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TAXONOMIC DIVERSITY AND DISTINCTNESS INDICES IN ASSESSMENT OF WEED COMMUNITIES

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Abstract

This paper contains an analysis of taxonomic weed biodiversity in the cultivation of spring barley in the period of 1990-2004, grown in crop rotation after potato with a 25% share of this cereal (potato – spring barley – field pea – winter triticale) as well as in crop rotation with its 75% share (potato – spring barley – spring barley – spring barley) in which barley was grown once and twice after the same barley crop. No weed control was used in the present experiment. Every year in the spring (at full emergence of the cereal crop) and before harvest, the species composition and the numbers of individual weed species were determined, as well as weed biomass before harvest. On this basis, the taxonomic diversity and distinctness indices were calculated. Potato/barley crop rotation with a 25% share of this cereal and growing spring barley once and twice after the same barley crop did not differentiate taxonomic weed biodiversity. However, it was positively correlated with rainfall abundance during the growing season and negatively correlated with mean temperature. The taxonomic diversity indices were positively correlated with species richness and species diversity, whereas the taxonomic distinctness indices did not generally show any relationship with these measures. Spring barley grain yield did not depend on taxonomic biodiversity of weed communities.

Key words: weeds, taxonomic diversity, taxonomic distinctness, spring barley, crop rotation

INTRODUCTION

Among many dimensions of biodiversity, taxonomic diversity is mentioned (Silvert, 2003). It relates to the representation of lower-rank taxa inside higher-rank taxa and is generally expressed by the number of the former ones within the latter ones. In the case of plant communities, the number of species within individual families identified in a patch under study is usually given (Trąba et al. 2006). Taxonomic diversity of weed communities in crop fields is more frequently determined by distinguishing mono- and dicotyledonous weed species (Feledyn–Szewczyk, 2008).

Expressing taxonomic biodiversity of an assemblage of organisms by a single number facilitates comparison of various groupings and allows a more efficient assessment of relationships of this diversity with some other traits of such an assemblage or its habitat. Warwick and Clarke (1995) proposed measures of taxonomic diversity of assemblages of organisms which are relatively easy to calculate. These measures, notably taxonomic diversity and taxonomic distinctness, are based on taxonomic differentiation of organisms within an assemblage (also an ecosystem, region) and hierarchization of such differentiation. Individual species are given the “distinctness weight”, depending whether they belong to the same genus, or only to the same family, or to a unit of higher systematic category. Taxonomic distinctness, relative to taxonomic diversity, ignores quantitative interspecific relationships. These measures are used with success in the analysis of assemblage of organisms in aquatic ecosystems (Heino et al. 2007), but less frequently – thus far – for assessment of plant communities (Gwali et al. 2010).

Taxonomy is based more and more frequently on findings relating to phylogenetic relationships made using molecular techniques (Schweiger et al. 2008) and probably the future of biodiversity will belong to this dimension. Nevertheless, the expensiveness of the above-mentioned methods is an important limitation, whereas the indices defined by Warwick and Clarke (1995) can be calculated using a simple spreadsheet.

The aim of the present paper is to verify the possibility of using the taxonomic diversity and taxonomic distinctness indices in assessment of field weed communities on the example of weed assemblages developed in a spring barley crop grown in crop rotation in different crop stands.

MATERIALS AND METHODS

This study is based on material originating from a strictly controlled, static field experiment carried out in the period 1990-2004 at the Bałcyny Production and Experimental Station (N = 53°35′49″, E = 19°51′20,3″). The object of the study was to investigate weed communities in spring barley (*Hordeum vulgare* L.) grown in two crop rotations with a 25% and 75% share of this cereal:

A – 25%: potato – spring barley – field pea – winter triticale;

B – 75%: potato – spring barley – spring barley – spring barley.

Three fields sown with barley were included in detailed analysis, notably: crop rotation A – after potato (potentially the best crop stand – A-p), and crop rotation B where barley was grown once (B-b) and twice (B-bb) after the same barley crop, that is, for the second and third time, respectively, in the same field.

No weed control was used in the experiment (throughout its whole duration) in order to make the role of the forecrop itself more evident in this respect.

