ORIGINAL ARTICLES AAEM

Ann Agric Environ Med 2001, 8, 151–161

EXPOSURE OF FARMERS TO DUST ON PRIVATE FARMS OF VARIOUS PRODUCTION PROFILES

Anna Mołocznik, Jerzy Zagórski

Institute of Agricultural Medicine, Lublin, Poland

Mołocznik A, Zagórski J: Exposure of farmers to dust on private farms of various production profiles. *Ann Agric Environ Med* 2001, **8**, 151–161.

Abstract: In the light of studies of dustiness in agriculture conducted in Poland and abroad, which deal exclusively with dust risk while performing selected occupations, the results presented in this article are a subsequent attempt to recognize annual exposure to dust at workplaces in agriculture. This recognition concerns the workplace of private farmers - typical of Polish agriculture - on family farms of various profiles of production. The study covered 10 selected farms: four animal breeding farms, four specialised cultivation farms, and two traditional mixed-production farms comprising animal breeding and plant cultivation. The results of the study showed an unequal distribution of the working time load and exposure to dust among the farmers examined during the whole year. The monthly working time limit ranged from 53.6–208.8% of the legal working time. The values of the mean weighted monthly concentrations of total dust ranged within 1.2–33.9 mg m^{-3}, and those of respirable dust - 0.3–4.0 mg m^{-3}, the highest values being observed in August and September. Mean weighted monthly concentrations describing an average level of farmers' exposure to total dust (7.7–21.9 mg m^{-3}), together with the confidence intervals, remain above the occupational exposure limit (4.0 mg m^{-3}), which is equivalent to hazardous conditions. In the case of respirable dust the results obtained show allowable conditions. Despite this, the dusty working conditions of the farmers in the study should be regarded as hazardous, due to the high level of exposure to total dust observed and potentially high contents of pathogenic components. The highest level of exposure was noted on farms engaged in potato production and marketing, followed by traditional farms carrying out mixed production, while the lowest level of exposure was observed on farms engaged in dairy cattle breeding.

Address for correspondence: Dr Anna Mołocznik, Department of Physical Occupational Hazards, Institute of Agricultural Medicine, Jaczewskiego 2, P.O. Box 185, 20-950 Lublin, Poland.

Key words: agricultural dust, occupational exposure, farmer, plant production, animal breeding, mixed production.

INTRODUCTION

Agricultural working environment is associated with many strenuous and hazardous factors, including dust which most often accompanies farmers at work. On an average private farm a farmer performs working tasks which are components of various production processes. Considering plant and animal production, the seasonal cultivation and breeding occupations, such as ploughing, harrowing or tilling, sowing and harvesting crops, threshing, breeding activities, preparation of fodder and feeding of animals, cleaning animals, as well as work activities associated with the storage of agricultural crops, repair and maintenance of agricultural machinery, are sources of dust. The above-mentioned work activities take place in contact with soil, plants and animals. Hence, particles associated with all these elements will occur in the air inhaled.

In general, microorganisms are present in the majority of types of agricultural dust, and apart from the mineral

Received: 10 May 2001
Accepted: 10 August 2001

component, are elements typical of this dust. The qualitative and quantitative studies of agricultural dust show a high level of these components at individual stages of agricultural production processes. Currently, it is commonly accepted that microorganisms are the primary etiologic factor of pathologic changes among people exposed to the inhalation of agricultural dust [2, 4, 7, 31, 35]. The levels of airborne microorganisms detected on farms ranged within: 10^3–10^9 cfu m^{-3} (colony forming units), while the concentration of bacterial endotoxin – up to 75 μg m^{-3}; the highest concentrations were observed in farm rooms during work activities associated with the storage of plant raw materials, and rearing and breeding of animals [1, 2, 3, 5, 8, 19, 20, 21, 30]. The levels of micro-organisms and endotoxins in the air of these rooms are considerably higher than the proposed hygienic standards [4]. Mineral components occur primarily during field work and crop cultivation. One of the main mineral pathogens - silica, was detected in the samples of respirable dust in the form of free crystal silica or quartz in amounts up to 66% [6, 9, 10, 11, 14, 18, 22, 26, 29].

Following Polish and international studies of dust, which concern exclusively the evaluation of dust-related risk while performing selected work activities [10, 11, 17, 23, 30], the results of the present study are the subsequent attempt to recognize exposure to dust at workplaces in agriculture [15, 16]. This recognition covered workplaces of private farmers on family farms carrying out agricultural production typical of the current agricultural economy. The study was conducted with the use of own strategy, which considered the changeable character of farmers' exposure to dust. This strategy allowed the proper evaluation of exposure, i.e. to determine the mean dust concentration for the whole work cycle, compared to the occupational exposure limit, and simultaneously to establish the sections of this cycle where an extreme exposure takes place, which is important from the point of view of prophylaxis [4, 12, 13, 16].

Currently in Poland, 42% of farms carry out mixed-production, 33% - plant production and 20% - rearing and breeding of animals [24, 25]. The document developed by the Ministry of Agriculture and Food Economy: "A compact structural policy concerning the development of rural areas and agriculture" adopted by the Polish government in July 1999, drew attention to the necessity of improvement with respect to the size of farms, their structure and the quality of production, and also considered the perspectives of development primarily for specialized farms. It is anticipated that this group of farmers will continue to perform the occupation of a farmer, and consequently will therefore be exposed to the noxious and hazardous factors of the agricultural working environment.

Hazardous health effects exerted by these factors on Polish farmers have not been fully recognized. Only few cases of occupational diseases are recognized each year due to lack of prophylactic health care which would cover this occupational group (e.g. 116 cases were detected in the year 2000, dust-related diseases constituting over 50% of these cases) [32]. Currently, efforts are being undertaken in order to solve the above-mentioned problem [33, 34].

MATERIAL

In order to select the material for the study the 1997 and 1998 records of the Main Statistical Agency, which concerned the whole country, were analysed as well as the documentation collected by the Department of Agriculture and Food Economy at the Lublin Regional Office based on the data from the 1996 "National Agricultural Directory". The subjects of analysis were primarily the goals and directions of production on farms, and selected elements of their economic situation, as well as future plans [24, 25]. Based on this analysis, the leading production profiles were established which were most commonly undertaken by private farmers, i.e. rearing of dairy cattle and swine, cultivation of sugar beets, wheat, potatoes and vegetables. The farms for the study were selected in association with the unions and associations of breeders and cultivators, as well as the local commune authorities.

