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Regular research paper

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NEMATODE COMMUNITIES ALONG THE TRANSECT SHELTERBELT- ECOTONE – CROP FIELD

ABSTRACT: The study was carried out in western Poland (Turew region) in two shelterbelts of different age (the younger – 6 years old and the older – 11 years old) planted across croplands, in adjacent fields and in the field located in deforested area (control field). Soil samples were taken twice: in the autumn and spring from the centre of each shelterbelt, from the ecotone, and in the field at a distance of 15 and 50 m from the edge of the shelterbelts. The density of nematode communities fluctuated unpredictably, in autumn it was very low and ranged from 276 to 641×10^3 in spring it ranged from 388 to 1931×10^3 individuals per 1 m². Most numerous trophic groups were: bacterivores, fungivores and obligate plant feeders, while facultative plant feeders, omnivores and predators achieved low level. The abundance of predators in older shelterbelt was significantly ($P \leq 0.05$) higher than that in the younger one and decreased with increasing distance from the shelterbelt towards the field. The communities in shelterbelt and its ecotone were more diverse, which was reflected by the higher number of genera (19–31) and higher values of Shannon-Wiener diversity index H' (3.3 – 4.0), than those in the fields where the number of genera ranged from 15 to 25 and Shannon-Wiener diversity index H' ranged from 2.5 to 3.5. In the younger shelterbelt and in the control field the soil food-web assessed with indices derived from analysis of nematode communities was considered as composed mainly of basal components, i.e. cosmopolitan species

feeding on bacteria and fungi occurring everywhere even in degraded environments. While the food web in older shelterbelt was consisted mainly of enrichment components, i.e. bacteria feeding species of very short life cycle, with high food requirements which occur in the environment rich in bacteria). The values of Channel Index which informs about the predominant pathway of decomposition (through bacteria or fungi) showed that in majority of sites bacterial processes predominated. Only in the older shelterbelt the participation of fungal decomposition channel was higher (>50%) and increased with increasing distance from the shelterbelt towards the centre of the field. The results of Correspondence Analysis showed that first two axis explained 40.3% of the variance. The generic composition of nematode communities in the 11-years old shelterbelt differed from that in the 6-years old shelterbelt. Nematode communities inhabiting the ecotone of younger shelterbelt were very similar to the communities in the shelterbelt, while the communities in ecotone of older shelterbelt differed from those in the shelterbelts. Nematode communities inhabiting the control field were similar to those inhabiting the field adjacent to younger shelterbelt.

KEY WORDS: nematode communities, shelterbelt, trophic groups, food web, decomposition pathway

1. INTRODUCTION

In the modern landscape planning there is a tendency to distinguish part of fields for the midfield shelterbelts planted with trees or shrubs. Such shelterbelts have to limit wind erosion and to prevent from water losses in adjacent fields. Moreover, the shelterbelts rich in various microhabitats might create appropriate conditions for the development of many animal species which eventually leads to the increase of biodiversity, so important for proper functioning of agroecosystems (Altieri 1999, Gromadzki 1970, Ryszkowski and Karg 1996). In Poland, the western part of the country – Wielkopolska (Poznań province) is rich in various midfield shelterbelts. In Turew locality the tradition of planting such belts reaches back to the middle of the XIX century. In the years 1993–2002 the existing network was supplemented by creating c. 30 km of new midfield shelterbelts.

Recent studies on new shelterbelts focussed mainly on plant and animal succession (Ryszkowski *et al.* 2003). In the years 1999–2001 broad studies were undertaken on the effect of the recently planted shelterbelts on adjacent fields. It was found that the content of organic matter in the soil, dehydrogenase activity and microbial biomass decreased with increasing distance from the shelterbelt towards the centre of the field. (Wojewoda and Russel 2003). The biomass and abundance of invertebrates: springtails, dipterans, ground beetles, spiders, enchytraeids followed the same pattern (Karg *et al.* 2003, Nowak 2004, Olejniczak 2004). In contrast, the abundance of nematodes was higher in the field than in the shelterbelts. However, the nematode communities inhabiting the 170 years old shelterbelt and the 6 years old shelterbelt were more taxonomically diverse than those from adjacent field (Wasilewska 2004).

Nematodes have many features which make them potentially good indicators of soil system: 1) they can easily be collected from the soil, 2) they occur in high densities of at least several hundred thousands individuals per 1 m², 3) they are taxonomically diverse represented by at least several genera in 250 ml of soil, 4) they cover several tro-

phic levels feeding on bacteria, fungi, algae, higher plants, or on small soil invertebrates (also on other nematodes). These complex trophic interactions make the nematodes a significant component of the soil food web, a participant in the turnover of microbial communities thus in the flux of plant nutrients (Ingham *et al.* 1985, Ettema and Bongers 1993, Bloem 1994, Bouwman *et al.* 1994, Wasilewska 1997). Several indices have been proposed based on the analysis of nematode communities that might be helpful in assessing environmental quality of soil habitat or in studying some soil processes. The indices include e.g. Channel Index – *CI*, Enrichment Index – *EI* and Structure Index – *SI* (see Methods). The indices derived from the weighted faunal concept (Ferris *et al.* 2001), where particular nematode guilds (species of similar life strategy and belonging to the same trophic group) are weighted by their fecundity, longevity and biomass.

The values of *CI* indicate the rate of fungal participation in the decomposition of organic matter; the values of *CI* above 50% indicate that the decomposition is mainly controlled by fungi, while lower values show the predominance of bacterial channel.

Based on the *EI* and *SI* indices one may characterise the food web structure. Ferris *et al.* (2001) distinguished three categories of the food web. *Basal food web* is composed mainly of bacterivorous and fungivorous species termed general opportunists which occur everywhere, even in degraded environments. *Enriched food web* is predominated by bacterivores of very short life cycle and high food requirements. This kind of food web is typical for the environments rich in organic matter with low C:N ratio and high activity of bacteria. *Structured food web* is characterised by a high contribution of species having large body size, long life cycles, being sensitive to environmental changes, omnivores or predators. The food web abundant in such species has many trophic links that provide stability of the soil system and its resistance to disturbances. Such a type of the food web can be found in natural habitats.

Indices described above were used in this paper to evaluate the functioning of the soil system in two shelterbelts differing in age (6 years old and 11 years old) and in

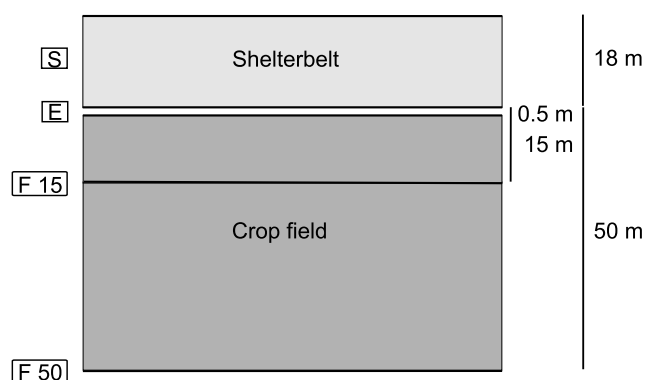


Fig. 1. Location of sampling sites in relation to the shelterbelt. S – shelterbelt, E – ecotone, F15 – field 15 m from the edge of the shelterbelt, F 50 – field 50 m from the edge of the shelterbelt.

