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Exposure to phenoxyacetic acid herbicides and predictors of exposure among spouses of farmers

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Abstract

The purpose of the study was to assess the environmental exposure to 2 commonly used pesticides: 2-methyl-4-chlorophenoxyacetic acid (MCPA) and 2,4-dichlorophenoxyacetic acid (2,4-D) among spouses of farmers, not directly involved in the process of spraying. Exposure to 63 sprayings 24 women in households from the rural area of the Łódż Voivodeship in Poland was assessed. The women were asked to collect 3 biological urine samples: in the morning before spraying (sample A), in the evening after spraying (sample B), and on the morning of the next day (sample C). The determination of pesticides in urine was performed by high performance liquid chromatography, coupled with tandem mass spectrometry and negative electrospray (LC-MS/MS-ESI$^-$). In the case of both active ingredient, the number of urine samples with the level of pesticides above limit of detection (LOD) increased from 30% in samples A to 45% in samples B and C. The average levels of herbicides increased from sample A (2.8 ng/g creatinine) to sample B (6.0 ng/g creatinine). The mean value of the C sample was 4.0 ng/g creatinine. Similar results were obtained when the average was calculated for all measurements, including those below LOD. The outdoor activity of the women during spraying was statistically significant (p=0.023), a predictor of exposure in multivariate analyses. The presented study indicates that farmers' spouses might be exposed to pesticides, even if they do not take part in the spraying.

Key words

exposure to pesticides, farmers spouses, predictors of exposure

INTRODUCTION

The widespread use of synthetic chemicals, pesticides after World War II has revolutionized agricultural practice. Despite the fact that the potential human toxicity of new compound is carefully assessed before introduction on the market, some of them are suspected of being related to various health problems, including health effects of pesticides on the developing foetus and in childhood [1, 2, 3].

The process of clarification of the relationship between exposure to pesticides and adverse health effect rely heavily on the success in developing valid methods for a critical time-window. Biological monitoring is becoming an increasingly important element of field studies designed to assess the risk from pesticide exposures because has the potential to provide both qualitative and quantitative measurement of the integrated exposure by all routes.

The phenoxy herbicides: 2,4-dichlorophenoxyacetic acid (2,4-D) and (4- chloro-2-methyl) phenoxyacetic acid (MCPA) are widely used in agricultural and residential settings to control broadleaf weeds. Their biological half-life in humans reportedly varies from 12-72 h [12, 13, 14]. Several recent studies have examined female exposure to herbicides and the adverse reproductive effects, such as spontaneous abortion [4], birth defects [5], infertility [6], and infant sex ratio [7]. In those studies, exposure was characterized based solely on a questionnaire.

Whereas bio-monitoring data for phenoxyacteic acid herbicides in urine samples have been reported in studies of pre-school-age children and farm applicators [8, 9, 10], there are very few data available on farm women's exposure to herbicides not directly engaged in the process of spraying.

The objectives of the presented analysis were to measure the environmental exposure to 2 active ingredients of 2 pesticides – MCPA and 2,4-D – among farmers' spouses who were not directly involved in the process of spraying. These herbicides were selected for study as they are the ones most often applied to crops in Poland.

METHODS

Study population. During the spring, exposure to 63 pesticide' sprayings on the farms of 24 women were assessed. The study population was selected from villages in the Łódź Voivodeship in Poland. Exposure to 2 active substances of popular herbicides, i.e. MCPA and 2,4-D, was evaluated. During the study period, 50 sprayings were carried out using MCPA and 13 with 2,4-D. All study participants completed a self-administered questionnaire which provided information on age, height, weight, education level, activities during spraying, washing after spraying, as well as data describing the sprayings: area and time of spraying, type of sprayed crops, and amount of active ingredients used during spraying.

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Samples collection. To measure the level of pesticides, 3 urine samples were collected. The women were asked to collect urine in the morning before spraying (sample A), in the evening after spraying (sample B), and on the next morning (sample C). Urine samples were collected in plastic jars, marked properly, and transported to laboratory.

Chemical analysis of samples. A liquid chromatography-based method was developed for the purpose of this study. The method was validated according to ISO/IEC 17025:2005 standard.

Determination of 2-methyl-4-chlorophenoxyacetic acid (MCPA) and 2,4-dichlorophenoxyacetic acid (2,4-D) in urine was performed by high performance liquid chromatography, coupled with tandem mass spectrometry and negative electrospray (LC-MS/MS-ESI$^-$). Compounds of interest were extracted from urine samples with dichloromethane.

