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Parasitological contamination of arable soil in selected regions of Poland – preliminary study

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Abstract

Introduction and Objective. The hygienic status of arable soils in most developed countries has been unknown. In the presented study, a preliminary investigation was undertaken to determine the contamination with eggs of parasitic nematodes in the soil of arable fields in Poland. The aim of the study was to determine whether such contamination is common enough to constitute a significant problem and what factors may influence it.

Materials and method. The study was conducted in 5 Polish provinces from autumn 2021 to spring 2022. The provinces differed significantly in terms of the area of agricultural land, agricultural suitability, type of soil, scale of cattle and pig breeding, production of manure and slurry, and the use of manures and organic fertilizers for fertilization. A total of 133 soil samples were collected. Parasitological examination of soil samples was carried out using the PN-Z-19006 method [1], with confirmed high sensitivity.

Results. Parasite eggs were found in a total of 67 samples, of which 56 samples contained eggs of roundworms of the genus *Ascaris* (an average of 3.29 eggs/100 g of soil), 23 contained eggs of whipworms (an average of 1.22 eggs/100 g), and 3 contained eggs of Toxocara (1 egg/100 g).

Conclusions. Differences in the percentage of positive samples were found depending on the period in which the samples were taken. The percentage of positive samples collected in autumn (53.57%) was higher than the percentage of positive samples collected in spring (48.05%). Similarly, the average number of eggs of in positive samples collected in autumn (3.43 eggs/100 g) was higher than the average number of eggs in samples collected in spring (2.90 eggs/100 g). Differences in the percentage of positive samples were also found depending on the region of origin of the samples.

Key words

soil analysis, parasite eggs, *Toxocara* spp, *Ascaris* spp.

INTRODUCTION AND OBJECTIVE

Parasite reproductive strategies are as diverse as the range of taxonomic units from which they originate [2]. Their life cycles are sometimes very complicated and may include many development stages living in different environments. A large group of parasites, especially nematodes that live in the digestive tract of their hosts, but use the external environment as a way of transmitting their dispersal forms. Fertilized eggs of these parasites are usually excreted into the environment along with the faeces of the host. In the environment, the larva is formed inside the egg. This environmental stage in the life cycle of many parasites is necessary to achieve invasiveness, i.e. to mature to a stage that is capable of infecting subsequent hosts. This may last from a few hours to even several weeks or month, and depends, among others, on temperature and humidity [3]. Infection generally occurs by eating food/feed contaminated with parasite eggs. Due to the randomness of the host's contact with invasive forms of the parasite, intestinal roundworm eggs are produced by females in huge quantities, which ensures the survival of the species [4]. Additionally, the eggs of these nematodes are very resistant to environmental conditions and, according to Strauch, they can survive in the soil for up to 14 years [5]. However, in tropical conditions in the soil of a sugar cane plantation, for example, live eggs of *Ascaris* spp. were found only up to 45 days after fertilization [6].

Nematodes that use this dispersal strategy, among others include: whipworms (*Trichuris* spp.) and roundworms of the *Ascaris* spp. and *Toxocara* spp. (which, however, may also include paratenic hosts in their development cycle). The eggs of these nematodes were selected as indicators in the parasitological assessment of manures and soils because of the features mentioned above: phenomenal resistance to environmental conditions, frequency of

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occurrence and, what is also important, pathogenicity for humans and animals.

The primary source of soil-transmitted helminths (STH) dispersion forms in the environment are the faeces of infected people and animals. In underdeveloped countries, environmental pollution is often direct, in which lack of hygiene, habit of defaecation in outside latrines, pouring excrement onto fields, and breeding animals without pens favour the dispersion of invasive parasite eggs. This situation poses a significant threat to human and animal health [7–12].

