and 64 y in the general population of the province of Córdoba[1], also present indirect evidence of intense occupational exposure.

The results obtained concerning the workers' health conditions together with the fact that those who suffer symptoms are more likely to belong to the high exposure categories of both the ILE and AEI indexes, demonstrate their applicability for monitoring in this context. Finally, we have not yet reported information about chronic disease, due to the cohort size until now.

5. Conclusion

Occupational exposure in agricultural settings in Córdoba presents a complex risk scenario in which the population is highly exposed and very vulnerable. Some causes of this are the increasing area in which pesticides are applied, the high number of active principles involved and the lack of safe working environments with training, technology and adequate health and safety measures. To this must be added the regulatory gap and the lack of enforcement.

Early involvement in the task, the proximity of applicator households to treated crops and the non-use or improper use of personal protective equipment are indicators of intense exposure and vulnerability; this is reflected in the high prevalence of symptoms and of medical consultation and hospitalization related to occupational exposure. The exposure indexes and scales developed in this work are useful tools that can be applied as part of the

[1]The hospital discharge rate was estimated with data of patient discharge (male 15 to 64 years old from Córdoba province) (Dirección de Estadísticas e Información de Salud, 2009) in the numerator and the census population for the same period (specific for sex and age group) in the denominator. The base population was adjusted with a factor of 0.458, corresponding to the proportion of the population attending public hospitals in the mentioned period, the available data on hospital discharge correspond only to official health providers (hospitals corresponding to national, provincial or municipal level) (Instituto Nacional de Estadísticas y Censos, 2011b).

assessment of occupational risks related to pesticide exposure. The goals proposed to address this complex problem are to implement epidemiological surveillance systems that allow permanent monitoring of human and environmental health, to encourage the development of alternatives to pesticide use such as integrated pest management, to encourage and strengthen citizen participation and especially that of the workers and communities most at risk, enabling their direct involvement in decision making, and improving control over compliance with existing legislation in this area and with health and safety conditions for farm workers and their families. Finally, our own challenge is to develop quality research to address the needs of this population and improve their quality of life.

6. Acknowledgment

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7. Apendix I

Percentiles	Intensity level		Cumulative Exposure	
	Index	Risk Levels	Index	Risk Levels
1%	0.21		0.46	
5%	0.56		2.77	
10%	0.88	LOW	6.38	LOW
15%	1.17	21%	10.55	24.8 %
20%	1.45		15.23	
25%	1.72		20.42	
30%	2.00		26.13	
35%	2.28		32.43	
40%	2.57		39.38	
45%	2.88		47.07	
50%	3.21	MEDIUM	55.63	MEDIUM
55%	3.56	51.7 %	65.24	50.6 %
60%	3.94		76.07	
65%	4.36		88.55	
70%	4.83		103.12	
75%	5.38		120.48	
80%	6.04		141.93	
85%	6.87	HIGH	169.80	HIGH
90%	8.02	27.3 %	209.36	24.6 %
95%	9.91		277.42	
99%	14.07		433.30	

Table A. ILE and CEI theoretical percentiles (three categories scale)

Percentiles	Intensity level		Cumulative Exposure	
	Index	Risk Levels	Index	Risk Levels
1%	0.21	LOW 21%	0.46	LOW 24.8 %
5%	0.56		2.77	
10%	0.88		6.38	
15%	1.17		10.55	
20%	1.45		15.23	
25%	1.72	MEDIUM 28.0 %	20.42	MEDIUM 27.5 %
30%	2.00		26.13	
35%	2.28		32.43	
40%	2.57		39.38	
45%	2.88		47.07	
50%	3.21	MEDIUM HIGH 23.6 %	55.63	MEDIUM HIGH 23.1 %
55%	3.56		65.24	
60%	3.94		76.07	
65%	4.36		88.55	
70%	4.83		103.12	
75%	5.38	HIGH 27.3 %	120.48	HIGH 24.6 %
80%	6.04		141.93	
85%	6.87		169.80	
90%	8.02		209.36	
95%	9.91		277.42	
99%	14.07		433.30	

Table B: ILE and CEI theoretical percentiles (four categories scale)

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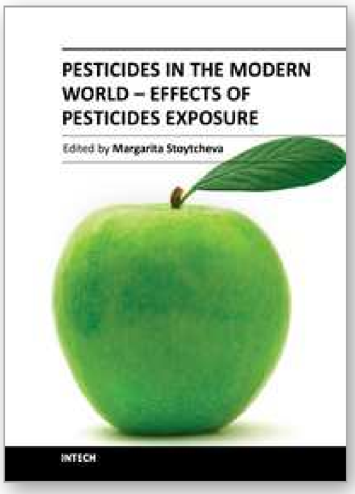

Pesticides in the Modern World - Effects of Pesticides Exposure
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The introduction of the synthetic organochlorine, organophosphate, carbamate and pyrethroid pesticides by 1950â€™s marked the beginning of the modern pesticides era and a new stage in the agriculture development. Evolved from the chemicals designed originally as warfare agents, the synthetic pesticides demonstrated a high effectiveness in preventing, destroying or controlling any pest. Therefore, their application in the agriculture practices made it possible enhancing crops and livestockâ€™s yields and obtaining higher-quality products, to satisfy the food demand of the continuously rising worldâ€™s population. Nevertheless, the increase of the pesticide use estimated to 2.5 million tons annually worldwide since 1950., created a number of public and environment concerns. This book, organized in two sections, addresses the various aspects of the pesticides exposure and the related health effects. It offers a large amount of practical information to the professionals interested in pesticides issues.

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