Chapter 5

Pesticides and Agricultural Work Environments in Argentina

M. Butinof, R. Fernández, M.J. Lantieri, M.I. Stimolo,
M. Blanco, A.L. Machado, G. Franchini, M. Gieco,
M. Portilla, M. Eandi, A. Sastre and M.P. Diaz

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1. Introduction

The use of chemical pesticides has brought benefits such as the increase of agricultural production, soil productivity and product quality, which is reflected in economic benefits, vector disease control and in general, in public health. However, given that only 10 percent of applied pesticides reach the target organism, a high percentage is deposited on non target-areas (soil, water, sediments) and, as well as affecting public health, impacts non-target organisms such as wild life [1]. Also, the extended use of pesticides commonly results in residues in foods [2] generating continued human exposure by different pathways, which has led to widespread concern over the potentially adverse effects of these chemicals on human health.

Pesticides are an important aspect of agricultural practice in both developed and developing countries and, despite the many technological advances brought by the modern intensification of agriculture, the increased yields were achieved primarily through the use of fertilizers and pesticides [3].

Argentina is one of the major crop producers in Latin America, with the export of cereals and oilseeds being one of the principal axes of the national economy. The frontiers of farming have expanded greatly in the past 30 years, from 15 to the current 30 million hectares, with an increase of the area planted for grain production, particularly for soybeans, from 34,700 ha in the 1969/70 season to about 18 million ha in 2011/12 [4]. Today, Argentina is the world's leading producer of vegetable oils, the fourth largest producer and second largest exporter of sunflower oil, and the fourth producer and leading exporter of soybean oil. The country has one of the highest yields in the world in soybean, corn and wheat [5].

Argentina's extensive production of cereals and oilseeds for the international market coexists with intensive horticulture and family farming, with wide geographical distribution, mainly close to urban centers, and diversity of cultivated species, occupying an area of about 230,000 ha [6], giving an annual production of over 10,000,000 tons, primarily for domestic consumption.

Crop production has been accompanied by a steady increase in the use of agrochemicals; pesticide marketing has grown strongly, from 155 million pounds in 1995 up to 700 m.p. in 2012 [7]. In technology used for spraying pesticides, the country has a wide variety of equipment ranging from self-propelled sprayers, which also involve high technological complexity, with filtered air cabins, to activated charcoal filters, spray drag and power and manual backpacks used particularly in intensive farming. Each of these different technological environments is associated with different health and environmental risks.

The Province of Córdoba is in the central region of Argentina, with a total area of 165,321 km^2. Its location, as well as its political and physical characteristics, make this province a hub of articulation between different natural regions of the country. It has a population of 3,304,825 inhabitants, 88.7% of whom live in urban areas and 11.3% in rural areas [8]. Among the inhabitants of rural areas, 45.9% live in towns of less than 2,000 inhabitants, and the rest dispersed in the open countryside [9]. The northern and western areas are less populated and are the ones which concentrate most indicators of structural and cyclical poverty. The agricultural roots of this province mean that the settlements are mixed with agricultural developments, increasing the risk of non-occupational exposure of communities adjacent to cultivated fields.

The rural area in Cordoba devoted to extensive crops (soybean, maize, sorghum, peanut, wheat and sunflower), has expanded from 3,397,050 ha in 1994/95 to 7,300,000 ha in 2011/2012 [4].

The country's extensive agricultural model, based on glyphosate-resistant transgenic soybean farming, no-till and the intensive use of fertilizers and pesticides [10], is highly dependent on modern technologies [11]. In contrast, intensive crops such as fruits and vegetables are characterized by high demand of labor per unit of output. Typically, this is a small-scale activity usually performed by the peasant family production unit [12, 13], with all its members participating. The incidence of pesticide poisoning in these agricultural settings includes non-intentional child exposure, occupational exposure of young farm laborers, para-occupational exposure of the farm workers and their families and the adjacent community, and exposure to banned pesticides [14].

In Córdoba Province, exposure to different pesticides linked to agricultural production has long been recognized [10, 15-16], as well as the unavoidable soil contamination even decades after its application [17]. Our previous results of a population-based study in the province of terrestrial applicators of pesticides in extensive crops (n=880), emphasized that workers were highly exposed to pesticides, and we studied various determinants of this exposure, including the pesticides most frequently used or still in use by the applicators. We also reported the

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negative health consequences associated with their employment status. The weakness of compliance with the rules governing the activity was also highlighted as a factor that increases the health risk of agricultural workers and the general population [10].

The greenbelt surrounding the provincial capital is a zone of fruit and vegetable farming, providing fresh food to the local urban population. Its extension includes neighboring towns, forming a strongly integrated commercial and productive system. Almost 90% of the fruits and vegetables it provides are produced within the urban area [17]. Horticultural smallholders and farmworkers are often immigrant workers from neighboring countries [18-20]: according to the Ministry of Education [21], sixty percent of them are Bolivian citizens, which increases their risk of environmental and occupational illness and injury, as well as the health disparities typically associated with poverty [22].

This chapter offers a comparative analysis of two widely different agricultural settings (extensive and horticultural crops) and characterizes the pesticide applicator populations in each, including the health conditions associated with occupational pesticide use. We introduce two pesticide exposure assessment proposals, consisting of intensity and accumulated exposure indexes for both scenarios. The proposals include new results about the pesticide applicators of extensive crops, including an update of the differential characteristics of worker populations in homogeneous ecological areas of the province. We also introduce a new scenario consisting of horticultural smallholders and farmworkers, and describe their working conditions. The study and comparison of these different work settings allows us to tailor the exposure indexes developed in our previous publication [10] to the particular pesticide exposure of greenbelt situations, as well as to develop proposals for preventive measures for the reduction of human exposure and environmental impact, according to each scenario.

2. Materials and methods

2.1. Population studies

We conducted a population-based study in Córdoba Province, Argentina, with two principal target populations: a) terrestrial applicators of pesticides of extensive crops; b) smallholders and farmworkers of the greenbelt of its capital city, Córdoba.

a. In the first case, all the applicators attending the mandatory courses for obtaining the applicator license, provided by the Agriculture, Livestock and Food Ministry, were asked to participate in the survey, during the period 2007-2012. A self-administered questionnaire was used to obtain demographic data, pesticides and technologies used, crops sprayed, workers' lifestyle and family health information, as already described in a previous publication [10]. From 1479 completed questionnaires, a consistency analysis for several responses was carried out, with a sample size of 1327 for further analysis. We also performed a stratified analysis taking into account the Homogeneous Ecological Areas (HEAs) divisions of the province in order to describe differences between these.

b. In the second case, 101 smallholders and farmworkers were contacted in Cordoba's wholesale fruit and vegetables market and in the greenbelt setting itself. The above questionnaire was adapted for this specific population, after an exploratory study through in-depth interviews during 2011. As described in the literature, the exploratory study shows that this is a difficult-to-reach population due to their migratory status and unstable working conditions.

2.2. Variables

2.2.1. Terrestrial applicators of pesticides of extensive crops

a. Social and demographic variables: age (in years, as from birth date), education level (highest level of educational attainment in the formal system) and marital status (married or cohabiting and others).

b. Technological and working practices variables: pesticide spray equipment (self-propelled crop sprayer with cab and activated charcoal filter; trailed crop sprayer with cab and activated charcoal filter), area worked (average hectares applied in the last year), seniority in the job (years mixing/applying), written pesticide prescription signed by an agricultural engineer (yes/no).