All chemicals were of the highest purity – LC-MS or p.a. Dichloromethane and water were purchase from J.T.Baker, analytical standards of MCPA and 2,4-D were from Fluka, and HPLC column XTerraC18 MS, 3.5µm, 150×2.1 mm was from Waters.

The Waters Alliance High Performance Liquid Chromatograph (HPLC) with analytical column XTerraC18 MS, 3.5µm, 150 × 2.1 mm (Waters), at the temperature 25°C with mobile phase of methanol – 0.01M acetic acid (60:40) and flow rate of 0.2 ml/min. were used. Determination of MCPA and 2,4-D was performed on Quattro Micro API tandem mass spectrometer (Micromass/Waters) in a MRM mode. The ions transitions used for quantitative analysis were: 199.2→141.0 for MCPA and 219.0→161.0 for 2,4-D. The identity of these compounds was confirmed by parent-daughter ions: 199.2→105.0 and 219.0→124.9 for MCPA and 2,4-D, respectively, as well as by appropriate retention time. Calibration curves were linear in a range of: 0.2-300 ng of MCPA/ml and 0.8 – 200 ng 2,4-D/ml.

Validation parameters of MCPA method are: Limit of Detection (LOD) 0.06 ng/ml; Limit of Quantification (LOQ) 0.2 ng/ml; extraction recovery 94%; precision 0.77.

Validation parameters of 2,4-D: LOD 0.06 ng/ml; LOQ 0.8 ng/ml; 2,4-D/ml urine; recovery of extraction 56%; precision 3,8.

Statistical analysis. In a large percentage of the urine samples, the concentrations of pesticides were below the LOD. The Maximum Likelihood Estimation (MLE) for left censored data was used to deal with non-detects. The parameters of the chosen distribution were estimated to best fit the distribution of the observed values above the detection limit, and compatibly with the percentage of data below the limit. Three most common choices for the assumed distributions: the log-normal, Weibull, and gamma distribution were tested. Akaike Information Criterion (AIC) was used to choose the Weibull that best fitted distribution.

Mean and 50 centile of concentration distribution were estimated from Weibull regression for left censored data. Confidence intervals were calculated using the method of parametric bootstrap. Percentages below LOD in 3 time points were compared using the McNemar test, and a similar model for identification of predictors of exposure was used. The model were extended by incorporation of random intercept for the women. Gamma distribution was used for random effect. In models for exposure after spraying, results were adjusted for pesticide concentration in sample A (before spraying). All statistical analyses were conducted using R statistical package [11].

RESULTS

Study population. Exposure to MCPA and 2,4-D was evaluated among 24 farmers' spouses, women not engaged in the processes of spraying performed on the crops near their farms. Study participants had mainly vocational (42%) or secondary education (29%) (Tab. 1). The mean age was 29 years. Work besides agriculture was performed among 12% of women, mainly as a shop assistant or hairdresser. Current smoking was declared by 38% of the women. The mean area of the farms was about 17 hectares (170,000m^2) (Tab. 1). Most of the women reported 1-2 sprayings on their farms (29%), 17% – 4 sprayings, and 12% – 3 and 6 sprayings (Tab. 1).

Table 1. Characteristics of study group.

Characteristics	Mean ± SD	No. of women (%)
Age of women	29.08 ± 3.97	-
Women's education		
– primary		5 (20.83)
– vocational		10 (41.67)
– secondary		7 (29.17)
– higher education		2 (8.33)
	–	
Women's work besides agriculture	-	
– shop assistant		2 (8.33)
– hairdresser		1 (4.17)
Women currently smoking		
Yes		9 (37.50)
No	–	15 (62.50)
Area of household (ha)	17.54 ± 9.43	
No. of sprayings per women		
1		7 (29.17)
2		7 (29.17)
3		3 (12.50)
4		4 (16.67)
6		3 (12.50)

Characteristics based on 24 women.

Characteristics of spraying performed on the cultivations. The 2 herbicides to which exposure was evaluated were used to protect grains. Sprayings using MCPA was mostly performed in May, June, July and October, whereas 2,4-D was used in May, September and October. MCPA was used in 50 sprayings and 2,4-D in 13 sprayings on the farms of the examined women. The mean amount of substances used was 4,68 l (Tab. 2). The mean duration of application was 134 minutes, and the average area covered was about 2 hectares (Tab. 2). The distance from spraying field to home, on average, was about 914 m (Tab. 2).

