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Regular research paper

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NEMATOFAUNA OF THE SHELTERBELTS IN THE AGRICULTURAL LANDSCAPE

ABSTRACT: Trophic structure, number and density of taxa, generic diversity, and maturity indices were compared for soil nematode communities inhabiting a 170-year-old shelterbelt, 6-year-old shelterbelt, and a maize field adjacent to the younger shelterbelt. The study was conducted in an area of long-term research near Turew (Wielkopolska Region, West Poland). Sampling sites in the crop field were located at distances of 0.5 m, 10 m and 50 m from the younger shelterbelt. In the soil of shelterbelts more taxa occurred in comparison with the cropland, the index of generic diversity was higher, the dominance of nematodes of the class *Secernentea* (r-strategists *s.l.*) over *Adenophorea* (K-strategists *s.l.*) was lower, community maturity indices and bacterivore maturity index were higher, and the ratio of plant parasite index to maturity index was lower, providing evidence for a more advanced stage of succession in the shelterbelts. In the maize field, fungivorous and plant feeding nematodes predominated, with a strong dominance of one of the taxa pathogenic to plants (*Pratylenchus*). The effect of 6-year old shelterbelt on nematode community in maize crop field was observed in the field part closest to the shelterbelt.

KEY WORDS: soil nematodes, shelterbelts, agrocoenosis, trophic structure, diversity, maturity indices

1. INTRODUCTION

It has been known for a long time that mosaic agricultural landscape made up of small crop fields, woods, meadows, water bodies, and non-agricultural components enhance the richness and diversity of organisms in contrast to large monocultures (Ryszkowski 1998). Wooded patches and meadows interspersed among crop fields, also balks, and hedges serve as refuges for plants and animals, and thus contribute to the protection of the living natural resources in the agricultural landscape (Ryszkowski *et al.* 1999). Shelterbelts enrich the landscape structure and perform many important functions. They create favourable microclimate for crop plants, markedly reduce land pollution as barriers and traps for nutrients flowing from cropland with ground waters, protect from eolian and water erosion, and ensure the presence of a large number of plant and animal species in the agricultural landscape (Ryszkowski 1984, Bartoszewicz and Ryszkowski 1996, Karg 1998, Kujawa and Karg 1998).

The fauna of crop fields is impoverished as compared with forests and grasslands (Karg and Ryszkowski 1996). The effect of shelterbelts on faunal richness in the agricultural landscape of the Turew area in West Poland was described by Karg and Ryszkowski (1996) and Karg (1998) with reference to such taxa as protozoans, nematodes, acarids, enchytraeids, earthworms, insects, spiders, reptiles, amphibians, birds, and mammals. However, no detailed data are available for soil invertebrates, including soil nematodes, to estimate the pattern of their occurrence in shelterbelts. It seems thus purposeful to characterize the composition of nematofauna (at the genus level), and to compare its richness and diversity between shelterbelts and crop fields. The role of nematodes as bioindicators arises from the fact that they are an important, species – rich and easy sampled group of organisms and that they immediately respond to disturbances. Many parameters of nematode communities can provide information on the functioning of ecosystems, and, when compared with crop fields, they can also provide a deeper insight to the role of shelterbelts.

Soil nematodes occupy a key position in the trophic web of the soil. Being heterotrophic, they are primary consumers (plant feeders), secondary consumers (predators), and consumers of decomposers (bacterivores and fungivores). Assessment and interpretation of the abundance and function, as well as the structure of the communities of these invertebrates, makes possible to evaluate site destructive factors (Bongers and Ferris 1999). Soil nematodes can influence soil processes, and they can also reflect them, as it is documented in the rich literature cited in several overviews (Bongers 1990, Wasilewska 1997, Bongers and Bongers 1998, Bongers 1999, Ferris *et al.* 2001, Neher 2001).

The objective of this paper is to characterize the richness and pattern of occurrence of nematofauna in shelterbelts, and also to recognize possible effects of shelterbelts on a crop field adjacent to one of them.

2. STUDY AREA

A preliminary survey of nematofauna in two shelterbelts and in an agrocoenosis adjacent to one of them was made in General De-

zydery Chłapowski Landscape Park in Turew, 40 km south of Poznań, which is a part of Wielkopolska Region, Western Poland. The climate of this region is the warmest in Poland (with a mean annual air temperature of 8°C) and the driest (mean annual precipitation is estimated at about 500–600 mm, of which 375 mm in the growing season). Grey brown podzolic soils are the major soil type in the Park (Ryszkowski 1991). Crop fields account for 72% of the area, meadows for 12%, and water bodies for 0.5%. Shelterbelts and small woods cover 14% of the area. In the Park, there are 539 shelterbelts. The oldest ones were planted by Gen. Chłapowski in the first part of XIX century, but some have been planted during the last six-year period (1990–1996). Shelterbelts and small woods are dominated by *Pinus sylvestris*, *Quercus petraea* and *Quercus robur*, *Robinia pseudoacacia*, *Betula pendula*, and *Larix europea*. In total, 24 species of trees were planted in shelterbelts and woods (Ryszkowski *et al.* 1999, Ryszkowski *et al.* 2003).

3. SAMPLING METHODS AND PARAMETERS ANALYSED

Two shelterbelts and one maize field were selected for analysis:

- **Shelterbelt aged 170 years.** It consisted of two stripes of trees separated by an alley. The stripes were 15 m wide on either side of the alley. At present, *Robinia pseudoacacia* and old oaks contribute up to 90% of the tree stand. Soil samples were taken mainly near oaks and acacias.

- **Shelterbelt aged 6 years.** This is an 18-m wide belt located within crop fields. It is characterized by a high species diversity of trees (about 10 coniferous and deciduous species were planted), and a high species diversity of forbs and grasses. The pH of the top soil layer (in H₂O) was 5.3 and carbon content was 0.50% (Kostro-Chomać 2003, Wojewoda and Russell 2003).

- **Maize field.** During the study period, maize was cultivated on both sides (eastern and western) of the 6-year-old shelterbelt. The field on the eastern side (lee-side) was selected as the experimental field. A cultivation technique typical of this area was used (sowing at the end of March 1999). Wheat was the forecrop. Soil samples for nematodes in the maize field were taken at three distances from the shelter-

belt along a perpendicular transect, namely at 0.5 m, 10 m, and 50 m. These three sampling sites were denoted as maize 0.5 m, maize 10 m, and maize 50 m. Soil acidity, pH (in H₂O), in the study year was 4.7, 4.3, and 4.3, respectively, and soil carbon contents 0.49%, 0.45%, and 0.44% (Kostro-Chomać 2003, Wojewoda and Russell 2003).