Weed infestation of spring barley was determined each year in the spring (at full emergence of the cereal crop) and before harvest, in duplicate in each field, determining weed density and species composition at designated fixed sites (1m^2). In the case of monocotyledonous weeds, the number of stems was counted in the analysis performed before harvest. During this second analysis, weed biomass was also determined with a breakdown into individual species.

Detailed information on the experimental conditions as well as a discussion of weed density and biomass can be found in the paper of Wanic et al. (2010), while an analysis of the species diversity of the communities in the article of Jastrzębska et al. (2010). The results on weed species composition and density in spring barley (in the spring and before harvest) as well as the results on biomass (before harvest) were used to calculate the taxonomic diversity index (Δ) and the taxonomic distinctness index (Δ$^+$) according to the formulas proposed by Warwick and Clarke (1995):

$$\Delta = \frac{\sum\sum_{i<j} w_{ij} x_i x_j + \sum_i 0 \cdot x_i (x_i - 1)/2}{\sum\sum_{i<j} x_i x_j + \sum_i x_i (x_i - 1)/2}$$

$$\Delta^+ = \frac{\sum\sum_{i<j} w_{ij} x_i x_j}{\sum\sum_{i<j} x_i x_j}$$

where: w_{ij} – the ‘distinctness weight” of the *i*th and *j*th species according to the hierarchical taxonomic classification: w = 0 – individuals within the same species; w = 1 – different species within the same genus; w = 2 – species within the same family but different genera; w = 3 – species within the same order but different family; w = 4 – species within the same class but different order; w = 5 – species within the same phylum but different class; w = 6 – species in different phyla of the plant kingdom;

x_i – density or biomass of the *i*-th species in the community;

x_j – density or biomass of the *j*-th species in the community.

The basic taxonomic categories in the plant kingdom as well as systematic positions of individual species followed Mirek et al. (2002). The indices were calculated for the communities from each crop stand (crop rotation-forecrop), year, and time of determination.

Variations in the indices between years are presented in the form of the variation range (min.-max.), coefficient of variation, and trends over years. Correlations between the biodiversity indices and precipitation and mean temperature in the study period were determined by calculating coefficients of linear correlation. Relationships between the taxonomic diversity and distinctness indices, on the one hand, and species richness (S) and the Shannon-Wiener species diversity indices (H’) (Shannon, 1948; Wiener, 1948), on the other hand, were expressed by linear trends.

RESULTS

Weeds of 35 species identified in the spring barley crops over the 15-year study (Jastrzębska et al. 2010) were classified hierarchically to 34 genera, 18 families, 15 orders, 3 classes, and 2 phyla. The phylum Pteridophyta was represented only by one species (*Equisetum arvense*), and the class *Liliopsida* (phylum *Spermatophyta*) – by four species (*Apera spica-venti*, *Avena fatua*, *Echinochloa crus-galli*, and *Poa annua*); the other species belonged to the class Magnoliopsida (phylum Spermatophyta).

The barley stand in crop rotation did not affect the taxonomic diversity and distinctness of the weed communities (Table 1). It is worth noting that the indices calculated for the summer communities (analysis before barley harvest) were slightly higher than the corresponding indices for the spring communities. However, the indices determined on the basis of weed density and on the basis of weed biomass were comparable. The range of variation of the analysed indices at a particular time of determination and in a particular crop stand was primarily determined by the less or more abundant occurrence, in the communities, of species of more distant taxonomic relatedness to the dominant species *Chenopodium album* and *Thlaspi arvense* (J a s t r z ę b s k a et al. 2010), thus *Equisetum arvense* as well as weeds of the family Poaceae. Variations in the indices in question between years did not have the character of a linear trend in any crop stand and at no time of determination.

The values of the taxonomic diversity and distinctness indices showed a clear correlation with precipitation and temperature during the growing season (Table 2). The value of all the analysed indices increased together with total precipitation for the period from the beginning of April until the end of August as well as together with an abundance of rainfall in May and July. Higher monthly average temperature from April to August was significantly correlated with lower values of the indices. The analysis also showed a significant negative correlation with temperature in May, July, and August in the case of the taxonomic diversity index based on weed density ($\Delta_{density}$) and with temperature in July – in the case of this diversity index calculated on the basis of weed biomass ($\Delta_{biomass}$).