In European and North American countries, but also in other countries with a sufficiently high level of hygiene, direct environmental pollution with faeces and the dispersal forms of parasites contained in them is much less important. Human excrement most often ends up in sewage systems, and farm animals are most often bred in closed farms, which isolates them completely, or at least partially, from contact with the environment. This allows for a significant reduction in STH transmission capabilities. However, also in developed countries, despite the lack of direct dissemination of invasive forms of parasites by their hosts, intestinal parasite invasions are still observed [13, 14], and their prevalence in farm animals can be high. One possible explanation for this situation is the use of organic waste for fertilizer purposes. Such waste includes, for example, so-called natural fertilizers (manure, slurry), the use of which is not subject to any hygienic control. These also include sewage sludge from municipal and industrial sewage treatment plants (e.g. from the agri-food industry), digestate from agricultural biogas plants, composts from municipal waste composting plants, etc. In this case, such substances should be tested (including parasitologically) before their introduction into the soil, and in fertilized soils their hygienic condition should also be controlled. However, these actions are not very effective due to, among others, the low sensitivity of the diagnostic methods [15]. Most studies concern urban areas where the soil in parks and sand in children's play areas is most often contaminated with *Toxocara* spp. eggs [16–22].

Parasitological soil examinations are relatively rare due to the belief that parasitological contamination is a problem only in underdeveloped countries and with a tropical climate. The limited number of such studies and the low effectiveness of the diagnostic methods used, mean that the hygienic status of soils in most developed countries is unknown.

Preliminary research for this study was undertaken to determine the contamination with eggs of parasitic nematodes in the soil of arable fields in Poland. The aim of the study was to determine whether such contamination is common enough to be a significant problem, and what factors may influence it. The answer to these questions will allow decisions to be made about the need for further, comprehensive research in this direction.

MATERIALS AND METHOD

Characteristics of the study area. The study was conducted in the 5 provinces of Poland – Dolnośląskie (DS), Mazowieckie (MZ), Podlaskie (PL), Pomorskie (PM) and Zachodniopomorskie Province (ZP). These provinces differed significantly in terms of the area of agricultural land, their agricultural suitability, type of soil, scale of cattle and pig breeding, production of manure and slurry, and the use of manures and organic fertilizers for fertilization [23]. These factors were assessed as having the greatest impact on the level of parasitological contamination of soils [24].

The general characteristics of the selected provinces in terms of the distinguished features of the agricultural economy are presented in Tables 1 and 2.

Table 1. Agricultural land by complexes of agricultural usefulness of soils in individual provinces (according to Statistics Poland, 2022 [25])

Province	Complexes of agricultural usefulness of soils [%]					
	1	2	3	4	5	6
DS	0.54	6.62	33.60	37.49	16.52	5.17
MZ	0.07	0.68	17.04	37.10	28.41	16.62
PL	0	0	6.86	46.00	29.48	17.63
PM	0.22	4.70	23.02	37.41	21.30	13.33
ZP	0	0.87	20.8	51.15	20.47	6.65

1–3 – soils of high productivity; 4–5 – soils of medium productivity; 6 – weak soils

Table 2. Sown area, cattle and pig population, and use of manure and slurry to fertilize fields in individual provinces (according to Statistics Poland, 2022 [25])

Province	Sown area [x1,000 ha]	Manure		Slurry		No. of animals per 100 ha	
		fertilized surface [ha]	t/ha	fertilized surface [ha]	[m³/ha]	cattle	pigs
DS	738	68,857	8,92	13,914	19.98	11.0	17.7
MZ	1269	532,774	13,09	117,565	21.35	58.7	64.0
PL	645	330,697	16,09	151,372	22.16	97.8	32.7
PM	604	104,574	11,83	30,856	20.61	29.4	102.0
ZP	667	74,153	7,58	13,501	19.41	12.1	22.4

As shown by the presented data, differences in selected elements of the agricultural economy between provinces are significant. For example, in the Dolnośląskie Province, up to 40% of the soils are high-productivity (complexes of agricultural usefulness of soils 1–3), while in the Mazowieckie Province, such soils constitute approximately 18% of all soils, and in Podlaskie Province only 6.86%. Most of the so-called natural fertilizers (manure and slurry) are used in the Mazowieckie and Podlaskie Provinces, and least in the Dolnośląskie and Zachodniopomorskie Provinces. Manure was used for fertilization from 9% (DS) to 51% (PL) of the sown area, and slurry from 2% (DS and ZP) to 23% (PL) of the sown area. Another feature that distinguishes the research areas is the structure of animal breeding: in the Podlaskie Province the cattle population reached 98 animals per 100 ha of agricultural land, while in Zachodniopomorskie and Dolnośląskie Provinces, 12 and 11 animals per 100 ha, respectively. In turn, pig breeding was the most developed in Mazowieckie and Pomorskie Provinces (64 and 102 pigs per 100 ha, respectively), and the least numerous were in Dolnośląskie and Podlaskie Provinces (18 and 33 pigs per 100 ha, respectively).

