ACTA AGROBOTANICA
Vol. 63 (1): 221–233
2010

INFLUENCE OF CROP ROTATION AND METEOROLOGICAL CONDITONS ON BIODIVERSITY OF WEED COMMUNITIES IN SPRING BARLEY (*Hordeum vulgare* L.)

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Received: 8.01.2010

A b s t r a c t

The paper presents the analysis of changes in weed biodiversity in spring barley cultivated in the years 1990–2004 in crop rotation with a 25% proportion of this cereal (potato – spring barley – sowing peas – winter triticale), when it was grown after potato, and in crop rotation with its 75% proportion (potato – spring barley – spring barley – spring barley), when it was grown once or twice after spring barley. In the experiment, no weed control was applied. Every year in the spring (at full emergence of the cereal) and before the harvest, the composition of weed species and numbers of particular weed species were determined, and before the harvest also their biomass. On this basis, the constancy of species in particular years, Shannon–Wiener species diversity indices and diversity profiles according to Rényi were determined. Weed species richness increased linearly at all plots during the 15-year period. *Chenopodium album* was a constant and dominant species in terms of weed species density and biomass year after year. The quality of the plot had no clear influence on the diversity of weeds in barley. Weed density and biomass showed high year–to–year variability and a positive correlation with the amount of precipitation and a negative correlation with temperature during the period of the study. The significance of the correlation between the productivity of barley and weed diversity was not confirmed.

Key words: spring barley, crop rotation, air temperature, precipitation, weed species, constancy, Shannon–Wiener index, Rényi profiles, year–to–year changes

INTRODUCTION

Contemporary weed growth control on cultivated fields is facing a dilemma how to reconcile the needs of crop protection and the need for protection of biodiversity. Competition between weeds and crops in relation to habitat resources is obvious and undoubted. Weeds can also be hosts for numerous pests and pathogens; they make the harvest more difficult and worsen the yields (S k r z y p c z a k and A d a m c z e w s k i , 2002). For years that perception of weeds resulted in a situation where efforts were undertaken to eliminate them at any price. At the same time, intensification of farming in agro-ecosystems supported intensified expansion of segetal plants, coupled with unfavourable changes in the communities in the direction of compensation for some species (H y v ö n e n , 2004; A d a m i a k , 2007). Only relatively recently a perception started to develop that the above measures might result in the impoverishment of the diversity of the world of organisms in those ecosystems. This applies to both weeds themselves and organisms related to them by trophic and para-trophic relations (A n d r e a s e n and S t r y h n , 2008). Many once common weed species are on the list of species that are extinct or threatened by extinction (C h e f f i n g s and F a r r e l l , 2005; Z a r z y c k i and M i r e k , 2006; T ü r e and B ö c ü k , 2008). Increasingly often the positive role of weeds in agrocenoses is noticed as well as the possibility of using them in many aspects of human life (H o c h ó ł , 2003).

Identification and preservation of species richness of the biosphere, in addition to clearly knowledge development aspects, have also a purely practical meaning for man as well as ethical and aesthetic importance. Investigation and protection of biodiversity are the duty of the countries that signed the relevant convention in 1992. Since the 1960s, there has been an ongoing debate about the correlation between species diversity in ecosystems and their functional stability and productivity (L e h m a n and T i l m a n , 2000; McCann, 2000; Hooper et al. 2005; Smith et al.

2008). In this aspect, not only the number of species in the community of organisms is important, but also the quantitative proportions among them. Proving the above-mentioned correlations has a special dimension in relation to agricultural ecosystems, that is, the systems focused on high yield of biomass per area unit and influenced by systematic destructive human intervention. The biodiversity of cultivated fields is divided into "planned" and "associated" (Altieri, 1999). Weeds represent an important component of the latter one, however, as opposed to communities rich with species such as, e.g., meadows, the species diversity of plants accompanying crops on arable land has so far been subject to much less attention (Hyvönen, 2004). In agricultural studies, the number of species has been and still is the most frequently applied measure for weed biodiversity (Blecharczyk et al. 2000; Buczyński and Marks, 2003; Lososová et al. 2004; Adamiak, 2007; Kaar and Freyer, 2008); assessment using measures considering quantitative proportions among species has appeared in papers less frequently and only since recently (Stevenson et al. 1997, Wesołowski et al. 2003; Jędruszczak and Antoszek, 2004; Stupnicka–Rodzynkiewicz et al. 2004; Wanic et al. 2005; Jastrzębska et al. 2006; Feledyn–Szewczyk, 2008). Numerous studies indicate that harmful effects of a community consisting of a few weed species are often greater than of a community consisting of several or more components (Stupnicka–Rodzynkiewicz et al. 2004). Weed control should be currently represented mainly not by their total elimination but by maintaining their presence at a certain harmless level and preventing compensation.

The aim of the presented work is to present the analysis of weed infestation changes in unprotected spring barley cultivated for 15 years in extreme positions, in terms of quality, with regard to the density of weeds and their biomass. An attempt was also undertaken to determine the correlation between cereal yield and biodiversity of weed communities.

MATERIALS AND METHODS

The full details of the experiment are reported in the publication by Wanic et. al. (2010)**.** The results concerning density (in spring and before harvest) and biomass (before harvest) of spring barley (*Hordeum vulgare* L.) weed communities served to determine species richness (number of species) of weeds, computation of species constancy (Braun–Blanquet, 1964), Shannon–Wiener species diversity index (Shannon, 1948; Wiener, 1948) and diversity profiles according to Rényi (Rényi, 1961). The Shannon–Wiener indices and Rényi profiles were determined on the basis of the number of individuals representing individual species in the weed community and biomass generated by each of the species.

In determining the species constancy, the phytosociological constancy method identifying classes according to the Braun–Blanquet cover–abundance scale was applied: V – species occurring constantly and frequently (present in 80.1–100% of years covered), IV – frequent species (in 60.1–80%), III – medium frequent (40.1–60%), II – not very frequent (20.1–40%) and I – occasional or rare (0.1–20% of the years).