The taxonomic diversity indices (Δ) showed a highly and very highly significant positive relationship with the number of species (S) composing the weed community; however, the indices based on weed density demonstrated a stronger relationship than those calculated based on weed biomass (Fig. 1). But species distinctness did not show any correlation with species richness of the community (Δ^+).

The taxonomic diversity indices showed an even stronger relationship with species diversity expressed by the Shannon-Wiener indices (H') than it was in the case of species richness, which is presented in Figure 2. Here, higher correlation coefficients were also recorded for the indices based on weed density than in the case of the biomass-based indices. The species distinctness indices for the spring communities ($\Delta^+_{density}$) and for the summer communities calculated on the basis of biomass ($\Delta^+_{biomass}$) showed independence of species diversity (H'), but a positive correlation with species diversity was confirmed in the case of the density-based indices ($\Delta^+_{density}$) determined for the time before harvest.

Barley grain yield did not show any dependence on taxonomic diversity or distinctness of the weed communities developed in the barley crop (Fig. 3). The correlation coefficients being measures for this relationship were not only insignificant, but also very low.

Table 1.
Taxonomic diversity and taxonomic distinctness of weeds in spring barley and their variation expressed by means of simple statistics

Index	Crop rotation field	Index value		V	Linear trend over years
		mean	min.-max.		
spring					
$\Delta_{density}$	A-p	2.78	1.82-4.13	20.4	n.s.
	B-b	2.70	1.96-3.29	14.2	n.s.
	B-bb	2.74	2.11-3.22	11.1	n.s.
$\Delta^+_{density}$	A-p	3.97	3.73-5.04	7.8	n.s.
	B-b	3.84	3.70-4.02	2.1	n.s.
	B-bb	3.90	3.53-4.90	7.7	n.s.
before harvest					
$\Delta_{density}$	A-p	3.11	1.87-5.18	29.9	n.s.
	B-b	2.87	1.51-4.88	29.7	n.s.
	B-bb	2.84	1.40-2.10	31.7	n.s.
$\Delta_{biomass}$	A-p	2.99	2.13-3.85	15.8	n.s.
	B-b	2.80	1.80-3.99	19.3	n.s.
	B-bb	2.78	1.57-5.45	33.5	n.s.
$\Delta^+_{density}$	A-p	4.30	3.67-6.12	15.6	n.s.
	B-b	4.06	3.61-6.05	14.0	n.s.
	B-bb	4.09	3.58-6.43	16.5	n.s.
$\Delta^+_{biomass}$	A-p	4.16	3.71-5.42	11.1	n.s.
	B-b	3.96	3.59-5.23	9.8	n.s.
	B-bb	4.21	3.55-8.41	28.4	n.s.

V– coefficient of variation over years, n.s. – not significant trend; location of spring barley (crop stand): A-p – crop rotation A after potato, B-b – crop rotation B the first time after spring barley, B-bb – crop rotation B the second time after spring barley; $\Delta_{density}$, $\Delta^+_{density}$ – indices determined based on weed density, $\Delta_{biomass}$, $\Delta^+_{biomass}$ – indices determined based on weed biomass

Table 2.
Coefficients of simple correlation between the taxonomic diversity and distinctness indices for weeds, on the one hand, and precipitation and temperature over the study period

Month	Precipitation and temperature	$\Delta_{density}$	$\Delta_{biomass}$	$\Delta^{+}_{density}$	$\Delta^{+}_{biomass}$
spring					
IV	P	0.29	x	–0.06	x
	T	–0.17	x	–0.09	x
before harvest (end of growing season)					
V	P	0.30*	0.38**	0.42**	0.41**
	T	–0.31*	–0.17	–0.25	–0.18
VI	P	0.43**	0.13	0.14	–0.01
	T	–0.29	–0.18	0.014	0.03
VII	P	0.56***	0.58***	0.50***	0.52***
	T	–0.60***	–0.50***	–0.18	–0.10
VIII	P	0.05	–0.08	–0.19	–0.20
	T	–0.39**	–0.17	0.00	–0.09
IV-VIII	P	0.70***	0.43**	0.46**	0.32*
	T	–0.82***	–0.65***	–0.41**	–0.36*