Table 1. Characteristics of the studied sites (see Fig. 1). S – shelterbelt, E – ecotone, F15 – field 15 m from the shelterbelt, F50 – field 50 m from the shelterbelt, C – control field, 11 – 11years old, 6 – 6 years old, A – autumn, S – spring.

Code	Plants	Height of the wood-lot	pH	Organic matter content %	Soil moisture (% of water in the field moist-soil)
11 S	Oak, maples, birch, beech, elm, linden, mountain ash, whitebeam, larch, pine, spruce, thorns, currant, euonymus, briar rose	9–10 m	5.0	2.2	A – 4.0 S – 7.5
11 E	2003 maize 2004 wheat		6.5	1.7	A – 2.9 S – 5.8
11 F15	2003 maize 2004 wheat		6.2	1.5	A – 4.0 S – 4.7
11 F50	2003 maize 2004 wheat		5.6	1.5	A – 4.9 S – 5.5
6 S	Oak, maples, birch, beech, elm, linden, mountain ash, whitebeam, larch, pine, spruce, thorns, currant, euonymus, briar rose	4 m	5.0	1.9	A – 3.5 S – 7.1
6 E	2003 wheat 2004 wheat		5.8	1.8	A – 6.3 S – 6.9
6 F15	2003 wheat 2004 wheat		4.8	1.4	A – 5.9 S – 6.6
6 F50	2003 wheat 2004 wheat		5.6	1.5	A – 6.0 S – 5.5
C	2003 wheat 2004 barley		6.0	1.8	A – 4.7 S – 6.6

fields adjacent to these shelterbelts. Values obtained for shelterbelts and adjacent fields were compared with the respective data for control field (devoid of midfield shelterbelts in closed vicinity).

Having in mind the results of cited above up-to-date studies on the effect of midfield shelterbelts on adjacent fields the differences were assumed in the indices calculated for both shelterbelts and for adjacent fields in a distance gradient from the middle of the shelterbelts towards the field. The differences were also expected between the indices obtained for fields adjacent to shelterbelts and for field devoid of such belt. Changes in previously agricultural forested areas are known to proceed rapidly so the differences might also be expected between the shelterbelts of different age.

2. STUDY AREA

The study was carried out in the Chłapowski Landscape Park in Turew locality, Wielkopolska, western Poland (16°45' to 16°50' E and 52° 01' to 52°05' N). Two shelterbelts different in age (6 years old and 11 years old in 2004) and the field devoid of shelterbelt hereafter termed control field (C) were selected for this study. From the middle of every shelterbelt a transect was drawn that run to the adjacent field and ended 50 m from the shelterbelt's edge. Four sites were established along each transect: in the middle of the shelterbelt (S), at the edge of the shelterbelt – ecotone (E), 15 m (F15) and 50 m (F50) from the shelterbelt's edge (Fig. 1). The site characteristics are given in Table 1.

3. METHODS

Soil samples were collected twice: in October 2003 and in April 2004. On every sampling occasion at each site 10 samples were taken with a soil corer (15 mm in diameter) from the depth of 0–15 cm. One sample consisted of 3 single cores taken close to each other. On each sampling occasion, water content of each sample was determined after drying at 105°C.

In 2004 pH (KCl) was determined in triplicate. The content of organic matter was

estimated also in 2004 as a loss on ignition in a muffle furnace at 550°C.

Nematodes were extracted separately from each sample (50 ml of soil) using the modified Baermann's method (Flegg and Hooper 1970). Extracted nematodes were counted, identified to genus (about 250 individuals in each site and sampling occasion) and divided into seven trophic groups according to the classification proposed by Ettema and Bongers (1993), Yeates *et al.* (1993): bacterivores – enrichment opportunists, which encompass species typical of environments rich in bacteria, bacterivores – general opportunists which occur everywhere, fungivores, obligate plant parasites, facultative plant feeders which include algae, moss feeders as well as parasites of vascular plants, omnivores, and predators attacking small soil invertebrates and small species of the nematodes.

The generic diversity of communities was assessed using three parameters: the total number of genera found in the site on one sampling occasion, mean number of genera in one site (average of ten samples taken in one site during one sampling occasion) and Shannon-Wiener diversity index H' (Pielou 1974).

Three indices derived from weighted faunal analysis: the Channel Index (CI) which indicates the predominating decomposition channel (through fungi or through bacteria), and two indices EI and SI informing about the structure of the food-web were calculated using equations described by Ferris *et al.* (2001).

$$CI = 100 \times 0.8Fu_2 / (3.2Ba_1 + 0.8Fu_2), \quad (1)$$

where:

CI – Channel Index (%)

0.8 – the weight assigned to the guild Fu_2 composed of fungivores with r-selection – i.e. general opportunists

Fu_2 – density of the species belonging to the guild Fu_2 (number of individuals m^{-2})

3.2 – the weight of the species belonging to the guild Ba_1 composed of bacterivores of r-selection – species of very short life cycle and high food requirements, developing in the environment rich in bacteria – i.e. enrichment opportunists.

Ba_1 – density of the species belonging to the guild Ba_1 (number of individuals m^{-2})

$$EI = 100 \times (e/e+b), \quad (2)$$

$$SI = 100 \times (s/s+b) \quad (3)$$

where:

EI – Enrichment Index (%)

SI – Structure Index (%)

$$b = \sum k_b n_b$$

b – basal component of food web,

k_b – the weight assigned to two guilds forming the basal component of food web: *Ba₂* (bacterivores of r- selection, inhabiting environments with limited food resources – i.e. general opportunists) and *Fu₂* (see above),

n_b – the density of nematodes belonging to the guilds forming the basal component of food web: *Ba₂* and *Fu₂* (number of individuals m⁻²),

e – enriched food web component,

k_e – the weight assigned to guilds forming the enriched component of food web: *Ba₁* and *Fu₂*,

n_e – the density of nematodes belonging to guilds forming the enriched component of food web: *Ba₁* and *Fu₂* (number of individuals m⁻²),

s – structured food web component,

k_s – the weight assigned to guilds forming the structured component of food web: *Ba₃*–*Ba₅* (bacterivores), *Fu₃*–*Fu₅* (fungivores), *Pr* (predators) and *Om* (omnivores). The species belonging to these guilds are K-selection species:

n_s – the density of nematodes belonging to guilds forming the structured component of food web: *Ba₃*–*Ba₅*, *Fu₃*–*Fu₅*, *Pr₂*–*Pr₅* and *Om₃*–*Om₅* (number of individuals x m⁻²).