Soil samples for nematodes were taken on one occasion, on 11 May 1999, using a soil corer 2 cm² in surface area of the opening, 50 cm³ in volume, and 25 cm deep. At each of the five sites, 20 soil cores were taken and combined to form a sample. Four subsamples (25 cm³ each) from the mixed soil were extracted using a modified method of Baermann funnels (Wasilewska 1979) and preserved in a 5% formalin solution. In each subsample, nematodes were counted and identified to genus or genus *s.l.*

The genera were classified to trophic groups according to Wasilewska (1971) and Yeates *et al.* (1993). These classes comprised bacterivores (B), fungivores (F), facultative plant feeders – partially potential fungivores (FPF), obligate plant feeders (OPF), omnivores (O), and predators (P).

The following parameters and indices were used for nematode communities:

- ◆ Densities (individuals m⁻²) of taxa and dominance structure of the community;
- ◆ Densities and percentage of trophic groups, also ratios of groups. Share of trophic groups can increase and decline in response to many factors;
- ◆ Ratio of bacterivores to fungivores by numbers (B/F), also in the variant with potential fungivores (B/(F+FPF)). This ratio can be indicative of decomposition pathway: mainly through bacteria or mainly through fungi;
- ◆ Ratio of bacterivores + fungivores to obligate plant feeders ((B+F)/OPF), also in the variant with facultative (potential) fungivores ((B+F+FPF)/OPF) and also when facultative plant feeders are combined with obligatory plant feeders ((B+F)/(FPF+OPF)). Differences between these two ratios derive from difference in the assignment of facultative plant feeders – either as fungivores or as plant feeders. These two approaches are a consequence of incomplete knowledge of the trophic status of facultative plant feeders. The ratio of bacterivores + fungivores to plant feeders may be indicative

of differences in the mineralization of dead or live plant tissues, that is, mineralization in the detritus food chain or in the grazing food chain (Wasilewska 1997);

- ◆ Taxon (generic) diversity in terms of the number of taxa in total community or in trophic groups, and Shannon diversity index (Shannon and Weaver 1949) for the total community (H'T), bacterivores (H'B), and plant feeders (H'(FPF+OPF));
- ◆ Dominance structure (%) of taxa within bacterivorous trophic group;
- ◆ Maturity Index – MI (Bongers 1990, 1999, Bongers *et al.* 1995). This is an index developed for nematode communities. It is based on species with different life strategies in the community (the ways of resource use). Taxonomic units (genera, families) are classified as colonizers – "c" (short life cycles, high reproduction, tolerance of disturbance), and were given a value 1, or as persisters – "p" (long life cycles, poor colonizing capacity, low reproduction rate, susceptibility to disturbance), and were given a value 5. The remaining taxa were intermediate on the colonizers – persisters (c-p) scale (Bongers 1990). In the broad sense, the position of a taxon on the c-p scale is becoming equivalent to the position on the r-K continuum.

The general equation for calculating the Maturity Index (Bongers 1990) is following:

$$MI = \sum v_i p_i \quad (1)$$

where v_i is the c-p value of i -th taxon and p_i is the proportion of i -th taxon in the nematode community abundance (in soil sample).

The maturity indices indicated below depend on what part of nematode community is considered and c-p values indicate the range of values e.g. c-p = 1 indicates taxa with value 1, c-p = 1–5 indicates taxa with values from 1 to 5.

The following MI indices were calculated:

- MI (c-p = 1–5) – based on the taxa without plant feeders. Lower MI values indicate earlier successive stages or environmental perturbation, whereas higher values indicate later successive stages or smaller environmental disturbance;
- MI (c-p = 2–5) – based on the same taxa as MI (c-p = 1–5) but without c-p 1 taxa, that is, the taxa associated with abundant

food supply, and those which form dauer-larvae when microbiological activity declines. The exclusion of the taxa c-p 1 from the index precludes the monitoring of short-term changes in the community, caused, for example, by the application of nitrogen fertilizers in agrocoenoses;

- Ba MI – Maturity Index of bacterivores: it should increase with succession;
- PPI – (Plant Parasite Index) comparable with MI, but based only on plant feeders. It increases with increasing soil fertility;
- PPI/MI – (ratio of Plant Parasite Index to Maturity Index) this ratio reflects the divergence in the values of the two indices, that is, when MI decreases, then PPI increases with increasing soil fertility;
- Ratio (R) of the density of nematodes of the class *Secernentea* (S) to the density of nematodes of the class *Adenophorea* (A):

$$R = S/A \quad (2)$$

It informs on the ratio of all more r-strategists *s.l.* in the community to all more K-strategists *s.l.* This classification follows that presented by Bongers (1999). In author's view, the ratio of numbers of these two groups informs about the closeness to natural environmental conditions: the higher the value of R , the greater the distance from natural conditions. This conclusion is based on observations that dorylaimids (*Adenophorea*) were more abundant in natural or slightly transformed habitats (Wasilewska 1974b).

- Index of community similarity (Marczewski and Steinhaus index) cited in (Romaniszyn 1972):

$$S = \frac{W}{200-W} \times 100\% \quad (3)$$

where: S – is the similarity of the communities compared, and W – is the sum of the lower percentage values of densities in pairwise comparisons of taxa from the two sites.

The value of this index ranges from 0% (no similarity) to 100% (complete similarity).

4. RESULTS

4.1. Richness of taxa

Taxonomic composition and density provided evidence that there were significant

differences between the two shelterbelts, as well as between the shelterbelt and the maize field (Table 1 and 2). In nematode communities of the two shelterbelts, 32–34 taxa were recorded, whereas 20–21 taxa in the maize field (Table 1). Almost each nematode trophic group comprised more taxa in the soil of the shelterbelts than in the soil of the maize field (if facultative and obligate plant feeders are combined) (Table 1).

Nematode parasites of insects of the family *Steinernematidae* occurred only in the old shelterbelt, implying rich regulatory interactions in the biocoenosis.

From faunistic viewpoint, it is interesting that a few nematodes of the genus *Chambersiella* Cobb, 1920 were recorded. So far only two species of this genus have been described from two different sites: *C. rodens* Cobb, 1920 in Florida, USA and *C. bakeri* Sanwal, 1957 in Ontario, Canada. But the latter was shifted to the genus *Geraldus* Sanwal, 1971. In both cases, these species were discovered under oak bark. The author has not found in the world literature more records of species of the genus *Chambersiella* Cobb, 1920. The finding near Turew area in West Poland may thus be the first record from Europe, waiting for taxonomic description.