P – precipitation, T – temperature; * – correlation significant at p = 0.05, ** – correlation significant at p = 0.01, *** – correlation significant at = 0.001; x – no determinations were made; $\Delta_{density}$, $\Delta^{+}_{density}$ – indices determined based on weed density, $\Delta_{biomass}$, $\Delta^{+}_{biomass}$ – indices determined based on weed biomass

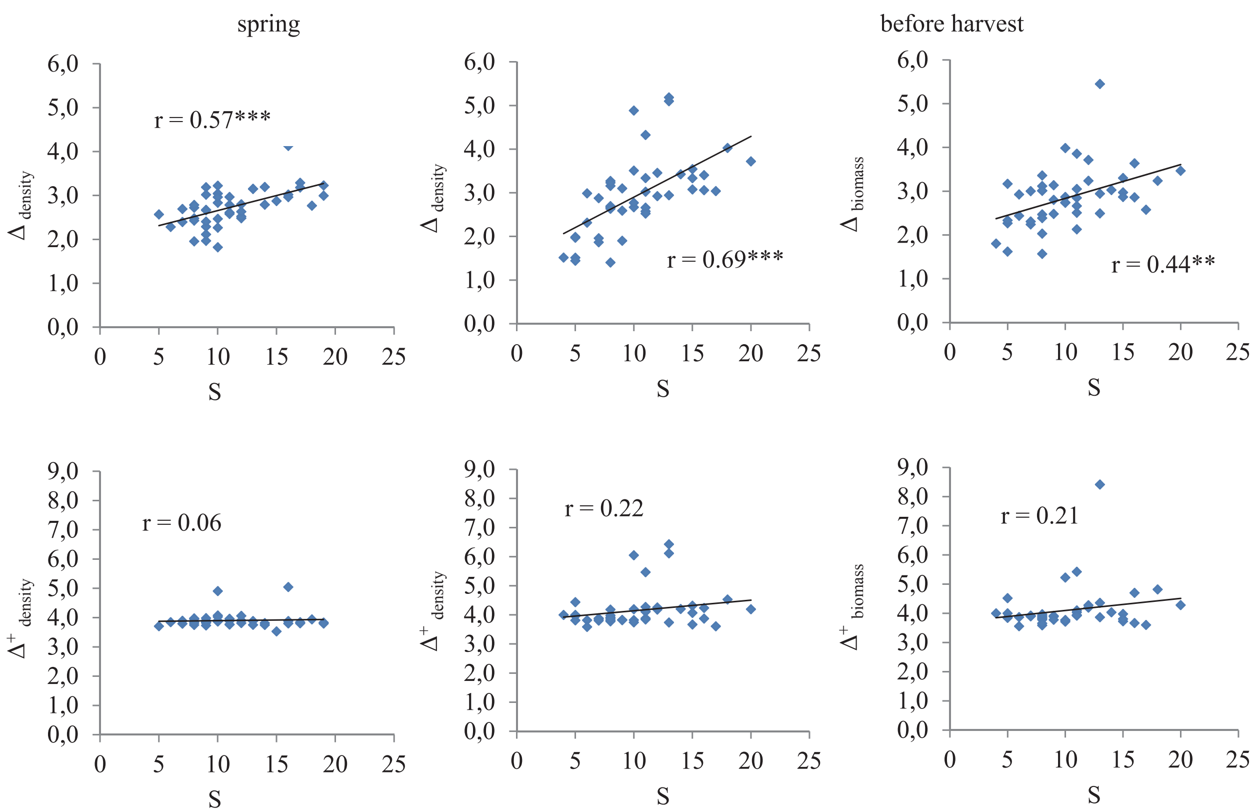

Fig. 1. Correlations between taxonomic diversity and distinctness indices (Δ, Δ^{+}) and weed species richness (S); $\Delta_{density}$, $\Delta^{+}_{density}$ – indices determined based on weed density, $\Delta_{biomass}$, $\Delta^{+}_{biomass}$ – indices determined based on weed biomass; ** – correlation significant at p = 0.01, *** – correlation significant at p = 0.001.