The Shannon–Wiener species diversity index (H') was computed for each year and time of determination by applying the formula:

$$H' = -\sum (p_i \cdot \ln p_i)$$

where:

p_i – proportion of the number of *i*–species individuals in the community (or biomass generated by species *i*) to the number (or biomass) of all individuals in the community.

Rényi profiles were determined for communities formed artificially on the basis of average values for the 15–year period for individual species and for actual communities from the extreme years of the studies (1991 and 2004), for the purpose of comparing the diversity of communities at different positions. In that way, the communities developing at the same positions at the beginning and the end of the study were also compared. 1991, which is the year during which two replications of spring barley after spring barley could be recorded, was assumed to represent the starting year of the study. The following formula was applied for computations:

$$H_\alpha = (\ln \Sigma p_i^\alpha)(1-\alpha)^{-1}$$

where:

p_i – as in Shannon–Wiener formula, α – diversity levels assuming that $\alpha \geqslant 0$, $\alpha \neq 1$. For $\alpha = 1$ in the formula the values of H' were substituted.

The correlation between the studied characteristics of weed communities and the amount of precipitation and average temperatures during the study period was determined by applying the linear correlation coefficients. The linear year–to–year trends were determined for the studied characteristics of weed communities. The linear correlation between weed diversity and barley yield was also analyzed. Those linear trends were determined according to the formula:

$$y = a + b \cdot x$$

where:

x – value of independent variable (here: consecutive years of study, yield)

y – value of the dependent variable corresponding to the value of x (here: species richness, Shannon-Wiener diversity index)

a – regression constant (free expression) – determines the intersection point of the determined regression straight with the dependent variable axis y

b – tangent of the slope of regression axis relative to the independent variable x axis; it indicates by how much the dependent variable y will change if the independent variable x changes by one unit.

The Latin names of the weeds followed M i r e k et al. (1995).

RESULTS

During the 15 years of the study, a total of 35 weeds species were identified in barley (Table 1), 32 of them were identified in the position after potato (crop rotation A) and 31 species in case of each of the positions once and twice following spring barley (rotation system B). In all three treatments, *Chenopodium album* predominated in terms of the number and weight in the communities of weeds, while during the spring period *Thlaspi arvense* was also represented in high numbers. Those species, germinating early and with relatively short vegetation periods, decreased significantly in numbers before harvest (many individuals died out after reaching maturity and dropped out from the community), although *Chenopodium* maintained its first position as regards the number of individuals and biomass, while *Thlaspi* gave precedence to the following species: *Stellaria media, Fallopia convolvulus, Sonchus arvensis* and *Matricaria maritima* ssp. *inodora*. The species: *Chenopodium album*, *Thlaspi arvense*, *Stellaria media, Matricaria maritima* ssp. *inodora*, *Fallopia convolvulus* and *Galium aparine* (in the first crop after barley), appeared in the communities constantly. The most numerous group consisted of species occurring rarely: 13 species were found in the community after potato, whereas 9 and 10 species, respectively, in the first and second barley crops after barley. Similar proportions between permanent and occasional species in the plots changed in relation to other groups. In the position after potato, only one species was included in class II and in the position with the first barley crops after barley only two species were allocated to class IV.

The number of species (species richness) in individual communities and seasons was much smaller as compared to the list of all species found during the 15-year period. The actual abundance of species in the weed communities varied within the range of 5–19 in the spring and 4–20 before harvest (Table 2). In case of the spring, attention is drawn by a slightly lower threshold of variability in the positions after barley than in the position after potato and the lower coefficient in the latter treatment. It is characteristic that year–to–year differences are larger than the differences between positions (Fig. 1). With the existing variability over time, both in the spring (with the exception of the position after potato) and before the harvest we succeeded in confirming the increase in the number of species during the study period (significant trends). The correlation coefficients before the harvest were higher than during the spring season. In the spring the largest number of species was usually determined in the position after potato, which translated into slight differences between the averages for 15 years. The average number of species decreased, although by not much, with deterioration of the position. During the time before harvest, on average slightly fewer species occurred at the position after the cultivation of barley for one year, but still during the 15 years of the experiment on five occasions the highest number of species of all the three positions was recorded in that position.

The species richness in the spring was positively correlated with the quantity of precipitation in April and before harvest it correlated positively with precipitation in June and negatively with temperature in July and August; it also correlated positively with precipitation and negatively with temperature for the period of April–August (Table 3).

The Shannon–Wiener index is considered one of the best measures of functional biodiversity in communities of organisms. The average values of that index for 15 years show that the largest diversity of communities developed in the position after potato; this applied to both the spring measurement and the measurement before the harvest and in the latter case it applied to both characteristics (density and biomass) assumed as the base of computations (Table 2). It is symptomatic that the Shannon–Wiener index computed on the base of biomass decreased systematically with the deterioration of the position, while according to the index value based on the density, the positions after barley (both of them) practically did not differ in biodiversity. Despite relatively low coefficients of year–to–year variability, the ranges of the index value for individual positions and times were rather wide, as the maximum values were more than twice higher than the minimum. The variation in year–to–year values of the Shannon–Wiener index was very dynamic (Fig. 1) and only in the position where spring barley was cultivated twice after spring barley, before the harvest, it assumed the character of a positively directed trend (confirmed by the applicable correlation coefficients – Table 2). Biodiversity increased under the conditions of higher precipitation and decreased with the increase of temperature during the vegetation period (Table 3).