The studies of private farmers' workplaces on farms of various profiles of production covered 10 family farms located in the Lublin region, within the communes of Niemce, Jastków, Konopnica and Niedrzwica Duża. Four farms in the study were engaged in animal breeding (farms 1–4), four farms had a specialist cultivation profile (farms 5–8), and two farms carried out traditional mixed plant and animal production (farms 9 and 10). Farms 1 and 2 bred swine (116 and 114 hogs respectively) as the only production profile, plant cultivation being carried out only with respect to animal fodder and own needs. Farm 3 specialised in dairy cattle breeding (65 cows) in a free station system with milking parlour, crops being cultivated only in order to provide fodder for the herd. Another farm engaged in dairy cattle breeding was Farm 4, where the free station system was applied with a milk cooling room; this farm additionally specialized in the cultivation of sugar beets. Among the producers of crops, two farms were also engaged in animal breeding: Farm 5 (20 ha) considered potato growing as the main production profile, with swine breeding as a supporting direction. The production on Farm 6 (15 ha) was mainly wheat and sugar beet cultivation, and additionally - dairy cattle breeding. Two further farms were exclusively engaged in plant cultivation, and mentioned vegetables (nearly 20 ha each) as their main production, followed by sugar beet (Farm 7–34 ha) and wheat cultivation (Farm 8–30 ha). Mixed production Farms 9 and 10 were engaged in the cultivation of cereal crops, root plants and green crops, as well as in the breeding of cattle (12 and 19 animals respectively) and swine (15 and 11 animals respectively). All farms were equipped with tractors (Farm 1–4), combine harvesters, as well as specialist mechanical harvesters for the crops in which they specialized. Farms

engaged exclusively in plant production were better equipped with agricultural machinery than the remaining farms. The size of the farms in the study was 18–66 ha, the farms carrying out the traditional mixed production and swine breeding being the smallest, and those engaged in crop cultivation the largest. The age of farmers was 37–52 years, therefore at productivity age, with half of them at productive mobile age (18–44 years). In most cases, they ran their farms together with two adult family members - a wife, one of the parents, son or son-in-law.

METHODS

The investigation covered environmental studies of dust on selected farms and laboratory analysis of the dust samples collected, i.e. measurements of the concentration of total inhaled dust, respirable dust and free crystal silica, as well as analysis of time-schedule documentation. The studies were preceded by the preparation of the documentation for characteristics of farms and for time-schedule measurements, selection of farms, and providing instructions to the farmers for keeping time-schedule records.

The sampling zone was located inside the cabins of tractors and combine harvesters, most frequently with the door open or windows half-open; in an open space while operating machines without cabins, while performing manual cultivation work activities, repair activities, those within the farmstead; in animal rooms, barns, fodder rooms and in workshops - always in the breathing zone of working farmers.

The levels of total and respirable dust were determined by the weighted method using the following personal equipment with cyclone selector: AP-2 aspirator, produced by ORMED, Łódź, Poland, and SKC/224-PCEX7 aspirators, produced by SKVC Ltd, Dorset, UK. The level of free crystal silica in total and respirable dust was determined by the colorimetric method, with the use of the following spectrophotometers: Specol 11 produced by CARL-ZEISS, Jena, Germany, and Marcel Mini Eco produced by MARCEL Ltd., Warsaw, Poland. The measurements were performed in series which covered two subsequent trials. The duration of a series was generally two hours. The samples of respirable dust designed for the determination of the level of free crystal silica were collected during joint longer periods in order to obtain large enough portions.

Time-schedule observations concerned an annual work cycle and covered the diaries of work activities kept by farmers. This documentation allowed us to obtain information necessary for the evaluation of exposure, and the data pertaining to the type of work activities performed, time devoted to these activities, as well as an effective working time. An annual time-schedule documentation concerning 10 selected farmers was analysed.

The measurements of dust covered all work activities contributing to work cycles of farmers on the farms in the study. For each work activity, mean geometric concentration was calculated from the values obtained in the series, as well as the confidence interval for the mean value on the probability level of 95%, with the number of degrees of freedom f = n - 1, where 'n' was the number of reference measurements in series. Farmers' exposure to dust was evaluated after the whole year of study by the method of comparing the mean weighted concentration with an occupational exposure limit value (OEL) [28] selected according to the level of SiO_2 in the agricultural dust examined, with the application of the criterion of confidence interval of this mean value. The value of the mean weighted concentration C_{TWA} was calculated by use of the following formula:

$$C_{TWA} = \frac{\sum_{i-1}^{n} C_i \cdot t_i}{8 \cdot N}$$

where:

C_i - mean geometric dust concentration (for each activity in a full work cycle) during the measurement period t_i, [mg m^{-3}]

t_i - duration of the measurement period (i. e. working time for each activity), [h]

N - number of obligatory work days in full working cycle

8 - is 8-hour work shift, [h]

In the case of the analysed workplace of a private farmer on a family farm the N· 8 product is the legal working time in a given annual work cycle of a farmer. The upper and lower limits of the confidence interval of the mean weighted values $C_{TWA}{}^{L}$ and $C_{TWA}{}^{U}$ were calculated similar to C_{TWA} , i.e.:

$$C_{TWA}{}^{L,U} = \frac{\sum_{i-1}^{n} C_i^{L,U} \cdot t_i}{8 \cdot N}$$

where:

$C_i{}^{L,U}$ are limits (lower L and upper U) of the confidence intervals of mean geometric dust concentrations C_i determined for individual measurement period 'i'.

The level of exposure to dust at workplaces is interpreted in the following ways:

• as hazardous - when confidence interval of the mean weighted value is above the allowable value OEL

$$OEL < \{ C_{TWA}{}^{L}, C_{TWA}{}^{U} \}$$

• as allowable - when OEL value remains within the confidence interval of the mean weighted value

$$\{ C_{TWA}{}^{L}, OEL, C_{TWA}{}^{U} \}$$

• as safe - when confidence interval of the mean weighted value is below the OEL value

$$\{ C_{TWA}{}^{L}, C_{TWA}{}^{U} \} < OEL$$

In order to determine the dynamics of changes in exposure to dust during an annual work cycle mean monthly weighted concentrations were calculated.

In the description of the results and their interpretation the symbols C_{TWA}, C_i and OEL take the form of Ct_{TWA}, Ct_i and OELt - for total dust, and Cr_{TWA}, Cr_i and OELr - for respirable dust.

Table 1. Annual working time-schedule of Farmer 2 – animal production (swine).