The specimens discovered in the soil of the old shelterbelt originally could also live under bark of old oaks growing at the sampling site. It is hard to believe that the farmland characterized by faunal impoverishment (Ryszkowski 1985), including nematofauna (Wasilewska 1986a), is the place of occurrence of a rare species, perhaps new to science, associated rather with mature ecosystems (under-bark niches are provided only by mature, fully grown trees). Probably it could be a relict of remote forests in the region.

Table 1. Number of nematode taxa (see Table 2) in the soil of two shelterbelts and in a maize field at three distances from the young shelterbelt.

| | Shelterbelt | | Maize field | | |
|---------------------------|---------------------|-------------------|-------------|------|------|
| | (aged 170 years) | (aged 6 years) | 0.5 m | 10 m | 50 m |
| Total community | 34 | 32 | 21 | 20 | 20 |
| Bacterivores | 15 | 13 | 11 | 9 | 9 |
| Fungivores | 5 | 2 | 3 | 2 | 1 |
| Facultative Plant Feeders | 4 | 7 | 4 | 4 | 5 |
| Obligate Plant Feeders | 5 | 5 | 3 | 3 | 3 |
| Omnivores + Predators | 4 | 5 | 1 | 2 | 2 |
| Parasites of Insects | 1 | | | | |

Table 2. Mean density (10^3 ind. m^{-2}) of nematode taxa in the soil of two shelterbelts and a maize field at three distances from the young shelterbelt ($n = 3$ or 4 subsamples); B – Bacterivores, F – Fungivores, FPF – Facultative Plant Feeders, OPF – Obligate Plant Feeders, O – Omnivores, P – Predators, PI – Parasites of Insects.

| Trophic group | Taxon | Site | | | | |
|---------------|------------------------------|----------------------------|--------------------------|-------------|------|------|
| | | Shelterbelt aged 170 years | Shelterbelt aged 6 years | Maize field | | |
| | | | | 0.5 m | 10 m | 50 m |
| B | <i>Protorhabditis</i> | 117 | 250 | 1350 | 1313 | 1467 |
| B | <i>Acrobeles</i> | | 33 | | 13 | |
| B | <i>Acrobeloides</i> | 2300 | 483 | 750 | 300 | 383 |
| B | <i>Eucephalobus</i> | 67 | 583 | 67 | 63 | 67 |
| B | <i>Panagrolaimus</i> | 100 | 200 | 50 | | |
| B | <i>Monhystera</i> | 917 | 33 | 117 | | |
| B | <i>Plectus</i> | 767 | 250 | 83 | 38 | 117 |
| B | <i>Prismatolaimus</i> | | | 250 | | 33 |
| B | <i>Diplogaster s.l.</i> | 33 | 33 | 100 | 188 | 167 |
| B | <i>Rhabditis s.l.</i> | 133 | 117 | 750 | 613 | 817 |
| B | <i>Tobrilus</i> | 17 | 17 | | | |
| B | <i>Cephalobus</i> | 233 | 33 | 100 | 38 | 33 |
| B | <i>Cervidellus</i> | 150 | 50 | | 13 | 17 |
| B | <i>Teratocephalus</i> | 800 | | | | |
| B | <i>Wilsonema</i> | 533 | | | | |
| B | <i>Chiloplacus</i> | 233 | | 33 | | |
| B | <i>Chambersiella</i> | 17 | | | | |
| B | <i>Diploscapter</i> | | | 50 | | |
| F | <i>Aphelenchoides</i> | 633 | 67 | 1533 | 513 | 2517 |
| F | <i>Paraphelenchus</i> | 17 | 17 | | | |
| F | <i>Aphelenchus</i> | | | | 13 | |
| F | <i>Paurodontus</i> | 83 | | | | |
| F | <i>Neotylenchus</i> | 17 | | 17 | | |
| F | <i>Nothotylenchus</i> | 33 | | | | |
| F | <i>Laimaphelenchus</i> | | | 17 | | |
| FPF | <i>Filenchus</i> | 83 | 67 | 100 | 50 | 17 |
| FPF | <i>Lelenchus</i> | | 17 | | | |
| FPF | <i>Malenchus</i> | | 17 | | | |
| FPF | <i>Miculenchus</i> | 17 | 133 | | | 150 |
| FPF | <i>Coslenchus</i> | | 33 | | 25 | 17 |
| FPF | <i>Tylenchus</i> | 950 | 33 | 50 | 38 | 33 |
| FPF | <i>Psilenchus</i> | | 17 | | | |
| FPF | <i>Ditylenchus</i> | 683 | | 117 | 113 | 83 |
| OPF | <i>Tylenchorhynchus</i> | 233 | 217 | 567 | 513 | 583 |
| OPF | <i>Pratylenchus</i> | 750 | 383 | 3383 | 2188 | 4067 |
| OPF | <i>Trichodorus</i> | | 150 | 17 | 13 | |
| OPF | <i>Paratylenchus</i> | 100 | 50 | | | 17 |
| OPF | <i>Heterodera</i> | | 17 | | | |
| OPF | <i>Helicotylenchus</i> | 117 | | | | |
| OPF | <i>Tetylenchus</i> | 33 | | | | |
| O | <i>Aporcelaimellus</i> | | 17 | | | 17 |
| O | <i>Eudorylaimus s.l.</i> | 33 | 67 | 17 | | |
| O | <i>Aporcelaimus</i> | 17 | 50 | | | |
| O | <i>Mesodorylaimus</i> | 33 | | | 13 | |
| O | <i>Dorylaimoides</i> | 33 | | | | |
| P | <i>Mononchus s.l.</i> | | 17 | | | |
| P | <i>Nygolaimus</i> | | 17 | | | |
| P | <i>Seinura</i> | | | | 13 | 50 |
| PI | <i>Steinernematidae juv.</i> | 33 | | | | |

□ high density: $> 1000 \times 10^3$ ind. m^{-2}

— moderate density: from 500 to 1000×10^3 ind. m^{-2}

low density: $< 500 \times 10^3$ ind. m^{-2}

4.2. Density of taxa and dominants

Using three classes of taxon densities (Table 2), the dominance structure can be compared in the shelterbelts and the crop field.