Table 1
Composition of weed communities in spring barley, weed density and biomass per 1m^2, average for the years 1990-2004 and species constancy (S) during the years of the experiment

Weed species	Position (crop rotation – previous crop)											
	A–p				B–b				B–bb			
	density		biomass		density		biomass		density		biomass	
	plants m^{-2}		g m^{-2}	S	plants m^{-2}		g m^{-2}	S	plants m^{-2}		g m^{-2}	S
	spring	before harvest			spring	before harvest			spring	before harvest		
Chenopodium album	109.2	53.5	23.32	V	113.9	52.2	32.16	V	99.5	57.2	40.16	V
Thlaspi arvense	77.3	6.9	6.05	V	75.6	4.3	5.92	V	89.1	6.3	4.86	V
Stellaria media	25.8	11.8	13.66	V	24.5	10.4	13.67	V	30.6	12.1	14.10	V
Matricaria maritima ssp. *inodora*	11.9	7.8	6.92	V	7.1	5.4	6.91	V	8.3	5.2	4.70	V
Fallopia convolvulus	10.8	21.5	12.44	V	17.7	23.9	12.66	V	12.7	23.6	13.57	V
Sonchus arvensis	4.9	7.9	10.55	III	8.0	13.4	16.86	III	9.4	11.9	17.66	IV
Equisetum arvense	4.9	3.3	3.27	III	0.7	2.7	2.87	II	0.7	5.5	9.41	II
Capsella bursa-pastoris	4.1	7.0	2.48	IV	4.8	8.1	2.10	IV	3.5	7.1	4.30	IV
Galium aparine	3.9	1.7	0.58	IV	5.5	2.2	1.31	V	4.5	5.3	2.59	IV
Viola arvensis	3.3	2.1	0.50	IV	3.2	1.8	0.79	IV	1.8	0.8	0.37	IV
Lamium amplexicaule	3.1	0.4	0.00	IV	2.2	0.5	0.00	III	2.6	1.3	0.13	IV
Myosotis arvensis	3.0	4.7	2.02	IV	0.9	0.8	0.35	II	0.7	1.0	0.52	III
Polygonum laphathifolium	1.9	2.6	1.33	IV	3.5	2.4	2.44	II	1.1	3.9	1.38	II
Fumaria officinalis	1.7	0.1	0.05	IV	1.7	0.1	0.00	III	1.5	0.3	0.19	III
Spergula arvensis	1.6	1.9	0.42	III	1.9	0.6	0.01	III	4.1	0.4	0.08	III
Echinochloa crus-galli	1.3	2.3	0.56	II	0.1	0.8	0.47	I	0.1	0.2	0.02	I
Veronica arvensis	1.2	2.9	0.47	III	3.4	2.5	0.54	III	5.3	2.8	0.96	III
Plantago major	0.9	0.9	0.03	I	0.0	0.1	0.01	I	0.5	0.5	0.04	II
Vicia hirsuta	0.5	0.4	0.34	I	0.3	0.4	0.18	I	0.7	0.4	0.56	II
Polygonum aviculare	0.4	5.1	2.07	III	0.1	2.7	1.18	III	1.2	3.1	3.87	III
Sinapis arvensis	0.3			I	0.4			II	0.3			I
Galeopsis tetrahit	0.3			I	0.2			I		0.3	0.23	I
Apera spica-venti	0.2			I	0.6			I	0.3			I
Galinsoga parviflora	0.2	4.1	0.92	III	3.2	4.8	0.70	II	7.3	6.7	1.68	III
Erodium cicutarium	0.1	0.2	0.23	I	0.1	0.2	0.08	I	0.3			I
Papaver rhoeas	0.1			I					0.1			I
Myosurus minimus	0.1			I	0.1			I				
Anchusa arvensis		0.3	0.19	I	0.1	0.2	0.35	I	0.2	0.1	0.16	II
Cirsium arvense					0.6	0.9	3.41	II	0.1	0.5	1.07	I
Crepis tectorum		0.7	0.32	I		1.2	0.50	I		0.1	0.00	I
Avena fatua		0.1	0.16	I								
Raphanus raphanistrum		0.1	0.15	I		0.9	0.96	II		0.5	0.77	I
Arenaria serpyllifolia		0.1	0.00	I								
Conyza canadensis						0.2	0.00	II				
Poa annua										0.2	0.06	I

Position of the spring barley (position): A–p – in crop rotation A after potato, B–b – in crop rotation B the first time after spring, B–bb – in crop rotation B the second time after spring barley

Table 2
Weed biodiversity in spring barley and its variability expressed using simple statistics

Weed community characteristic	Position (crop rotation – previous crop)	Average for 15 years	Min. – max	V, %	Equation of the linear year–to–year trend	r
			spring			
Species richness	A–p	12.0	9.0–19.0	24.9	y = 0.2429x + 10.057	0.31
	B–b	11.1	5.0–17.0	32.5	y = 0.5036x + 7.0381	0.63*
	B–bb	10.7	7.0–19.0	33.2	y = 0.4607x + 6.981	0.58*
$H'_{density}$	A–p	1.58	1.02–2.20	23.3	y = 0.0121x + 1.481	0.15
	B–b	1.53	0.98–2.26	24.1	y = 0.0381x + 1.2216	0.46
	B–bb	1.53	1.03–2.04	21.3	y = 0.0344x + 1.2578	0.49
			before harvest			
Species richness	A–p	10.5	5.0–18.0	34.9	y = 0.6607x + 5.2476	0.80*
	B–b	9.9	4.0–20.0	41.6	y = 0.5893x + 5.1524	0.64*
	B–bb	10.5	5.0–16.0	37.3	y = 0.6214x + 5.4952	0.71*
$H'_{density}$	A–p	1.70	0.92–2.47	28.8	y = 0.0546x + 1.2586	0.50
	B–b	1.60	0.73–2.44	29.3	y = 0.0381x + 1.2216	0.51
	B–bb	1.59	0.74–2.30	29.6	y = 0.0344x + 1.2578	0.60*
$H'_{biomass}$	A–p	1.62	0.95–2.19	21.0	y = 0.0175x + 1.4809	0.23
	B–b	1.58	0.81–2.04	21.7	y = 0.037x + 1.2834	0.48
	B–bb	1.54	0.83–2.20	27.1	y = 0.0727x + 0.9556	0.78*

V– year–to–year variability coefficient, r – linear correlation coefficient determining the significance of the year–to–year linear trend; * – r significant at p =0.05; position of the spring barley (position): A–p – in crop rotation A after potato, B–b – in crop rotation B the first time after spring barley, B–bb – in crop rotation B the second time after spring barley; $H'_{density}$ – Shannon–Wiener diversity index computed on the basis of weed density, $H'_{biomass}$ – Shannon–Wiener diversity index computed on the basis of weed biomass