During spraying, most of the women stayed at home (60.32%).

In the case of 64% of sprayings, the working clothes were washed immediately after spraying by the farmers' wives. In 56%, the clothes were washed in a washing machine, whereas in 54% they were washed by hand (Tab. 2).

Level of MCPA and 2,4-D in women's urine. In the case of both active ingredients: MCPA and 2,4-D, the number of samples where the level of pesticides were above the LOD increased from samples taken before spraying to samples

Table 2. Characteristics of spraying performed in households of examined women

Spraying characteristics	No. of sprayings (%)	Mean ± SD
Active ingredients used:		
MCPA	50 (79.37)	
2,4-D	13 (20.63)	
Women's activities during spraying:		
Inside home	38 (60.32)	
Outside home	25 (39.68)	
Duration of spraying (min.)		134 ± 83.47
Whole area of spraying field (ha)		1.86 ± 1.40
Amount of substances used (l)		4.68 ± 2.52
Distance from sprayed field to home (m)		914.68 ± 979.58
Washing immediately after spraying		
No	23 (36.51)	
Washing in washing machine	34 (53.97)	
Washing by hand	6 (9.52)	

Characteristics is based on 63 sprayings.

taken after spraying (Tab. 3). In the morning sample (A), only in 31% the levels of 2,4-D were above the LOD, whereas in the urine taken in the evening after spraying (sample B), and in urine taken the next day (sample C) – 46%. MCPA level in the morning sample was detected in 26% of examined samples, in the evening in 40%, and on the next day in 40% of samples (Tab. 3).

Table 3. Distribution of pesticide concentrations above limit of detection (LOD).

Analysis	2,4-D (N=13)			MCPA (N=50)		
	A	B	C	A	B	C
<LOD	9 (69%)	7 (54%)	7 (54%)	37 (74%)	30 (60%)	30 (60%)
>LOD	4 (31%)	6 (46%)	6 (46%)	13 (26%)	20 (40%)	20 (40%)

Analyses of the pesticides were carried out separately in the group of women with detectable levels of the examined pesticides, and in the whole examined population (including subjects with levels below LOD). In both analyses, an increase was observed in the level of pesticides in urine samples taken before spraying and samples taken after spraying. In the group of women with detectable levels of pesticides, the level of MCPA found in urine was 2.3 ± 4.2 ng/ml in sample A, 3.9 ± 5.6 ng/ml in sample B, and 3.3 ± 5.2 ng/ml in sample C. Arithmetic mean for the whole population of women in the morning sample was 0.6 ng/ml, whereas in the sample collected in the evening – 1.6 ng/ml, and in the sample taken the next – 2.0 ng/ml (Tab. 4). Median (50 centile) for the women with detectable and non-detectable levels of MCPA was 0.01 ng/ml in sample A, 0.07 ng/ml in sample B,and 0.4 ng/ml in sample C (Tab. 4).

The mean level of 2,4-D found in women's urine (for women with detectable level of pesticides) was 3.0 ± 2.4 ng/ml in sample A, 2.0 ± 0.5 ng/ml in sample B, and 7.9 ± 10.5 ng/ml in sample C (Tab. 4). The arithmetic mean for the whole population of women in the morning samples was 1.0 ng/ml, in the evening samples – 0.9 ng/ml, and the next day – 3.8 ng/ml (Tab. 4). The 50 centile for samples including < LOD was 0.4 ng/ml in sample A, 0.3 ng/ml in sample B, and 0.4 ng/ml in sample C (Tab. 4).

The adjustment for creatinine was carried out separately in the group of women with detectable levels of the examined pesticides and among the whole examined population.

Table 4. The level of MCPA and 2,4-D in urine (ng/ml).