To assess the level of protection implemented by the terrestrial applicators, we adopt the proposal in [23], considering eight categories of personal protective equipment (PPE) used, alone or in combination: waterproof clothing, gas mask, chemical-resistant gloves, face shields or goggles, hat or helmet and other protective clothes (boots, apron, waterproof pants). The weighting of PPE elements is based on monitoring and measurement of occupational exposure during the task. A new measure called protection level was constructed [10]: unprotected (0% protection), partially protected (20 to 70% protection) and protected (90% protection).

These variables were analyzed comparatively between homogeneous ecological areas (HEAs) of the province, according to soil and climatic characteristics, land use and production activities, as described in [10].

c. Good agricultural practices: we considered two practices included in the local regulation aimed at reducing human risks and negative environmental impacts [24]: a) the triple washing of pesticide containers (yes/no). This practice consists in washing the empty container three times and draining for thirty seconds in upload position; and b) correct end use of pesticide containers (yes/no): properly cleaned containers must be transferred to an authorized registered storage center, to be destroyed in a pyrolytic oven; burial, burning, storage, sale or reuse are prohibited.

2.2.2. Smallholders and farm workers of the greenbelt surrounding the capital city of Cordoba

To highlight the particularities of the horticultural work scenario and its worker population, new variables were incorporated into the analysis when necessary.

a. Socio-demographic variables: age, education and marital status are described as mentioned above; origin (country and province of birth); household (members and their participation in horticultural work). Dwelling infrastructure and public services: running water installed (yes/no), bathroom installed (yes/no), domestic gas distribution network (yes/no); public service of urban solid waste collection (yes/no).

b. Work practices, technology and other exposure variables: pesticides sprayed, use of PPE (as described above); crops grown in the last year (type of crop and annual average harvests); greenhouse for crop (yes/no); household distance to the nearest crop (meters); extension of the productive unit in hectares: small: up to 10 ha; medium: between 11 to 40 ha; and large, more than 40 ha [25]: seniority in the job (years mixing/applying); pesticide spray equipment (self-propelled crop sprayer with cab and activated charcoal filter; trailed crop sprayer with cab and air intake activated charcoal filter or without air intake filter; trailed crop machine without cabin, manual and engine backpack).

c. Good agricultural practices (as described above).

2.2.3. Health worker conditions in both agricultural settings

a. Symptoms: Perception of acute and sub-acute manifestations: Irritative symptoms (skin, nose and eye irritation, nausea or vomiting, chest discomfort); fatigue/tiredness; nervousness or depression; headache; excessive sweating. Occurrence of symptoms: Never/Rarely/Sometimes/Frequently;

b. Medical consultations related to pesticide use effects: yes/no; and Hospitalization linked to tasks with pesticides: yes/no;

c. Workers' risk perception of different pesticides: not dangerous/slightly dangerous/dangerous/highly dangerous.

2.3. Exposure assessment

Based on proposed indexes of our previous work [10], the present study incorporates intensity level (ILE) and accumulated exposure (CEI) indexes into pesticide exposure, adapted to the smallholder and farmworker population of the greenbelt of Cordoba city, describing the principal differences among them. These indexes measure instantaneous exposure intensity and cumulative exposure taking into account the life years of worker exposure. To use these indexes in the horticultural worker population, we have carefully adapted the weighting score procedure to this particular context.

2.4. Statistical analysis for association

We used a modeling approach to check 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). The latter was used since the empirical distributions of both indexes presented skewness. Association between two or three variables was studied through log-linear models in order to estimate the odds ratio as association measures.

3. Results

3.1. Population of extensive crops

In a previous work [10] we identified different agricultural settings in the province, based on homogeneous ecological area (HEAs) divisions (Figure 1). Differences in basic characteristics of this population, such as their average age, instruction level and length of occupational exposure to pesticides allow us to hypothesize the existence of diverse risk scenarios in the province. In this chapter, an update of the characterization of workers was performed with an increased sample size, n=1327.

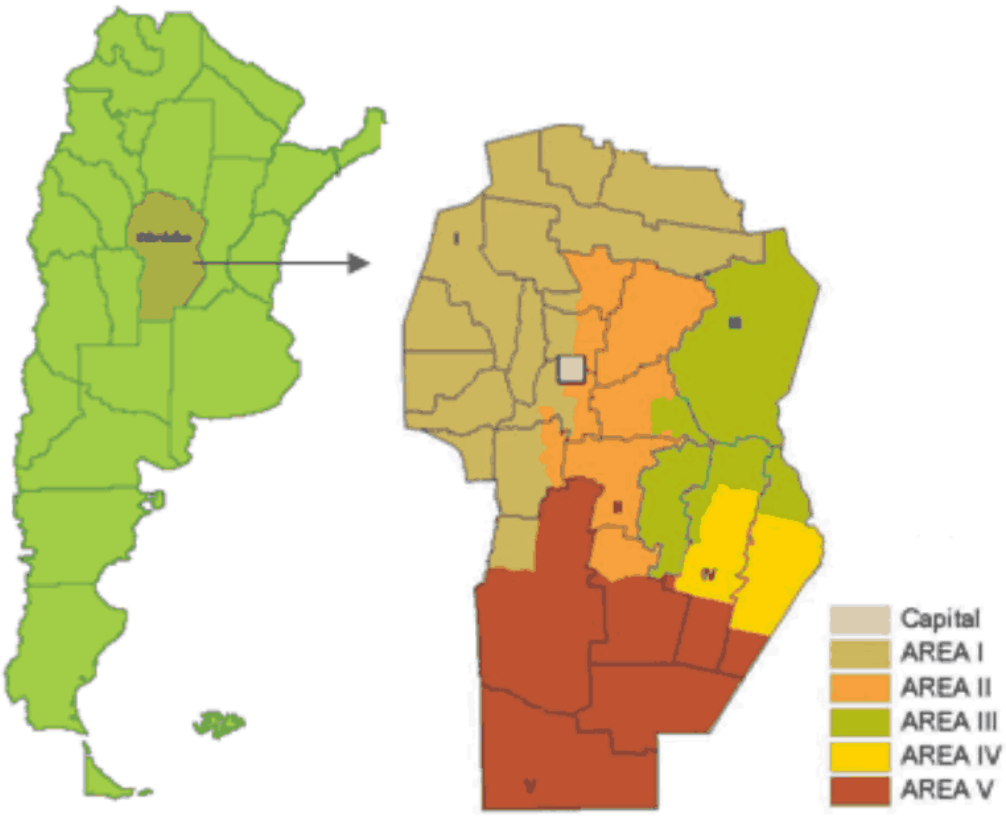

Figure 1. Homogeneous ecological areas (HEAs) of Córdoba province.