Table 3
Linear correlation ratios between weed biodiversity indicators and precipitation (mm) and temperatures (°C) during the study period

Item		Weed species richness	Indexes	
			$H'_{density}$	$H'_{biomass}$
		spring (tillering stage)		
April	– precipitation	0.45*	0.40*	
	– air temperature	–0.22	–0.22	
		before harvest (end of vegetation)		
May	– precipitation	0.25	0.14	0.08
	– air temperature	–0.15	–0.27	–0.16
June	– precipitation	0.50*	0.48*	0.20
	– air temperature	–0.14	–0.42*	–0.43*
July	– precipitation	0.15	0.39*	0.38*
	– air temperature	–0.30*	–0.66*	–0.61*
August	– precipitation	0.00	0.15	0.11
	– air temperature	–0.60*	–0.55*	–0.42*
April-August	– precipitation	0.52*	0.63*	0.43*
	– air temperature	–0.62*	–0.87*	–0.73*

$H'_{density}$ – Shannon–Wiener diversity index computed on the basis of weed density; $H'_{biomass}$ – Shannon–Wiener diversity index computed on the basis of weed biomass; * – correlation significant at p = 0.05

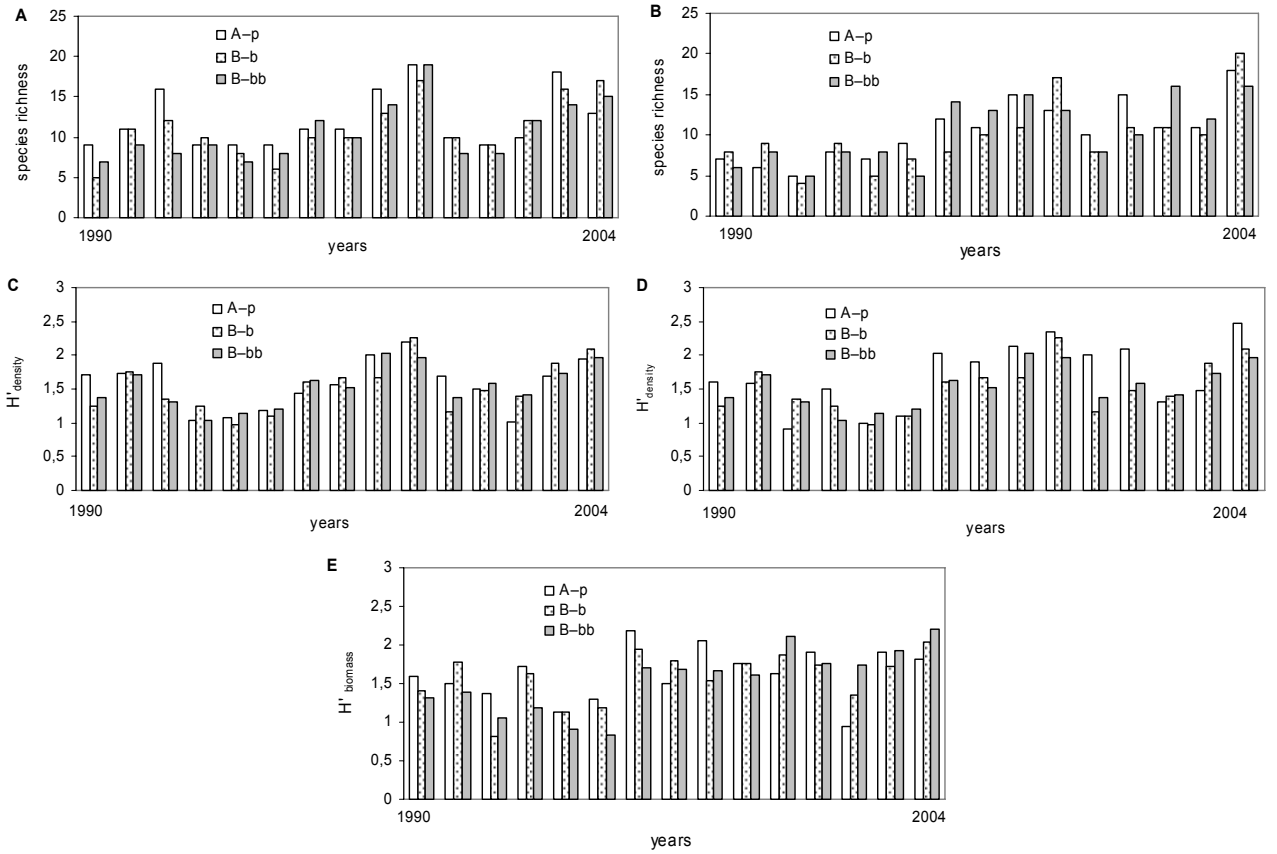

Fig. 1. Diversity of weeds species in spring barley field during the years 1990–2004; (A, C) in the spring, (B, D, E) before barley harvest; position of spring barley (position): A–p – in crop rotation A after potato, B–b – in crop rotation B the first time after spring barley, B–bb – in crop rotation B the second time after spring barley; $H'_{density}$ –Shannon–Wiener diversity index computed on the bases of weed density, $H'_{biomass}$ – Shannon–Wiener diversity index computed on the bases of weed biomass

Rényi profiles determined for artificial formations built on the basis of the averages from 15 years of the studies show high analogy of the compared positions as concerns biodiversity (Fig. 2). The corresponding curves almost overlap with one another. For the extreme years of study, this analysis was also conducted for the actual communities. At the start of the study period (1991), the spring communities formed at the analyzed positions were incomparable according to Rényi's theory. And before the harvest the communities in the position after barley were more bio-diversified, in terms of both density and biomass, than the communities in the other two positions, and those two did not allow their organization according to the Rényi system. In 2004 the spring communities in both positions after barley differed in biodiversity at all levels in favor of the first crop after spring barley. The communities from the treament after potato could not be compared with the other two. Before barley harvest, the communities developed after potato and after barley (one consecutive crop) were incompatible, but both were more diversified than that which formed in barley cultivated for the second time after barley; it was not possible to compare them according to the Rényi system if biomass was taken as the base for computation of the family of biodiversity indicators.