	MCPA			2,4-D		
	A	B	C	A	B	C
AM (SD) Concentrations >LOD	2.3 (4.2)	3.9 (5.6)	3.3 (5.2)	3.0 (2.4)	2.0 (0.5)	7.9 (10.5)
AM (95%CI)	0.6 (0.17-1.4)	1.6 (0.6-2.8)	2.0 (1.0-3.4)	1.0 (0.1-2.1)	0.9 (0.4-1.5)	3.8 (0.6-8.5)
50 centile (95%CI)	0.01 (0-0.07)	0.07 (0-0.3)	0.4 (0.15-0.9)	0.08 (0-0.5)	0.3 (0-0.9)	0.4 (0-1.8)

AM – arithmetic mean; SD – standard deviation

When adjusted for creatinine, the mean level of MCPA in the samples >LOD collected in the morning before spraying was 2.4 ± 4.2 ng/g creatinine, in the samples in the evening after spraying 6.5 ± 12.3 ng/g creatinine, and in the samples collected the next day 3.6 ± 7.3 ng/g creatinine (Tab. 5). Arithmetic mean for the population was 0.6 ng/ml 95%CI (0.16-1.4) in the morning, 2.6 ng/ml in the evening, and 2.2 ng/ml the next day (Tab. 5). The 50 centile for samples including < LOD was 0.01 ng/ml (range (0-0.05)) in samples A; 0.05 ng/ml in samples B, and 0.4 ng/ml (range 0.1-0.8) in samples C (Tab. 5).

The level of 2,4-D adjusted for creatinine in the samples >LOD collected in the morning before spraying was 3.6 ± 1.7 ng/g creatinine, in the samples in the evening after spraying – 3.3 ± 1.9 ng/g creatinine, and in the samples collected the next day – 5.9 ± 4.9 ng/g creatinine (Tab. 5). The arithmetic mean for whole examined group (including the samples <LOD) was 1.1ng/g creatinine) in samples A, 1.5 ng/g creatinine in samples B, and 2.7 in samples C (Tab. 5). The 50 centile for samples including < LOD was 0.06 ng/g creatinine in samples A, 0.3 ng/ g creatinine in samples B, and 0.4 ng/g creatinine in samples C (Tab. 5).

Table 5. Level of MCPA and 2,4-D in urine (ng/g creatinine)

	MCPA			2,4-D		
	A	B	C	A	B	C
AM (SD) Concentrations >LOD	2.4 (4.2)	6.5 (12.3)	3.6 (7.3)	3.6 (1.7)	3.3 (1.9)	5.9 (4.9)
AM (95%CI)	0.6 (0.16-1.4)	2.6 (0.7-5.2)	2.2 (0.9-4.0)	1.1 (0.3-2.1)	1.5 (0.6-2.7)	2.7 (0.8-5.3)
50 centile (95%CI)	0.01 (0-0.05)	0.05 (0-0.2)	0.4 (0.1-0.8)	0.06 (0-0.4)	0.3 (0-1.2)	0.4 (0-1.7)

AM – arithmetic mean; SD – standard deviation

As there were no differences in the levels of 2,4-D and MCPA in the urine samples collected 3 times during the exposure evaluation: in the morning, evening, and next day, and the analyzed pesticides were from the same chemical class (chlorophenoxyacids), the samples for both pesticides in 3 different time points were analyzed together.

For the women with detectable levels of pesticides in their urine samples, the mean level of MCPA or 2,4-D was 2.3 ± 5.3 ng/ml in sample A, 3.5 ± 10.7 ng/ml in sample B, and 4.2 ± 13.4 ng/ml in sample C (Tab. 6). The arithmetic mean for the whole population of women in the morning sample was 0.68 ng/ml, in the evening – 1.44 ng/ml, and the next day – 2.35 ng/ml (Tab. 6). The 50 centile including samples <LOD was 0.005 in samples A, 0.066 ng/ml in samples B and 0.34 ng/ml in samples C (Tab. 6).

Table 6. Level of pesticides in urine samples (ng/ml)

	Urine concentration (ng/ml)		
	A	B	C
AM (SD) Concentrations >LOD	2.3 (5.3)	3.5 (10.7)	4.2 (13.4)
AM (95%CI)	0.68 (0.24-1.32)	1.44 (0.70-2.39)	2.35 (1.21-3.75)
50 centile (95% CI)	0.005 (0-0.06)	0.066 (0.007-0.26)	0.34 (0.10-0.77)

AM – arithmetic mean; SD – standard deviation

When adjusted for creatinine, the mean level of pesticides in the samples collected in the morning before spraying was 2.87 ± 15.2 ng/g creatinine, in the samples in the evening after spraying 5.98 ± 61.3 ng/g creatinine, and in the samples collected the next day – 4.04 ± 15.02 ng/g creatinine (Tab. 7). The arithmetic mean for the population was 0.73 ng/ml in the morning, 2.40 ng/ml in the evening, and 2.31 ng/ml the next day (Tab. 7). The 50 centile for all samples (including < LOD) was 0.004 ng/ml in A; 0.046 ng/ml in B, and 0.33 ng/ml in C samples (Tab. 7).

