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Influence of 90-Year Potato and Winter Rye Monocultures under Different Fertilisation on Soil Mites

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Abstract

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The influence of the cultivation of a single crop (potato or winter rye) on mite assemblages was evaluated. Both crops were cultivated in a long-term monoculture (90 years). The response of mites to fertilisation treatment (mineral with manure or mineral alone) was also studied. It was hypothesised that the density of mites as a community and the density of particular mite groups are higher in winter rye crop in comparison with potato. Secondly, the fertilisation with manure is more beneficial for mites than the use of mineral fertilisers alone, both in winter rye and potato crops. Results showed significantly higher mite abundance in potato, mainly due to Prostigmata dominance. Oribatida and Gamasida groups were significantly more numerous in winter rye. The fertilisation type, except for the suborder Astigmata, had no significant influence on the mite community.

Keywords: Acari; long-term monoculture; crop; mineral fertilisation; manure

Mites (Acari) constitute the most abundant group of arthropods in soil throughout the world, and can reach up to 100 000 individuals per m^2. Soil mites, living in the upper soil horizon, are classified into four main suborders: Gamasida, Prostigmata, Astigmata, and Oribatida (Gulvik 2007). Luxton (1972) distributed mites into 5 (or 4?) feeding groups: macrophytophages (Oribatida and saprophagous Gamasida), microphytophages (most of Astigmata and some Prostigmata), microphytophages that are facultative predators (other Gamasida), and necrophages. Additionally Siepel and de Ruiter-Dijkam (1993) found 5 (or 4?) major groups within the suborder Oribatida with different feeding guilds: herbivorous grazers, fungivorous grazers, herbo-fungivorous grazers, fungivorous browsers. These trophic groups use a wide range of ecological strategies in order to exploit all resources available in the soil layer (Vannier 1985). The main part of mites found in the arable fields are mostly secondary decomposers (especially Oribatida and some Astigmata), and act by stimulating the activity of microorganisms within the soil (Walter & Proctor 1999; Gulvik 2007). Considering the vertical distribution of mites, Prostigmata and Gamasida live mostly in the upper soil layer and litter, Oribatida in all soil layers, while Astigmata in deeper organic soil horizons (Petersen & Luxton 1982). The upper level of the soil food web is represented mostly by predatory Gamasida mites (Koehler 1999). Prostigmata are considered as the most differentiated group of Acari, both in morphological and ecological characteristics.

Because soil mites respond relatively quickly to land use changes, ecological groups or single species are used as significant indicators of soil quality and health (Koehler 1999; Gulvik 2007). Especially

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Oribatida abundance and species diversity indicate different changes in the soil ecosystem, for example heavy metal contamination (Skubała *et al*. 2014). However, as described by Gergós and Hufnagel (2009), the response of Oribatida to different environmental factors, such as temperature, heavy metal concentration, organic matter content or agricultural management, is usually complex and needs wider studies. For example Smrž *et al.* (2015), analysing the migration of Oribatida between arable field and unploughed area, distinguished groups with different levels of adaptation from ubiquitous species to specialist ones. Another study of this author (Smrž 1996) showed differentiated adaptation of Oribatida to extreme moisture conditions.

Agricultural treatments have a negative impact on mite density. This mostly results from the destruction of upper horizons, exposure to desiccation, modification of habitat, and disruption of access to food sources (Fox *et al*. 2014). Probably for these reasons, soil Acari generally occur in greater numbers in no-till farming in comparison with the conventional tillage system (Twardowski 2010). The influence of monoculture and crop rotation on another mesofauna group, i.e. springtails, was previously studied (Gruss & Twardowski 2016; Twardowski *et al.* 2016). Only few authors have studied the influence of plant species on Acari. Wissuwa *et al*. (2012) indicated that Gamasida in grassland ecosystems are associated with a single plant species. Badejo *et al*. (2002) reported the preference of Oribatida for legumes. To our knowledge only one paper considers the effect of a single crop on mite assemblages (Gruss *et al*. 2013).