In the analysis of the communities formed in the same positions and at the same times in 1991 with 2004 (Fig. 3), it was established that in the plot after potato, in terms of density (in the spring and before harvest), the community of 2004 was more diversified, while in the case that weed biomass was assumed as the base the curves intersected by the alpha positioned between levels 1 and 2. In the positions after barley once and twice, the curves obtained for the spring dates intersect, while before the harvest the communities found in 2004 proved to be more diversified at all alpha levels than in 1991 (taking for the base for computation of the family of indicators both the density of individuals representing different species and the biomass generated).

The significance of correlation between the productivity of barley and weed diversity expressed by the number of species and the Shannon–Wiener index value, irrespective of the base of its determination, was not confirmed (Fig. 4).

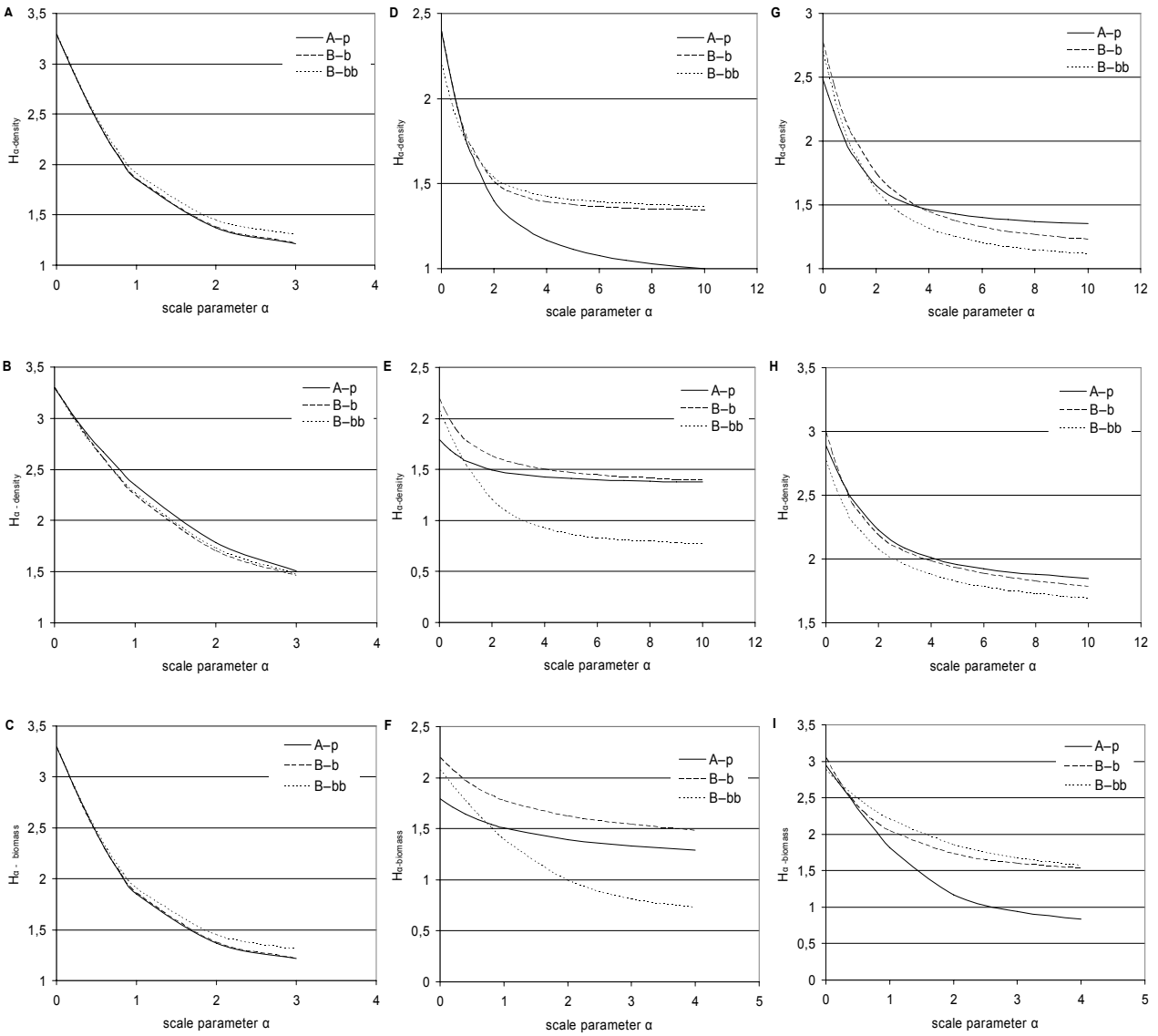

Fig. 2. Diversity profiles according to Rényi established for „artificial" communities of weeds formed on the basis of the averages from years 1990–2004 and actual communities formed during the years 1991 and 2004 in spring barley at different crops rotation system positions; (A) in the spring for 1990–2004, (B, C) before harvest for 1990–2004, (D) in the spring for 1991, (E, F) before harvest for 1991, (G) in the spring for 2004, (H, I) before harvest for 2004; position of spring barley (position): A–p – in crops rotation system A after potato, B–b – in crops rotation system B the first time after spring barley, B–bb – in crops rotation system B the second time after spring barley; $H_{\alpha\text{–density}}$ – family of Rényi indexes computed on the bases of weeds density, $H_{\alpha\text{–biomass}}$ – family of Rényi indexes computed on the bases of weeds biomass