Significant differences among HEAs were found for age ($p<0.01$), education level ($p=0.03$) and marital status ($p<0.01$), as well as for seniority in the task ($p<0.05$), average/year of hectares sprayed ($p<0.03$), use of pesticides with written prescription signed by an agricultural engineer ($p<0.03$), and self-propelled crop sprayer with cab and activated charcoal filter ($p<0.03$) (Table

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1). Protection level ($p<0.05$) also showed differences between HEAs I, II, III and HEA V ($p<0.05$), the latter having the fewest completely protected workers (31%). Only trailed crop sprayer with cab and activated charcoal filter results were similar in all the areas. It is important to highlight that HEA I showed the lowest percentage of applicators with complete secondary school level or higher (29.2%) and in subjects married or cohabiting (56.8%), but the most workers using complete protection (54%) and using pesticides with written prescription (58.1%) followed by HEA II (54.8%)

	AREAS					
	I	**II**	**III**	**IV**	**V**	**Total**
n	41	641	230	156	259	1327
Age (years)						
Mean	32.3	35.8	34.9	37.6	34.8	35.6
Standard Deviation	8.6	11.6	9.9	10.9	11.9	11.3
14 – 24	16.2	16.5	16.1	12.8	21.2	16.9
25 – 24	48.6	36.0	38.1	30.2	32.8	35.4
35 – 44	27.0	24.9	28.7	30.2	25.2	26.3
> 45	8.1	22.6	17.0	26.8	20.8	21.4
Marital Status (%)[1]						
Married or cohabiting	56.8	66.8	61.7	78.9	58.6	65.5
Unmarried, separated, divorced or widower	43.2	33.2	38.3	21.1	41.4	34.5
Education (%)						
Incomplete Primary	2.4	11.1	13.5	7.1	10.8	10.7
Complete Primary	29.3	27.9	27.8	29.5	32.0	28.9
Incomplete Secondary	39.0	26.6	21.3	22.4	23.9	25.1
Complete Secondary, Technical or University studies	29.2	34.3	37.4	41.0	33.2	35.2

[1]Percentage considering the total of responses.

Table 1. Sociodemographic characteristics of pesticide applicators by Homogeneous Ecological Areas. Córdoba, Argentina. 2007- 2012.

Pesticide with prescription signed by an agricultural engineer was used by only 33.7% of applicators in HEA V, which was different from the others ($p<0,03$); self-propelled crop sprayer with cab and activated charcoal filter was highest in HEA III (74,1%) and this was significantly different from HEAs II and V ($p<0,05$). No significant differences were found between areas in the use of the trailed crop sprayer with cab and activated charcoal filter, but this is a crop sprayer that is very little used in all the areas (Table 2).

	AREAS					
	I	II	III	IV	V	Total
N	41	641	230	156	259	1327
			Protection Level (%)[1]			
Unprotected	12.2	12.5	12.2	9.0	17	12.9
Partially Protected	34.1	48.8	46.1	55.8	52.1	49.4
Protected	53.7	38.7	41.7	35.3	30.9	37.8
			Average area/year applied (ha)			
Mean	9717	5226	9923	6535	7182	6767
			Years personally mixed/applied pesticides (%)			
≤ 1	26.3	11.2	22.4	10.3	17.0	14.6
2 – 5	36.8	31.6	34.5	27.7	38.3	33.1
6 – 10	18.4	23.5	23.8	23.9	21.3	23.0
11 – 20	10.5	21.4	13.5	23.9	15.8	18.9
21 - ≥ 30	2.6	11.7	5.4	14.2	6.3	9.5
			Use pesticides with prescription signed by an agricultural engineer (%)			
Yes	58.3	54.8	46.4	53.8	33.7	49.9
			Apply with Self-propelled Crop Sprayer with Cab and Activated Charcoal Filter (%)			
Yes	63.9	49.7	74.1	67.9	63.2	58.7
			Apply with Trailed Crop Sprayer with Cab and Activated Charcoal Filter (%)			
Yes	2.9	8.4	4.9	6.2	7.9	7.3

[1]Percentage considering the total of responses.

Table 2. Protection Level, Area/year applied Seniority in the Job and Technology in the different Homogeneous Ecological Areas. Córdoba, Argentina, 2007-2012.

Good agricultural practices were established to reduce the contamination that may be caused by empty pesticide containers and their geographical dispersion. Not all applicators carry out the triple washing of pesticide containers (89.9% do so), and only 10.5% are included in formally regulated programs to ensure the correct end use of empty pesticide containers; in many cases, empty containers of chemicals are burned, buried or reused.

3.2. Population of smallholders and farmworkers of the green belt around the capital city of Córdoba

The green belt, in place since the founding of the city, has seen its landscape transformed over time through a steady process of land use change [26], extending to the nearby towns.

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Currently, the green belt is situated within an urban area with a sum of overlapping environmental hazards caused by agricultural activity and industrial activity (Figure 2).

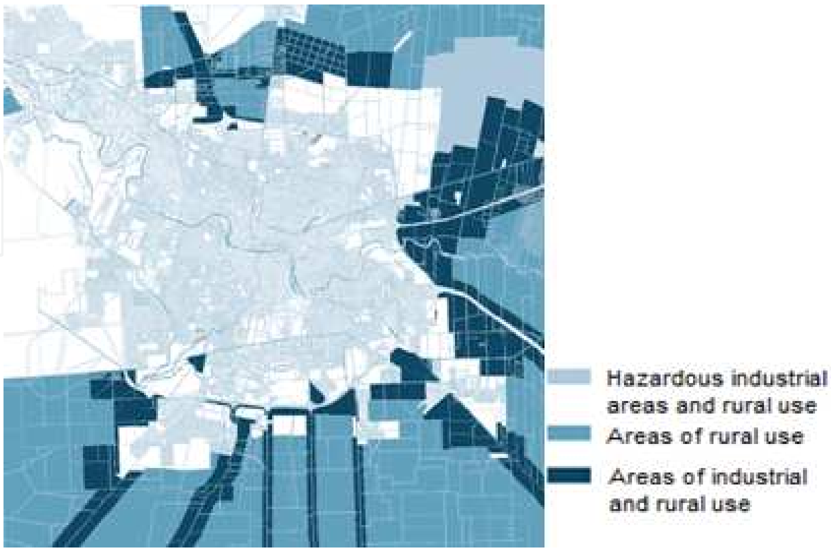

Figure 2. Land use map of the urban area of the city of Córdoba. Municipality of Córdoba, 2004 [17].

Our population consisted of male subjects, with only a single registered female. The mean age was 42.94 years (SD: 13.34), with 67% over 35 years (Table 3). 52% of subjects achieved low levels of education, with 24% who did not complete primary school and 28% who completed only this level. 71% were Argentine and 29% Bolivians. Of the Argentine farmers and workers, 13% were migrants from other provinces. One of the distinguishing characteristics of horticultural farms was their family origin, and this situation, with variations, was maintained over time [27]. 23% of respondents lived alone, while the remaining 77% lived with family members. Of these, 11% lived only with their partner, while 66% also lived with children and 14% with extended family members (older adults, uncles/aunts, cousins). In 31% of families, all took part in the horticultural work with different tasks and hourly loads (involving spouses, children and extended family members).

Among the job roles reported by the horticulturists are the owner, tenant, "mediero" and permanent or temporary employee, and combinations of the above. "Mediería" is a form of associative contract farming: the existence of a partner who provides land and part of the capital, while the other participant contributes labor and other inputs, sharing the product between them.

Part of the population of these small farmers and workers had unsatisfied basic needs, lacking such basic public services as a water network (23%) and a bathroom installed within the dwelling (13%). Precarious living conditions were associated with employment status and land tenure, with the "medieros" and employees having the highest chance of not satisfying these needs ($p < 0.048$), as well as with nationality, to the detriment of the Bolivian-born small farmers ($p < 0.014$, Table 3). An urban solid waste collection service was absent in 23% of cases and domestic gas network provision was lacking in large areas of the green belt (80%).