Type of occupation	Working time of individual occupations in particular months during one year (hours)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Spring ploughing				2.5	9.5								12.0
Post-harvest ploughing									10.0	14.5	3.0		27.5
Harrowing				4.5	2.5				5.5				12.5
Cultivating of soil			3.0	11.5									14.5
Rolling of soil					0.5								0.5
Mechanical crop cultivating						1.0							1.0
Manual crop cultivating					3.0	4.0							7.0
Sowing of mineral fertilizers				3.5	4.0								7.5
Spreading of natural fertilizers					4.5								4.5
Sowing seeds with a seeder				11.5					6.5				18.0
Potato planting					4.0								4.0
Manual sowing, planting					6.0								6.0
Spraying					12.0	7.0	5.0		6.5				30.5
Combine harvesting							48.0	104.0					152.0
Pressing of straw, hay								46.0					46.0
Potato digging									7.0	6.0			13.0
Harvesting, sorting of potatoes				4.5					5.5				10.0
Care of animal stock	99.0	86.0	88.5	92.5	95.5	80.5	67.0	65.0	67.5	94.0	100.0	103.5	1039.0
Mixing of fodder	12.0		16.5										28.5
Cleaning of grain				9.5					13.5				23.0
Other farm/indoor activities											4.0		4.0
Manual reloading													
- grain, straw							3.0						3.0
- ensilage, manure	5.0	5.0	10.0	11.0	6.0	5.0	4.0		5.0	8.0	9.0	8.5	76.5
Repair	3.0	0.5					38.5	8.5				2.0	52.5
Transport	3.5	8.5											12.0
Effective working time:													
- in hours	122.5	100.0	118.0	151.0	147.5	97.5	165.5	223.5	127.0	122.5	116.0	114.0	1605.0
- in % of legal working time	72.6	59.8	61.5	86.1	88.1	58.3	89.8	121.5	69.0	69.6	65.9	62.0	75.4

The following obligatory OEL values (OELt and OELr) [27] were used for the interpretation of the results of the studies of dustiness:

- containing 10% or more of free silica
  - total dust—2.0 mg m^{-3}
  - respirable dust—1.0 mg m^{-3}
- containing less than 10% of free silica
  - total dust—4.0 mg m^{-3}
  - respirable dust—2.0 mg m^{-3}

RESULTS

Working time load

Time-schedule studies were conducted on 10 selected farms during the whole year. Based on the time-schedule documentation obtained, 48 types of working activities were established connected with cultivation of soil and crops, fertilizing, sowing, planting, plant protection, harvesting of agricultural crop and farming occupations, such as care of farm animals, grain threshing, winnowing and crushing, potato sorting, mixing of fodder components, and other activities, such as repair, transport or reloading.

Tables 1, 2 and 3 present time-schedule records concerning the effective work of farmers, i.e. the activities associated directly with running a farm, based on the examples of the following farmers: Farmer 2 - engaged in swine breeding, Farmer 3 - in cattle breeding, and Farmer 8 - in plant production (vegetables, wheat). Figures 1, 2, and 3 present working time distributions of the farmers examined, on animal, plant and mixed production farms.

The total time of performing all work activities registered in the annual time-schedule records was as follows: in the group of farmers engaged in animal production - from 1,605.0 to 3,131.5 hours; in plant production - from 2,260.0 to 3,463.5 hours; in mixed

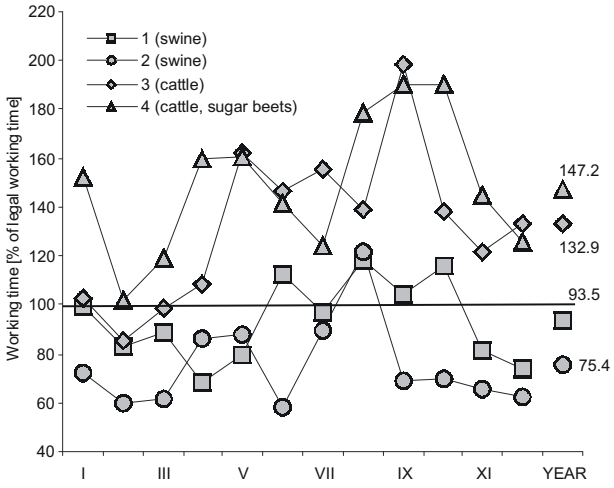

Figure 1. Distribution of relative working time of private farmers (animal production).

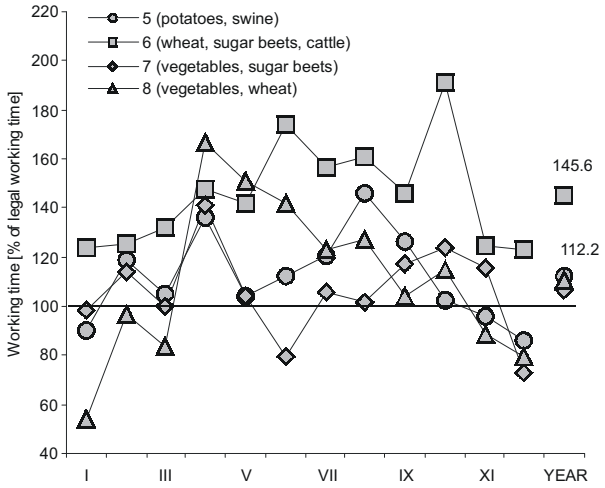

Figure 2. Distribution of relative working time of private farmers (plant production).

production from 2,904.5 to 3,248.5 hours. These values expressed as percentages of the legal working time were: for animal production - 75.4–147.2%; for plant production - 106.2–162.8%; and for mixed production - 135.5–157.3%.

The values of annual working time limits for farmers in the study confirmed that their work was very time-consuming. Only in swine breeders (Farms 1 and 2) the annual outlay of working time was lower than the legal working time limit. This was probably due to the usage of

Table 2. Annual working time-schedule of Farmer 3 - animal production (cattle).

Type of occupation	Working time of individual occupations in particular months during one year (hours)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Harrowing			4.0	2.0	8.0								14.0
Cultivating of soil				2.0	16.0								18.0
Rolling of soil				2.0									2.0
Sowing of mineral fertilizers				6.0	11.0	12.0							29.0
Spreading of natural fertilizers			18.0	26.0		22.0				18.0	5.0	25.0	114.0
Sowing seeds with a seeder				3.0	25.0								28.0
Spraying						6.0							6.0
Manual harvesting of sweet corn							22.0	6.0					28.0
Combine harvesting of sweet corn									165.0				165.0
Grass mowing with self-propelled cutter					22.0		22.0			19.0			63.0
Care of animal stock	154.5	140.0	162.0	142.5	171.0	174.0	189.0	95.0	152.0	164.0	146.0	162.0	1853.0
Other farm/indoor activities					4.0	2.5	11.0	53.0	14.5	19.0	56.5	41.0	201.5
Manual reloading:													
- grain, straw						6.0	12.0	50.0					68.0
- ensilage, manure	4.0												4.0
Work with “Tur” loader									27.5	6.0			33.5
Repair	3.0				15.0	24.0	32.0	35.5	6.0	5.0			120.5
Transport	12.0	4.0	6.0	8.0				14.0		13.0	7.0	17.0	81.0
Effective working time:													
- in hours	172.5	144.0	190.0	191.5	272.0	246.5	288.0	253.5	365.0	244.0	214.5	245.0	2828.5
- in % of legal working time	102.7	85.7	99.0	108.8	161.9	146.7	155.4	138.9	198.4	138.6	121.9	133.2	132.9