Research scheme. Soil samples were collected between autumn 2021 and spring 2022 from 133 arable fields. Samples were obtained from fields in accordance with the principles of collecting soil samples (according to PN-R-04031:1997 [26]) using a soil stick from a depth of up to 20 cm, with at

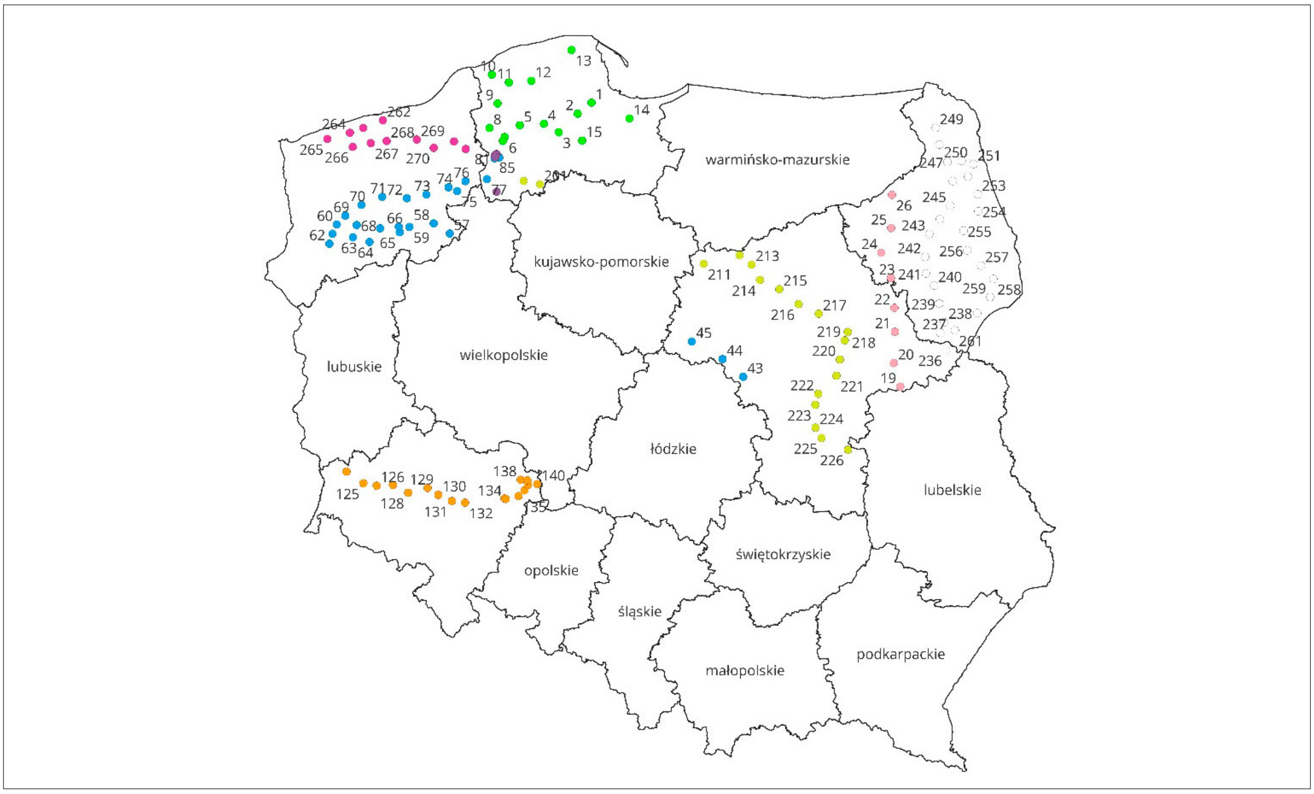

Figure 1. Locations of samples collection

least 10 punctures. An average sample was created from the original samples collected in this way. Sampling locations are shown in Figure 1.