Sociodemographic characteristics	Number	Valid (%)[1]
Age (years)		
Mean	42.94	
Standard Deviation	13.34	
≤ 25	13	13
26 – 34	20	20
35 – 44	19	19
45 – 54	26	26
> 55	22	22
Education		
Incomplete Primary	24	24
Complete Primary	28	28
Incomplete Secondary	18	18
Complete Secondary, Technical or University studies	31	30
Marital Status		
Married or cohabiting	75	77
Unmarried, separated, divorced or widowed	22	23
Other members of the household working in crops		
Yes	33	31
Running water installed in the household		
Yes	75	77
Bathroom installed in the household		
Yes	85	87
Domestic gas distribution network		
Yes	20	20
Public service of urban solid waste collection		
Yes	66	67
Country of origin and internal migration		
Bolivia	29	29
Argentina	71	71
Born in Cordoba	62	87
Internal migrants	9	13

[1]Percentage considering the total of responses.

Table 3. Social and demographic characteristics of smallholders and farm workers of the Córdoba capital city green belt. 2012.

Table 4 shows that 58% of the productive units were classified as small in extension. Most of the smallholders and farm workers had long experience in the field, 61% with more than 15 years. 69% had their and their family's dwelling within the production unit where they work. 38% of the dwellings were located in close proximity to crops (less than 100 meters) and 50% within 500 m. The pesticide sprayer used by almost all the smallholders and farmworkers in the greenbelt was the backpack (85%), with the self-propelled crop sprayer with cab and activated charcoal filter reported by only one farmer. 13% of the productive units grew crops in greenhouses in the last year.

Work characteristics	Number	Valid (%)[1]
Extension of the productive unit (hectares)		
Small (≤ 10 ha)	57	58
Medium (11 to 40 ha)	34	33
Large (≥ 41 ha)	9	9
Area cultivated by worker (ha)		
≤ 10	70	71
11 - 20	11	11
21 - 40	9	9
≥ 41	7	6
Seniority in the horticultural work		
Average (years) 21.34 (SD: 14.58)		
≤ 5	15	17
6 - 10	13	14
11- 15	8	9
16 - 20	14	16
> 20	40	44
Dwelling distance to the nearest crop (meters)		
≤ 50	16	25
51 - 100	8	13
101 - 500	7	11
≥ 501	32	51
Greenhouse for crops in the productive unit		
Yes	13	13
Pesticide spray equipment		
Manual backpacks	77	77
Motor backpacks	7	7
Trailer crop sprayer without cab	28	31

[1]Percentage considering the total of responses.

Table 4. Work practices and technology used by smallholders and farm workers of the Córdoba capital city greenbelt. 2012.

The main vegetable crops cultivated in the green belt of Cordoba are leafy vegetables (Table 5): chard, lettuce, spinach, etc., with the particularity that they are grown throughout the year in a phased manner (Table 5). This means that on the farm at the same time there will be a patch prepared, a patch with the crop planted, another patch growing and another being harvested. These farms, located primarily in the northern greenbelt, are diversified with a large number of crops in many small lots. In these units, the farmer, tenant, and "mediero" work with their families or with hired laborers, carrying out the various farming tasks: transplanting, manual weed control, irrigation, pest control with manual (backpacks) sprays, harvesting, packing for market, loading and transport. The type of contract may be daily or for quantities.

In the southern area of the green belt, specialized farms have developed, devoted to potatoes as their main activity (22%) and rotation is incorporated into the production system with carrots (10%), wheat (9%) and soybeans (9%) variably according to the conditions of each crop year. These are large production units, with a greater degree of mechanization and automation. Most of the tasks are carried out with machinery, and pesticide application is performed with tractor-drawn and in some cases self-propelled machines. In these cases, labor is incorporated as needed, for example: chopping the seed potatoes and preparing them for planting, and harvesting at the manual collection stage. While potato harvester machines exist, they are not widespread in the green belt. The situation with carrots is similar.

Crops sprayed	Number	Valid (%)[1]	Average harvests per year
Chard *Beta vulgaris L. var. cicla*	71	75	3.75
Spinach *Spinacia oleracera L.*	70	69	3.28
Chicory *Cichorium intybus L.*	64	68	3.34
Scallion *Welsh onion Allium cepa L.*	68	67	2.79
Summer squash *Cucúrbita maxima*	66	65	2.46
Broccoli *Brassica oleracea L.*	65	64	2.93
Parsley *Petroselinum sativum Hoffm.*	62	61	2.98
White cabbage *Brassica oleracea*	61	60	3.22
Butterhead lettuce *Lactuca sativa L. var. Romana*	59	58	3.47
Lettuce *Lactuca sativa L. var. crispa*	58	57	3.83
Lettuce *Lactuca sativa L. var. capitata*	57	56	3.61
Leek *Allium porrum L.*	56	55	2.13
Beet *Beta vulgaris L.*	56	55	3.59
Purple cabbage *Brassica oleracea L. var. capitata*	55	54	3.11
Arugula *Eruca sativa L.*	55	54	4.08
Eggplant *Solanum melongena L.*	47	47	1.61
Cauliflower *Brassica oleracea var. botrytis L. subvar. Cauliflora*	41	41	2.40
Chinese cabbage *Brassica chinensis L.*	35	38	2.54
Radish *Raphanus sativus L.*	38	38	3.04

[1]Percentage considering the total of responses.

Table 5. Principal crops grown in Córdoba capital city green belt, 2012.

The most frequently used pesticides were herbicides (Table 6): glyphosate for 81% of the responses and metolachlor for 65%. In the group of insecticides, those most commonly handled were deltamethrin (72%), cypermethrin (65%), Imidacloprid (66%) and Chlorpyrifos (57%).

The fungicides most frequently used were cabendazin (71%), mancozeb (63%), zineb (62%), and captan (50%).

Pesticides	(%)[1]
Insecticides	
Deltamethrin	72
Cypermethrin	65
Lambda-cyhalotrin	33
Cartap	40
Carbofuran	36
Carbaryl	34
Methiocarb	25
Chlorpyrifos	57
Dimethoate	50
Methamidophos	23
Imidacloprid	66
Endosulfan	46
Abamectine	35
Fungicides	
Azoxystrobin	47
Azoxystrobin + Ciproconazole	23
Carbendazim + Epoxiconazole	9
Mancozeb	63
Zineb	62
Maneb	15
Carbendazim	71
Captan	50
Chlorothanolil	38
Herbicides	
Glyphosate	81
Fluazifop p butil	46
Metolaclhor	65
2,4 D	19
Atrazine	12
Dicamba	14
Phenmediphan	27
Linuron	61
Metribuzin	31

[1]Percentage considering the total of responses.

Table 6. Most frequently used pesticides in the Córdoba capital city green belt, 2012.

The use (current or past) of banned pesticides was also surveyed: 33% reported having used Parathion, 16% Lindane, 10% Monocrotophos, 8% Methyl Bromide, 7% Malathion, 5% Aldicarb. Current use of Aldicarb was reported by two farmworkers; Monocrotophos and Aldrin were reported by a single case. Regarding good agricultural practices in this setting, 90% performed the triple washing of pesticide containers; but this was not accompanied by correct end use of the empty containers: 57% were stored, 17% were burned, 7% buried, and there were other misuses of contaminated containers.