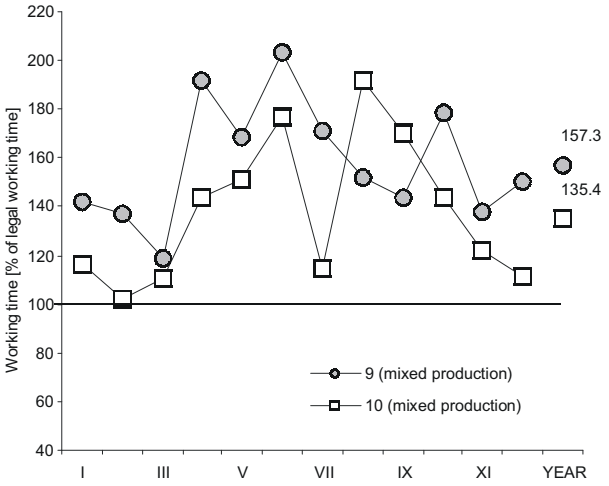

Figure 3. Distribution of relative working time of private farmers (mixed production).

concentrated feeding stuff instead of traditional fodder ingredients, e.g. potatoes, which require more work and time to prepare. The annual working time of the eight remaining farmers exceeded the legal limit by 7.5–62.8%. The producers of vegetables devoted the smallest amount of time to running their farms, although these were farms of the largest size, and vegetable growing is associated with many time-consuming activities. This situation is due to the way of managing the farms, where during the harvesting season (August-November) work activities are performed by hired workers. One-sided production with the simultaneous breeding of dairy cattle, as well as traditional mixed production proved to be most time-consuming.

The analysis of monthly data indicated great irregularities in loading the farmers with work during the annual work cycle. It also confirmed a high monthly working time span, most frequently exceeding the legal working time; the maximum values observed reaching 200% of the legal time. Only on swine breeding farms was the workload generally lower than legally accepted. The outlay of the working time of farmers engaged in cattle breeding was significantly greater than among swine breeders (Fig. 1). Among farmers engaged in plant production the highest working time load was noted for a farmer who, apart from the cultivation of wheat and sugar beet roots, was additionally engaged in dairy cattle breeding (Fig. 2). The distribution of working time of the owners of traditional mixed-production farms was also high, compared to the remaining farmers (Fig. 3). The characteristic feature of the distributions were maximum values which were primarily due to the technology of plant production and occurred during sowing and planting and also with harvesting; work activities connected with animal breeding were equally distributed throughout the whole year and potential changes might be caused by changes in the state of the herd.

The analysis also covered the ratios of working time directly devoted by individual farmers to animal and plant production during the whole year. Farmers who were engaged exclusively in plant production devoted the greatest amount of time to work activities associated with this production (Farm 7 - 72.0% and Farm 8 - 67.1%), whereas swine and dairy cattle breeders devoted the greatest amount of time to animal production (Farm 2 - 66.5% and Farm 3 - 65.5%). Farmers engaged in animal breeding as a main or supportive production profile devoted the greatest amount of time to work activities associated with the care of animals: 50–66% on average, except for the potato-producing farm with simultaneous swine breeding - where the farmer devoted 21.4% of his working time to animal care. On plant production farms, repair, transport and reloading activities took the greatest amount of time. Among occupations directly connected with the technology of production the following activities should be mentioned: digging sugar beets, harvesting and sorting vegetables, sowing seeds - on Farm 7 with

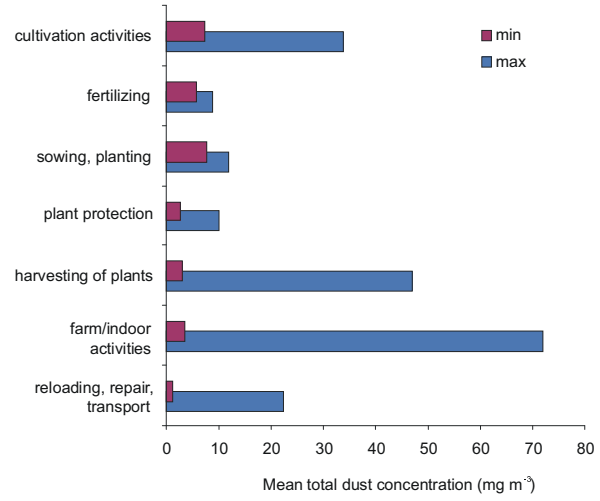

Figure 4. Range of maximal and minimal mean concentration of total dust while performing individual occupations in an annual work cycle.

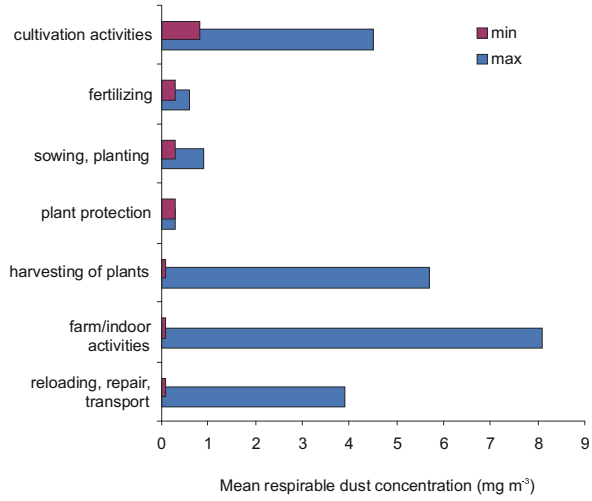

Figure 5. Range of maximal and minimal mean concentration of respirable dust while performing individual occupations in an annual work cycle.

vegetable and beets profile, as well as ploughing, chemical spraying and threshing of beans - on Farm 8 engaged in the cultivation of vegetables and wheat. These two farmers devoted 4.4–16.6% of the annual working time to the above-mentioned activities. On mixed-production farms (Farms 9 and 10) the ratio between the working time devoted to plant production to that devoted to animal production was 30.7/58.9 and 27.8/55.8 respectively.

Level of dustiness

Total dust. The level of dustiness in the respiratory zone of a farmer while performing individual work activities on a family farm varied widely according to the type of activity, which is confirmed by wide confidence intervals; e.g. during post-harvest ploughing the confidence interval was {10.0–114.0 mg m^{-3}}. The range of calculated mean values for individual work activities was 1.1–71.9 mg m^{-3}. The greatest amounts of dust were

Table 3. Annual working time-schedule of farmer 8 – plant production (vegetables, wheat).