Information about the type of soil occurring in the area from which the samples were taken was obtained from soil and agricultural maps of Poland with a scale of 1:5,000 and 1:25,000, and grouped into appropriate classes according to the World Reference Base for Soil Resources (WRB) soil classification system. Parasitological examination of soil samples was carried out using the PN-Z-19006 method [1]. In each analytical sample weighing 100 g, the detected eggs of *Ascaris* spp., *Trichuris* spp. and *Toxocara* spp. nematodes were counted. The percentages of positive samples (containing parasite eggs) taken in spring and autumn and the percentages of positive samples in individual provinces were compared. The average number of eggs isolated from positive samples taken in both periods and in individual provinces was determined. The number of positive samples taken from soils belonging to particular complexes of agricultural usefulness and soils belonging to particular classes according to WRB.

Statistical calculations. The presence of relationships between the results regarding the presence of eggs in soil samples, the sampling period, location, type of soil, livestock breeding in individual provinces, and fertilization with organic fertilizers were assessed. Statistical analyzes were conducted using the Statistica 7 Pl software by Statsoft. Normality of the distribution of the trait – the number of eggs found – was assessed using the Lilliefors K-S test and the Shapiro-Wilk W test. Due to rejection of the hypothesis about the normal distribution of the trait, further calculations were carried out using the non-parametric tests, U Mann-Whitney, Kruskall Walis's ANOVA, Spearman's R, and comparison of frequencies using the Chi^2, V^2 test (depending on the number of samples). The level of significance in all calculations was $\alpha=0.05$.

RESULTS

Altogether, 139 samples were taken for testing. Parasite eggs were found in a total of 67 samples, of which 56 samples contained eggs of *Ascaris* spp., 23 – whipworms (*Trichiris* spp.) and 3 – *Toxocara* spp. In 53 samples, eggs of only one species of nematode were found (in 43 samples, eggs of *Ascaris* spp., and in 10 eggs of *Trichuris* spp.), in 13 samples eggs of 2 parasite species (in 11 samples eggs of *Ascaris* spp. and *Trichuris* spp., in one sample – *Ascaris* spp. and *Toxocara* spp. and in one sample – *Trichuris* spp. and *Toxocara* spp.). Eggs of all 3 types of parasites were found in one soil sample.

In positive samples containing *Ascaris* spp. eggs, an average of 3.29 eggs/100g (1–18, SD=3.571) was found; in samples containing *Trichuris* sp. eggs, an average of 1.22 eggs/100 g (1–4, SD=0.671), and in samples containing *Toxocara* spp. eggs – one egg in each sample. In the autumn of 2021, 56 samples were collected and in the spring of 2022 – 77 samples, among which 30 and 37 samples containing parasite eggs were found, respectively. The percentage of positive samples collected in autumn (53.57%) was higher than in spring (48.05%), and this difference was statistically significant (Chi^2 test; p=0.002). Similarly, the average number of eggs of all 3 parasite species together in positive samples collected in autumn was 3.43 eggs/100 g, which was higher than in samples collected in spring (2.90 eggs/100 g). This difference was statistically significant, as confirmed by the Mann-Whitney U test (p=0.003834). The number of positive samples and the average number of parasite eggs found in individual provinces are presented in Table 3.

Table 3. Number of positive samples and average number of parasite eggs in soil samples from individual provinces

Province	*Ascaris* spp.		*Trichuris* spp.		*Toxocara* spp.		Total	
	No./% positive samples	Average No. of eggs /100 g	No./% positive samples	Average number of eggs. /100 g	No./% positive samples	Average No. of eggs /100 g	No./% positive samples	Average No. of eggs/100 g
DS (n=21)	4/19.05	1.75	3/14.29	1.00	2/9.52	1.00	5/23.81	2.00
MZ (n=25)	9/36.00	6.22	7/28.00	1.57	2/8.00	1.00	13/52.00	5.31
PL (n=29)	14/48.28	1.79	3/10.43	1.00	0/0	0	16/55.17	1.75
PM (n=27)	22/81.48	4.05	6/22.22	1.17	1/3.70	1.00	22/81.48	4.22
ZP (n=31)	7/22.58	1.00	4/12.90	1.00	0/0	0	11/35.48	1.00