3.3. Exposure assessment

In a previous work [10], we proposed two indexes to describe pesticide exposure in applicators. The Intensity Level of pesticide Exposure (ILE) index measures instantaneous exposure intensity and the Cumulative Exposure Index (CEI) takes into account the average period of exposure, including the previous ILE information. Both indexes were constructed based on the Dosemeci proposal [23], carefully adapting the weighting procedure to our own context, and particularly to local professional opinion. The expressions of these measures are as follows:

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

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

where *mix* represents 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 dwelling proximity to the nearest crop, and *55* the average of ha treated with a single load in the crop sprayer. These measures were denoted ILE_{EC} and CEI_{EC} for extensive crop worker's population. Lantieri et al. [10] calculated both measures for all subjects in the opening sample of terrestrial pesticide applicators of extensive crops (n=880) and using Bootstrap and Monte Carlo resampling methods, identified the most suitable theoretical stochastic distribution for each measure. In the present work, we assessed the two indexes once again but on a larger sample of applicators (n=1327) and stratifying by HEAs.

The ILE_{EC} and CEI_{EC} indexes were adapted to assess the specific exposure conditions of the population involved of farmworkers and smallholders in the green belt of Cordoba city. The methodology and definition criteria for the preliminary version of these two indexes were as described in [10]. These indexes are presented bellow (ILE_{GB} and CEI_{GB}):

$$IL\ E_{GB} = \left[(mix / load\ * \mathrm{syst}) + \sum_{i=1}^{n} \frac{(meth\ \_apl)}{\# meth} \right] * PPE1 + (wash\ * PPE2) + (r\mathrm{ep} * PPE3) * h\,\mathrm{yg} * spill$$

$$CE\,I_{GB} = IL\ E_{GB} * Duration * Frequency$$

where *mix/load* represents a dichotomic response about mixing or loading pesticide; *syst* the sprayer system (open or closed); *meth_apl* the method of performing pesticide application; *PPE*1, the score of use of Personal Protective Equipment for spraying crops, as described before;

wash is also a dichotomic variable for washing the pesticide application equipment (backpack or machine); *PPE*2, the score of use of Personal Protective Equipment, as described before, for washing the machine and/or backpack; *Rep*, whether repairing application equipment; *PPE*3, the score of use of Personal Protective Equipment for repairing equipment; *hyg* hygiene mode after completing the task with pesticides; and *spill* the behavior during a pesticide spill on clothing, thus, whether the worker changes clothes immediately after the spill or not. The cumulative exposure index incorporates the intensity level of pesticide exposure, the *duration* (years) and *frequency* of exposures (number of days of applications per year).

Tables 7 and 8 show summary statistics for both the measures, constructed for exposure assessment in first population (extensive crops). As can be seen, mean values for both indexes were generally quite different from their medians, indicating empirical distributions different from the normal distribution. Significant differences between ecological areas were found for ILE_{EC} ($p=0.013$) and CEI_{EC} ($p=0.003$). For the former, areas I and III showed the lower and similar values ($p=0.201$) for exposure index, while area V had the highest average ($p<0.01$). As an intermediate group, there was no difference between areas II and IV ($p=0.203$), and these yielded higher values than those obtained in areas I and III ($p<0.001$).

	AREAS					
	I	II	III	IV	V	Total
n	41	641	230	156	259	1327
Statistics	Exposure Index distribution					
Mean	2.04	3.02	2.37	2.76	3.59	2.92
Standard Deviation	2.14	2.36	2.29	2.19	2.57	2.40
Median	0.94	2.61	0.94	2.49	3.24	2.6
Standard Error	0.29	0.09	0.13	0.17	0.15	0.06
p25	0.61	0.86	0.72	0.84	0.89	0.82
p75	2.61	4.47	3.66	3.74	5.66	4.34
Minimum	0	0	0	0	0	0
Maximun	8.80	10.15	9.23	8.94	10.93	10.93

Table 7. Summary statistics of Exposure Index distribution based on pesticide applicators of Extensive Crops (EI_{EC}) information, regarding to Homogeneous Ecological Area Classification. Córdoba, Argentina.

	AREAS					
	I	II	III	IV	V	Total
N	41	641	230	156	259	1327
Statistics	**Cumulative Exposure Index distribution**					
Mean	23.28	44.43	42.34	62.13	59.97	48.02
Standard Deviation	56.46	67.88	66.84	78.25	86.38	72.76
Median	2.18	16.18	13.80	28.52	27.56	17.83
Standard Error	7.61	2.61	3.70	6.17	5.14	1.88
p25	0	0	0	4.31	2.58	0
p75	21.48	56.98	50.62	89.15	84.61	62.36
Minimum	0	0	0	0	0	0
Maximun	383.3	534.877	383.34	370.96	514.2	534.87

Table 8. Summary statistics of Cumulative Exposure Index distribution based on pesticide applicators of Extensive Crops (EI_{EC}) information, regarding to Homogeneous Ecological Areas Classification. Córdoba, Argentina.

For the cumulative exposure index, the differences structure between areas was slightly different. Only areas II and IV were similar ($p=0.270$) showing intermediate values, while areas I and V yielded lower and higher averages ($p<0.001$) of the cumulative exposure measure. Figure 3 (first row) presents the box plots for both indexes for the five ecological areas.

When the log of applicator age was included as a covariate, the above results held. The estimate of regression coefficient (slope) for this covariate was equal to b=-0.40 (SE 0.15) and significant ($p=0.044$), showing that there is an inverse ratio between the exposure index and the log of age. Since the log is a mathematical monotone (increasing) function, this coefficient indicates that the younger workers have higher exposure. In contrast, the age pattern for the cumulative exposure index indicated a direct ratio: the coefficient estimate was 0.43 (SE 0.18), which means that, as expected, that older workers have higher values of cumulative exposure. Figure 3 (second row) illustrates this behavior.

Finally, personal protection was strongly associated with the differences between the areas for both indexes ($p<0.001$), indicating that in ecological areas with rural workers with lower cumulative exposure, the protection feature used was ideal (Figure 4). There was no association ($p=0.695$) between CEI_{EC} and the marital status of subjects.