In the present study, we investigated a possible influence of the cultivation of a single crop (potato or winter rye) on mite assemblages. Both crops were cultivated in a long-term monoculture (90 years), whereby there was no influence of other plants. Twardowski *et al*. (2016) indicated that springtails inhabiting the soil cultivated under long-term monoculture have a longer adaptation time to a particular crop in comparison with crop rotation. We suppose that the same mechanism occurs in the case of mites, classified with Collembola to soil mesofauna. In the soil cultivated under long-term monoculture it is possible to study the direct effect of the crop on soil mites, and reduce the influence of other factors. Secondly, we considered the response of mites to fertilisation treatment (mineral with manure or mineral alone).

In the study the following hypotheses were tested:

(1) Potato and winter rye are plants which distinctly differ in cultivation treatments and affect soil conditions and soil biodiversity in different ways. The density of mites as a community and the density of particular mite groups are higher in winter rye crop in comparison with potato. Winter sown crops, being bacteria-dominated systems, are beneficial for soil fauna (DuPont *et al*. 2009).

(2) Fertilisation with manure is more beneficial for mites than the use of mineral fertilisers alone, both in winter rye and potato crops. Manure increases the soil organic matter content, improves other soil physicochemical properties (Bogužas *et al*. 2015), and increases microbial biomass and activity (Scherer *et al*. 2012). All these factors create a more preferable habitat for mites.

MATERIAL AND METHODS

Experimental site. The potato and winter rye crops were sited at the Experimental Station in Skierniewice, affiliated to the Faculty of Agriculture and Biology at Warsaw University of Life Sciences (SGGW) in Poland (51.966135N, 20.163874E). The experiments were established in both crops in 1923 and have continued uninterrupted to the present time. This specific experiment was conducted in 2011–2013, on the potato and winter rye crop, cultivated in 90-year monocultures. The agricultural treatments in potato and winter rye are presented in Table 1. The cultivars did not change during the study period. Crop type and fertilisation type were two experimental factors. Both crops were fertilised with either CaNPK alone or CaNPK with farmyard manure (30 t/ha every 5th year).

In the experiment a split-plot design with five replicates was used. The plots of 36 m^2 (12 m × 3 m) in potato and winter rye were randomly arranged in two blocks. The distance between the blocks was 3 m and 1 m between the plots. The distance from the edge of the field was at least 12 m which allowed us to avoid edge effects. The soil from individual plots was not mixed during the agricultural practices.

The climate of the study area is transitional, between maritime and continental, with a mean temperature of +8.6°C (the highest in July and the lowest in winter time) and mean rainfall of 538 mm (the highest in July and the lowest in January or February). Potato and winter rye were grown on Stagnic Luvisol,

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Table 1. Agricultural treatments in potato and winter rye crops

Treatment	Potato cv. Bila	Winter rye cv. Dankowskie Złote
Fertilisation CaNPK	CaO – 1.6 t/ha every 4 years (applied in 2008 and 2012), N (ammonium nitrate) – 90 kg/ha, P_20_5 (superphosphate) – 60 kg/ha, and K_2O (potassium salt) – 91 kg/ha every year	
CaNPK+manure	CaO – 1.6 t/ha every 4 years (applied in 2008 and 2012), N (ammonium nitrate) – 90 kg/ha, P_20_5 (superphosphate) – 60 kg/ha, and K_2O (potassium salt) – 91 kg/ha every year, 30 t/ha of farmyard manure every 5 years (applied in 2010)	
Plant protection	herbicides: linuron, clomazone fungicides: fluazinam, mancozeb, propamocarb, chlorothalonil	herbicides: iodosulfuron, 2,4-D acid from 2 EHE, 2,4-dichlorophenoxyacetic acid, chlorsulfuron
Other	ploughing to a depth of 25 cm harrowing ploughing to a depth of 15 cm potato planting ridging	disking to a depth of 10 cm oloughing to a depth of 25 cm harrowing (5–8 cm) winter rye sowing

with clay and silt content in soil layers (IUSS 2015). Selected soil physico-chemical parameters were measured since spring 2012 in each of soil samples (soil moisture) or in one sample from each plot (pH). The soil temperature was measured on each plot. Soil organic matter was analysed only in one year (spring 2012) from a single composite sample from each treatment. The soil temperature on particular sampling dates ranged from 10°C to 18°C and did not differ between treatments. The soil moisture oscillated from 3.8% to 12.8% during the study. Only in autumn 2013 did the soil moisture differ distinctly between treatments. Relatively lower soil moisture was measured in potato in comparison with the rye crop. Soil pH measured in H_20 ranged from 5.7 to 7.7 and when measured in KCl, it was from 5.5 to 7.0. Only on one sampling date, i.e. in spring 2012, was the soil pH distinctly lower in the potato crop