Changes in generic composition were analysed based on the absolute numbers of genera using Correspondence Analysis (CA) option from the programme package CANOCO (Ter Braak 1987). Correspondence analysis allows to group the sites similar in species composition.

The effect of the distance from the shelterbelt on the total abundance, abundance of trophic groups and mean number of gen-

era was estimated using analysis of variance of the rank transformed data – ANOVA Kruskal-Wallis test (Statistica for Windows 6.00 software package). The differences in total abundance, the abundance of particular trophic groups, and mean number of genera between respective sites of two transects were estimated using Mann-Whitney test (Statistica for Windows 6.00 software package). The same test was applied to evaluate the differences in all mentioned above parameters between control field and the fields adjacent to the shelterbelts. All analyses were based on ten replications. Differences with $P \leq 0.05$ were considered significant.

The correlation between the total and mean number of genera in the sites was measured by Pearson's correlation index.

The differences between the values of *H'* were evaluated with Student t-test.

4. RESULTS

The total abundance did not depend on the age of the shelterbelt; the differences in the abundance of nematodes between respective sites in both transects (one running from the 6 years old shelterbelt, the second – from the 11 years old shelterbelt) were insignificant. In both transects the total abundance of nematodes did not depend on the distance from the shelterbelt either. The total abundance of nematode communities depended, however, on the season. In the autumn 2003 the density of nematode communities ranged from 276 to 641 × 10³ individuals per m² while in the spring 2004 nematode communities were more abundant and ranged from 388 to 1931 × 10³ individuals per 1 m². Bacterivores predominated in all communities followed by fungivores or obligatory plant feeders, while facultative plant feeders, predators and omnivores were less numerous. The abundance of obligatory plant parasites depended on the season. In spring this group was significantly ($P \leq 0.05$) less abundant than in autumn. In spring the abundance of bacterivores – enrichment opportunists in all sites along the transect of the 11 years old shelterbelt was significantly higher ($P \leq 0.05$) than that in respective sites of the

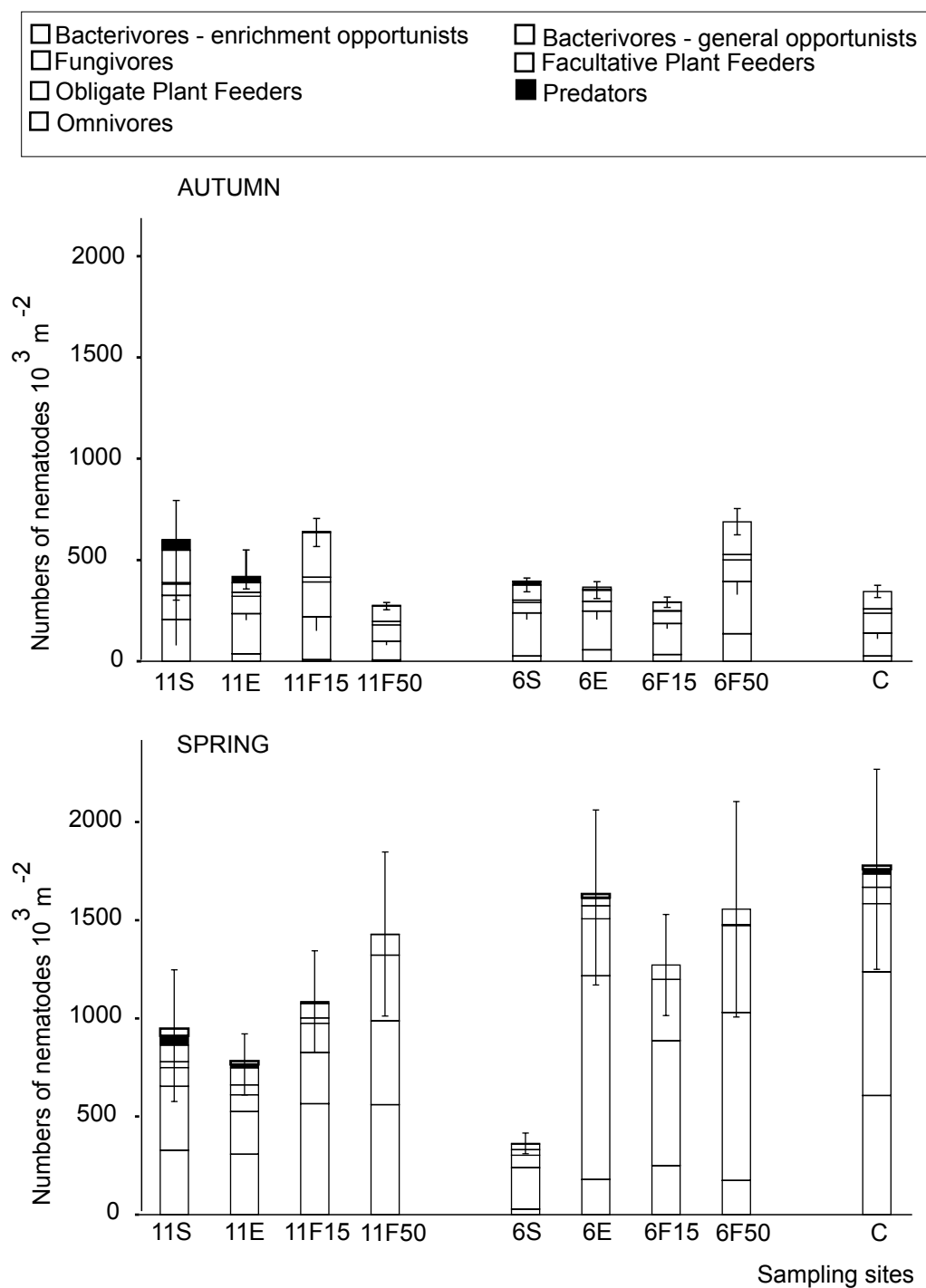


Fig. 2. The density of particular trophic groups in two shelterbelts of different age, ecotones, adjacent fields and control field. Means of ten replications. Bars – standard error for total density, abbreviations as in Fig. 1, Table 1.