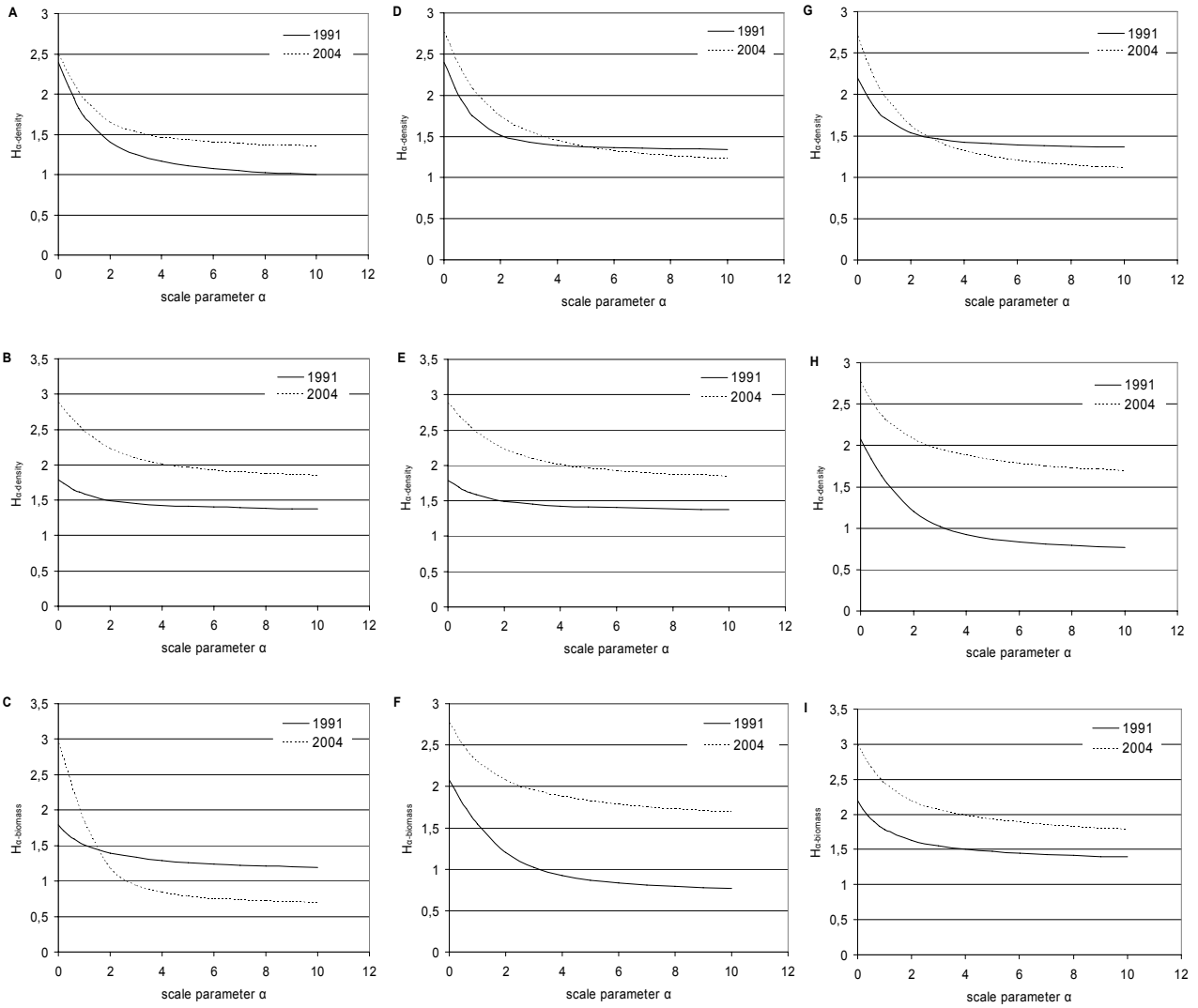

Fig. 3. Comparison of weed communities species diversity in spring barley forming at the same plot at the beginning (1991) and at the end (2004) of the experimental period based on diversity profile by Rényi; (A) in the spring for A–p, (B, C) before harvest for A–p, (D) in the spring for B–b, (E, F) before harvest for B–b, (G) in the spring for B–bb, (H, I) before harvest for B–bb; position of spring barley (position): A–p – in crops rotation system A after potato, B–b – in crops rotation system B the first time after spring barley, B–bb – in crops rotation system B the second time after spring barley; $H_{\alpha\text{–density}}$ – family of Rényi indexes computed on the bases of weeds density, $H_{\alpha\text{–biomass}}$ – family of Rényi indexes computed on the bases of weeds biomass