Table 4. Chi^2 * or V^2 ** test value/test probability (p) for differences in the number of positive and negative samples in individual provinces

Province	DS	MZ	PL	PM	ZP
DS (n=21)	-	3.73**/0.0536	4.82**/0.0281	15.63**/0.0001	0.79**/0.3754
MZ (n=25)	3.73**/0.0536	-	0.05*/0.8157	5.03**/0.0249	1.54*/0.2144
PL (n=29)	4.82**/0.0281	0.05*/0.8157	-	4.36**/0.0368	2.35*/0.1256
PM (n=27)	15.63**/0.0001	5.03**/0.0249	4.36**/0.0368	-	12.24**/0.0005
ZP (n=31)	0.79**/0.3754	1.54*/0.2144	2.35*/0.1256	12.24**/0.0005	-

Statistically significant differences are marked in red at significance level α=0.05

As shown in Table 3, in all provinces the most numerous samples contained *Ascaris* spp. eggs (from 19.05 – 81.48% of all samples collected in the province), and the least numerous samples contained *Toxocara* spp. eggs (0 – 9.52% of samples). The highest percentage of positive samples was found in Pomorskie Province (85.19%), and the lowest in Dolnośląskie Province (23.81%). The statistical significance of the differences between the number of positive samples in individual provinces was calculated using the Chi^2 andV^2 test (Tab. 4).

Also, the average number of eggs of all 3 types of parasites detected in soil samples was the highest in the Pomorskie and Mazowieckie Provinces (4.22 and 5.31 eggs/100 g, respectively), and the lowest in the Zachodniopomorskie and Podlaskie Provinces (1.00 and 1.75 eggs/100g, respectively). The statistical significance of differences between the number of eggs detected in soil taken in individual provinces was determined by the Kruskall-Wallis ANOVA Rank test. The value of the Kruskall-Wallis test was H (4, N= 133) =30.45159, and the test probability level was p=0.0000, which allows the conclusion that the place (province) where the soil was collected has a significant impact on the number parasite eggs found in the sample (Tab. 5).

As shown by the data presented in Table 5, statistically significant differences occurred between the number of eggs isolated from samples taken in the Pomorskie Province and Dolnośląskie, Podlaskie, Zachodniopomorskie Provinces.

Table 5. P-value of multiple comparisons for the average number of parasite eggs isolated from soil samples collected in different provinces

Province	DS R:48.262	MZ R:74.340	PL R:66276	PM R:95.241	ZP R:49.855
DS		0.222503	1.000000	0.000279	1.000000
MZ	0.222503		1.000000	0.507014	0.180988
PL	1.000000	1.000000		0.049477	0.990728
PM	0.000279	0.507014	0.049477		0.000077
ZP	1.000000	0.180988	0.990728	0.000077	

R – average rank for the tested method. Statistically significant differences are marked in red at significance level α=0.05. Kruskall-Wallis test: H (4, N=133) =30.45159; p=0.0000.

The obtained results were related to animal breeding, i.e. the number of cattle and pigs per 100 ha of agricultural land and the use of manures in a given province. In the provinces where the lowest percentage of soil positive samples was found (DS and ZP), the lowest amount of manure per one ha of fields was used for fertilization (8.92 and 7.58 t/ha, respectively). In other provinces (MZ, PL and PM), the amount of manure used to fertilize fields was higher and ranged from 11.83 – 16.35 t/ha. Similar relationships occurred in the case of slurry application, although the observed differences were smaller. A similar relationship was observed between the results obtained and the density of animal breeding, especially pigs. The largest number of pigs per 100 ha of agricultural landwais recorded in the PM (102 pigs/ 100 ha). This province also had the highest percentage of positive samples and a high average number of parasite eggs isolated from the sample (4.36). In turn, in provinces with the least numerous pig farms (DS and ZP – 17.7 and 22.4 pigs/100 ha, respectively), the lowest percentage of positive samples (23.8 and 35.5%, respectively) and the lowest average number of eggs ithe sample (average 2 and one egg/positive sample). These relationships were assessed using the non-parametric Spearmann's R correlation test (Tab. 6).