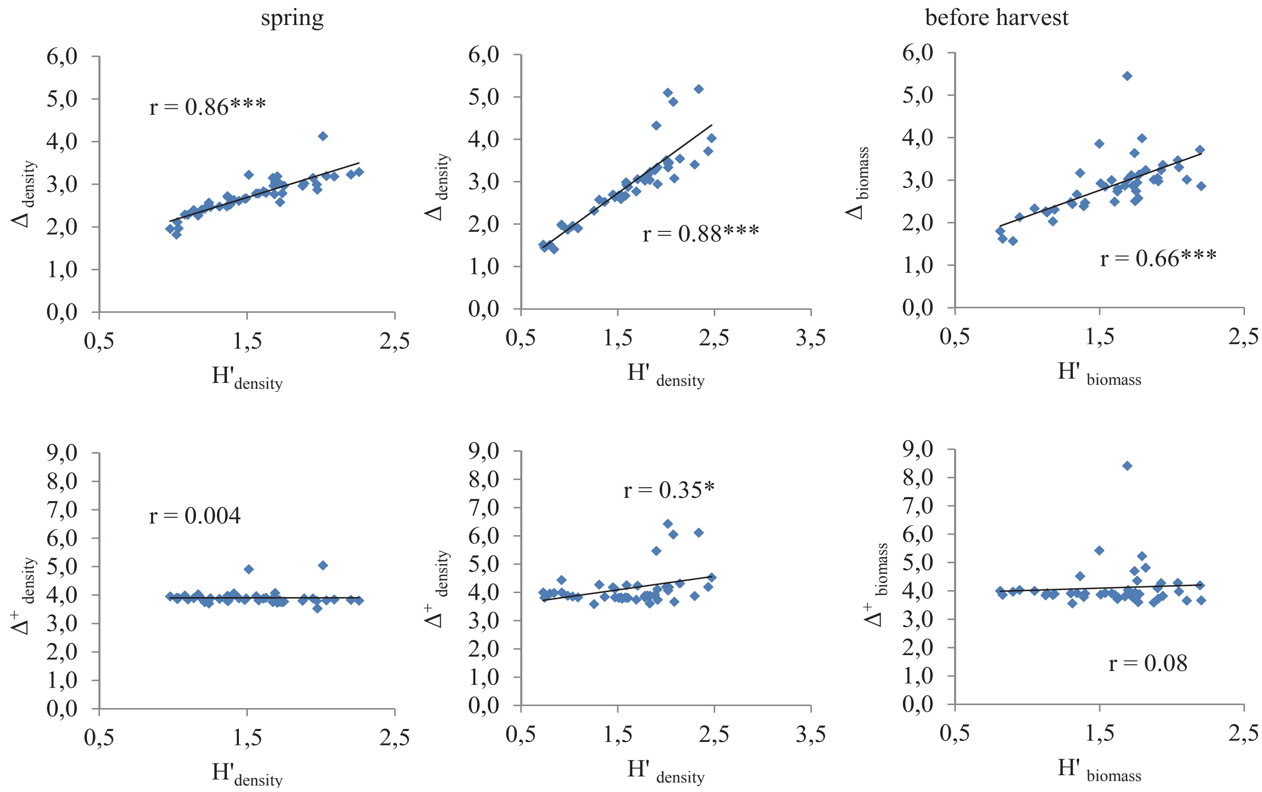

Fig. 2. Correlations between taxonomic diversity and distinctness indices (Δ, Δ^+) and weed species diversity indices (H'); $\Delta_{density}$, $\Delta^+_{density}$, $H'_{density}$ – indices determined based on weed density; $\Delta_{biomass}$, $\Delta^+_{biomass}$, $H'_{biomass}$ – indices determined based on weed biomass; * – correlation significant at p = 0.05, *** – correlation significant at p = 0.001;