Table 2. Soil physicochemical properties in potato and winter rye crops

	Crop	Fertilisation	Spring 2012	Autumn 2012	Spring 2013	Autumn 2013
Temperature (°C)	rye	CaNPK	13.3 ± 0.2	13.1 ± 0.2	17.4 ± 0.2	10.0 ± 0.4
		CaNPK+manure	12.9 ± 0.4	13.2 ± 0.6	17.2 ± 0.4	9.9 ± 0.9
	potato	CaNPK	11.5 ± 0.4	13.1 ± 0.3	18.0 ± 0.3	10.0 ± 0.2
		CaNPK+manure	11.9 ± 0.2	13.2 ± 0.1	17.8 ± 0.32	10.1 ± 0.2
Moisture (%)	rye	CaNPK	12.6 ± 0.2	10.4 ± 0.2	11.7 ± 0.4	10.8 ± 0.3
		CaNPK+manure	11.0 ± 2.7	12.5 ± 1.1	11.5 ± 1.9	12.8 ± 3.4
	potato	CaNPK	9.5 ± 0.3	10.6 ± 0.3	10.5 ± 0.3	7.4 ± 0.2
		CaNPK+manure	10.9 ± 0.2	12.6 ± 0.2	11.1 ± 0.2	7.4 ± 0.2
pH_{H_20}	rye	CaNPK	7.1 ± 0.05	7.6 ± 0.4	7.2 ± 0.6	7.3 ± 0.3
		CaNPK+manure	6.9 ± 0.2	7.7 ± 0.1	7.3 ± 0.2	7.0 ± 0.1
	potato	CaNPK	6.3 ± 0.2	7.7 ± 0.2	7.3 ± 0.3	7.0 ± 0.2
		CaNPK+manure	5.7 ± 0.3	7.6 ± 0.2	7.4 ± 0.1	7.1 ± 0.2
pH_{KCl}	rye	CaNPK	6.4 ± 0.1	6.3 ± 0.3	6.6 ± 0.4	7.0 ± 0.1
		CaNPK+manure	6.1 ± 0.1	6.3± 0.3	6.8 ± 0.2	6.9 ± 0.3
	potato	CaNPK	5.8 ± 0.2	5.9 ± 0.2	6.6 ± 0.1	6.4 ± 0.2
		CaNPK+manure	5.5 ± 0.2	7.1 ± 0.3	6.7 ± 0.3	6.6 ± 0.3
			Organic matter (%)		Humus content (%)	
Potato		CaNPK	0.41		0.71	
		CaNPK+manure	0.38		0.66	
Rye		CaNPK	1.45		2.50	
		CaNPK+manure	1.85		3.18	

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in comparison with rye. Organic matter and humus contents were distinctly higher in the winter rye crop in comparison with potato, regardless of the fertilisation treatment (Table 2).

Sampling. Soil samples in potato and winter rye were collected on the same dates. In potato soil samples were collected twice in spring two weeks before potato planting, and twice in autumn two weeks after harvest. In winter rye in autumn the soil was sampled when plants were at the germination stage (BBCH 1–5, i.e. according to the scale used to identify the phenological development stages of a plant) and at the leaf development stage (BBCH 11–15). In spring the soil samples were taken at the stage of two tillers and stem elongation (BBCH 22–33) and during inflorescence emergence (BBCH 51–55).

On each sampling date 25 soil samples were collected from each treatment (5 per plot, across the plot diagonal) using a metal core sampler (5 cm diameter, 10 cm depth) with a cutting edge. Samples were placed in plastic bags and then transported to the laboratory. Soil arthropods were extracted from the soil over 24 h with the use of Tullgren funnels modified by Murphy (1962). The efficacy of Tullgren funnels was checked in preliminary studies. It was proved that 24 hours are a sufficiently long period to extract all mites from soil samples. After extraction mites were counted under a stereomicroscope and classified to the following groups: suborder Oribatida, order Gamasida, suborder Prostigmata, cohort Astigmata. For the determination the keys of Walter and Proctor (2001) and Gerson (2007) were used.

