LOG-LINEAR AND CORRESPONDENCE ANALYSIS OF VARIABILITY OF WEED INFESTATION OF SEVERAL WINTER WHEAT CULTIVARS IN RELATION TO TILLAGE SYSTEM AND PRECEDING CROP STUBBLE HEIGHT

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Abstract: The objective of the study was to analyse the variability of the weed infestation of several winter wheat cultivars in relation to the soil tillage system applied and to the height of preceding crop stubble. The study was conducted in the years 2008–2010 in Lower Silesia, Poland. The following factors were studied in the experiment: factor I – stubble height a/ short stubble (10 cm) b/ tall stubble (40 cm); factor II – soil tillage systems a/ no-till b/ reduced tillage c/ conventional tillage – ploughing; factor III – winter wheat cultivars a/ Mewa, b/ Rapsodia, c/ Legenda. After the harvest of the preceding crop, glyphosate was sprayed on plots with short and tall stubble, in the first 10-days of August. The number of weeds on each analysed plot was estimated at random, with the frame method. For statistical analysis, the 8 most frequent weed species were selected: *Viola arvensis, Sinapsis arvensis, Lamium purpureum, Veronica persica*, *Apera spica-venti*, *Capsella bursa-pastoris*, *Anthemis arvensis* and *Geranium pusillum*. Based on the log-linear analysis, it was determined that *V. arvensis* and *S. arvensis* w ere the dominant weed species, whereas *A. spica-venti* and *C. bursa-pastoris* were characterised by significantly smaller numbers per 1 m^2. Significantly greater weed infestation was observed on plots with tall stubble. Increased weed infestation of winter wheat was noted in the reduced tillage treatments compared to those with conventional tillage. Only the numbers of *S. arvensis* were considerably lower under the conditions of no-till than in the conventional or reduced tillage systems. Cultivar Mewa limited the number of weeds per unit of area to a significant degree, while cv. Legenda increased weed infestation.

Key words: winter wheat, cultivars, tillage systems, stubble height, log-linear analysis, correspondence analysis

INTRODUCTION

At present, in the structure of crops in Poland, cereals take up approximately 70–80% of the arable area. High costs of conventional soil tillage, related to high labour requirements and fuel consumption, mean that alternative systems of ploughless tillage have become more and more extensively applied (Khaledian *et al*. 2010). Reduced tillage reduces water and wind erosion, enhances the biological activity of soil, stabilises soil aggregates and increases the content of organic matter and macroelements in the upper layers of the soil (Weber 2004). In some regions of Germany the reduced tillage method is used on 60% of arable lands. The fundamental criterion that largely limits the development of ploughless systems of tillage is the problem of weed infestation. Especially in the initial years of application of reduced tillage systems, when an increase is observed in the level of weed infestation on farm fields (Samarajeewa *et al*. 2005; Ozpinar 2006). The reason for the increase in weeds may be because of the lower effectiveness of herbicides resulting from the inhibited action of the herbicides in the thick layer of mulch from post-harvest residues (Torresem *et al*. 2003). Also, repetitive application of non-selective herbicides in reduced tillage or direct drilling may have caused some weed species to develop resistance to certain active substances (Perston 2004; Cerdeira and Duke 2006). Application of reduced tillage variants, especially no-till, creates additional problems related to the large amounts of straw remaining on the soil surface. Frequently, the post-harvest residues avoid fragmentation and are pressed into the soil, causing unfavourable conditions for seed germination. To improve the effectiveness of no-till of the after-crop, modified harvesting of cereals is currently promoted in Germany. Modified harvesting means cutting the straw high, and leaving the stubble at a height of about 30–40 cm. Cutting the straw high results in improved operation of the combine harvester. The quality of sowing with drills for no-till is also better, because long straw is laid along the path of the drill movement and there is no accumulation of post-harvest residues in the drilling groove (Köller and Linke 2001).

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The objective of the study was the analysis of the variability of weed infestation of winter wheat cultivars in relation to the tillage system and the height of the preceding crop stubble.