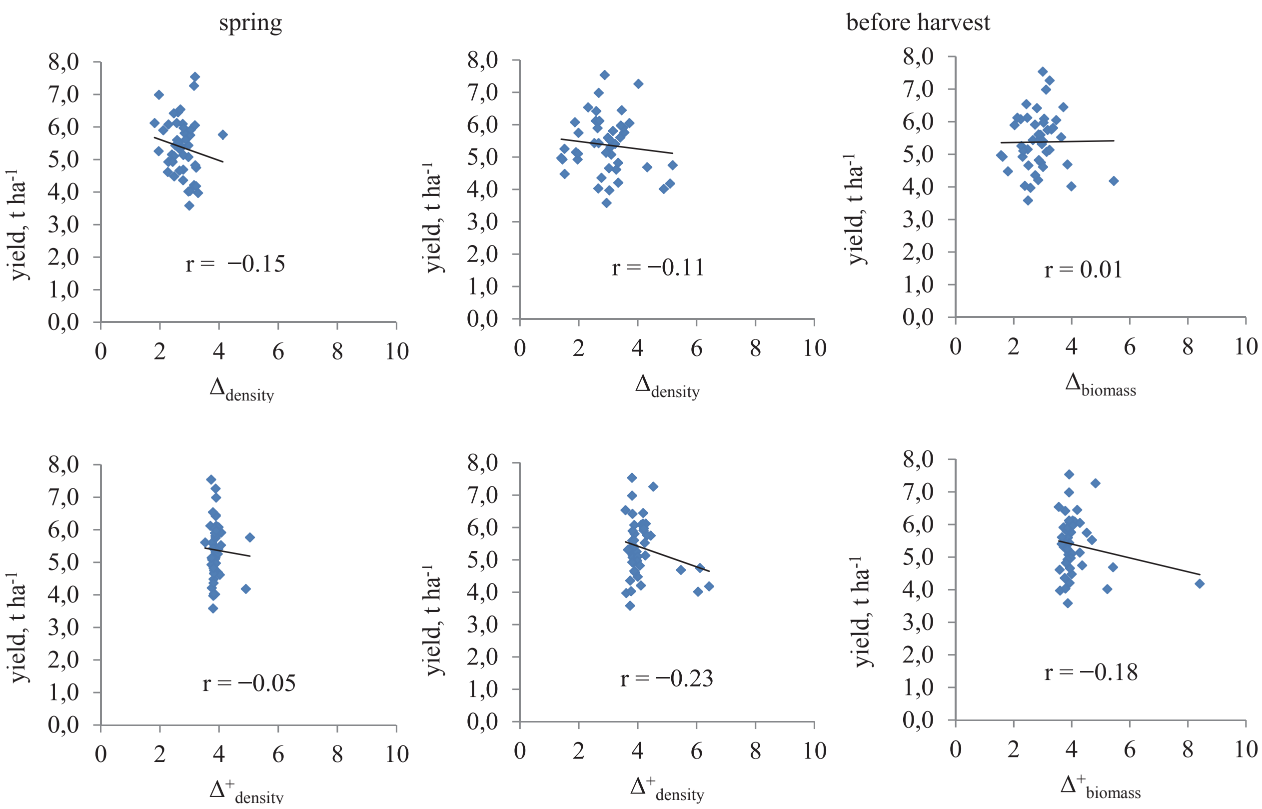

Fig. 3. Correlations between spring barley yield and weed taxonomic diversity and distinctness indices (Δ, Δ^+); $\Delta_{density}$, $\Delta^+_{density}$ – indices determined based on weed density, $\Delta_{biomass}$, $\Delta^+_{biomass}$ – indices determined based on weed biomass;

DISCUSSION

Weed biodiversity is nowadays determined most frequently at its species level and expressed by the number of species (Blecharczyk et al. 2000; Lososová et al. 2004; Kaar and Freyer, 2008) or – which is considered to be more accurate – by the Shannon-Wiener species diversity indices (Stevensen et al. 1997; Jędruszczak and Antoszek, 2004; Jastrzębska et al. 2006; Feledyn-Szewczyk, 2008). These measures (without looking at relative species abundance, captured by the Shannon-Wiener index, which defines in a certain way the importance of each species in an assemblage) treat equally all species present in a community, irrespective of the role performed by them in the ecosystem or their relatedness. Researchers have started to analyse weed diversity from the functional side relatively recently (Lemerle et al. 2004; Puricelli and Tuesca, 2005; Singh et al. 2008). Taxonomic diversity is yet another platform from whose perspective it is worth considering the biodiversity of segetal associations. One can sense intuitively that an assemblage composed of taxonomically more distant species is more diverse than in the case where it is made up of closely related individuals (Desrochers and Anand, 2004). It is known that, under the influence of disorders in assemblages of organisms, their taxonomic range is reduced, and in extreme cases only siblings species can occur in them, even belonging to one genus or very closely related (Warwick, 2008). Therefore, taxonomic diversity can be a measure of stress induced on plant associations by different factors.