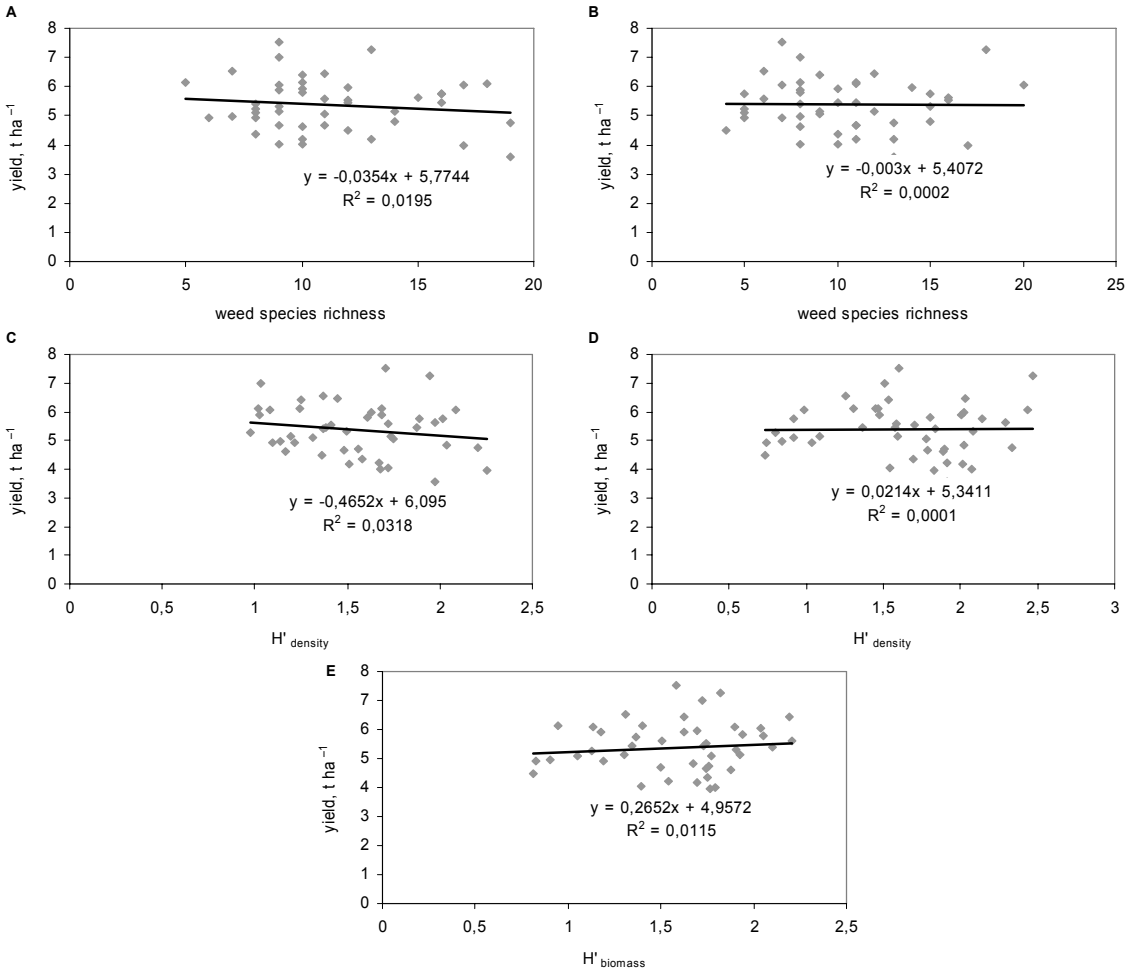

Fig. 4. Correlation of spring barley harvest with weed species diversity in the spring (A, C) and before harvest (B, D, E); $H'_{density}$ – Shannon–Wiener diversity index computed on the bases of weeds density, $H'_{biomass}$ – Shannon–Wiener diversity index computed on the bases of weeds biomass; R^2 (*) – determination coefficient (significant at p = 0,05)

DISCUSSION

Among phytosociologists and herbologists dealing with the dynamics of weed growth in time periods encompassing a few decades and under the influence of various factors, the opinion exists that the general level of weed infestation measured by weed coverage of the crop field and the number of weeds is not subject to significant changes, while as a consequence of changes taking place in agriculture the number of species in weed communities decreased and the dominance of a few taxa increased (Albrecht, 1995). Lososová et al. (2004) confirmed the decrease in natural richness of species in the fields of the Czech Republic and Slovakia during the years 1954–2003 using a highly significant correlation coefficient (r = –0.768). In the presented experiment of much shorter duration, i.e. 15 years, limited in space and additionally based on different methodological assumptions, no decrease in the richness of species was found in the studied phytocenoses over time or under the influence of less favorable spring barley positioning in the rotation system, and even – with the exception of the position after potato in the spring – a significant straight line increase in the number of species in the spring and summer communities was confirmed. The increase in the number of weed species was also found by Wanic et al. (2005) in an 11–year experiment with oats positioned after potatoes and twice in succession after oats, without herbicide protection, and by Feledyn–Szewczyk (2008) in a 12–year experiment with ecological cultivation of winter wheat.

The richness of species is currently still the most frequently applied measure of weed diversity in agricultural studies (Zawiślak, 1997; Blecharczyk et al. 2000; Buczyński and Marks, 2003; Lososová et al. 2004; Adamiak, 2007; Kaar and Freyer, 2008). Also, an increasing number of

studies appear where such analysis is based on indicators considering quantitative proportions between species, which is more justified in assessment of the functioning of phytocenoses. The most frequently used measure is the Shannon–Wiener diversity index based on density of individuals representing individual species in the community (Stevensen et al. 1997; Wesołowski et al. 2003; Jędruszczak and Antoszek, 2004; Stupnicka–Rodzynkiewicz et al. 2004; Wanic et al. 2005; Jastrzębska et al. 2006; Feledyn–Szewczyk, 2008), biomass produced by those species (Jastrzębska et al. 2007) or coverage of the field by plants of individual species (Jastrzębska et al. 2009). From the agricultural perspective, considering that the competitive power of weeds against the crop is determined by the biomass and even quite numerous but small seedlings are of little harm, the two latter approaches seem more reasonable. In the presented studies, the Shannon–Wiener indices calculated on different bases (density and biomass) showed high convergence. This is surely justified by the fact that *Chenopodium album,* which was the most numerously represented weed species for all three positions, also dominated in the community in terms of the biomass produced. A similar correlation was established by Jastrzębska et al. (2007) for weed communities in field beans, although logic indicates that this does not have to be the rule.

Kostrzewska and Wanic (2005) draw attention to the fact that the Shannon–Wiener index value for weed communities developing in spring barley increases with the consecutive return of spring barley to the same field in the rotation system with its 75% share, but for the treatment where the cereal was positioned after potato in the rotation system with its 50% share, the value of the index was higher than in case of successive cultivation and lower than in case of successive cultivation twice after spring barley in the same field. Wesołowski et al. (2003) recorded a slightly higher diversity of weeds in winter wheat when it was cultivated in monoculture than in the crop rotation system, but Jędruszczak and Antoszek (2004) prove that the cultivation of wheat in monoculture has a degenerative influence on weed communities and with the passage of years a decrease in biodiversity occurs. Our own studies indicate a rather minor decrease in the diversity of weeds in spring barley under poorer crop rotation conditions. Stevensen et al. (1997) report that both the number of species and their diversity measured using the Shannon–Wiener index were higher in the field of barley cultivated in a 3–year fodder crop rotation system than in monoculture (irrespective of the weed control method). Stupnicka–Rodzynkiewicz et al. (2004), on the basis of their studies with winter wheat and spring barley in different crop rotation systems, conclude that the influence of the rotation system on the diversity of a weed community develops differently depending on the crop species and its development phase, although the differences are small. The papers by Stupnicka–Rodzynkiewicz et al. (2004) and Feledyn–Szewczyk (2008) indicate that the biodiversity of weeds in the summer is larger than in the spring, which was also reflected in the average values in our studies, but Jędruszczak and Antoszek (2004) recorded opposite relations in the monoculture of wheat, while Jastrzębska et al. (2006) point at different effects in that aspect obtained for three different spring cereals.