Type of occupation	Working time of individual occupations in particular months during one year (hours)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
Spring ploughing				55.0	5.0	5.0							65.0
Post-harvest ploughing									29.5	26	26		81.5
Harrowing				4.5	1.5	1.0			7.0		48		62.0
Cultivating of soil				35.0	24.0								59.0
Disk harrowing				14.5				10.0	35.0		23.0		82.5
Rolling of soil					10.0								10.0
Cultivation with agricultural unit				10.5	18.5	7.0			25.0	10.0			71.0
Mechanical cultivation of crop						36.0	30.0						66.0
Manual cultivation of crop						23.0	56.0	8.0					87.0
Sowing of mineral fertilizers				23.0	10.5	2.5			17.0	4.0			57.0
Sowing seeds with a seeder				20.5	21.5	5.0			7.0	7.0			61.0
Manual sowing and planting					9.0	18.0							27.0
Spraying				3.0	46.5	50.0	6.0	3.0	3.0		3.0		114.5
Chemical treatment of seeds			8.0	7.0	6.0			1.5		5.0			27.5
Combine harvesting								50.5					50.5
Pressing of straw									4.0				4.0
Combine harvesting of beans							28.0	33.0					61.0
Harvesting of rape								5.0					5.0
Cutting of leaves										43.0			43.0
Digging of sugar beet roots										50.5	10.0		60.5
Threshing of beans		42.0	32.0	24.0						5.0			103.0
Cleaning of grain		16.0	33.0	9.0									58.0
Manual harvesting of vegetables								3.0	20.5			35.0	58.5
Farm/indoor activities	8.0				1.5	6.0			2.0	2.0	17.0	34.5	71.0
Manual reloading													
- grain, straw		30.0			10.5	1.0	12.0		6.0				59.5
- ensilage, manure		35.0	42.5	18.5				24.5	13.0	21.5		15.0	170.0
Repair	82.0	24.0	32.0	16.5	17.5	49.0	62.0	21.0		13.0	17.5	56.0	390.5
Transport		16.0	13.0	52.5	71.5	35.0	32.5	74.5	22.0	15.0	10.5	5.5	348.0
Effective working time:													
- in hours	90.0	163.0	160.5	293.5	253.5	238.5	226.5	234.0	191.0	202.0	155.0	146.0	2353.5
- in % of legal working time	53.6	97.0	83.6	166.2	151.2	142.0	123.1	126.4	103.8	114.8	88.1	79.3	110.6

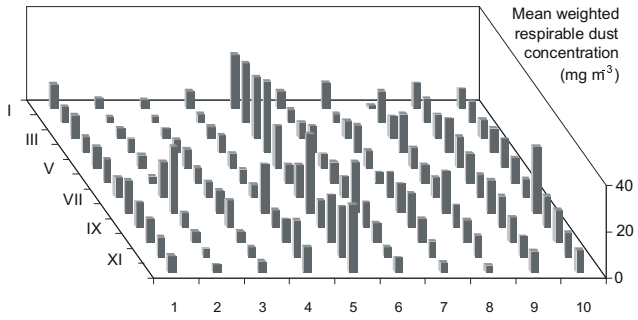

Figure 6. Monthly distribution of exposure to total dust in individual farmers 1-10.

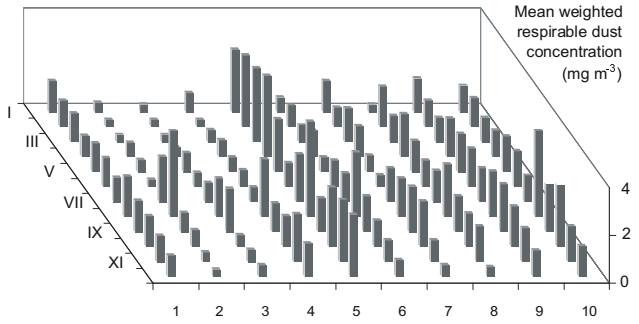

Figure 8. Monthly distribution of exposure to respirable dust in individual farmers 1-10.

observed during sorting and packing of potatoes - 71.9 mg m^{-3} {52.1–99.3}, threshing of grain with a thresher in a farm room - 51.8 mg m^{-3} {21.3–125.9}, in a combine harvester's cabin while harvesting cereals - 47.0 mg m^{-3} {27.2–81.3} and in a fodder room during grain crushing - 43.9 mg m^{-3} {21.6–89.5}.

Figure 4 presents the range of mean dust concentrations obtained for individual groups of work activities. For cultivation and plant care activities mean values were within 7.2–33.0 mg m^{-3}, for fertilizing - 5.7–8.9; sowing and planting - 7.5–11.8; chemical plant protection - 2.8–10.0; harvesting of plants - 3.2–47.0; farm/indoor activities - 3.4–71.9; and other work activities - 1.1–22.3 mg m^{-3}.

Respirable dust. The size of the particles of dust inhaled at the workplaces analysed varied according to the type of work activity. The highest respirable dust concentration was noted during sorting and prepacking of potatoes - 8.1 mg m^{-3} (i.e. 11.1% of total dust), in the fodder room while crushing grain - 6.1 mg m^{-3} (13.9%), in a combine harvester's cabin during harvesting of cereals - 5.7 mg m^{-3} (12.1%), and during grain threshing with a thresher in a farm room - 5.4 mg m^{-3} (14%). Similar to total dust, individual values of the measured respirable dust concentrations remain within a wide range of values, which is confirmed by wide confidence intervals, e.g. while ploughing after harvesting season the confidence interval was {1.6–12.9 mg m^{-3}}.

The percentages of respirable fraction in total dust for individual work activities were as follows: crop cultivation and care - 9.7–25.5%; fertilizing - 5.8–7.2%; sowing and planting - 3.6–7.5%; plant protection - 2.8–11.2%; harvesting of plants - 3.8–17.8%; farm/indoor activities - 4.0–13.9%; other activities - 5.0–25.0%. The smallest dust particles were observed during rolling of soil after sowing, driving along field roads and cleaning farm/indoor activities.

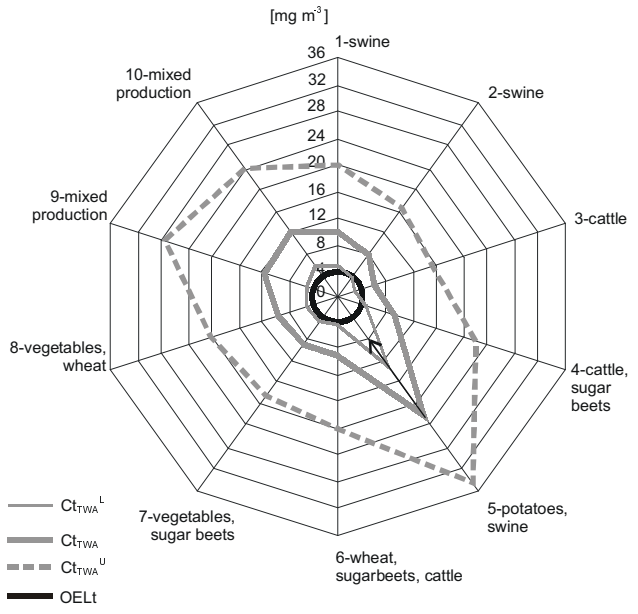

Figure 7. Mean weighted concentrations of dust Ct_{TWA} and lower and upper limits of the confidence intervals {Ct_{TWA}^{L},Ct_{TWA}^{U}} determined for farmers 1–10 (an arrow indicates the reduction in Ct_{TWA} value on Farm 5 after the subtraction of acivities associated with marketing).