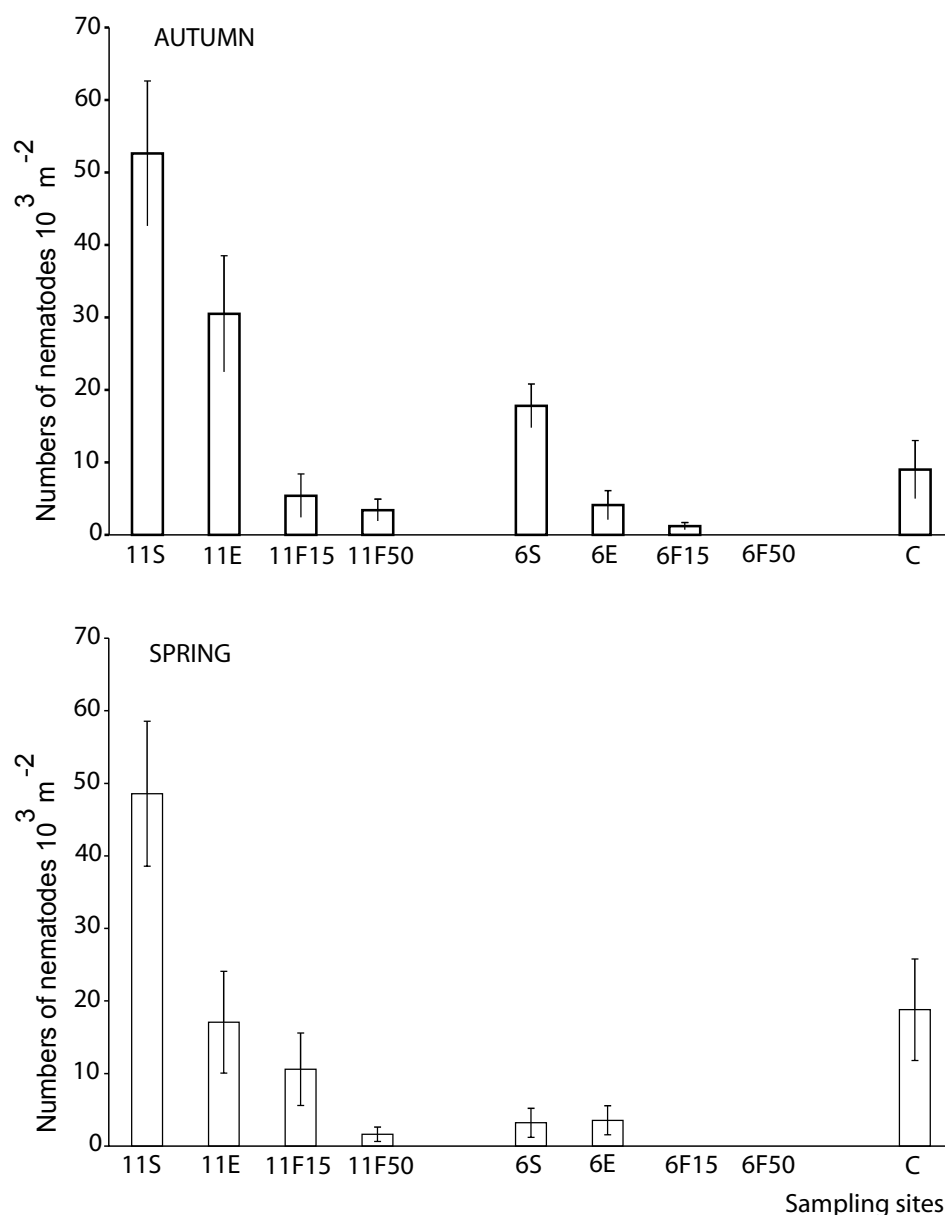


Fig. 3. The density of predators in two shelterbelts of different age, ecotones, adjacent fields and control field. Means of ten replications. Bars – standard error for total biomass, abbreviations as in Fig. 1, Table 1.

6 years old shelterbelt's transect (Fig. 2). In both transects the number of predators decreased with increasing distance from the shelterbelt. Predators were significantly ($P \leq 0.05$) more abundant in the transect of the 11 years old shelterbelt in comparison with the transect of the 6 years old shelterbelt (Fig. 3).

In autumn in both shelterbelts and in both ecotones the total number of genera, mean number of genera and the values of Shannon-Wiener diversity index H' were significantly higher ($P \leq 0.05$) than in the fields. The correlation between the total and mean number of genera for autumnal samplings was significant ($r = 0.61$, $P \leq 0.05$) but for

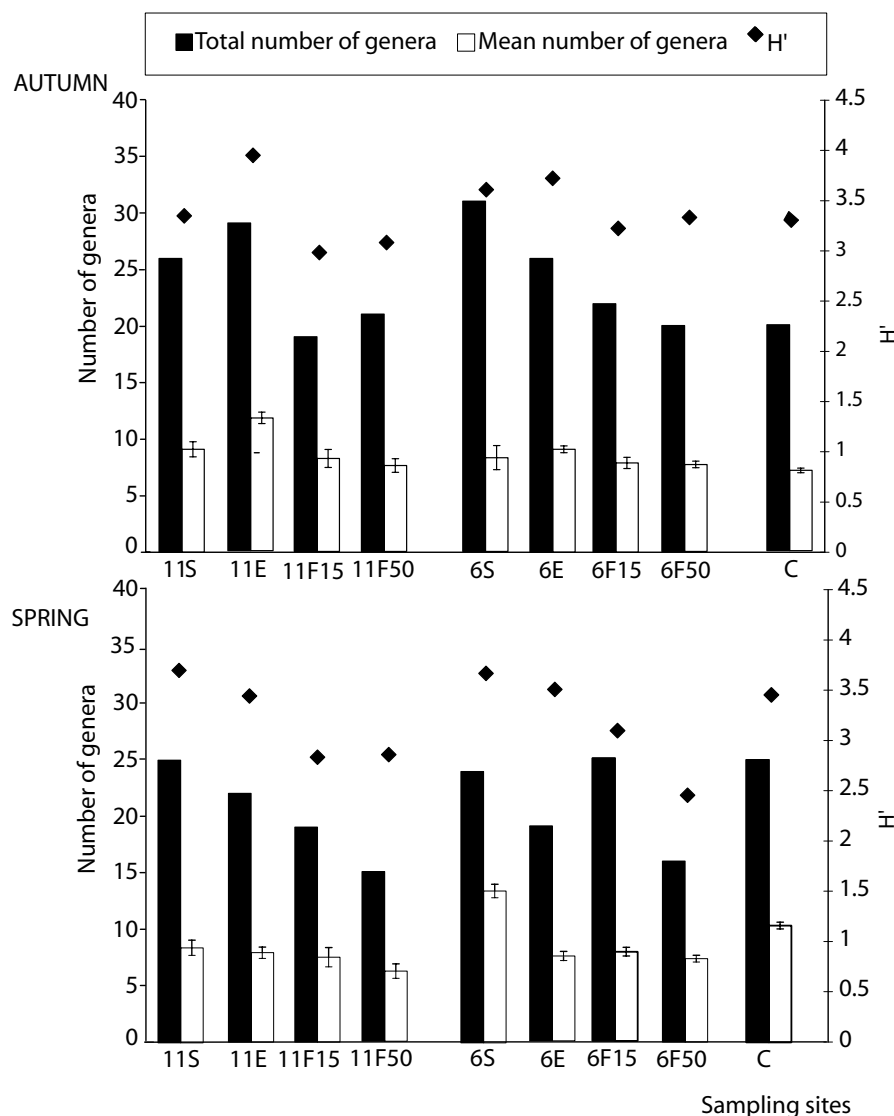


Fig. 4. The total and mean number (average of 10 replications) of genera and Shannon-Wiener diversity index H' in two shelterbelts of different age, ecotones, adjacent fields and control field. Means of ten replications. Bars – standard error, abbreviations as in Fig. 1.

samples taken in the spring was insignificant ($r = 0.46$, $P \geq 0.05$).