The old shelterbelt supported taxa with high densities (*Acrobeloides*), and moderate densities (*Monhystera*, *Plectus*, *Teratocephalus*, *Wilsonema*, *Aphelenchoides*, *Pratylenchus*, *Tylenchus*, and *Ditylenchus*), whereas in the shelterbelt aged 6 years only two taxa of bacterivores attained moderate densities (*Acrobeloides* and *Eucephalobus*). In the maize field, high and moderate densities were noted for bacterivores (*Protorhabditis*, *Rhabditis s.l.*, *Acrobeloides*), fungivores (*Aphelenchoides*), and also for plant feeders (*Pratylenchus* and *Tylenchorhynchus*). An agrocoenosis differed from the other habitat types with respect to the highest density of one of the taxa of obligate plant feeders (*Pratylenchus*) (Table 2).

4.3. Community similarity

The old and young shelterbelts were occupied by 21 taxa in common. The shelterbelts and the maize shared 20–22 taxa (Table 2).

Marczewski and Steinhaus index showed a low similarity between the old and the young shelterbelts (27%). The similarity of the maize field at three distances from the young shelterbelt varied from 67% to 78% (Table 3).

Table 3. Marczewski and Steinhaus index of community similarity (modified by Romanişzyn 1972) (in %) for soil nematodes at the study sites (see Table 2).

| | Shelterbelt Shelterbelt | | Maize field | | |
|-------------------------------|-------------------------|-------------------|-------------|------|------|
| | (aged 170 years) | (aged 6 years) | 0.5 m | 10 m | 50 m |
| Shelterbelt aged 170 years | | | | | |
| Shelterbelt aged 6 years | 27 | | | | |
| Maize field 0.5 m | 21 | 27 | | | |
| Maize field 10 m | 17 | 23 | 72 | | |
| Maize field 50 m | 15 | 22 | 78 | 67 | |

It follows from the results above, that the similarity index in nematode taxa between the two shelterbelts of very different ages, (27%) was similar to that between the peripheral part of the maize field and the young shelterbelt (Table 3).

The small index of similarity between the two shelterbelts (only 27%), probably due to differences in the species composition and age of the tree stands (170 and 6 years) provides an additional evidence for ecosystem diversity in this agricultural region.

The similarity indices between the shelterbelt aged 6 years and selected sampling sites in the maize field (at distances of 0.5 m, 10 m, and 50 m from the shelterbelt) were 27%, 23%, and 22%, respectively (Table 3). The similarity was still lower between the sampling sites in the maize field and the shelterbelt aged 170 years, not adjacent to this field, the respective values being 21%, 17%, and 15% (Table 3). In both cases, the similarity between the shelterbelt and the peripheral site of the maize field was higher by 4–6% as compared with that in central part of the field. This suggests that the shelterbelt influenced the nemato-fauna occurring in the maize field.

4.4. Diversity of community and trophic groups

The index of generic diversity was higher for the shelterbelts compared with the maize field in terms – of the total community ($H'T$), bacterivores ($H'B$), and plant feeders ($H'(FPF+OPF)$) ($P < 0.001$ in all cases). This was especially the case of $H'(FPF+OPF)$ with the diversity index almost three times that of the shelterbelts (Table 4).

In the young shelterbelt compared with the old one, the values of $H'T$ and $H'(FPF+OPF)$ were higher ($P < 0.01$) and those of $H'B$ not statistically different. The level of the significance of differences between the two shelterbelts was lower than between the shelterbelts and the maize field (Table 4).

The diversity indices also differ between three sampling sites inside maize field. $H'T$ value was highest at the distance from shelterbelt 0.5 m and 10 m (not significant differences between them), and it was lowest at 50 m, the difference being statistically significant ($P < 0.001$). $H'B$ value was the highest at 0.5 m and significantly different from the values at the other two sites, whereas no significant difference was noted between distance 10 m and 50 m. $H'(FPF+OPF)$ value was lowest at 50 m and significantly different only from that at the distance 10 m ($P < 0.01$) (Table 4).

Table 4. Significance level (P) of differences between values of Shannon generic diversity index based on A – total community, B – bacterivores and C – facultative + obligatory plant feeders in studied sites (see Table 2).

| | Shelterbelt | | Maize field | | |
|-------------------------------|-------------------|-----------------|-------------|--------|------|
| | aged 170 years | aged 6 years | 0.5 m | 10 m | 50 m |
| A | | | | | |
| H' T | 3.91 | 4.15 | 2.90 | 2.83 | 2.64 |
| Shelterbelt aged 170 years | | | | | |
| Shelterbelt aged 6 years | <0.01 | | | | |
| Maize field 0.5 m | <0.001 | <0.001 | | | |
| Maize field 10 m | <0.001 | <0.001 | (n.s.) | | |
| Maize field 50 m | <0.001 | <0.001 | <0.001 | <0.001 | |
| B | | | | | |
| H' B | 2.91 | 3.04 | 2.43 | 2.01 | 2.09 |
| Shelterbelt aged 170 years | | | | | |
| Shelterbelt aged 6 years | (n.s.) | | | | |
| Maize field 0.5 m | <0.001 | <0.001 | | | |
| Maize field 10 m | <0.001 | <0.001 | <0.001 | | |
| Maize field 50 m | <0.001 | <0.001 | <0.01 | (n.s.) | |
| C | | | | | |
| H' (FPF+OPF) | 2.41 | 2.83 | 1.02 | 1.21 | 0.98 |
| Shelterbelt aged 170 years | | | | | |
| Shelterbelt aged 6 years | <0.01 | | | | |
| Maize field 0.5 m | <0.001 | <0.001 | | | |
| Maize field 10 m | <0.001 | <0.001 | <0.02 | | |
| Maize field 50 m | <0.001 | <0.001 | (n.s.) | <0.01 | |

4.5. Total density and percentage of trophic groups

Total density of soil nematodes in the old shelterbelt and maize field were high, whereas lower by more than half in the young shelterbelt (Table 5).

Almost all the analysed trophic groups occurred in the soil of the shelterbelts and the maize field, but in different proportions. The soil of the shelterbelts was dominated by bacterivores (though the density of this group showed large differences, in the old shelterbelt it was almost three times higher than in the soil of the young shelterbelt), and the soil of the maize was dominated by plant feeders, with bacterivores on the second position (Table 5, Fig. 1). Facultative plant feeders (or facultative fungivores) were more abundant and contributed to a higher proportion of the community in the shelterbelts compared with the maize field. In the maize field fungivores showed highest density and proportions in the community, though at one sampling site in the maize their density was similar to that in the old shelterbelt.

Omnivores combined with predators were a few times more abundant in the shelterbelts than in the maize field, while parasites of insects occurred only in the old shelterbelt (Table 5).