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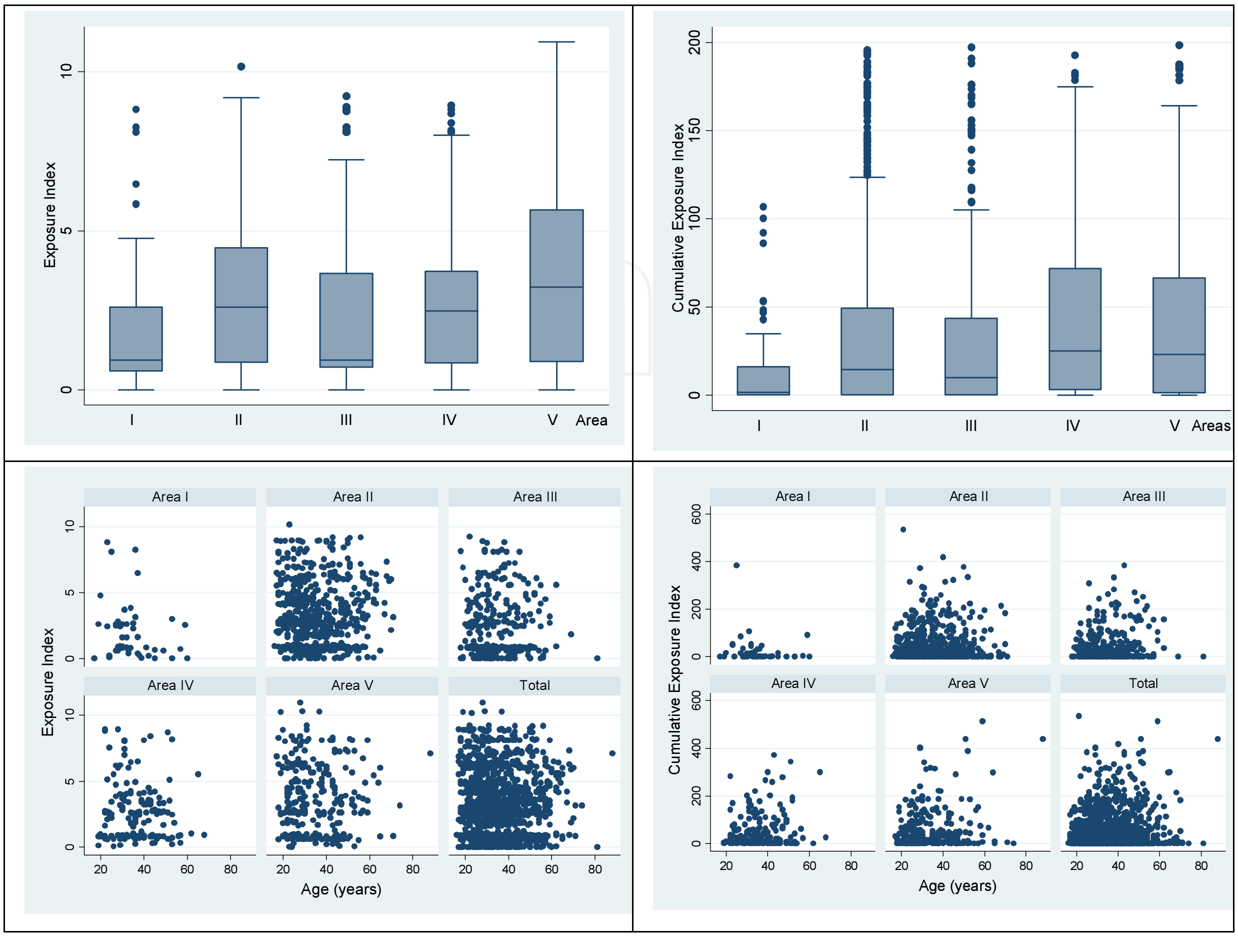

Figure 3. Box plots (above) of Exposure Index (EI_{EC}) and Cumulative Exposure Index (CEI_{EC}) and scatter plots (below) for these indexes *versus* age (years) of workers, for Ecological Areas.

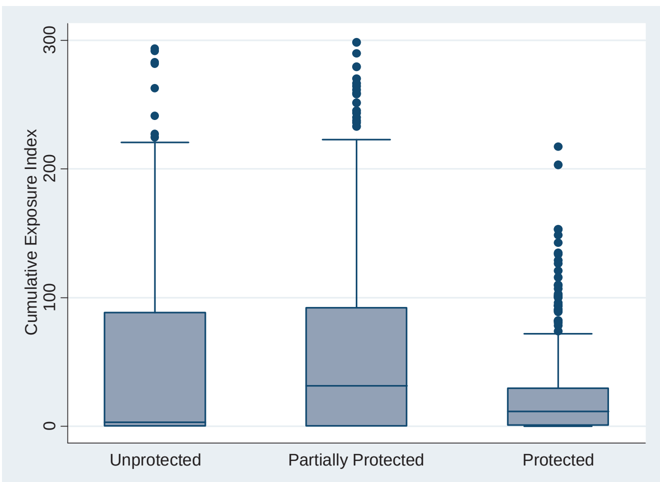

Figure 4. Box plot of Cumulative Exposure Index (CEI_{EC}) in terms of the personal protection category, Córdoba, Argentina.

3.4. Health status of workers related to pesticide exposure

a. Extensive crop pesticide applicator population.

A previous study reported a high prevalence of symptoms: 47.4% with occasional or frequent irritative symptoms, 35.5% fatigue, 40.4% headache and 27.6% anxiety or depression [1]. Increased frequency of medical consultation and hospitalization was associated with the use of chlorpyrifos ($p<0.001$ and $p=0.05$) and endosulfan ($p<0.001$ and $p=0.021$) insecticides, exposure to multiple pesticides ($p<0.001$) and seniority in the job ($p<0.001$). Only 32% of workers were adequately protected. The proper use of Personal Protective Equipment (PPE) (OR: 0.45, SE. 1.56) and marital status (OR 0.16, SE. 1.62) were protective factors for hospitalization.

Within HEAs, there was a difference between Homogeneous Ecological Areas II and III in the probability of medical consultation at least once for reasons related to occupational exposure to pesticides ($p<0.02$), with agricultural workers of HEA III having more probability of medical consultation. In the other health-related variables, no statistical differences were found.

b. Smallholders and farmworkers of the green belt population

In this sensitive population, occasional or frequent manifestation of irritative symptoms affected 49.3%, fatigue 35.6%, headache 52.6%, nervousness or depression 30.6%, dizziness 13.7% and excessive sweating 16.7%, and 18% had had an accident with pesticides. The prevalence of medical consultation and hospitalization was lower than expected: 22.2% and 4% respectively (Table 9). No statistical association was found between these two variables and exposure to specific pesticides.

Symptoms	Never / Rarely	Sometimes / Frequently	Number
Fatigue - tiredness	64.4	35.6	73
Nervousness ordepression	69.4	30.6	72
Headache	47.4	52.6	73
Irritative Symptoms	50.7	49.3	73
Dizziness or vertigo	86.3	13.7	73
Excessive sweating	83.3	16.7	72
Health assistance	**Never**	**Once or more times**	**Number**
Medical consultation	78.8	22.2	80
Hospitalization	96.0	4.0	75
Accident with pesticide			
Yes	82	18	95

[1]Percentage considering the total of responses.

Table 9. Prevalence of symptoms, health assistance and accidents related to occupational exposure among smallholders and farmworkers of the Córdoba capital city green belt. 2012

c. Workers' risk perception of different agrochemicals

We studied the perceived threat level of pesticides used. In the extensive crop pesticide applicator population, there was a high perception of danger (85.76 - 98%) only for insecticides, with the highest perception of danger for organophosphate. Herbicides and fungicides were considered less hazardous (35.09% - 91.54% and 49.07 - 58.55% respectively). Glyphosate, the most widely used pesticide in crops (98% use in the past year), was considered hardly or not at all dangerous. The level of protection used did not vary according to the perception of risk.

Among workers and smallholders of intensive crops, the insecticide group was also seen as presenting the highest perception of risk: between 33.3% and 86% felt that they are dangerous or very dangerous, with organophosphates and organochlorines seen as the most dangerous. Fungicides and herbicides were perceived as less dangerous (29% - 38% and 33% - 65%).

4. Discussion

This work presents an interesting update of our previous work on extensive crops of Córdoba province, stratified by the Homogeneous Ecological Areas (HEAs) [10]. It also includes, for first time in our country, a characterization of the horticultural smallholder and farmworker populations of the greenbelt of the provincial capital, both settings being recognized as vastly different in pesticide exposure determinants, based on professional judgment. The analysis of each agricultural scenario enabled groups with occupational exposure to pesticides to be identified in each particular labor context (extensive and horticultural crops), as well as the health conditions associated with occupational agrochemical use.