In spring the total number of genera varied without any clear trend. In site C, in shelterbelts and ecotones the mean number of genera was significantly higher ($P \leq 0.05$) than in the fields adjacent to shelterbelts. Similar tendency was observed in respect to the values of Shannon-Wiener diversity index H' . (Fig. 4).

The results of Correspondence Analysis showed that first two axis explained 40% of the variance. The first ordination axis (hori-

zontal, with eigenvalue 0.44) separated nematode communities in the 11-years old shelterbelt from the communities in the 6-years old shelterbelt. The genera: *Diphterophthora*, *Clarcus*, *Prismatolaimus*, *Thornia*, *Paratylenchus* and *Ecumenicus* were characteristic for older shelterbelt, while *Paraxonchium*, *Anaplectus*, *Eumonhystera* and *Laimaphelenchus* – for the younger. The nematode communities inhabiting ecotone adjacent to the younger shelterbelt were very similar to the communities in the shelterbelt. On the contrary, the communities inhabiting eco-

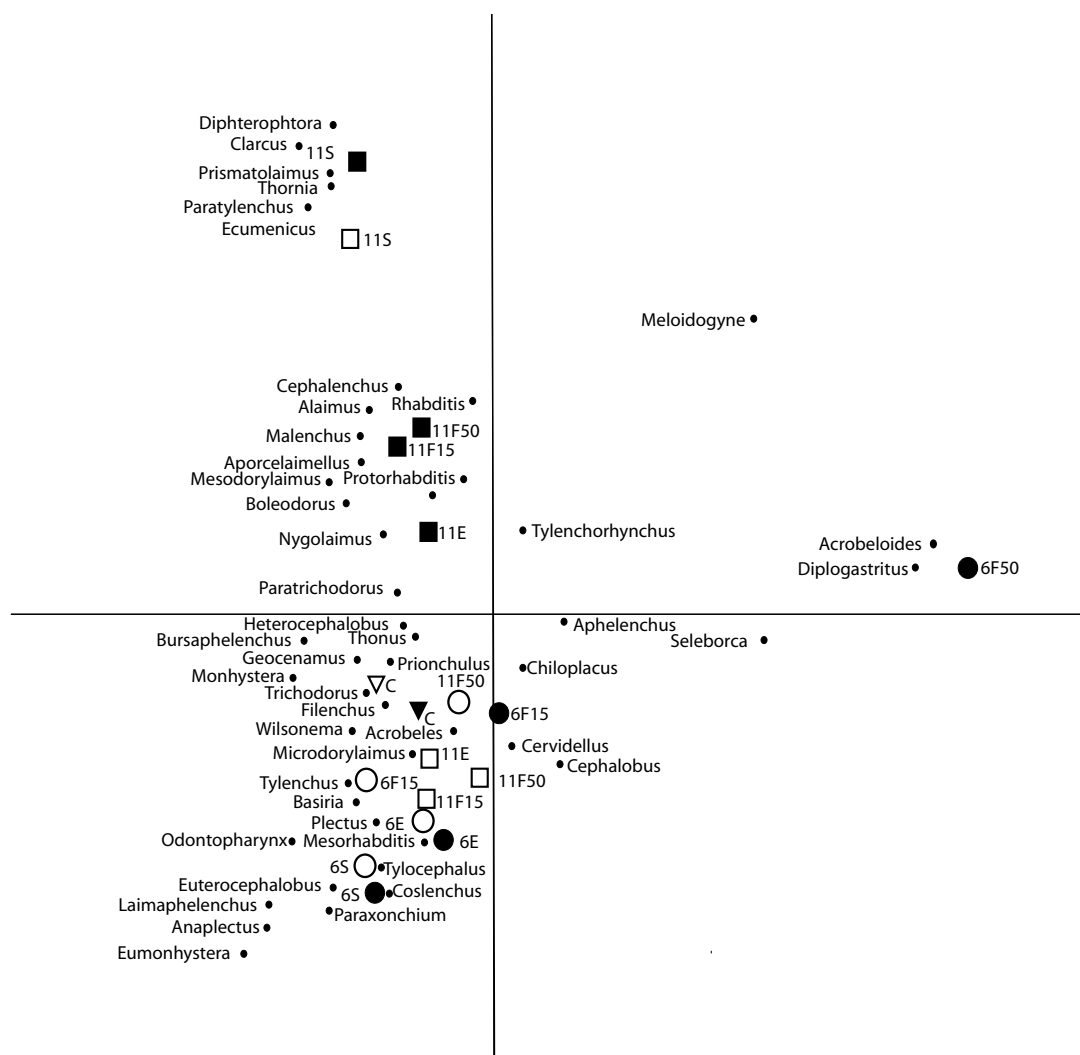


Fig. 5. Species-environmental biplot. The sites (squares) and the genera (points) display variation in species composition over the sites.

Black squares – sites belonging to the transect of the 11 years old shelterbelt in spring, open squares – sites belonging to the transect of the 11 years old shelterbelt in autumn, black circles – sites belonging to the transect of the 6 years old shelterbelt in spring, open circles – sites belonging to the transect of the 6 years old shelterbelt in autumn, black triangle – control field in spring, open triangle – control field in autumn.

tone adjacent to the older shelterbelt differed from those in the shelterbelt. The second ordination axis (vertical with eigenvalue 0.258) separated nematode communities occurring in spring in the field adjacent to younger shelterbelt from the communities inhabiting others sites. The site SF50 was evidently dominated by two genera: *Acrobeloides* and *Diplogastritus*, while characteristic genera of the site SF15 were: *Cervidellus* and *Cephalo-*

bus. Nematode communities inhabiting the control field were similar to those present in the field adjacent to younger shelterbelt and to autumnal communities in the ecotone and in the field adjacent to older shelterbelt (Fig. 5).