Table 5. Mean density (10^3 ind. \pm SE \times m⁻²) of total community and of trophic groups of nematodes, and ratios of these groups in the soil of two shelterbelts and a maize field at three distances from the young shelterbelt (n = 3 or 4 subsamples).

| Trophic group | Shelterbelt aged | Shelterbelt aged | Maize field | | |
|---------------------------------|------------------|------------------|----------------|----------------|------------------|
| | 170 years | 6 years | 0.5 m | 10 m | 50 m |
| Bacterivores (B) | 6417 \pm 250 | 2332 \pm 510 | 3450 \pm 360 | 2579 \pm 400 | 3101 \pm 170 |
| Fungivores (F) | 783 \pm 30 | 84 \pm 40 | 1567 \pm 220 | 526 \pm 80 | 2517 \pm 400 |
| Facultative Plant Feeders (FPF) | 1733 \pm 200 | 317 \pm 120 | 267 \pm 40 | 226 \pm 40 | 300 \pm 70 |
| Obligate Plant Feeders (OPF) | 1233 \pm 140 | 817 \pm 40 | 3967 \pm 260 | 2714 \pm 120 | 4667 \pm 700 |
| Omnivores + Predators (O+P) | 116 \pm 20 | 167 \pm 40 | 17 \pm 17 | 26 \pm 10 | 67 \pm 40 |
| Parasites of Insects (PI) | 33 | | | | |
| Total* | 10282 \pm 140 | 3718 \pm 460 | 9268 \pm 860 | 6071 \pm 540 | 10652 \pm 1270 |
| Ratio | | | | | |
| 1. B/F | 8.2 | 27.8 | 2.2 | 4.9 | 1.2 |
| 2. B/(F+FPF) | 2.6 | 5.8 | 1.9 | 3.4 | 1.1 |
| 3. (B+F)/OPF | 5.8 | 3.0 | 1.3 | 1.1 | 1.2 |
| 4. (B+F+FPF)/OPF | 7.2 | 3.3 | 1.3 | 1.2 | 1.3 |
| 5. (B+F)/(FPF+OPF) | 2.4 | 2.1 | 1.2 | 1.1 | 1.1 |

* excluding PI

4.6. Ratios of trophic groups

The ratio of bacterivores to fungivores (B/F), and the same ratio with facultative plant feeders considered as potential fungivores (B/(F+FPF)) was more or less higher in the shelterbelts compared with the maize field (except for the site maize 10 m) (Table 5, Ratios 1 and 2). This may imply that the decomposition of organic matter in the soil of the shelterbelts was more dependent on bacteria than on fungi. This was also in the case of the soil under maize but to a lesser degree.

The ratio of bacterivores + fungivores to plant feeders was higher in the soil of the shelterbelts than in the maize soil, no matter whether facultative plant feeders were included or not (Table 5, Ratios 3, 4 and 5). This implies that the detritus pathway in the shelterbelts predominated (at least twice) that in the maize field. In the maize field, probably both pathways of mineralization in the detritus-and grazing food web had nearly similar ranks.

4.7. Maturity indices and a ratio (by numbers) of *Secernentea* to *Adenophorea*

Indices MI (c-p = 1–5), MI (c-p = 2–5), and Ba MI were much higher in the soil of the shelterbelts compared with the maize field (Table 6). The values of MI (c-p = 1–5) and Ba MI in the maize field accounted for 60–66% of their values in the shelterbelts, and the values of MI (c-p = 2–5) for as many as 84–90%. Thus, nematode communities without taxa c-p 1 were more similar to each other. Taxa c-p 1 were one of the main factors making difference between the crop field and the shelterbelts. Also c-p 1 taxa, more abundant in the young than in the old shelterbelt, accounted for a large increase in the value of MI (c-p = 2–5) (up to value 2.35 for the young shelterbelt). This situation was not observed in the old shelterbelt where taxa c-p 1 were much less abundant. But the highest increase in MI (c-p = 2–5) compared with MI (c-p = 1–5) was found in the crop field, implying that r-strategists (c-p 1) were most abundant there.

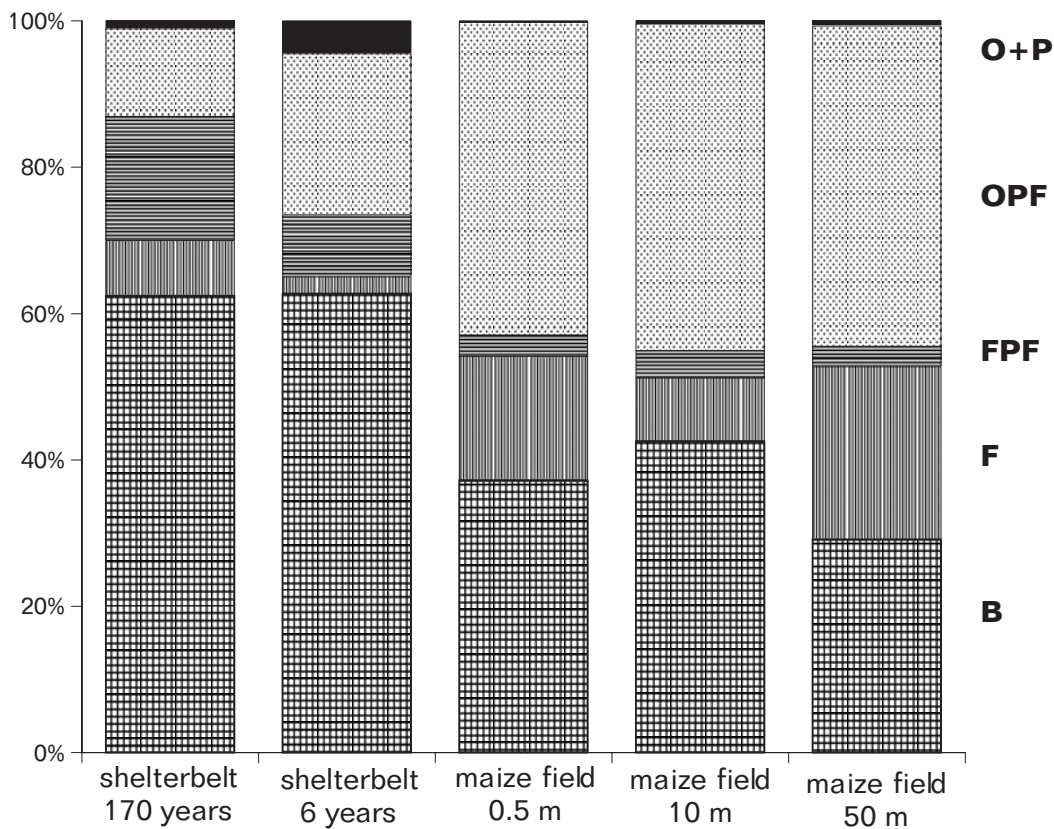


Fig.1. Percentage of trophic groups at different study sites. B – Bacterivores, F – Fungivores, FPF – Facultative Plant Feeders, OPF – Obligate Plant Feeders, O+P – Omnivores + Predators.