In the present study, the long-term cultivation of barley in crop rotation with the cropping frequency of this species up to 75%, in relation to barley grown after potato in control crop rotation (50% cereals, 25% barley), proved to be too mild a factor to have a negative effect on taxonomic diversity of weed associations. No corresponding articles have been found in the available literature in which weed diversity would be expressed by a related index, but signals about changes in communities in the direction of compensation of some species (Albrecht, 1995; Hyvönen, 2004), in particular in cereal monocultures (Blecharczyk et al. 2000; Jędruszczak and Antoszek, 2004; Adamiak, 2007) can also indicate the taxonomic impoverishment of segetal associations. A postulate to expand research on weed ecology, carried out by numerous national research centres, by also including this aspect in such research seems to be justified.

The relationship of the taxonomic diversity and distinctness indices with meteorological conditions is similar to the one that was determined in the case of the species diversity indices (Jastrzębska et al. 2010). This outcome seems to be understandable in the case of taxonomic diversity, given the mutual correlation of its indices with the species diversity indices.

Since no references at the level of plant associations had been found in the available literature, the correlations, found in our study, between the taxonomic indices and the Shannon-Wiener species diversity indices were confronted with the results of a Finnish study on biodiversity of stream invertebrates (Heino et al. 2007). These proved to be surprisingly coincident: the Shannon-Wiener index showed a strong correlation with taxonomic diversity, whereas taxonomic distinctness was not correlated with it.

Similarly to the species diversity indices in the study under consideration (Jastrzębska et al. 2010), but also in the research relating to cereal phytocoenoses presented in our earlier papers (Wanic et al. 2005; Jastrzębska et al. 2006), the taxonomic indices did not also show significant relationships with barley yield. Nevertheless, this thesis about the lack of correlation between weed biodiversity and yield of crop plants should yet be verified repeatedly, both in terms of effects of different factors and the degree in which their variants are contrasted.

CONCLUSIONS

1. Potato/barley crop rotation with a 25% share of this cereal and growing spring barley once and twice after the same barley crop did not differentiate taxonomic weed biodiversity.
2. Taxonomic weed biodiversity was positively correlated with abundance of rainfall during the growing season and negatively correlated with mean temperature.
3. The taxonomic diversity indices were positively correlated with species richness and species diversity, whereas the taxonomic distinctness indices did not generally show any relationship with these measures.
4. Spring barley grain yield did not depend on taxonomic biodiversity of weed communities.

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Wskaźniki różnorodności i odmienności taksonomicznej w ocenie zbiorowisk chwastów

Streszczenie

Praca zawiera analizę bioróżnorodności taksonomicznej chwastów w jęczmieniu jarym uprawianym w latach 1990-2004 w płodozmianie z 25% udziałem tego zboża (ziemniak – jęczmień jary – groch siewny – pszenżyto ozime) w następstwie po ziemniaku i w płodozmianie z 75% jego udziałem (ziemniak

– jęczmień jary – jęczmień jary – jęczmień jary) w jedno- i dwukrotnym następstwie po sobie. W eksperymencie nie stosowano ochrony przed chwastami. Corocznie, wiosną (w pełni wschodów zboża) i przed zbiorem oznaczano skład gatunkowy i liczebność poszczególnych gatunków chwastów, a przed zbiorem także ich biomasę. Na tej podstawie obliczono wskaźniki różnorodności i odmienności taksonomicznej. Następstwo jęczmienia po ziemniaku w płodozmianie z 25% udziałem tego zboża oraz jedno- i dwukrotne jego następstwo po sobie nie różnicowało taksonomicznej bioróżnorodności chwastów. Była ona zaś dodatnio skorelowana z obfitością opadów w okresie wegetacji i ujemnie ze średnią temperaturą. Wskaźniki różnorodności taksonomicznej były dodatnio skorelowane z bogactwem gatunkowym i różnorodnością gatunkową, natomiast wskaźniki odmienności taksonomicznej zwykle nie wykazywały z nimi związku. Wydajność ziarna jęczmienia jarego nie zależała od bioróżnorodności taksonomicznej zbiorowisk chwastów.