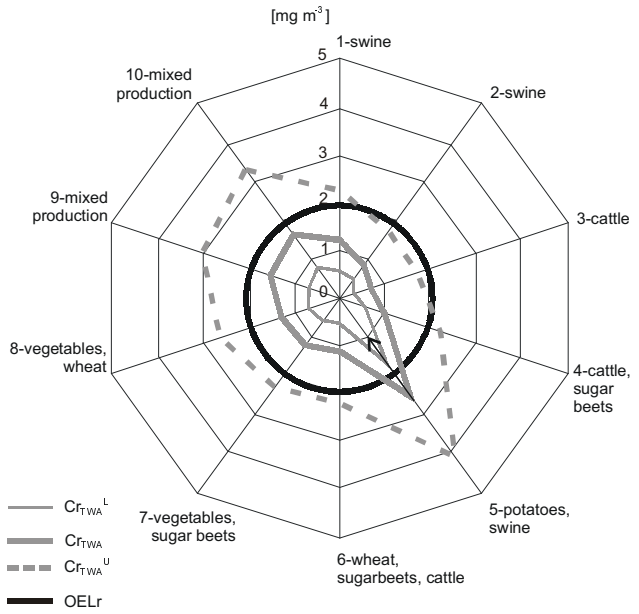

Figure 9. Mean weighted concentrations of respirable dust Cr_{TWA} and lower and upper limits of the confidence interval {Cr_{TWA}^{L}, Cr_{TWA}^{U}} determined for individual farmers 1–10 (an arrow indicates the reduction in Cr_{TWA} value on Farm 5 after the subtraction of activities associated with marketing).

The discrepancy between mean values for individual activities was 0.1-8.1 mg m^{-3}. For particular activities, the following minimum and maximum values of mean dust concentration were obtained: plant cultivation and care - 0.8–4.5 mg m^{-3}; fertilizing - 0.3–0.6; sowing and planting - 0.3–0.9; plant protection - 0.3; harvesting of plants - 0.1–5.7; farm/indoor activities - 0.1–8.1; other work activities - 0.1–3.9 mg m^{-3} (Fig. 5).

The following mean values of the level of free silica in dust were observed in the respiratory zone of farmers while performing individual activities: plant cultivation and care - 8.5–18.0%; fertilizing, sowing and planting - 6.4–19.0%; harvesting of cereals - 9.3–10.4%, farm/indoor activities, such as grain threshing in a barn - 4.4–11.6%; grain cleaning and crushing - 2.8–5.9%; sorting and prepacking of potatoes 10.5–20.5%; wood cutting - 3.0% and care of animals - 2.3%. The contents of free silica in respirable dust was determined at workplaces with the highest level of this dust, i.e. during sorting and prepacking of potatoes, grain threshing in barns and during harvesting of cereals with a combine harvester. The contents of free silica in respirable and total dust generally remained on a similar level. A considerable spread of individual measurements was associated with the heterogenous character of dust at the sources of its origin, as well as in the respiratory zone.

Level of exposure. The level of farmers' exposure on the 10 selected farms was evaluated based on the results of annual time-schedule records and mean values of total and respirable dust accompanying individual work activities. For all farmers in the study the mean weighted values were calculated for the annual work cycle, as well as monthly distributions of mean weighted concentrations which provided information concerning the dynamics of changes in farmers' exposure to dust for the whole annual work cycle and indicated periods of the greatest intensity of exposure.

The analysis of mean monthly dust concentrations (Fig. 6) showed an unequal distribution in the level of farmers' exposure, similar to the unequal distribution of work load observed during the period analysed. The mean values of monthly dust concentrations calculated for individual farmers remained within the range 1.2–33.9 mg m^{-3} and were the highest in August and September, i.e. during harvesting of cereals and root plants. The confidence intervals calculated for mean monthly dust concentrations were generally wide, which confirmed the occurrence of changeable conditions accompanying work and exerting an effect on the level of dust measured. A high level of exposure of a farmer engaged in potato production (Farm 5) deserves special notice. This was due to marketing and particularly with the sorting and packing of potatoes, which were carried out nearly all year round. These activities are highly dust-inducing and they were performed in a room without air conditioning and dust extraction facilities. When this part of exposure is subtracted, the dusty working conditions of this farmer remain on a level similar to other farms (arrowed in Figure 7).

Mean weighted concentrations representing an average annual level of exposure in the 10 farmers in the study remained within the range of 7.7-21.9 mg m^{-3}, whereas the confidence intervals for these extreme values were {2.6-14.4} and {13.1-37.1 mg m^{-3}} respectively.

The occupational exposure level of 4 mg m^{-3}, most suitable for the features of the dust examined, were adopted for the hygienic interpretation of the results obtained. This was a multi-component dust, containing changing proportions of plant, animal and mineral components, including not more than 10% of free crystal silica. Figure 7 presents a compilation of mean annual weighted concentrations of total dust determined for the farmers in the study, and the OEL value. All mean weighted values with confidence intervals were above the allowable value, which is equivalent to hazardous conditions.

The analysis of mean monthly concentrations of respirable dust (Fig. 8) indicated an unequal distribution of the level of farmers' exposure, similar to that observed for total dust. The values of mean monthly dust concentrations calculated for individual farmers were within the range of 0.3-4.0 mg m^{-3}, and were the highest in August and September, i.e. during the harvesting season of cereals and root plants. The highest values of respirable and total dust concentrations were noted in a farmer engaged in potato production. The subtraction of the part of exposure associated with the preparation of potatoes for market reduces the dusty working conditions of this farmer to a level noted on other farms (arrowed in Fig. 9).

Mean weighted annual concentrations of respirable dust among 10 farmers remained within the range of 0.7–2.5 mg m^{-3}, the confidence intervals for these extreme values being {0.3–1.6} and {1.7–4.1 mg m^{-3}} respectively (Fig. 9).

The value of 2 mg m^{-3} was adopted as the OEL for the hygienic interpretation of the results obtained. Figure 9 shows the compilation of mean weighted concentrations of total dust determined for the farmers examined with the OEL value. The mean weighted concentrations of respirable dust with confidence intervals, determined for farmers in the study, remained within the allowable value which is equivalent to allowable conditions. Nevertheless, dusty working conditions for private farmers examined should be considered as hazardous, due to the high level of exposure to total dust and potentially high level of pathogenic components.