Ba MI value was significantly higher in the soil of the shelterbelts compared with the crop field, and higher in the old than in the young shelterbelt. Ba MI was the only index with a higher value in the maize 0.5 m compared with the maize 10 m and 50 m (Table 6).

PPI value was lower in the shelterbelts (and lower in the old than in the young stand) and higher in the maize field. Thus the divergence between PPI and MI (PPI/MI) was the highest in the crop field (Table 6).

Table 6. Maturity indices (see formula 1 in the text) of the nematode community inhabiting the soil of shelterbelts and a maize field at three distances from the young shelterbelt. For the explanation of the symbols see the text.

| Indices | Shelterbelt | | Maize field | | |
|----------------|-------------------|-----------------|-------------|------|------|
| | aged 170 years | aged 6 years | 0.5 m | 10 m | 50 m |
| MI (c-p = 1-5) | 2.10 | 2.03 | 1.54 | 1.34 | 1.58 |
| MI (c-p = 2-5) | 2.16 | 2.35 | 2.00 | 2.04 | 2.03 |
| Ba MI | 2.07 | 1.85 | 1.33 | 1.18 | 1.22 |
| PPI | 2.38 | 2.79 | 2.94 | 2.93 | 2.94 |
| PPI/MI | 1.13 | 1.37 | 1.91 | 2.18 | 1.86 |

The values of *Secernentea* to *Adenophorea* (R (S/A)) ratio for the shelterbelts, about 3.3, were much lower than for the crop field where they amounted to 38–94 (Table 7). Characteristically, in the crop field this ratio was lowest and close to the value found in shelterbelt aged 6 years, where it was only 38.6 (maize 0.5 m), whereas at larger distances it was about 1.5 to 2.4 times higher (maize 10 m and maize 50 m) (Table 7).

Table 7. Density (10^3 ind. m^{-2}) of nematodes of the classes *Secernentea* and *Adenophorea*, and their ratio (R (S/A)) in the studied sites (see Table 2).

| Class | Shelterbelt | | Maize field | | |
|------------------------|-------------------|-----------------|-------------|------|-------|
| | aged 170 years | aged 6 years | 0.5 m | 10 m | 50 m |
| <i>Secernentea</i> (S) | 7932 | 2850 | 9034 | 6007 | 10485 |
| <i>Adenophorea</i> (A) | 2350 | 868 | 234 | 64 | 167 |
| R (S/A) | 3.4 | 3.3 | 38.6 | 93.8 | 62.8 |

4.8. Plant feeding and bacterivorous groups

Plant feeders, especially obligate plant feeders, inhabit roots of host plants. In the maize field, the dominant obligate plant

feeder was *Pratylenchus* that accounted for 81% to 87% of abundance of this group. In the old and young shelterbelt its dominance was lower (from 61% to 47%, respectively) (Table 2 and Table 5). It is difficult to assess the dominance of facultative plant feeders because of incomplete knowledge of their trophic status.

Bacterivores occur in all places with organic matter and decomposers. But the kind of organic matter and physico-chemical conditions, created mainly by plants, differentiate this group.

As already noted (Table 2), bacterivores occurring in the maize field were dominated by *Rhabditis s.l.* and *Protorhabditis* (Rhabditidae), whereas the soil of the young shelterbelt bordering on the crop field was dominated by *Acrobeloides* and *Eucephalobus* (Cephalobidae) (Table 8). Except for *Tobrilus*, all the other taxa in the young shelterbelt and maize field were the same but in different proportions. A characteristic feature was the weaker dominance of *Rhabditis s.l.* and *Protorhabditis* and a higher dominance of *Acrobeloides* in the maize 0.5 m compared with other sampling sites in the maize field (Table 8).

Table 8. Relative abundance (%) of taxa in bacterivorous group of nematodes in studied sites (see Table 2).

| Taxon | c-p value* | Shelterbelt | | Maize field | | |
|-------------------------|---------------|-------------------|-----------------|-------------|------|------|
| | | aged 170 years | aged 6 years | 0.5 m | 10 m | 50 m |
| <i>Diplogaster s.l.</i> | 1 | 0.5 | 1.4 | 2.9 | 7.3 | 5.4 |
| <i>Diploscapter</i> | 1 | | | 1.4 | | |
| <i>Panagrolaimus</i> | 1 | 1.6 | 8.6 | 1.4 | | |
| <i>Protorhabditis</i> | 1 | 1.8 | 10.7 | 39.1 | 50.9 | 47.3 |
| <i>Rhabditis s.l.</i> | 1 | 2.1 | 5.0 | 21.7 | 23.8 | 26.3 |
| <i>Acrobeloides</i> | 2 | 35.8 | 20.7 | 21.7 | 11.6 | 12.4 |
| <i>Cephalobus</i> | 2 | 3.6 | 1.4 | 2.9 | 1.5 | 1.1 |
| <i>Cervidellus</i> | 2 | 2.3 | 2.1 | 0.5 | 0.5 | |
| <i>Chiloplacus</i> | 2 | 3.6 | | 1.0 | | |
| <i>Eucephalobus</i> | 2 | 1.0 | 25.0 | 1.9 | 2.4 | 2.2 |
| <i>Monhystera</i> | 2 | 14.3 | 1.4 | 3.4 | | |
| <i>Plectus</i> | 2 | 12.0 | 10.7 | 2.4 | 1.5 | 3.8 |
| <i>Wilsonema</i> | 2 | 8.3 | | | | |
| <i>Chambersiella</i> | 3 | 0.3 | | | | |
| <i>Prismatolaimus</i> | 3 | | 10.7 | | | 1.1 |
| <i>Teratocephalus</i> | 3 | 12.5 | | | | |
| <i>Tobrilus</i> | 3 | 0.3 | 0.7 | | | |

* c-p (colonizers-persisters) scale acc. to Bongers (1990)

A deeper interpretation of Ba MI values (Table 6) will give an analysis of the proportions of bacterivores on the coloni-

zers-persisters scale (c-p) (Table 9). In the soil of the maize field, taxa c-p 1 were dominant and they accounted for 66% to 82% of total bacterivores. In the shelterbelts taxa c-p 2 were dominant (63%–81%), but the old shelterbelt differed from the young with respect to the minimum proportion of c-p 1 bacterivores.