Table 7. Level of pesticides in urine samples (ng/g creatinine).

	Urine concentration (ng/g creatine)		
	A	B	C
AM (SD) Concentrations >LOD	2.8 (15.2)	6.0 (61.3)	4.0 (15.0)
AM (95%CI)	0.73 (0.29-1.33)	2.40 (0.79-4.34)	2.31 (1.16-3.83)
50 centile (95%CI)	0.004 (0-0.047)	0.046 (0.003-0.23)	0.33 (0.11-0.78)

AM – arithmetic mean; SD – standard deviation

Predictors of women's exposure to pesticides. When assessing the predictors of exposure, the B and C samples were analyzed together, which reflects the exposure to the whole process of spraying. The model assessing the predictors of exposure was applied for women where the level of pesticides found in urine < LOD. The predictors of exposure were evaluated using regression, on the assumption that dependent variables have the Weibull distribution. In such a model, only the women's outdoor activity during spraying, compared with the activities of women who stayed at home during spraying, were statistically significant predictors of spraying exposure (p=0.023) (Tab. 8). Other predictors: active ingredients that used MCPA *vs.* 2,4-D, amount of substances used, area of sprayed field, distance from sprayed field to home (>500 m), washing after spraying, were not statistically significant (Tab. 8). The model was adjusted for the level of pesticide before spraying (sample A).

Table 8. Predictors of women' exposure to pesticides.

Variable	Pesticide concentration after spraying		
	B	95%CI	p
Active ingredients used: MCPA *vs.* 2,4-D	-0.27	-1.13-0.58	0.53
Amount of substances used	0.01	-0.13-0.13	0.98
Area of sprayed field	0.04	-0.19-0.27	0.71
Women's outdoor activities	0.77	0.1-1.44	0.023
Distance from sprayed field to home (>500 m)	-0.26	-0.89-0.37	0.42
Washing after spraying	-0.14	-0.85-0.57	0.70

Adjusted for the level of pesticides before spraying (A sample)

DISCUSSION

This study has shown that women not directly involved in the process of spraying are exposed to pesticides used on their farms, which indicates that there is a transfer of pesticides from the field to the home environment.

In the morning samples, the levels of pesticides were the lowest and increased in the evening after spraying and the next day. This indicates that the spraying performed on the farm has a measurable impact on the women's level of exposure. This observation is consistent with thbiological half-life of both MCPA and 2,4D which is 12-72 h [12, 13, 14].

The average exposure in this rural area seems to best be reflected by the levels of pesticides in samples taken before spraying, whereas after spraying, the levels of pesticides reflect environmental exposure after the spraying.

Although the examined women were not actively engaged in the application of pesticides on farms, they might have been exposed indirectly through contact with contaminated surfaces, clothing (washing after spraying), and indoor or outdoor air. There are very few data available on farm women's exposure to herbicides, and on how their exposures compare to the general population and the sprayers. To the best of our knowledge, this is the first study to measure the environmental levels of pesticides among women not engaged in the spraying process in a rural region in Poland.