DISCUSSION

The results of the study confirmed the changeable character of exposure to dust among farmers engaged in agricultural production of various profiles. The features of this exposure are the variety of work activities performed, changes in the levels and composition of dust, as well as changes of workplaces, time of daily exposure and duration of work cycle, which in the case of plant and

animal-plant production covers the whole year. The level of farmers' exposure to dust changes from month to month, which is due to technologically conditioned distribution of work activities, which are time-consuming, and to differences in the level of dustiness accompanying these activities.

The location of agricultural work, the type of activities associated with this occupation, and finally, the elements of agricultural environment accompanying a farmer at work, determine the heterogenous character of dust, both in the aspect of structure and space. The lack of uniformity is connected with the variety of production processes which take place in contact with the elements of the natural environment, i.e. soil, water, air, plants and animals, as well as with the presence of pollution due to civilisation. Diversity with respect to space, manifested by the differences in concentrations and composition of subsequently taken samples, becomes clear especially at work in an open space, inside open cabins of tractors and self-propelled machines, and also at work within the household performed at places which are only roofed over.

Differences in the level of dustiness are not only associated with the type of work activity, but also with the changeable character of conditions accompanying the work, such as: weather conditions, soils, degree of humidity of the raw material collected, as well as the way and conditions of its storage - the factors which determine the amount of microorganisms in the air, type of equipment and machinery applied, and method of operating them. A particularly high spread of results which should be ascribed to the above-mentioned conditions, concerned field work - e.g. during ploughing after the harvesting season. Studies by other authors confirmed high variability in the level of dust accompanying agricultural activities. This concerns the concentration of both total and respirable dust, as well as the contents of pathogenic dust components - microbes, bacterial endotoxin and silica [7, 8, 10, 17, 18, 19, 20, 21, 23].

Differences are observed in the distribution of working time and the type of exposure according to the production profile. The level of exposure of a farmer - the owner of a private farm is connected with the character of the farm: type of crops, technologies applied, size of cultivated land, amount of animal breeding, number of people participating in running the farm, type of activities characteristic for the production profile undertaken, work tasks shared between a farmer and others engaged, or finally, the provision of neighbour services, e.g. harvesting of cereals with one's own combine harvester on a neighbour's field. Therefore, the variations observed among the farmers in the study result from the individual character of the farms in the study. Changes in exposure of farmers to dust during subsequent years depend on the changes within their own farms. Thus, it may be anticipated that the exposure will be repeated during subsequent years if there are no alternations in the production profile of the farm, the technologies applied, size of the cultivated land and the number of breeding animals.

The results presented, therefore, should be approached as a confirmation of the actual risk caused by the dust inhaled by farmers engaged in selected types of agricultural production. A more universal value of the results of these studies is the indication of the work activities, from among working tasks contributing to an annual production cycle, which create the highest health risk for workers, due to high concentrations of respirable dust, high levels of pathogenic components, as well as their being time-consuming. These activities should be taken into consideration as a priority while planning and introducing prophylactic solutions.

Studies of private farmers' exposure to dust, conducted by the Institute of Agricultural Medicine from the aspect of workplaces, covered an annual work cycle and are unique in the area of agricultural work hygiene.

CONCLUSIONS

• An annual working time of the farmers in the study ranged within 75.4%-157.3% of the legal working time and was the highest on mixed-production and cattle breeding farms, whereas the lowest values were noted on farms engaged in swine breeding; this time was unequally distributed during the whole year, with the maximum values observed during sowing and planting, as well as during harvesting of crops.

• Exposure to soil and plant components of the dust inhaled was noted only on farms carrying out plant production; while on the remaining farms exposure was determined by animal, as well as plant and soil components associated with the production of fodder, and engagement in additional types of agricultural production.

• The level of dustiness while performing individual work activities varied according to the type of activity, as well as technical, technological and weather conditions. High levels of dust were noted during work within the household: potato sorting - 71.9 mg m^{-3}, grain threshing with a thresher in a farm room - 51.8 mg m^{-3}, in the fodder room during grain crushing - 43.9 mg m^{-3}.

• The results confirmed a high level of exposure to dust among all farmers in this study. The concentrations of dust were within the range of values considered as hazardous working conditions; the highest level of exposure was noted in a farmer engaged in production and marketing of potatoes, and on traditional mixed-production farms, whereas the lowest level was on a dairy breeding farm with additional cultivation of corn for fodder.

• The distribution of farmers' exposure to dust during the whole year was uneven, and the maximum values observed were associated with plant cultivation (sowing, planting, harvesting).

• The results of the studies showed that there exists a potential dust-related health risk for private farmers,

irrespective of the production profile. This risk results from a high level of exposure to dust and the presence of pathogenic components, the greatest risk being anticipated on farms carrying out both animal and plant production.

• The results of the study constitute a basis for preventive technical solutions, as well as medical prophylaxis for workers on private farms, by indicating the work activities which cause an especially high risk due to agricultural dust.

Acknowledgements

The study was supported by the Long-Term Programme (formerly the Government Strategic Programme): "Safety and Protection of Human Health in the Working Environment" as research task 04.12.1: Determination of the actual level of farmers' exposure to agricultural dust on private farms of various production profiles. Main Co-ordinator: Central Institute for Labour Protection. Task Director: Dr A. Mołocznik.

REFERENCES

1. Attwood P, Brouwer R, Ruigewaard P, Versloot P, DeWit R, Heedrik D, Boleij JSM: A study of the relationship beetween airborne contaminants and environmental factors in Dutch swine confinment buildings. *Am Ind Hig Assoc J* 1987, **48,** 745-751.

2. Dutkiewicz J: Bacteria and fungi in organic dust as potential health hazard. *Ann Agric Environ Med.* 1997, **4**, 11-16.

3. Dutkiewicz J, Pomorski ZJH, Sitkowska J, Krysińska-Traczyk E, Skórska C, Prażmo Z, Cholewa G, Wójtowicz H: Airborne microorganisms and endotoxin in animal houses. *Grana* 1994, **33**, 85-90.

4. Dutkiewicz J, Mołocznik A: Pyły organiczne pochodzenia roślinnego i zwierzęcego (Organic dusts of plant and animal origin). Podstawy i Metody Oceny Środowiska Pracy. Międzyresortowa Komisja do spraw Najwyższych Dopuszczalnych Stężeń i Natężeń Czynników Szkodliwych dla Zdrowia w Środowisku Pracy, Warszawa 1998, **18**, 151-185 (in Polish).

5. Eduard W: Exposure to non-infectious microorganisms and endotoxins in agriculture. *Ann Agric Environ Med* 1997, **4**, 179-186.

6. Green FHY, Yosida K, Fick G, Paul J, Huhg A, Green WF: Characterization of airborne mineral dusts associated with farming activities in rural Alberta, Canada. *Int Arch Occup Environ Health* 1990, **6**, 423-430.