Biological indices and data analysis. The abundance of Acari was calculated separately for spring and autumn, and the soil chemical data were analysed for each sampling date. The mite abundance from each sample was calculated per 1 m^2. For this purpose the proportion was used, comparing the mite number from the surface of soil sampler (0.0019625 m^2) to the number of mites per 1 m^2. Some of the data did not show the normal distribution. Thus the nonparametric test was chosen for analysis. Data were analysed by the Kruskal-Wallis test ($P \leq 0.05$) in Statistica v12 software package. In order to show significant differences, multiple comparisons of *P*-values were used.

The relationship between the occurrence of Acari suborders and different crops, sampling season (spring and autumn), fertilisation treatment, as well as soil moisture was explored using the Canonical Correspondence Analysis (CCA), CANOCO Version 4.5 (Ter Braak & Smilauer 2002). The statistical significance of the first canonical axis and of all canonical axes was tested by a Monte Carlo permutation test ($P \leq 0.05$) (499 permutations under reduced model).

RESULTS

During the 3-year study 15 201 individuals were collected. The abundance of mites differed significantly between the crops in the spring season (H = 14.30, P = 0.0002) (Figure 1). In spring the mites were significantly more numerous in the potato crop in comparison with winter rye in both fertilisation treatments. However, relatively high values of standard deviations were computed, especially in potato crop. In potato, the number of mites was 15 026 individuals per m^2 in CaNPK fertilisation treatment and 12 263 individuals per m^2 in CaNPK with manure treatment. In winter rye about 4086 individuals per m^2 were noted in CaNPK fertilisation and 4996 individuals per m^2 in CaNPK with manure fertilisation. In autumn no significant differences were found either between crops or fertilisation treatments.

The density of mite groups was presented separately for the spring and autumn seasons (Table 3). In spring, Oribatida and Gamasida were significantly more numerous in winter rye in comparison with potato crop in treatment where CaNPK and manure were applied (H = 36.67, $P < 0.001$; H = 106.18, $P < 0.001$, respectively) (Table 3). Prostigmata were significantly more abundant in potato crop, but only in CaNPK fertilisation. Only Astigmata were significantly affected by fertilisation. In winter rye crop relatively more mites were found in treatment where CaNPK and manure were applied (H = 4.60, P = 0.032).

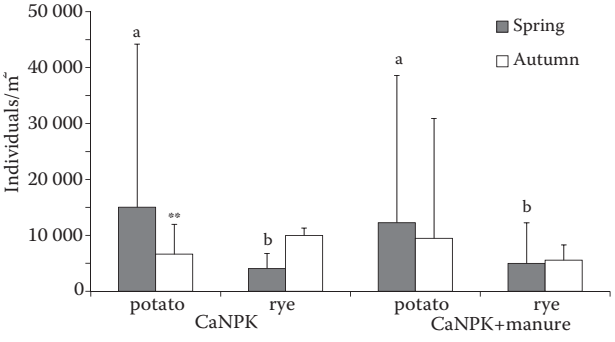

Figure 1. Mean density of mites per m^2 in potato and winter rye crops in three experimental years

Different small letters denote significant differences between sites based on the Kruskal-Wallis test, $P \leq 0.05$; **standard deviation

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Table 3. Mean density of mite groups per m^2 in potato and winter rye crops in spring and autumn in three experimental years