The changes of the two indices *EI* and *SI* (equation 2, 3) informing about the structure of the food web in sites from both transects and from control field are presented

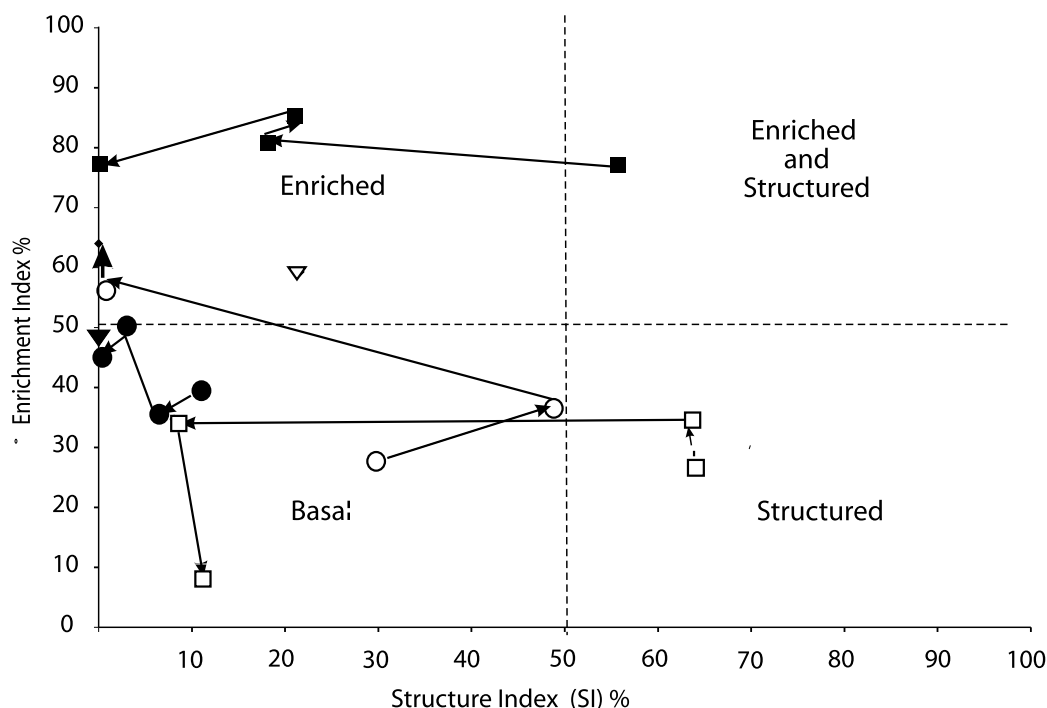


Fig. 6. Diagramme presenting changes in food – web condition in two shelterbelts differed in age, ecotones, adjacent fields and unsheltered field. A food web characterized at the proximal end of coordinates could be considered the basal food web – typical for degraded environments; one at the distal end of *SI* (equation 3) coordinate – the structured food web and indicates stable environment. The one at the distal end of *EI* (equation 2) coordinate reflects an increase in enrichment opportunists in response to increased food (bacteria) resources. A food web at the distal end of *EI* and *SI* coordinates indicates the structured food – web with a large contribution of enrichment opportunists. Points represent samples taken from the sites during the study.

Black squares – sites belonging to the transect of the 11 years old shelterbelt in spring, open squares – sites belonging to the transect of the 11 years old shelterbelt in autumn, black circles – sites belonging to the transect of the 6 years old shelterbelt in spring, open circles – sites belonging to the transect of the 6 years old shelterbelt in autumn, black triangle – control field in spring, open triangle – control field in autumn.

Arrows indicate the direction of changes from the shelterbelt through ecotone, field 15 m from the edge of the shelterbelt towards field 50 m from the edge of the shelterbelt.

in Fig. 6. Knowing the localisation of points corresponding to the values of *SI* and *EI* it is possible to assess the condition of the soil food web structure. The points localised in the right lower square indicate the structured food web typical for stable environmental conditions, resistant to disturbance. The points located in the left lower square suggest the basal food web with very simple structure because it is composed mainly of cosmopolitan bacterivores and fungivores. Such food web occurs in disturbed environments of limited food resources. The points located

in both upper squares indicate a high contribution of enrichment component to the food web (species taking part in decomposition of organic matter with high N content). Such food web is typical for environments rich in bacteria (Ferris *et al.* 2001).

Location of points respective to the values of *EI* and *SI* indices calculated for particular sites showed that food web structure along the 6 years old shelterbelt's transect was dominated by the basal components and the enrichment components had a slightly greater share in the field's soil only in autumn. On

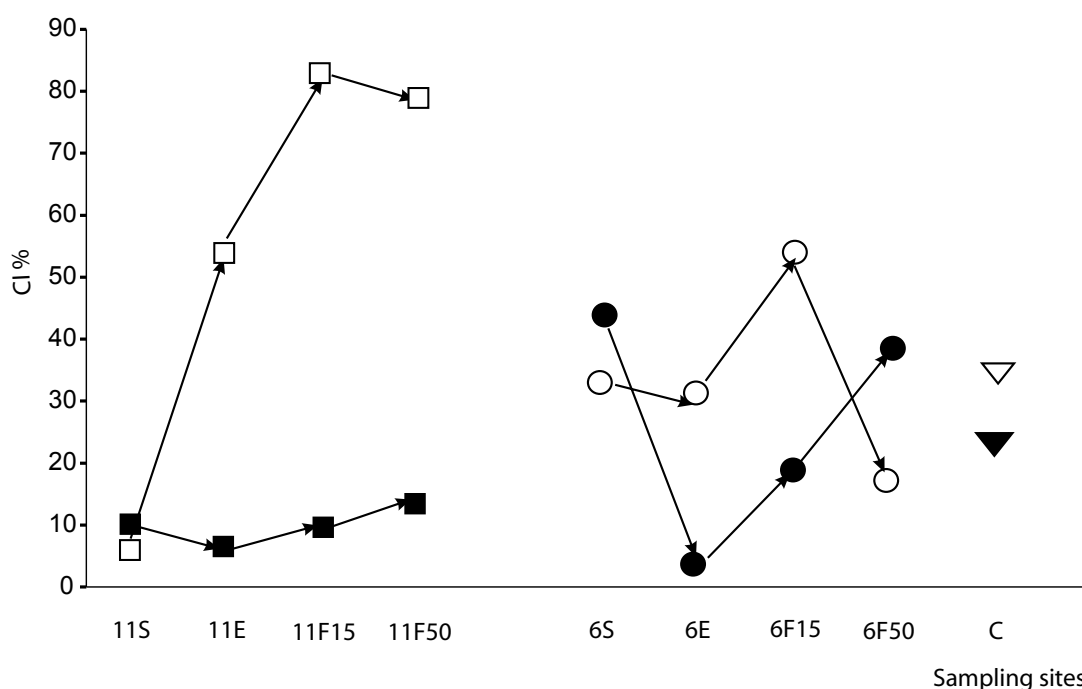


Fig. 7. Values of the Channel Index CI (%) (equation 1) in two shelterbelts of different age, ecotones, adjacent fields and control field. Abbreviations – see Table 1.