In these categories, maize 0.5 m occupied an intermediate position between the young shelterbelt and the maize 10 m or maize 50 m (Table 9).

Table 9. Percentage of bacterivorous taxa grouped according to their values on the colonizers-persisters scale (c-p value after Bongers 1990 and Bongers *et al.* 1995) in the studied sites. As 100% accepted the total numbers of bacterivorous nematodes (see Table 2).

| Site | c-p value | | |
|----------------------------|-----------|------|------|
| | 1 | 2 | 3 |
| Shelterbelt aged 170 years | 6.0 | 80.9 | 13.1 |
| Shelterbelt aged 6 years | 25.7 | 62.7 | 11.4 |
| Maize field 0.5 m | 66.5 | 33.3 | 0 |
| Maize field 10 m | 82.0 | 18.0 | 0 |
| Maize field 50 m | 79.0 | 20.0 | 1.0 |

5. DISCUSSION

According to the theory of ecosystem development, nematode communities become increasingly diverse with advancing succession, and, consequently, both the richness of taxa and the diversity index undergo the same trends (Pate *et al.* 2000).

Ryszkowski's (1984) statement that the fauna of crop fields is impoverished and less complex than the fauna of forests or grasslands is totally valid for the soil nematofauna (Wasilewska 1974a, 1975, 1979, 1981, 1984, 1985, 1986b, 1987, 1989a, b, 1991b, 1995, Wasilewska and Paplińska 1975, Wasilewska *et al.* 1985, Karg *et al.* 1990).

With reference to the nematofauna of shelterbelts and crop fields, there is only one paper (Zamszyn 1987) and data of Zamszyn in Karg and Ryszkowski (1996). Zamszyn described the seasonal changes in numbers of nematodes occurring in 170 years old shelterbelt near Turew area, in the period between March 1981 to January 1982; he found that the maximal and minimal abundance is equal to ca

$8 \times 10^6 \text{ m}^{-2}$ and ca $2 \times 10^6 \text{ m}^{-2}$, respectively. From March to June, numbers of nematodes increased, then they decreased until October, but the period of increased abundance extended over the summer. It is highly probable that the dynamics of nematofauna could followed a similar pattern in the year when the samples analysed in this paper (May) were taken from the same area. Zamszyn (1987) used the same method of sampling. The similarity of the results is also suggested by comparable maximal abundance of nematodes i.e. ca $8 \times 10^6 \text{ m}^{-2}$ in Zamszyn (1987) and ca $10 \times 10^6 \text{ m}^{-2}$ in the present paper. Another indication of the similarity between our results is reflected in rather high numbers of plant feeders in the shelterbelts.

Total nematode density is not a sensitive parameter differentiating communities of these animals between different habitats. The evidence is provided by the fact, that nematode densities in the soils under the maize were similar to those under the shelterbelts, whereas large differences were noted between the young and old shelterbelts. Wasilewska (1979) found an extensive overlapping of similar densities between forest and cropland nematofauna for a greater number of the study areas. Differences between forest and cropland ecosystems should be looked for in other parameters.

Taxa richness in the soils of the two shelterbelts and crop field does not seem to be lower than in the agricultural region of Masurian Lakeland (North-East Poland), where also crop fields and shelterbelts were examined (Wasilewska 1987). Especially predators (e.g. *Mononchidae*) were scarce in studied area near Turew, as already described (Wasilewska 1974a, Zamszyn 1987).

The parameters indicative of differences between the shelterbelts and the crop field involve the richness of taxa, their dominance structure, and diversity index of genera, trophic structure and maturity indices for total nematode communities, and similar parameters for the important group such as bacterivores. With reference to these indices, the similarity of nematode communities at different sampling sites in the same crop was high, but low between the shelterbelts and the crop.

The above rule concerns the ratio of nematodes of the class *Secernentea* (r-str-

tegiests *s.l.*) to the class *Adenophorea* (K-strategists *s.l.*). Densities of the former were 39–94 times higher than the densities of the latter in the crop, whereas only about 3 times in the shelterbelts.

The shelterbelts were richer in taxa for almost all trophic groups. The richer biocoenosis, multi-level trophic systems, and biocoenotic regulation are evidenced by the occurrence of entomopathogenic nematodes in the old shelterbelt. Also taxonomic diversity was much higher in the shelterbelts.

Fungivorous nematodes were more abundant and accounted for a higher percentage of the community in the crop compared with the shelterbelts. This was likely to be related with acid soil reaction caused by the application of mineral fertilizers in the maize field (pH of the top soil layer was 5.3 in the shelterbelts versus 4.7–4.3 in the crop field according to Wojewoda and Russel 2003). It is possible that facultative plant feeders feed on fungi, and they were more abundant in the shelterbelts. Their high densities in the old shelterbelt may provide evidence for mycorrhiza (e.g. Hánel 2000).

Plant feeders, in particular obligatory plant feeders, were highly dominant in the crop, with a strong dominance of one of the taxa pathogenic to plants. Obligatory plant feeders also occurred in the shelterbelts, and they were represented even by more taxa than in the crop field, but their dominance was not as strong as in the maize field. In the group of obligatory plant feeders, *Pratylenchus* sp. contributed to 81%–87% of this group in the soil under the maize, whereas only to 47%–61% in the soil of the shelterbelts, where other pathogenic taxa co-occurred. A high dominance of pathogenic nematodes is known under stressing situations, for example, on drained meadows situated on alder peat (Wasilewska 1991c) and in a spruce forest under the impact of acid rains (Wasilewska 1996). The natural character and stability of the shelterbelt biocoenosis is also indicated by a higher, than in the crop field, density of omnivores and predators (so called K-strategists), this being observed on many occasions (Wasilewska 1985).