		CaNPK		CaNPK+manure		*F*, *P*	
		potato	rye	potato	rye	crop	fertilisation
Spring	Oribatida	1215.09 ± 1572.71	1278.98 ± 1087.08	1111.75 ± 796.20^b	1234.25 ± 1143.20^a	**36.67**, **< 0.001**	0.168, 0.68
	Gamasida	2052.32 ± 4152.32^b	3062.42 ± 3162.31^a	2024.63 ± 1997.78^b	2352.44 ± 2926.56^a	**106.18**, **< 0.001**	1.096, 0.29
	Prostigmata	10000.00 ± 46084.08^a	420.94 ± 724.81^b	20897.38 ± 86157.01	20799.07 ± 64087.58	**140.28**, **< 0.001**	1.000, 0.32
	Astigmata	5925.05 ± 12689.49	1153.20 ± 122.96^B	3945.99 ± 3509.61	1528.66 ± 2010.73^A	3.42, < 0.064	**4.60**, **0.032**
Autumn	Oribatida	642.70 ± 1142.90^b	1844.59 ± 1598.56^a	1194.80 ± 1021.60^b	3124.62 ± 1193.99a	**12.31**, **0.004**	0.10, 0.75
	Gamasida	1066.10 ± 1666.7^b	4100.70 ± 1991.96^a	1554.60 ± 2882.10^b	7327.53 ± 2893.32^a	**91.93**, **< 0.001**	0.60, 0.44
	Prostigmata	5454.20 ± 10908.40^a	2390.05 ± 3137.78^b	10220.80 ± 63721.80^a	2982.39 ± 3182.36^b	**114.79**, **< 0.001**	0.02, 0.88
	Astigmata	3401.30 ± 6431.30^a	2157.64 ± 2006.87^b	2377.90 ± 3497.90^b	4569.55 ± 2440.80^a	**29.22**, **< 0.001**	1.12, 0.29

Different superscript letters denote significant differences between sites based on multiple comparisons of *P*-values (Kruskal-Wallis test, $P \leq 0.05$); small letters (a, b) marked on the line, denote significant differences between crops in the same fertilisation treatment whereas capital letters (A, B) denote significant differences between fertilisation treatments within the same crop; bold values denote significant differences

In autumn Oribatida, and Gamasida were significantly more numerous in winter rye than in potato in both fertilisation treatments (H = 12.31, $P = 0.004$; H = 91.93, $P < 0.001$, respectively) (Table 3). The opposite results were obtained in the case of Prostigmata. The mean number of Prostigmata was significantly higher in potato than in winter rye, regardless of the fertilisation treatment (H = 114.79, $P < 0.001$).

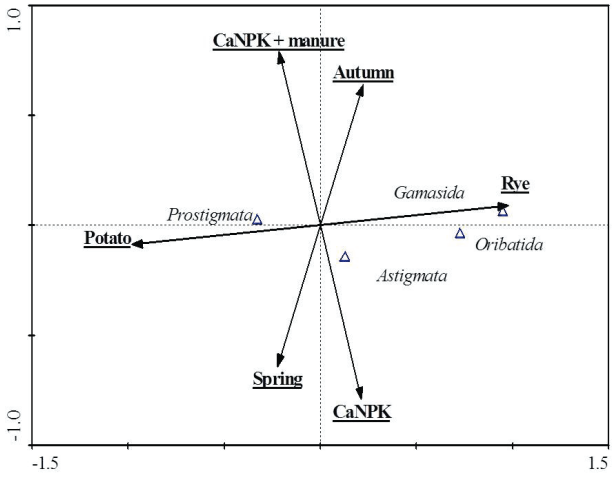

Figure 2. Canonical correspondence analysis biplot of Acari suborders in potato and winter rye crops

Considering Astigmata, they were significantly more numerous in potato but only with CaNPK fertilisation. In the second fertilisation treatment (CaNPK with manure) they were significantly more abundant in winter rye (H = 29.22; $P < 0.001$).

In CCA the cumulative percentage variance of the species-environment relation was 95.8% for the first canonical axis (Monte Carlo test: $P = 0.002$) (Figure 2). This axis was positively correlated with soil moisture and rye crop and negatively with potato crop. Fertilisation and sampling date were in gradient 2 of CCA and had only a low impact on mite occurrence. Gamasida and Oribatida were more abundant in winter rye crop and were positively correlated with soil moisture. Conversely, Prostigmata were more abundant in potato crop. Astigmata were located between these two crops.