MATERIALS AND METHODS

The study was conducted in the years 2008–2010, at the Experimental Station of the Institute of Fertilisation and Soil Science in Lower Silesia. The experiment was set up in the split-split – plot design with 4 replications, on a podzolic soil – strong loamy sand overlying light loam. The forecrop was spring wheat. The experiment included the following factors: factor I – wheat stubble height a/ short stubble (10 cm), b/ tall stubble (40 cm); factor II – soil tillage systems: a/ no-till, b/ reduced tillage, c/ conventional tillage – ploughing; factor III – winter wheat cultivars a/ Mewa, b/ Rapsodia, c/ Legenda. On the plots with both short and tall stubble the remaining post-harvest residue was cut into chaff and spread evenly on the field. The experimental plots area was 15 m^2. After harvest of the preceding crop, glyphosate was applied on the plots with short and tall stubble, in the first 10-days period of August. The number of weeds on each analysed plot was estimated at random, with the frame method, on an area of 0.25 m^2, at the stage of the 3rd leaf of winter wheat. On each plot, analysis of the total numbers of weeds of the particular species was performed, covering the 4 replications and three years of the experiment. For statistical analysis, the 8 most frequent weed species were selected: *Viola arvensis*, *Sinapsis arvensis*, *Lamium purpureum*, *Veronica persica*, *Apera spica-venti*, *Capsella bursa-pastoris*, *Anthemis arvensis* and *Geranium pusillum*.

Many biological phenomena are qualitative in character, so comparison of research results concerning them cannot be made with the use of typical analysis of variance for quantitative variables. For this reason, various types of transformations are applied (*e.g.* $y = \arcsin\sqrt{x}$). In studies on the biodiversity of weed assemblages, the most frequent method is the estimation of the degree of coverage of a unit of surface area by a given species. The degree of coverage is expressed by means of the 6-step Braun-Blanquet scale, calculating the index of coverage and phytosociological constancy. Species diversity is also estimated by means of the Shannon diversity index or the Simson domination index. The results of such studies, however, may be burdened with a certain error resulting from the transformation of primary data (numbers of weeds of various species) into numbers – variables of quantitative character. In biological sciences, the log-linear analysis is the most frequently applied method of testing the statistical significance of the effect of various factors on the variability of a qualitative feature under study. That analysis was presented in a study by Goodman (1979). In the log-linear analysis, all significant deviations of observed frequencies from the expected ones, indicate the existence of a relation (interaction) between the variables studied. After the logarithmic transformation of the expected values, the model assumes a linear form, which in the simplest case, can be expressed by the following formula:

$$\mathrm{Ln}(E_{ij}) = M. + \lambda_i^X + \lambda_j^Y + \lambda_{ij}^{XY}$$

where:
E_{ij} – expected values,
M. – general mean based on equal frequencies in each cell,
λ_i^X – effect of i-th value of variable,
X; λ_j^Y – effect of j-th value of variable Y,
λ_{ij}^{XY} – effect of interaction of i-th value of variable X and j-th value of variable Y.

The log-linear model permits verification of the zero hypothesis which assumes the lack of interactions of two or more of the variables under analysis. After the rejection of insignificant interactions, the log-linear model allows us to estimate the effect of the particular factors on the variability of the population studied. The relations among the number of weeds of particular species per 1 m^2, wheat cultivars, soil tillage systems and stubble height were estimated with the help of the log-linear analysis. To analyse the variability of the frequency of weed species in relation to wheat cultivars, tillage systems, and stubble height, the correspondence analysis was applied. Correspondence analysis permits evaluation of the structure of the dependence of the cultivars on the other experimental factors under analysis. The analysis presents the cultivars from a 24-dimensional space (3 tillage systems x 8 weed species) in the form of two-dimensional graphs. The graphs are used so as to retain the greatest scope of variability of the studied genotypes from the original multi-dimensional space.

RESULTS

The calculated Chi^2 statistics for the primary effects and the second, third, and fourth order interactions were characterised by considerable values. Therefore, the hypothesis that there is a lack of relation of weed species frequencies with the tillage systems, cultivars, and stubble height should be rejected at the level of $p < 0.01$. The choice of the optimal statistical model defining the effect

Table 1. Tillage systems

Tillage system	Cultivation measures
Plough tillage	post-harvest cultivation – gruber at 15 cm + string roller basic land preparation – ploughing to the depth of 25 cm + harrow pre-plant tillage – combined tillage unit (cultivator + string roller)
Reduced tillage	post-harvest cultivation – gruber at 15 cm + string roller pre-plant tillage – combined tillage unit (cultivator + string roller)
No-till – direct drilling	direct sowing – great plains drill with a double disc drilling unit and a cultivating disc

Table 2. Tests of main effects, marginal and partial associations and interactions between experiment factors