The studies by Wanic et al. (2005) on weed communities in oats indicate higher year–to–year variability of weed biodiversity than that depending on previous crops differing extremely in quality (potato and oats second time after oats) and the differences between biodiversity of species determined in the spring and in the summer developed in different ways during different years.

In our own studies, the Shannon–Wiener index values formed a significant increasing year–to–year trend only for the summer communities in the positions with successive cultivation of spring barley twice after spring barley; in other cases, the correlation was positive but insignificant. Wanic et al. (2005) determined the increasing, during a period of 11 years, trend of the Shannon–Wiener index (according to density) values for summer weed communities in oats cultivated after potato and after oats. A similar trend was determined by Jastrzębska et al. (2006) in oats cultivated in the component of potato – Persian clover – oats, but it did not apply to spring barley and the mix of barley with oats cultivated in the same sequence. In the referred experiments (Wanic et al. 2005; Jastrzębska et al. 2006), the crops were not protected against weeds. In the earlier referenced studies on winter wheat, Feledyn–Szewczyk (2008) did not determine the mathematical trends, but she mentioned that the values concerned indicated an increase in weed biodiversity (indicator H') in spring and summer communities during 12 years of ecological cultivation with weed control by means of a weed harrow. Lundkvist et al. (2008), on the basis of an experiment with various crops cultivated in two rotation systems under an organic farming system, report that biodiversity of weeds measured by Simpson index (C) did not show a significant year–to–year trend.

The variability of biodiversity measures (number of species and Shannon–Wiener indexes) was strongly correlated with weather – positively with precipitation and negatively with temperature, which is also confirmed by the studies conducted by Wanic

et al. (2005) and Jastrzębska et al. (2006), similar in methodology and habitat conditions.

Authors increasingly more often refer to the concept formulated by Rényi (1961) in assessment of biodiversity of organism communities, including plant communities, undertaken in ecological studies on various formations. According to that concept, the biodiversity of a community of organisms is multidimensional in character and we can say about one community that it is more diversified than the other if it is more diversified at all levels of biodiversity, starting with level $\alpha = 0$, at which the index is the derivative of the number of species, through level 1, which corresponds to Shannon–Wiener (H') diversity index, level 2 – that involves Simpson index (C) and the level of "infinity", which is the derivative of Berger–Parker diversity index (Tóthmérész, 1995; Kindt et al. 2006). The diversity profiles can be used for comparison of actual phytocenoses as well as abstract groupings while maintaining homogeneity of material and procedures. In the study presented here, an attempt was made to apply both these approaches. As regards organization, they seem to correspond with the assessment made on the basis of richness of species and Shannon–Wiener index as concerns the major year–to–year diversities between actual phytocenoses, then between positions, as well as minor deviations in case of comparing "artificial" systems established on the basis of the averaged results from the long-term period. Observations based on the Rényi profile should be treated as signals, because only the phytocenoses from the extreme years of the experiment were used for comparison of the actual phytocenoses. It is also difficult to confront our own findings in that area with the opinions expressed by other authors because, while in the available literature there are articles comparing forest (Kindt et al. 2006) or meadow communities (Szoszkiewicz and Szoszkiewicz, 1999) using Rényi entropy, attempts at finding articles discussing weed communities from that perspective were not successful.

The composition of species in the analyzed communities, particularly the set of permanent species and species occurring during the most abundant years, was to a large extent consistent with other reports (Zawiślak, 1997; Buczyński and Marks, 2003, Kostrzewska and Wanic, 2005; Jastrzębska et al. 2006; Adamiak, 2007). In view of the opinion of Latowski (2002), these were species very common and common in Poland. In our own studies, *Chenopodium album* was ranked first as regards the density and biomass produced in all the three positions analyzed. This taxon is considered to be one of more dangerous competitors of barley (Kostrzewska and Wanic, 2005), although numerous papers indicate that with the saturation of the rotation systems with cereals, mainly spring ones, in case of spring barley the dominance of *Avena fatua* increases (Blecharczyk et al. 2000; Buczyński and Marks, 2003). In view of other studies (Zawiślak, 1997; Kostrzewska and Wanic, 2005) this is not the rule because even in unprotected monoculture of barley *Avena fatua* may occupy a farther place in the structure giving priority to numerous other taxa, mainly dicotyledonous, similar to the situation in the here presented own studies.

In the presented studies, similar to the earlier studies on phytocenoses of cereals (Wanic et al. 2005; Jastrzębska et al. 2006), the significance of the correlation between barley yield and weed diversity was not confirmed.

CONCLUSIONS

1. The richness of weed species increased linearly at all plots during the 15-year period.
2. *Chenopodium album* was a constant and dominant species in terms of weed species density and biomass year after year.
3. The quality of the plot had no clear influence on the diversity of weeds in barley.
4. Weed diversity showed high year–to–year variability and a positive correlation with the amount of precipitation and a negative correlation with temperature during the period of the study.
5. Significance of the correlation between the productivity of barley and weed diversity was not confirmed.

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Wpływ płodozmianu i warunków meteorologicznych na bioróżnorodność zbiorowisk chwastów w jęczmieniu jarym (*Hordeum vulgare* L.)

Streszczenie

W pracy przedstawiono analizę zmian bioróżnorodności 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 ustalono stałość pojawiania się gatunków w latach, wskaźniki różnorodności gatunkowej Shannona-Wienera i profile różnorodności wg Renyiego. Bogactwo gatunkowe chwastów wzrastało liniowo w ciągu 15 lat we wszystkich stanowiskach. Jakość stanowiska nie miała wyraźnego i jednoznacznego wpływu na różnorodność chwastów w jęczmieniu. Stałym w latach i dominującym gatunkiem było *Chenopodium album*. Różnorodność chwastów wykazywała dużą zmienność w latach badań oraz dodatnią korelację z ilością opadów i ujemną z temperaturą w okresie badań. Nie potwierdzono istotności związku wydajności jęczmienia z różnorodnością chwastów.