When evaluating the pesticide applicator population of extensive crops, we founded statistically significant differences between areas in age, education, marital status, seniority in the task, average/year of hectares sprayed, use of pesticides with prescription signed by an agricultural engineer, self-propelled crop sprayer with cab and activated charcoal filter, and protection level. Only trailed crop sprayer with cab and activated charcoal filter was similar in all the areas. Self-propelled and trailed crop sprayer combined showed an average 55.5% use in all areas, which means that a large percentage of workers used unsafe machinery, i.e., sprayer with no cab or cab without activated charcoal filter, and this was an important determinant of exposure and was more pronounced in HEA II (“Middle Agricultural and Livestock Area”), followed by HEA V (“South-eastern Agricultural and Livestock Area”). HEA I (“North-western Extensive Livestock Area”) was traditionally characterized by grazing cattle but it is now a newly developed agricultural region, due to the nationwide agriculturization process. This area's applicators had the highest level of personal protection and of using pesticides with written prescription, followed by HEA II. Others areas with a historical agricultural tradition, such as HEA IV (“South-eastern Agricultural Area”) and HEA V, did not have similar protective measures or a safe work environment; in fact, the highest rates of unprotected or partially protected applicators were found in these areas.

Our current results confirm previous works [10, 16] and MacFarlane's study [28] reporting no association between instruction level and personal protection. Indeed, HEA IV, with the highest percentage of applicators that had completed secondary school or higher, had only 35.3% of workers completely protected during the task. Likewise, we found no association between marital status and PPE use, as in the case of HEA IV, with the highest percentage of married or cohabiting subjects.

Based on two indexes proposed in previous work [10] for the assessment of pesticide exposure risk, the intensity and accumulated exposure indexes (ILE and CEI), the current assessment was performed in a larger sample of terrestrial pesticide applicators of extensive crops, stratifying by HEAs and showing significant differences among these for ILE_{EC} ($p=0.013$) and CEI_{EC} ($p=0.003$). The results reinforce the previous hypothesis of the emergence of different new risk scenarios in the province. As expected, HEA V yielded the highest averages for both indexes, followed by areas II and IV. It should be stressed that the differences between areas in both measures were strongly associated with the personal protection used (PPE).

As reported in a previous study, we continue to find a lack of enforcement of existing regulations (Law Nº 9164) in all the agricultural settings of the province, with low use of pesticide prescriptions signed by an agricultural engineer, and poor implementation of good agricultural practices such as triple washing of pesticide containers and their correct disposal. Burning, burying or reusing agrochemical containers, a common practice in the study populations, add other risk factors for applicators, as well as abiotic and biotic environmental contamination.

As expected, in contrast with extensive crop settings, wide differences were found in exposure determinants in the greenbelt population of Cordoba city, between their social and demographical characteristics and compared with other agricultural scenarios of the province, as shown above and in previous works [10, 16]. Horticultural workers had a greater average age, long experience in the task, lower educational level, and a high proportion of Bolivian workers and national migrants. Part of the population had unsatisfied basic needs: 23% lacked a running water supply and 13% a bathroom in the dwelling. Precarious living conditions were associated with being a “mediero” (see below), or an employee and a migrant, particularly Bolivian. It is thus a heterogeneous and highly vulnerable population, which favors lax labor structures for their work, leading to scenarios in which a higher rate of occupational health risk is to be expected. Seniority in the job was associated with higher cumulative exposure to pesticides, in turn associated with various deleterious effects on health [29].

The heterogeneity of this population is also seen in the different job roles, employment status and land tenure conditions of the smallholders and farmworkers. The agrarian structure has become dominated by family farms, giving rise to processes of social differentiation, concentration of land and capital, and the emergence of a new social actor: the "mediero", a kind of sharecropper that almost monopolizes the supply of labor by having their family take part in the work. This has transformed the social organization of horticultural work and is extremely functional [30] in that the existence of "medieros" often hides the figure of an unregistered employee, with the advantage for the farmers of transferring some of the risk, while avoiding compliance with labor legislation, social security and occupational risk prevention [31]. It enables them to turn fixed labor costs into variable costs, distribute downward the fluctuations in prices and profitability that are typical of fresh vegetable production, obtain a more stable workforce, delegate responsibilities and reduce the need for control, among others.

The active participation of the family (31%), as in the greenbelt, and the short distance from the home to the cultivation sites (38% less than 100 m), as also reported by applicators in extensive crops, (almost half of them live within 500 m of the nearest crop), leads to non-occupational exposure of the worker after work and para-occupational exposure of the other family members. McCurdy et al., Chaio-Cheng et al., Clifford et al., Loewenherz et al, and Lu et al., [as cited by 32] reported studies suggesting a take-home pathway for pesticides. Applicators and farmworkers accumulate chemicals on their clothing and skin, and can carry these into their homes. The homes of agricultural workers have higher pesticide concentrations in house dust than other homes in the same agricultural community. Children living there have elevated urinary metabolites of organophosphorus pesticides. Regarding dwelling location, higher levels of pesticides were found in dust samples in farmers' dwellings and non-agricultural reference homes closer to orchards [33].

In the greenbelt, the staggered mode in which a diversity of crops are grown allows farmers to grow a large number of crops in small plots, leading to a higher frequency of pesticide application. There is thus a heavy burden of pesticides in both scenarios: in extensive crops, due to the extensive areas sprayed, and in horticultural crops, to the process of spraying throughout the year. This also implies significant environmental pollution, with approximately 47% of the product deposited in adjacent soils and waters or dispersed in the atmosphere [34], depending on climatic conditions such as rain and wind direction, geological features such as soil type and the presence of water currents, and other factors such as the formula and presentation of the product as well as the application technique. Other phenomena promoting environmental spread are photodegradation and volatilization, leaching and surface soil washing, both related to streams and rainfall [35].

Other modern phenomena aggravate the level of pollution and affect the dynamics of farming in the greenbelt. The advance of crops such as cereals and oilseeds, mainly soybeans, over horticultural production, causes the greenbelt to shift towards other neighbouring districts [36]. Moreover, the increase of housing and of informal settlements in urban residential areas, coupled with inadequate planning and land management, further reduces and displaces horticultural production [37]. This is exacerbated by industrial development: the dominant industrial area (including dangerous industrial areas), increased from 8,000 ha (15.1%) to 12,000 (21%) between 2004 and 2012, while the predominantly rural area fell from 29% to 27.5% in the same period [38]. While about 40% of the area sown in the Capital Department is horticultural production [39], it is estimated that it has fallen from 11,000 hectares in 2004 [40] to an area of 5,500 hectares in 2012 [36]. Thus the greenbelt is now located in an urban area with a sum of overlapping environmental risks (caused by agriculture and pesticide pollution as well industrial pollution), making the Capital Department of Cordoba an area of high environmental risk [41].

The informality and precariousness of the situation endured by greenbelt workers is more complex than that of those in extensive crops, whose working conditions are more modern, regulated and safer. The wide diversity of greenbelt workers' tasks in contact with pesticides, the greater burden of insecticides resulting from the type of crops grown, and the application of risky technologies such as spraying with backpacks, also make this group of workers more vulnerable. The broad spectrum herbicide glyphosate, the most frequently used pesticide in this setting, is applied in the vicinity of the crops. Insecticides are also used several times during the crop cycle, as well as fungicides. The level of exposure and the likelihood of acute poisoning in these groups are thus substantially higher due to the continuous contact [34], which is for relatively short periods but is still intense and repetitive during the work day, causing toxic effects that vary depending on the type and amount of pesticide.