As shown by the data presented in Table 6, statistically significant correlations at α = 0.05 were obtained between the percentage of positive samples and the number of pigs kept in individual provinces per 100 ha of agricultural land. Statistically significant correlations also occurred between cattle breeding (number of animals per 100 ha of agricultural land) and the use of natural fertilizers. Such correlation was not observed in the case of pig farming.

In the next stage, parasitological contamination of samples belonging to different soil classes was analyzed. The number of samples assigned in individual provinces to different soil classes according to WRB, along with the number of samples in which parasite eggs were found, are presented in Tables 7 and 8.

The presented data show that the soils belonging to the Cambisols, Luvisols and Brunic Arenosols classes were most represented in the study, and the Fluvisols, Histosols, Podosols and Hemic Histosols classes were the least numerous. In

Table 6. Spearman's rank correlation of the results of parasitological examination of soil samples in individual provinces, the use of natural fertilizers and the density of cattle and pig farms

Zmienna	Positive samples (%)	Average no. of eggs in positive sample	Manure-fertilized surface (ha)**	Manure (t/ha)	Slurry-fertilized surface (ha)**	Slurry [m³/ha]	Cattle (animal /100 ha)**	Pigs (animal /100 ha)**
Positive samples (%)	-	0.300000	0.600000	0.600000	0.600000	0.600000	0.700000	0.900000
Average No. of eggs in positive sample	0.300000	-	0.500000	0.400000	0.400000	0.400000	0.200000	0.600000
Manure – fertilized surface (ha)**	0.600000	0.500000	-	0.800000	0.800000	0.800000	0.900000	0.700000
Manure (t/ha)	0.600000	0.400000	0.800000	-	1.000000	1.000000	0.900000	0.500000
Slurry- fertilized surface (ha)**	0.600000	0.400000	0.800000	1.000000	-	1.000000	0.900000	0.500000
Slurry [m³/ha]	0.600000	0.400000	0.800000	1.000000	1.000000	-	0.900000	0.500000
Cattle (animal/100 ha)**	0.700000	0.200000	0.900000	0.900000	0.900000	0.900000	-	0.600000
Pigs (animal /100 ha)**	0.900000	0.600000	0.700000	0.500000	0.500000	0.500000	0.600000	-

Statistically significant correlations are marked in red at α=0.05 significance level

Table 7. Number of samples taken in individual province from fields with different soil types and the number of samples containing parasite eggs

Province	Soil types (according to WRC)									
	No. of samples tested/number of samples containing parasite eggs									
	Arenosols	*Brunic Arenosols*	*Cambisols*	*Fluvisols*	*Gleyosols*	*Hemic Histosols*	*Histosols*	*Luvisols*	*Podosols*	*not classified*
DS	1/1	1/0	4/0	0/0	6/2	0/0	0/0	6/1	2/1	1/0
MZ	2/1	4/3	2/2	1/0	2/1	2/0	1/1	11/5	0/0	0/0
PL	1/1	6/5	12/6	0/0	4/3	1/0	0/0	5/1	0/0	0/0
PM	2/2	13/11	7/4	1/1	0/0	0/0	1/1	2/2	0/0	1/1
ZP	4/1	4/1	13/4	0/0	3/3	0/0	0/0	6/1	0/0	1/1
Total	10/6	28/20 */**	38/16**	2/1	15/9	3/0	2/2	30/10*	2/1	3/2

*/**statistically significant differences V^2 (α=0.05).

individual provinces, samples from the following soil types predominated – in DS Gleyosols and Luvisols. in MZ – Luvisols. in PL and ZP Cambisols. and in PM – Brunic Arenosols. Among soil samples with a total number (in all provinces combined) of ≥10, parasite eggs were most often found in soil samples of the Brunic Arenosols type (71.4% contained parasite eggs), and the least in soil samples of the Luvisols type (33.3% of samples) and Cambisols (42.1% of samples). The differences between the number of samples containing eggs in Brunic Arenosols and Luvisols and between Brunic Arenosols and Cambisols soils were statistically significant (V^2 test). Due to the too small number of samples of individual types of soil in individual provinces, no statistical analyzes in this direction were carried out for individual regions. The relationship between the type of topsoil and the occurrence of parasitological contaminants in the soil was also analyzed (Tab. 8).