The majority of women in our study had no detectable levels of 2,4-D and MCPA in their urine; however, the percentage of such samples significantly decreased in the 3 periods of measurements. In the morning sample, about 70% of the women had no detectable level of pesticides in their urine; in the sample collected in the evening after spraying and on the next day, this was about 55%. In a study performed in Minnesota, USA, among families living on farms where the LOD was 1 ng/ml (in our study, the LOD was 0.06 ng/ml), the level of 2,4-D >LOD was found in 70% of samples after application, and in 41% before spraying [15]. On the other hand, fewer detectable samples were found in a study performed in Ontario, Canada, where urinary concentrations of the herbicides 2,4-D and MCPA were measured in 125 women living on farms where these herbicides had recently been used for the first time in the growing season [16]. In that study, approximately 80% of the women had no detectable level of either herbicide (2,4-D and MCPA) in their urine [16]. The limit of detection used in the study was also 1 ng/ml. This can explain the larger number of detectable samples in our study. The detectable level of pesticides in the Canadian study would be about 20% higher if the limit of detection was the same as in our study. Similarly, in a pilot study on 6 farms carried out for a US Agricultural Health Study, during the application season, residues of 2,4-D, atrazine, metolachlor, and dicamba were detected on the hands of wives who had not been working on the farm, in 30% during non-application visits and increased to 79% during the application season [17]. Eight herbicides were measured in blood plasma in a study of rural residents, most of whom were farmers or family members of farmers, in Saskatchewan, Canada, in the winter season [18]. 2,4-D or MCPA were detected only in approximately 2% of the females in this survey [18], which can be explained by fact that during the time of samplings no sprayings were performed. The bio-monitoring of farmers and their children was also performed in South Carolina [19]. A small percentage of exposed spouses (4%) had detectable levels of the herbicide glyphosate in their 24-h urine on the day of application in both South Carolina and Minnesota [19]; however, the LOD in this study was also rather high – 1ng/ml.

In our study, the average level of pesticides found in all samples (including those <LOD) collected before spraying was 0.6 ng/ml in case of both MCPA and 2,4-D – 1 ng/ml, while those found in the evening – 1.6 ng/ml (MCPA) and 0.9 ng/ml (2,4-D), and the next day after spraying – 2.0 ng/ml and 3.8 ng/ml, respectively. There were similar results obtained when the average was calculated for samples >LOD. In the study performed in Canada [16], the level of 2,4-D before application was 0.7 ng/ml, and the day after – 1.32 ng/ml. The results for MCPA were 0.63 ng/ml and 0.64 ng/ml, respectively. Similar changes in the level of pesticides was found in the study performed in Minnesota [15] where the median pre application level of 2,4-D was 0.5 ng/ml, and the day after – 1.2 ng/ml [15]. Much higher levels of 2,4-D in urine have also been reported for a small group of women employed in herbicide production, with values as high as 3,562 ng/ml reported in spot samples during a working shift [20]. A high level of 2,4-D was also found in the urine of one pregnant Hispanic farm worker – average 120 ng/ml) [21]. Data from the 2 previous studies suggest that occupational activities were the main source of exposure. Summing up, most of the studies among women working in agriculture, not engaged in the process of spraying, have levels of exposure similar to the findings presented in the Polish study.

The level of herbicide residue excreted in the urine will be altered by individual differences in absorption, metabolism, distribution and excretion. If a person has come into contact with a pesticide, a number of factors can affect absorption, including: breathing rates, amount of physical exertion, area and location of skin exposed, duration of exposure, skin damage and the number of hair follicles in the exposed area [22]. Environmental factors such as temperature and humidity, the form and concentration of the pesticide product and presence of other chemicals on the skin or in the pesticide product may also impact on the degree of absorption of the herbicide [22, 23]. In our studies, we had no possibility to control any of above factors. From the limited number of those we did control, only the outdoor activity of the women during spraying was found to be a significant predictor for the level of spraying pesticides exposure.

Several limitations in our study should be considered. Given the costs associated with conducting bio-monitoring studies of pesticides, the sample size was limited, and selection bias may be a factor if the participants were different from non-participants in any important factors affecting pesticide exposure. However, we did endeavour to document and include several of them in the analyses.

Our data clearly document that epidemiological studies which categorize by-standers' pesticide exposure solely on the basis of subjects' recall might suffer from serious exposure misclassification. The majority of women in our study had no detectable levels of 2,4-D or MCPA in their urine. If exposure for these women had been estimated based solely on a report by the farm applicator that these herbicides had been used on the farm during a specific time window, such a report could introduce considerable misclassification of exposure.

CONCLUSIONS

Measurements of MCPA and 2,4-D in urine 3 times during spraying is a good method for assessing exposure to those pesticides because they are relatively short-lived, with a urinary half-life of 12-72 hours.

The presented study confirms that farmers' spouses are exposed to pesticides after spraying, which indicates that there is transfer of pesticides from the field to the home environment. This is very important, especially in Poland were the data on exposure to pesticides, based on biological monitoring, are rare. The level of environmental pesticide exposure among people living in rural Polish regions, and the threat to persons potentially exposed, should be the subject of future studies. Further research is required to be identify the predictors of persons' environmental exposure to pesticides.

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