7. Jolie R, Bäckström L, Gunderson P: Airborne contaminants and farmers health in swine farms with high and low prevalence of respiratory diseases in pigs. *Ann Agric Environ Med* 1998, **5**, 87-92.

8. Kullman GJ, Thorne PS, Waldron PF, Marx JJ, Ault B, Lewis DM, Siegel PD, Olenchock SA, Merchant TA: Organic dust exposure from work in dairy barns. *Am Ind Hyg Assoc J* 1998, **58**, 403-413.

9. Lawson RJ, Schenker MB, McCurdy SA, Jenkins B, Lischak LA, John W, Scales D: Exposure to amorphous silica fibers and other particulate matter during rice farming operations. *Appl Occup Environ Hyg* 1995, **10**, 677-684.

10. Louhelainen K, Kangas J, Husman K, Terho EO: Total concentrations of dust in the air during farm work. *Eur J Respir Dis* 1987, **71**, **suppl 152**, 73-79.

11. Louhelainen K: Farmers' Exposure to Dusts and Gases in Dairy Farms. Doctoral Dissertation. Department of Environmental Sciences, University of Kuopio, Kuopio 1997.

12. Mołocznik A: Ocena ekspozycji pracowników na pyły rolnicze – stan aktualny i potrzeby (Evaluation of workers' exposure to agricultural dusts – actual state and research needs). *Bezpieczeństwo Pracy* 1993, **5**, 7-11 (in Polish).

13. Mołocznik A: Zapylenie w rolniczym środowisku pracy jako otwarty problem higieniczny (Dustiness in agricultural working environment as an open problem). **In**: Solecki L (Ed): *Zagrożenia Fizyczne w Rolnictwie*, 58-66. Institute of Agricultural Medicine, Lublin 1999 (in Polish).

14. Mołocznik A: Składniki pyłu rolniczego jako potencjalne czynniki patogenne (Components of agricultural dust as potential pathogenic agents). **In**: Zagórski J (Ed): *Choroby Zawodowe i Parazawodowe w Rolnictwie*, 61-67. Institute of Agricultural Medicine, Lublin 2000.

15. Mołocznik A, Zagórski J: Exposure to dust among agricultural workers. *Ann Agric Environ Med* 1998, **5**, 127-130.

16. Mołocznik A, Zagórski J: Exposure of female farmers to dust on family farms. *Ann Agric Environ Med* 2000, **7**, 43-50.

17. Nieuwenhuijsen MJ, Kruize H, Schenker MB: Exposure to dust and its particle size distribution in California agriculture. *Am Ind Hyg Assoc J* 1998, **58**, 34-38.

18. Nieuwenhuijsen MJ, Noderer KS, Schenker MB, Vallyathan V, Olenchock S: Personal exposure to dust, endotoxin and crystalline silica in California agriculture. *Ann Occup Hyg* 1999, **43**, 35-42.

19. Olenchock SA, May JJ, Pratt DS, Morey PR: Occupational exposures to airborne endotoxins in agriculture. *Prog Clin Biol Res* 1987, **231**, 475-487.

20. Olenchock SA, May JJ, Pratt DS, Piacitelli LA, Parker JE: Presence of endotoxins in different agricultural environments. *Am J Ind Med* 1990, **18**, 279-284.

21. Pickrell JA, Heber AJ, Murphy JP, Henry SC, May MM, Nolan D, Oehme FW, Gillespie JR, Schoneweis D: Characterization of particles, ammonia and endotoxin in swine confinement operations. *Vet Human Toxicol* 1993, **35**, 421-428.

22. Popendorf WJ, Pryor A, Wenk HR: Mineral dust in manual harvest operations. *Ann Am Conf Gov Ind Hyg* 1982, **2**, 101-115.

23. Popendorf W, Donham KJ, Easton DN, Silk J: A synopsis of agricultural respiratory hazards. *Am Ind Hyg Assoc J* 1985, **46**, 154-161.

24. *Powszechny Spis Rolny 1996. Cele i kierunki produkcji w gospodarstwach rolnych a uzytkowanie gruntów, powierzchnia zasiewów i pogłowie zwierząt gospodarskich.* Główny Urząd Statystyczny, Warszawa 1998.

25. *Powszechny Spis Rolny 1996. Wybrane elementy sytuacji ekonomicznej gospodarstw rolnych i ich zamierzenia na przyszłość.* Główny Urząd Statystyczny, Warszawa 1998.

26. Preller L, Heederik D, Kromhout H, Boleij JSM, Tielen MJM: Determinants of dust and endotoxin exposure of pig farmers: development of a control strategy using empirical modelling. *Ann OccupHyg* 1995, **39**, 545-557.

27. Rozporządzenie Ministra Pracy i Polityki Socjalnej z dnia 17 czerwca 1998 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników dla zdrowia w środowisku pracy. Dz. U. 1998, nr 79, poz. 513. Warszawa 1998 (in Polish).

28. Rozporządzenie Ministra Pracy i Polityki Socjalnej z dnia 2 stycznia 2001 r. zmieniające rozporządzenie w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników dla zdrowia w środowisku pracy. Dz. U. 2001, Nr 4, poz. 36. Warszawa 2001 (in Polish).

29. Stopford CM, Stopford W: Potential for respirable quartz from North Carolina farm soils. *Scand J Work Environ Health* 1995, **21**, **suppl 2**, 44-46.

30. Vinzents P, Nielsen BH: Variations in exposures to dust and endotoxin in Danish piggeries. *Am Ind Hyg Assoc J* 1992, **53**, 237-241.

31. Virtanen T, Kalliokoski P, Vilhunen P, Taivainen A, Mäntyjärvi R: Concentrations of specific dusts in swineries and the humoral response of swinery workers. *Allergy* 1990, **45**, 354-362.

32. Wypadki przy pracy i choroby zawodowe rolników oraz działania prewencyjne KRUS w 2000 roku. Kasa Rolniczego Ubezpieczenia Społecznego, Warszawa 2001 (in Polish).

33. Zagórski J, Jastrzębska J: Koncepcja systemu profilaktycznej opieki zdrowotnej nad pracującymi w rolnictwie indywidualnym. (Concept of a system of prophylactic health care of private farmers) *Medycyna Ogólna*, 1997, **3**, 1-9 (in Polish).

34. Zagórski J, Delekta M: Nowe rozwiązania bezpieczeństwa i higieny pracy oraz opieki zdrowotnej nad rolonikami indywidualnymi w Polsce (New solutions concerning occupational safety and hygiene and health care of Polish private farmers). *Ubezpieczenia w Rolnictwie. Materiały i Studia.* KRUS, 1999, **1**, 25-32 (in Polish).

35. Zejda JE, Barber E, Dosman JA, Olenchock SA, McDuffie HH, Rhodes C, Hurst T: Respiratory health status in swine producers relates to endotoxin exposure in the presence of low dust levels. *J Occup Med* 1994, **136**, 40-56.