If nematodes may be considered as bioindicators, then all combinations of the ratios of bacterivores plus fungivores to plant feeders, that were lower in the crop,

will imply a faster nutrient cycling in the soil of the maize field compared with the shelterbelts. This may reflect, to some extent, what Ryszkowski (1974) stated that mineral cycling is more intense in agroecosystems. The ratio $(B+F)/(FPF+OPF)$ in the maize field from the Masurian Lakeland was a little higher (1.33 as calculated from Wasilewska 1987) than in the study sites in Turew area (1.06–1.18). The values of this ratio in drained peat meadows of the river Biebrza Basin (North-East Poland) were 2.68 – on the moss peat, 1.89 – on the sedge peat, and 0.67 – on the alder peat (Wasilewska 1991a). It appeared that the value found for the drained alder peat was an additional parameter characterizing the similarity of this degraded peat meadow to crop fields of the studied area. Such similarity was earlier inferred from the biocoenotic structures of microorganisms and invertebrate animals (Wasilewska *et al.* 1985).

The decrease of MI values in the gradient of contamination and other environmental disturbances was confirmed in many papers (Wasilewska 1997, Bongers 1999), and no exceptions to this rule are known. The increase in MI values with succession was found on peat and on mineral meadows (Wasilewska 1994a, 1994b). These responses seem to explain differences in MI (c-p = 1–5) values between the shelterbelts and the crop field (2.03–2.10 versus 1.34–1.58). Similar differences though not so acute were obtained in the value MI (c-p = 2–5). The omission of taxa c-p 1 had a stronger effect on the reduction of this index in the soil of the crop field compared with the shelterbelts, implying that taxa c-p 1 were more important in the former.

According to Bongers (1999) and Bongers *et al.* (1997), the ratio PPI/MI does not exceed 0.9 in natural habitats where higher plants use nutrients at the optimum. Even small disturbances to nutrients are followed by the increase of the ratio to 1.2. Higher values of PPI/MI can be interpreted as an excess of nutrients and a high microbiological activity. The value of 1.6 or more may be indicative of an extremely abundant nutrient pool in the soil, and the use of these nutrients by plants can be far from optimum (at least for a short time), as concluded by Bongers (1999) mainly for Dutch farmland. Thus, using the scale for soils of the Dutch

farmland, the maize field in the study area in Turew seems to be heavily overfertilized (PPI/MI = 1.86–2.18).

Bacterivores are one of the most important groups involved in the regulation of organic matter decomposition. Using this group, we can "read" decomposition, this being facilitated by the analysis of the proportions of taxa with differentiated life strategies forms (Wasilewska 1998). Taxa c-p 1 (called enrichment opportunists) are indicative of an extremely enriched environment, taxa c-p 2 survive under poorer trophic conditions, whereas taxa c-p 3 and 4 live in non-perturbed habitats (Bongers 1999). These statements perfectly explain the results concerning the proportions of taxa with diverse life strategies among bacterivores in the shelterbelts and the crop field. Taxa c-p 1 dominated in the crop field, c-p 2 in the shelterbelts, and c-p 3 supplemented the nematofauna of bacterivores mainly in shelterbelts. Bacterivorous taxa c-p 4 were totally absent, although occasional occurrence of *Alaimus* sp. and *Cylindrolaimus* sp. was noted in the same area in earlier years (Wasilewska and Paplińska 1976, Wasilewska *et al.* 1981). They were also recorded from crop fields and woodlots of the Masurian Lakeland (Wasilewska 1987). The structure of taxa with different life strategies in the bacterivorous trophic group described above is well reflected in the values of BaMI for the old shelterbelt (2.07), young shelterbelt aged a few years (1.85), and crop field (1.18–1.33). These values indicate more advanced successional stages of bacterivorous nematodes in the shelterbelts compared with the crop field, and their more advanced successional stage in the old shelterbelt compared with the young shelterbelt.

When analysing nematode communities in a maize field at distances of 0.5 m, 10 m, and 50 m from the shelterbelt aged 6 years, it was noticed that some parameters of the sampling site closest to the shelterbelt (maize 0.5 m) had a distinct character:

- they contained more taxa in the groups of bacterivores and fungivores;
- dominance of *Rhabditis s.l.* and *Protorhabditis* was lower, whereas that of *Acroboloides* (the dominant in the shelterbelt soil), was higher;
- the Shannon diversity index of total nematodes (T) was higher (statistically sig-

nificant difference between the maize 0.5 m and 50 m);

- the Shannon diversity index of bacterivorous nematodes (H'B) was higher (statistically significant differences between the maize 0.5 m and 10 m, also between maize 0.5 m and 50 m);
- a lower proportion of taxa c-p 1 and a higher proportion of c-p 2 than in more distant sampling sites of the maize field;
- a lower ratio of nematodes of the classes *Secernentea* to *Adenophorea* (R(S/A)), implying that r-strategists were less dominant over K-strategists than in more distant sampling sites of the crop field. This is also indicative of a more natural character of the environment;
- the index of community similarity between the maize 0.5 m and the shelterbelt was higher (27%) than at greater distances from the shelterbelt (23% and 22%).

The general conclusion may be formulated as following: shelterbelts have richer and more stable nematode communities than crop fields. The effect of shelterbelt on nematode community in maize crop-field was observed in the field part closest to the shelterbelt. The dominance of some nematode taxa and their diversity indices in cropfield were affected by shelterbelt.

6. SUMMARY

The paper was focused on the richness and distribution of nematofauna in shelterbelts and on the possible effects of shelterbelts on the nematofauna of the adjacent crop fields.

Abundance of taxa, their trophic structure, generic diversity, and maturity indices of nematode communities were compared for shelterbelts aged 170 years and 6 years and a maize field adjacent to the younger shelterbelt. Sampling points in the crop field were located at distances of 0.5 m, 10 m, and 50 m from the younger shelterbelt.

The study was conducted near Turew, about 40 km south of Poznań, West Poland.

Soil samples for nematodes were taken in May 1999. From each of the five sites, 20 soil cores were taken. Nematodes were extracted by using a modified Baermann method, and they were identified to genus. In the soil of the shelterbelts, compared with the crop field, the number of taxa was higher (Table 1 and 2), predominance of nematodes of the class *Secernentea* (r-strategists *s.l.*) over *Adenophorea* (K-strategists *s.l.*) was lower (Table 7), the index of generic diversity was higher (Table 4), maturity indices were higher (MI (c-p = 1–5),

MI (c-p = 2–5), Ba MI)), and the ratio PPI/MI was lower (Table 6). In the maize field, fungivores and plant feeders prevailed (Table 5, Fig. 2), with a strong dominance of *Pratylenchus*, a taxon pathogenic to plants (Table 2). The group of bacterivores in the crop field was dominated by so called extreme r-strategists (c-p 1), whereas in the shelterbelts taxa c-p 2 were most abundant (Tables 8 and 9).

The effect of 6-years old shelterbelt on nematode community in maize cropfield was observed in the field part closest to the shelterbelt.

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