Effect	Degrees of freedom	Chi² partial association	Significant level [p]	Chi² marginal association	Significant level [p]
Weed species (1)	7	3,309.06	0.0000	3,309.06	0.0000
Tillage systems (2)	2	58.32	0.0000	58.32	0.0000
Stubble height (3)	1	5.62	0.0177	5.62	0.0177
Cultivars (4)	2	13.17	0.0013	13.17	0.0013
1x2	14	616.61	0.0000	614.31	0.0000
1x3	7	87.92	0.0000	81.30	0.0000
1x4	14	53.84	0.0000	56.16	0.0000
2x3	2	12.84	0.0016	6.74	0.0343
2x4	4	28.58	0.0000	31.43	0.0000
3x4	2	3.30	0.1920	1.83	0.4000
1x2x3	14	76.26	0.0000	81.04	0.0000
1x2x4	28	64.56	0.0001	69.67	0.0000
1x3x4	14	22.39	0.0710	24.44	0.0404
2x3x4	4	2.84	0.5845	8.61	0.0714

Table 3. Marginal frequencies of weed species in relation to tillage systems (No./m² – average from years 2008–2010)

Tillage systems	Weed species – tall stubble field								
	ANTAR	CAPBP	GERPU	LAMPU	APESV	SINAR	VERPE	VIOAR	total
Direct drilling	67	56	48	71	30	**10**	36	384	702
Reduced tillage	25	14	41	86	7	156	28	284	641
Plough tillage	15	6	13	27	5	120	14	319	519
Average	35.7	25.3	34.0	61.3	14.0	95.3	26.0	329.0	620.7
	Weed species – short stubble field								
	ANTAR	CAPBP	GERPU	LAMPU	APESV	SINAR	VERPE	VIOAR	total
Direct drilling	68	36	50	**70**	18	**13**	**90**	348	693
Reduced tillage	49	**4**	51	13	10	197	18	173	515
Plough tillage	32	21	24	28	15	127	31	226	504
Average	49.7	20.3	41.7	37.0	14.3	112.3	46.3	249.0	570.7

Designation: ANTAR – *Anthemis arvensis;* CAPBP – *Capsella bursa-pastoris;*
GERPU – *Geranium pusillum;* LAMPU – *Lamium purpureum;* APESV – *Apera spica-venti*
SINAR – *Sinapsis arvensis;* VERPE – *Veronica pesica;* VIOAR – *Viola arvensis*

Table 4. Marginal frequencies of weed species in relation to cultivars (No./m² – average from years 2008–2010)

Cultivars	Weed species – tall stubble field								
	ANTAR	CAPBP	GERPU	LAMPU	APESV	SINAR	VERPE	VIOAR	total
Legenda	27	18	36	76	12	122	23	374	688
Rapsodia	55	27	34	69	15	77	31	295	603
Mewa	25	31	32	39	15	87	17	318	564
Average	35.7	25.3	34.0	61.3	14.0	95.3	26.0	329.0	620.7
	Weed species – short stubble field								
	ANTAR	CAPBP	GERPU	LAMPU	APESV	SINAR	VERPE	VIOAR	total
Legenda	49	22	47	39	10	138	67	227	599
Rapsodia	57	18	35	43	19	85	42	267	566
Mewa	43	21	43	29	14	114	30	253	547
Average	49.7	20.3	41.7	37.0	14.3	112.3	46.3	249.0	570.7

of the cultivars, stubble height, and tillage systems on the frequencies of the weed species studied can be done with the help of table 2. Considerable differentiation was noted among the weed species in the experiment. The analysis also revealed significant differences in the frequency of the weed species with relation to the tillage systems, stubble height, and cultivars. Based on the results of the log-linear analysis, one can only state a lack of interaction between the cultivars and the stubble height. This means that, irrespective of the stubble height, the cultivars significantly differentiated the numbers of weeds of the species studied. Based on the log-linear analysis in tables 2 to 4, one can conclude that *V. arvensis* and *S. arvensis* were the dominant weed species. Whereas, *A. spica-venti* and *C. bursa-pastoris* were characterised by significantly lower numbers per 1 m^2. Significantly greater weed infestation was observed on plots with tall stubble. On plots with the reduced tillage systems, there was also noted an increased weed infestation of winter wheat, compared to conventional tillage. Only the frequency of *S. arvensis* under the conditions of direct drilling was notably lower with relation to ploughing or reduced tillage. The Mewa cultivar limited the number of weeds per unit of area to a significantly greater degree, while cv. Legenda was characterised by increased weed infestation.