Black squares – sites belonging to the transect of the 11 years old shelterbelt in spring, open squares – sites belonging to the transect of the 11 years old shelterbelt in autumn, black circles – sites belonging to the transect of the 6 years old shelterbelt in spring, open circles – sites belonging to the transect of the 6 years old shelterbelt in autumn, black triangle – control field in spring, open triangle – control field in autumn.

Arrows indicate the direction of changes from the shelterbelt towards the centre of the field.

the other hand, the food web structure of soil in the 11 years old shelterbelt and its ecotone was dominated by the enrichment and structured components while in the field the basal component was important in autumn and the enrichment components – in spring. In the control field the soil food web was basal in autumn and enriched in spring.

In spring the values of CI index (equation 1) for the older shelterbelt and in adjacent field were very low (6–13%). In autumn the CI was low only in site 11S (7%) and increased with increasing distance from the shelterbelt (54–84%). On the contrary, in the younger shelterbelt the values of CI were low and varied without any clear pattern (3.7–42%). In site C the value of CI was similar to that calculated for site 11F50, in autumn the CI in site C was significantly higher ($P \leq 0.05$) than in 11F50 and 6F50 (Fig. 7).

5. DISCUSSION

New planted midfield shelterbelts undergo rapid succession. Initially they are overgrown by vegetation of early successional stages (Rees *et al.* 2001). After 2–3 years, vegetation of the shelterbelts is mainly composed of woods, grasses and herbs (Ryszkowski *et al.* 2003). Falling leaves provide a constant input of organic matter so the content of organic substances in the soil of shelterbelts gradually increases (Bartoszewicz 1996, Kajak *et al.* 2002) to produce a litter layer already 3–4 years afterwards. This process favours the development of microorganisms and soil fauna (Wojewoda and Russel 2003, Karg *et al.* 2003). Due to these successional changes and because no agrotechnical measures like tillage, fertilisation or chemical treatments are applied to shelterbelts, one might assume that the soil

of midfield shelterbelts provides different habitat conditions for soil fauna than the soil of adjacent fields.

Shelterbelts affect the soil of adjacent fields. This impact decreases with increasing distance from the shelterbelt. The soil in a belt adjacent to the shelterbelt (ecotone) being shadowed by tree crowns is less exposed to drying than soil in the middle of the field. Moreover, leaves falling from trees in the shelterbelt are the source of organic matter not only for the soil in the shelterbelt, but also for the soil in an ecotone as well as for the soil of the field 15 m apart. This is beneficial for the development of epigeic and litter fauna in the ecotone (Olechowicz 2007), which in turn supplies the soil with organic matter excreted in faeces or various material of invertebrate origin such as: corpses, invertebrate remnants, spider cocoons. An analysis of arable soil layer in studied sites demonstrated that organic matter content decreased along the transect from shelterbelt to field and sites along the 11 years old shelterbelt's transect contained more organic matter than sites along the transect starting from the 6 years old shelterbelt.

Studies carried out in shelterbelts of different age, in adjacent fields and in control field allowed to analyse changes in nematode communities in three series: 1) between four sites located along the transect from the shelterbelt towards the centre of the field, 2) between analogous sites located in the transects of two shelterbelts differing in age, 3) between the fields adjacent to shelterbelts and the field situated in non-forested area.

Total abundance of nematodes in studied sites was low, particularly in samples collected in autumn. Wasilewska (2004) who carried her studies in the same area in 1999 found as many as 3718×10^3 individuals per m^2 in the 6 years old shelterbelt and from 6071 to 10652×10^3 nematodes per m^2 in adjacent field. In the present study the respective densities were 363×10^3 and from 1272×10^3 to 1556×10^3 individuals per m^2 in the 6 years old shelterbelt in spring. Low densities were probably associated with low soil moisture. Precipitation rates in the months preceding sampling were lower than usual in this region. In September and October 2003 the precipitation were 15 mm and

24 mm, respectively, and in March and April 2004 the precipitation were 20 and 23 mm, respectively, while the long term averages are about 40 mm.

Since the total abundance varied in analysed sites without any clear tendency in this study, it seems that this parameter was not sufficiently sensitive to differentiate nematode communities between sites along the transects of both shelterbelts or between the shelterbelts of different age and the control fields.

Differences were, however, found in the abundance of some trophic groups in studied sites. Obtained data indicate that in spring in sites of the older shelterbelt's transect the abundance of bacterivores – enrichment opportunists was higher than in sites corresponding to the younger shelterbelt.

The abundance of predators was lower in the transect running from the younger shelterbelt in comparison with the older one. Moreover, the abundance of predators decreased with increasing distance from the shelterbelts towards the centre of the field. That resulted from particular susceptibility of this trophic group to agrotechnical measures. That's why predators are scarce or practically absent in soils of arable fields. Their presence in midfield shelterbelts suggests that soil conditions several years after planting changed enough to allow the development of sensitive nematode taxa. Significant difference in predator densities between the 11 years old and 6 years old shelterbelts indicates that favourable changes in soil conditions were more advanced in the former than in the latter. The occurrence of predators in ecotones is the evidence for favourable conditions in the field soil directly adjoining the shelterbelt though predator density was significantly ($P \leq 0.05$) lower in the ecotone than in the shelterbelt.

Differences in the density of both bacterivores – enrichment opportunists and predators decided on differences in the food web structure in studied sites since the method used in this study for diagnosing the structure of food web (Ferris *et al.* 2001) considers the proportion of particular nematode guilds (one guild encompasses species belonging to the same trophic group representing similar life strategy). According to Fer-

ris *et al.* (2001) the assessment of the soil food web based on nematode faunal analysis is sufficient because the nematodes have many relations with other soil dwellers. The nematodes affect microbial populations and small invertebrates by feeding on them, affect also primary production by feeding on plant roots and finally the nematodes influence the populations of small arthropods being a food source for them. The more complex is the structure of nematode communities and the larger contribution of long living predators and omnivores the less functional gaps in soil system and the greater chances for better functioning of the soil system.

In this study the food web in older shelterbelt and in adjacent ecotone differed from that in younger shelterbelt, its ecotone and in adjacent fields. The food webs in majority of sites in the 11 years old shelterbelt's transect were structured or enriched. On the contrary, in the majority of sites belonging to the younger shelterbelt and in the control field the food web was basal.

Based on obtained results on the food web structure in studied sites one may draw three conclusions: 1) soil system in the 11 years old shelterbelt and in its ecotone is more stable and resistant to disturbances than that in the 6 years old shelterbelt and its ecotone, 2) soil system stability decreases with increasing distance from shelterbelt and 3) in the fields, especially in spring in the field adjacent to older shelterbelt, bacterial processes proceed more intensely which is evidenced by a large contribution of enrichment component there.