Table 8. Parasitological contamination of samples taken from fields with different soil textural classes

Soil textural classes	No. of samples		Average number of parasite eggs in a positive sample
	Collected	Positive (with parasite eggs)	
clayay silt	2	2	2.0
fen peat	2	2	3.0
heavy silty loam	1	0	0
light loam	10	7**	3.4
light silty loam	4	0	0
loamy heavy sand	11	7	3.0
loamy light sand	37	12*/**	1.7
loamy silty heavy sand	4	1	5.0
loamy silty light sand	7	2	3.0
loose sand	5	3	5.3
medium silty loam	4	1	2.0
muck	1	0	0
not classified	3	2	1.0
sandy gravel	1	0	0
silt	5	3	2.0
slightly loamy sand	36	25*	4.0

statistically significant differences (– Chi^2. ** – V^2.) (α=0.05)

The data in Table 8 indicate that in the areas from which samples were taken for testing, the topsoil layers were dominated by loamy light sand (37 samples), slightly loamy sand (36 samples), loamy heavy sand (11 samples), and light loam (10 samples). Together, these four soils textural classes occurred in over 70% of all samples. Parasite eggs were found in 63–70% of samples with such characteristics; only in samples taken from fields with the topsoil layers classified as loamy light sand, the percentage was approximately twice as low and amounted to 32.4%. These differences were statistically significant. The average number of parasite eggs isolated from these samples was also twice as low than in the remainder, and amounted to 1.7 eggs/positive sample (the remaining 3 types averaged 3.0–4.0 eggs/positive sample).

DISCUSSION

The study was carried out on soil samples collected in autumn 2021 and spring 2022 from 133 fields located in the Dolnośląskie, Mazowieckie, Podlaskie, Pomorskie and Zachodniopomorskie Provinces. The presence of nematode eggs from the *Ascaris* spp., *Trichuris* spp. or *Toxocara* spp. was found in 67 samples (50.38%). The eggs of *Ascaris* spp. were the most frequently and abundantly found, the eggs of *Trichuris* spp. were less numerous and the eggs of *Toxocara* spp. were found only occasionally in soil samples taken from arable fields. It is difficult to compare these data directly with data published by other authors due to the lack of publications on parasitological contamination of strictly defined arable soils, both in Poland and worldwide. This is scarcely understandable because parasitological contamination of soil is considered primarily as a threat to human health. Most of the available data from the last 20–30 years come from studies carried out in soils from inhabited areas – cities and villages [20, 27–30], including places used as children's play areas, e.g. sandboxes and city parks [16, 17, 32–36], as well as from school premises (including rooms used as classrooms) [37, 38]. Subsequently, these include, for example, soil collected from farm animal farms and their immediate vicinity [24, 39, 40], from gardens and fields fertilized with sewage, and from where plants intended for direct consumption (vegetables and fruits) are cultivated [9, 24, 41]. There are very few articles describing research conducted on specific agricultural fields, e.g. on the so-called organic farms [22]. Often, soil samples from fields have only supplemented the main research conducted by the authors, and the number of samples taken from the fields was small [42]. As mentioned in the Introduction, research on parasitological contamination of soil has been dominated by studies carried out in countries with a tropical climate, primarily in underdeveloped countries.

It should be emphasized that in the cited publications the percentage of positive samples and the number of isolated eggs varied greatly. In soil samples taken from the vicinity of residential houses, schools, markets, etc., they range from 3.3% of samples containing STH eggs [38] to 70–75% [28], and even up to 100% [36]. In most studies, roundworms of the *Ascaris* spp. were the dominant species. In soil samples collected from pig farms, all samples were contaminated with parasite eggs [39]. In arable soil samples, the percentage of samples containing STH eggs ranged from a few to over 40%, with surprisingly similar results obtained in places as distant and with different climatic conditions, as e.g. Poland and the Philippines [22, 24]. In the current study, the percentage of positive samples (50%) is close to the latter two studies, even though the research in the presented work includes samples taken from arable fields, i.e. from places that are not so carefully tended (but also fertilized with organic fertilizers), such as vegetable gardens. In the current study, a higher percentage of positive samples was recorded in autumn. Research by many authors indicates differences in the occurrence of parasite eggs in the soil depending on the period of sampling. However, most of them found a more frequent occurrence of eggs in spring and summer [21, 41, 43]. The more frequent occurrence of parasite eggs in samples taken in autumn can be explained by the timing of fertilizing fields with natural fertilizers, where many farmers prefer fertilization in late summer and autumn (i.e. after harvest). In spring in such fields, after the winter, the number of parasite eggs may decrease as a result of unfavourable weather conditions during the winter, as well as due to the movement of eggs with rainfall into the soil to a level below the layer from which the samples were taken. This possibility is confirmed by research showing that STH eggs disappear from the topsoil very quickly [44].