Work activity as a source of exposure to pesticides has been widely recognized in farm workers who mix, transport, carry, store or apply them [42]. The magnitude and severity of occupational pesticide exposure, its effects and consequences, cannot be measured exclusively by the classical indicators of mortality and morbidity. The apparent underreporting of cases of acute pesticide poisoning [43] hides the true extent of the problem in rural areas, where some authors report a deficit of up to 50% in reporting these events [44]. The adverse health effects reported in this study show a serious impact on exposed workers. The prevalence of acute and subacute symptoms reported in our study in both groups – extensive and intensive farming – with 47.4% and 49.3% irritative symptoms, 35.5% and 35.6% fatigue, 40.4% and 52.6% headache, 27.6% and 30.6% nervousness or depression, 35.6% and 22.2% rate of activity-related medical consultation, and 5.4% and 4% of hospitalization, respectively, show the high occupational exposure, and may be categorized as indirect indicators of the exposure level, unlike the recording of cases of pesticide poisoning. Argentina reported one of the highest indexes of agricultural accidents at work (94.8‰), with a mortality rate of 195 cases per million workers, only surpassed by the construction sector (229‰) [45]. The Province of Córdoba concentrates 88% of the labor sector in that area.

There are several factors involved in the occurrence of these high levels of accidents. The higher consumption of pesticides (kg/year), the toxicity and diversity of agrochemicals applied, the extent of the areas sprayed, the laxity of State monitoring, the prevailing weather conditions and, particularly, the everyday working conditions of applicators, are among the main variables that shape the patterns of occupational exposure to pesticides. This study provides evidence for this hypothesis and helps to analyze the risk. The association between the symptoms reported, as well as the increased hospitalizations and medical consultation among those exposed to certain insecticides, such as chlorpyrifos and endosulfan, as observed previously [46], provide evidence in this regard. Symptoms reported here, and the frequency of their occurrence, match other reports in Argentina and elsewhere showing a positive correlation between health effects and occupational exposure to pesticides [47-50].

Pesticide hazard perception can be associated with the occupational exposure risk prevention in agricultural settings. Our study found a low perception of hazard in relation to herbicides and fungicides and a higher perception to the group of insecticides in both populations, although the smallholders and farmworkers reported lower risk perceptions in all pesticide groups than terrestrial applicators of extensive crops. But it should be noted that the different risk perception reported in our study did not lead to variations in PPE. The hazard perception of insecticides may be explained by the acute toxicological data, and not by the volumes applied, the possibility of dispersal, environmental persistence and the likelihood of chronic health effects. Another explanation proposed for this behaviour is that the pesticide use in agriculture is not perceived as risky for the environment due basically to trust in the improvement of product quality, in the technological innovation that has taken place in the last few years and in the work of official agencies responsible for approving pesticides [51].

The absence of the agrochemical prescription, as well as the lack of implementation of formally regulated programs to ensure the correct end use of empty pesticide containers in both agricultural settings studied, indicate the weakness of compliance with the provincial regulations in force [24].

The results of the two subject groups present a picture of highly vulnerable populations, which must be considered in risk assessment, and in particular in the implementation of prevention strategies. Comprehensive knowledge of the study population is a priority in designing and strengthening protective measures for improving the health and safety conditions of workers and their families. The presence of highly vulnerable groups, such as women of childbearing age and children at all stages of growth, must be taken into account in assessing the problem, including approach strategies [14].

We proposed an analytical approach to assess workers' exposure to pesticides that takes advantage of existing comprehensive information about pesticide uses as well as about the main working habits of subjects, which is of relatively simple application. The information from assessing the indexes includes some observations relative to the specific local exposure scenario [10] in which the different variables that influence or determine exposure have been weighted and combined. Even though this approach does not give accurate estimates of individual exposure but rather pragmatic information on the risks faced by the workers and, consequently, of the presence or absence of a need for preventive interventions, we believe that these measures provide a valuable monitoring tool in our context.

There are some limitations to this study. Because of the complexity described in labor relations in the greenbelt, there is some selection bias in this study population due to difficulties in accessing directly exposed workers. The laxity in the employment relationship, the informality with which employment contracts are made, the uncertainty regarding operating times and the undocumented status of many of these workers [18], are some of the reasons for this, as has also been reported by other authors [52]. Secondly, information on pesticide use and on PPE, as well as some work practices, was based on self-reporting in the interview questionnaires. Thus, errors in recall and reporting may have occurred. A preliminary validation study was conducted, though only for the population of extensive crop workers (n=60), using a short version of questionnaire. Results (not shown here) indicated that the match between the volunteer farmers' questionnaire responses on both occasions was acceptable. Finally, the potential for differential exposure misclassification as reported by terrestrial applicators has been recognized in the present study by proposing the assessment of specific indexes describing the exposure. However, these measures weight, substantially, the use and the amount of pesticides applied in their usual work. Data from the National Cancer Institute studies found little evidence for differential recall of pesticides by farmers [53]. Since applicators are heavily involved in all aspects of pesticide manipulation/operation and this is practically their single occupation, they have a good memory for all the pesticides used. Further research will be carried out explore this in our populations.

5. Conclusion

The evidence presented describes a problem whose complexity is difficult to cover through the usual approaches. Exposure to pesticides in workers responsible for applying these is high. A variety of economic and socio-cultural factors affect exposure and only through a proper evaluation can its true dimension be identified and quantified. The assessment and monitoring of these populations allows us to obtain information about the risk factors associated with occupational exposure and the consequent health damage.

Recognizing the complexity of the processes underlying the vulnerability of these populations to pesticide exposure is a first step to significant change in preventive health. Adopting a comprehensive view of the different aspects of the problem will favor the reception of preventive proposals and their chances of application. The exposure reported here seriously conspires against this activity's desired goal of sustainability, creating serious health and environmental risks with costs that are underestimated in the balance of these operating models. From an economic perspective, action to reduce the risks of exposure and adverse effects of the use of pesticides and to contribute to maintaining and improving public health and the quality of life, supports economic development in all sectors of the country, especially in production. Workers and their families improve their quality of life and their family's economy and social security. Companies do not incur high costs of care for acute and chronic intoxication, disability and compensation. Employers benefit from a real decrease in absenteeism and staff turnover, and the country has a more dynamic and competitive work force. Consequently, such action is a factor that strengthens the development of the country.

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Author details

M. Butinof[1], R. Fernández[2], M.J. Lantieri[1], M.I. Stimolo[3], M. Blanco[4], A.L. Machado[5], G. Franchini[1], M. Gieco[1], M. Portilla[1], M. Eandi[1], A. Sastre[5] and M.P. Diaz[1*]

*Address all correspondence to: pdiaz@fcm.unc.edu.ar

1 Faculty of Medical Sciences, National University of Córdoba, Córdoba, Argentina

2 Faculty of Medicine, Catholic University of Córdoba, Córdoba, Argentina

3 Faculty of Economics, National University of Córdoba, Córdoba, Argentina

4 Faculty of Agricultural Sciences, National University of Córdoba, Córdoba, Argentina

5 Faculty of Psychology, National University of Córdoba, Córdoba, Argentina

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