The last conclusion is supported by the *CI* values calculated for spring samples from both sites in field adjoining the 11 years old shelterbelt. These values were very low (13%), which suggests that decomposition channel in these sites was evidently predominated by bacteria. In sites associated with the younger shelterbelt and in the control field the *CI* values were slightly higher (24–39%) but still indicated the prevalence of bacterial decomposition. In autumn, however, in ecotone and in field adjacent to the older shelterbelt the decomposition processes were dominated by fungi – *CI* ranged from 77 to 84%.

Fungi participate in the decomposition of organic matter rich in cellulose and

lignin thus having a high C:N ratio. Such a type of organic matter is common in forests and meadows since a constant input of leaves and litter is taking place there. In croplands fertilised with organic fertilisers, however, organic matter is rich in nitrogen and has a low C:N ratio. That organic matter is decomposed primarily by bacteria. It is thus interesting why fungal decomposition prevailed in autumn in the field while in the shelterbelt, whose floristic composition resembles that of a forest ecosystem, bacterial decomposition prevailed. Probably stubbles are the source of organic matter rich in cellulose in autumn. For part of fields that adjoined midfield shelterbelts an additional source of organic matter with high C:N ratio could be leaves falling from trees and blown by wind onto the field. In the younger shelterbelt trees are much smaller and hence the supply of organic matter with high C:N ratio is also smaller. Consequently, the *CI* values were smaller there than in field adjacent to the older shelterbelt. There were no leaves i.e. an additional source of organic matter rich in cellulose in the control field devoid of forested area thus the values of *CI* for this field were similar to those obtained for the field adjacent to younger shelterbelt. In shelterbelts and in ecotones the input of organic matter with high C:N ratio was equilibrated by the input of organic matter rich in nitrogen. The source of the latter might be animal faeces and inanimate organic matter of invertebrate origin which is more abundant in shelterbelts and ecotones than in fields (Karg *et al.* 2003, Nowak 2004, Olechowicz 2007, Olejniczak 2004).

It is difficult to point to one trend in changes for each of the three parameters used in this study to evaluate taxonomic diversity. However, the range of the total number of genera in shelterbelts (24–31) was broader than in ecotones (19–26) or fields (15–25). The total number of genera found in my study was similar to those recorded by Wasilewska (2004) for the 6 years old shelterbelt (32), for the ecotone (21) and for the field (20 genera). In this study the values of Shannon-Wiener diversity index calculated for both shelterbelts (3.63 and 3.70) and both ecotones (3.63 and 3.70) were similar, but lower than the values given by Wasilewska

(2004) for the 6 years old shelterbelt ($H'=3.91$) and for the ecotone ($H'=4.15$). On the contrary, the values of Shannon-Wiener diversity index calculated in this study for fields (2.48–3.48) were similar to those given by Wasilewska (2.64–2.83) and significantly lower in comparison with H' for shelterbelts and ecotones.

Taxonomic diversity of nematodes is important for the proper functioning of the soil system because these animals play crucial role in soil environment affecting decomposition of organic matter and nutrient cycling (Ingham *et al.* 1985, Ettema and Bongers 1993, Bloem *et al.* 1994, Bouwman *et al.* 1996). The greater diversity of nematode community the bigger chance for high stability of the soil system and for its resistance to disturbance. The greater diversity means also, in the case of disturbance, more chances for recovery. At a high diversity of the community which is important for the environment the loss of one genus is known to have a weak effect on the whole since its functions can be taken over by other related genera. In a community poor in genera, however, the loss of one genus may hamper some processes and may finally negatively reflect on the functioning of the whole soil system. Having in mind that diversity of nematode communities dwelling shelterbelts was slightly higher than those in adjacent fields one may expect more stable conditions for soil processes in the former than in the latter.

Very low and insignificant ($P \geq 0.05$) correlation between the total number and mean number of genera in shelterbelts and in ecotones suggests spatial diversity of nematodes in these sites. In contrast to the shelterbelts, spatial diversity of nematodes in the fields was low (relatively high and significant – $P \leq 0.05$ – correlation between the total number of genera and mean number of genera). This results are in accordance with the common opinion that the level of spatial diversity of nematode communities in the environment reflects mosaic character of the habitat resulting from the diversity of vegetation and thus from diverse soil conditions (moisture, temperature, chemical and physical conditions). For this reason a high spatial diversity of nematode communities was observed first of all in forest ecosystems (Háněl 1999,

Lazarova *et al.* 2004). Shelterbelts in this study covered with different plants typical for forest ecosystems certainly showed more mosaic pattern than fields sown by single crop species and growing on uniform soils due to agrotechnical practices.

The results concerning spatial diversity of nematodes are another argument to confirm the thesis that nematode communities inhabiting shelterbelts differed from those in the fields. It was earlier demonstrated that the communities dwelling shelterbelts were more diverse trophically and richer in genera than those from fields.

The results of correspondence analysis showed differences between the communities inhabiting older and younger shelterbelt. It appeared that the community of the older shelterbelt was built of other genera than that of the younger. Present nematode communities of shelterbelts were formed as a result of reconstruction of former field communities. Obtained results might indicate that 6 years after planting the succession is still proceeding and some time in the future a community would eventually appear that will markedly differ from present communities. It is also conceivable that the reconstruction of nematode communities proceeded with participation of different genera in the two shelterbelts. Nevertheless the direction of changes was the same: an increase of trophic and generic diversity.

Some results obtained in this study indicate that the composition of nematode communities depended to some extent on the season. Higher densities of obligatory plant feeders were found in autumn than in spring samples. This trophic group includes ectoparasites of crops. In the vegetative season they have excellent conditions for growth and reproduction since they feed on roots of crop plants. After harvesting the density of ectoparasites gradually decreases because of food shortage. That's why the density of obligatory plant feeders is low in spring. Similar seasonal dynamics of their density was observed in barley crops (Kozłowska, Dmowska 1987).

Moreover, as seen from correspondence analysis, the composition of nematode communities in both shelterbelts, in the ecotone of the younger shelterbelt and in control field

was similar in spring and autumn. In the ecotone of older shelterbelt and in fields, however, autumn and spring communities differed in composition.

In conclusion, the results obtained in this study confirmed assumptions presented in the introduction. Nematode communities inhabiting both shelterbelts differed from communities in adjacent fields. The former were more diversified and formed more complex food web. Differences were also found between communities of older and younger shelterbelts' transects. Those from the 11 years old shelterbelt's transect were richer in predatory nematodes than communities from the younger shelterbelt. Obtained results indicate some effect of the older shelterbelt on directly adjacent ecotone belt. Nematode communities in this ecotone were more diversified than field communities; they were also richer in predatory nematodes so presented more complex food web. There was no, however, distinct effect of shelterbelts on farther parts of studied fields which was reflected in similar values of such parameters as: the total number of nematodes, total number of genera, genera diversity H' , and indices like: El , SI , CI calculated for field nematode communities sampled 15 and 50 m from shelterbelt's edge and for communities from the control field.

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