The differences in the occurrence of STH eggs in individual provinces are interesting. Positive samples were found more than twice as often in Podlaskie Province (in Pomorskie even 4 times more often) than in Dolnośląskie Province. Importantly. these differences were statistically significant. In the opinion of the authors of the presented study, the explanation for this phenomenon should be sought primarily in the differences in agricultural practices in these regions. As farm animals generally do not have direct access to agricultural fields, it should be assumed that the main source of STH eggs contaminating soils are organic fertilizers, above all the so-called natural fertilizers used to fertilize fields. However, the statistical analyzes performed did not show any statistically significant correlations between the percentage of positive samples in provinces, and the amount of natural fertilizers used. However, it should be noted that the available statistical studies do not specify the origin of these fertilizers.

A high and statistically significant positive correlation between the number of cattle per 100 ha of agricultural land and the area of fields fertilized with manure and slurry, as well as the amount of these fertilizers used per 1 ha (and additionally the lack of a strong correlation in the intensity of pig farming), indicate that mainly cattle manure and cattle slurry are used to fertilize fields. Manures from pig farming do not constitute such a significant contribution to the fertilization process of arable fields which, however, does not negate their significant impact on the level of parasitological contaminations occurring in the soil. It should be emphasized that the two main species of STH whose eggs were found in soil samples (*Ascaris* spp. and *Trichuris* spp.) are associated with pigs in their development cycle, and are commonly found in this host species, while in cattle, only whipworms may occur in a small percentage of animals [45–48]. Therefore, the results (percentage of positive samples) show a strong positive and statistically significant correlation with the number of pigs kept in a province per 100 ha, and not with the total amount of natural fertilizers used or the density of cattle breeding. Therefore, the number of soil samples containing STH eggs in the Pomorskie Province (where the number of pigs bred per 100 ha is 2–5 times higher than in other provinces) is significantly higher than the number of such samples obtained from other regions. Similarly, the average number of eggs isolated from samples taken in the Pomorskie Province is significantly higher than those collected in the Dolnośląskie, Podlaskie and Zachodniopomorskie Provinces.

The presented study also showed statistically significant differences between the numbers of samples of different types of soil containing parasite eggs. A significantly higher percentage of samples containing parasite eggs was found in Brunic Arenosols soils than in Cambisols and Luvisols soils. Similarly, when analyzing the top layer of soil in loamy light sand soils, a lower percentage of positive samples was found than in slightly loamy sand and light loam soils. These differences were statistically significant. This uneven parasitological contamination of different types of soil may result from a number of reasons, starting from differences in soil permeability and the rate of leaching of particles (e.g. parasite eggs) from the top layer of soil into deeper layers [49, 50]. It may also be caused by differences in the survival period of parasite eggs in different types of soil. It was found that heavy, clay, water-retaining soils are an environment more favourable to the development of roundworm and whipworm eggs than sandy, less water-retaining soils, although these relationships are not easy to describe with a simple correlation [49]. In the current study, the emerging (statistically significant) differences in the frequency of eggs in different types of soil may result, for example, from the occurrence of such types of soil in areas with intensive pig breeding, and not their properties. Finally, they may result from the agrotechnical treatments used on arable fields with different productivity (including fertilization with natural fertilizers). However, confirmation of these relationships require further investigations.

CONCLUSIONS

1) Arable soils in Poland are commonly contaminated with STH eggs, although the number of eggs per unit of mass of the surface soil layer is not high.
2) Contamination of arable soils with STH eggs is higher in autumn than in spring.
3) There is a relationship between the contamination of arable soils with STH eggs, and the structure of livestock breeding in a given area.

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