DISCUSSION

Petersen and Luxton (1982) found in different habitats mostly 20 000 (arable field) to 200 000 (forest) mites per m^2. In grassland ecosystems the mite abundance reached up to 100 000 individuals

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per m^2 (Curry 1994). In the present study the mite abundance did not exceed 15 000 individuals per m^2. Against expectations and the findings of other authors (Gruss *et al*. 2013), mites as a community were generally more numerous in potato. However, considering the high values of standard deviations especially in potato crop, these results should be interpreted carefully. Also analysing other groups of invertebrates, such as springtails (Frampton & van den Brink 2002) and nematodes (DuPont *et al*. 2009), higher abundance was found in winter-sown crops than in spring crops.

The abundance of all groups of mites in the present study shows relatively high values of standard deviations, which indicates high spatial heterogeneity. This could be caused by environmental factors, especially soil pH (Zhang *et al.* 2015) or soil moisture (Sylvain *et al.* 2014). Another reason could be the food supply inside the ecosystem and the level of microhabitat transformation (Smrž *et al.* 2015). The belowground source of organic matter like decaying roots often shows the heterogeneity of spatial patterns, which corresponds with the spatial patterns of mites (Ducarme & Lebrum 2004). Berg and Bengtsson (2007) observed that the differences in the spatial scale of aggregation are related with taxon and life stage of organisms, ecosystem, soil horizon, as well as the spatial scale of sampling. The spatial heterogeneity grows with the distance of sampling (Berg & Bengtsson 2007). In the present study the variability of soil conditions in the field could be a reason for high spatial heterogeneity. The distance between soil samplings on a single plot was relatively short (about 2 m), but the average was calculated from 5 plots in a randomised plot design spaced by a distance of even 30 m.

We can agree only in part with the first hypothesis. The results of the abundance of mite groups in spring and autumn as well as the results of CCA indicate different habitat preferences of particular mite taxa. We suppose that the higher Oribatida and Gamasida abundance in rye was mostly caused by the relatively higher level of organic matter in that habitat. High levels of organic matter in the soil benefit biodiversity and are an important determinant of mesofauna abundance on a local scale (Mäder *et al*. 2002). We also observed that these two mite suborders were positively related with soil moisture. Wissuwa *et al*. (2013) and Zhu and Zhu (2015) found a significant positive correlation between soil organic matter content and Oribatida abundance. Bedano and Ruf (2007), Salamon *et al*. (2011) as well as Wissuwa and Salamon (2012) reported a significant influence of soil organic matter on Gamasida density. The relationship between Gamasida and soil organic matter is indirect. Some studies demonstrated that high amounts of organic matter are beneficial for bacterial and fungal growth (Scheder *et al.* 2012). Microorganisms in turn are a food base for Collembola, nematodes and Oribatida, which influence higher trophic levels like predatory mites (Scheu & Falca 2000). We agree with the suggestions of Frampton and van den Brink (2002) explaining the higher springtail abundance in winter-sown crops, and suppose that a similar mechanism occurs in the case of mites. These authors indicated as the most important factors the late development of canopy vegetation in the case of spring crops, creating unfavourable soil conditions for mesofauna. Secondly, spring crops are negatively affected by the timing of agricultural practices. The timing of practices in spring crops (spring and autumn) coincides with the increasing activity of soil mesofauna (Twardowski *et. al.* 2016). We observed a distinct preference of Prostigmata to potato crop, especially in the autumn season. Prostigmata are a group with heterogeneous life history traits (Gulvik 2007) and even some of them, e.g. Tetranychoidea, are considered as plant pests (Zhovnerchuk 2006). Therefore it is relatively difficult to indicate the reason for their greater abundance in this crop. This issue needs more detailed studies with determination of their taxonomic diversity. The impact of the crop on Astigmata abundance is unclear. In spring we observed the significantly higher abundance of these mites in rye crop with manure fertilisation. In autumn Astigmata were significantly more abundant once in potato (in CaNPK fertilisation) and once in rye (in CaNPK+manure fertilisation). On the CCA plot they were also placed indirectly between potato and rye.

In contrast to the second hypothesis, with the exception of Astigmata the fertilisation treatment did not influence either mites as a community or the density of particular mite groups. Fertilisation treatments did not cause any clear differences in the organic matter content either.

Our results show that winter rye crop creates better conditions for Gamasida and Oribatida groups in comparison with potato crop. In contrast, Prostigmata were more abundant in potato. The occurrence of Astigmata was unstable in the investigated crops, but only this group was sensitive to fertilisation with manure.

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