The next stage of the study was devoted to the determining the dependence structure of the weed species frequencies on the experimental factors under analysis: cultivars, tillage systems and stubble height. The graph representing the response of the cultivars, at various stubble heights, to the analysed experimental factors is presented in a two-dimensional space (Fig. 1). Both the eigen values and the cumulative percent of inertia for the two dimensions, indicate that the adoption of a two-dimensional space permitted the representation of the total inertia in 69.07% (Table 5). The term inertia in correspondence analysis is a measure of scatter that in statistics is covered by the term variance. Analysing the distribution of the particular cultivars in the two-dimensional space, it is possible to note significant differences in the variability of the frequency of the weed species under analysis. Points defining the cultivars under the conditions of high stubble are located in sectors 1 and 2 of the graph, while points defining the cultivars on plots with low stubble occur in sectors 3 and 4. Cultivars Mewa and Rapsodia display a certain similarity in terms of weed infestation variability in the experimental plots. Whereas, cv. Legenda is characterised by significantly greater differentiation of weed species diversity, compared to the other cultivars.

In table 6, the first column presents the values of mass. These can be treated as information on the rank of importance of the particular wheat cultivars in the differentiation of the frequency of the weed species studied. It should be noted, that cv. Legenda contributed largely to increased weed infestation in the experiment. Quality in the next column of the table, defines the accuracy of the estimation of the particular cultivars in space reduced to two dimensions. Values close to one, indicate good representation of the cultivars in the two-dimensional space. In the experiment under analysis, only cv. Rapsodia poorly represents the actual variability of the number of weeds per 1m^2, in the graph. Relative inertia defines the share of a given cultivar in the total inertia, in the original multi-

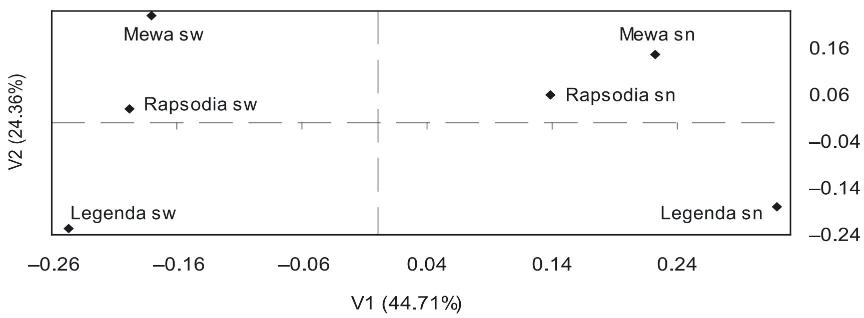

Fig. 1. Variability (V1, V2) of the wheat cultivars weed infestation depending on field stubble height (standardization: row and column profiles)
sw – tall stubble; sn – short stubble

Table 5. Specific values and inertia for all dimensions of analysed space

No. of dimensions	Singular values	Eigen values	Inertia [%]	Cumulative percentages	Chi^2
1	0.2260*	0.0511*	44.70*	44.70*	182.28*
2	0.1668*	0.0278*	24.36*	69.07*	99.34*
3	0.1352	0.01828	15.99	85.06	65.20
4	0.0959	0.00921	8.05	93.12	32.86
5	0.8867	0.0078	6.87	100.00	28.04

*significance at p = 0.05

Table 6. Row (cultivars) coordinates and contributions to inertia

Cultivars	Mass	Quality	Relative inertia	Inertia dimension 1	Inertia dimension 2
Tall stubble field					
Rapsodia	0.1690	0.5842	0.1531	0.1287	0.0053
Legenda	0.1928	0.8868	0.2138	0.2300	0.3564
Mewa	0.1581	0.6828	0.1736	0.1002	0.3025
Short stubble field					
Rapsodia	0.1586	0.5276	0.0961	0.0589	0.0209
Legenda	0.1679	0.8851	0.2224	0.3347	0.1937
Mewa	0.1533	0.6766	0.1407	0.1471	0.1209

dimensional space comprising the years of the study, soil tillage systems, and sowing dates.

Based on that column, it can be stated that cv. Legenda was characterised by considerable variability of the number of weeds, while cv. Rapsodia was characterised by a greater stability of that feature under the conditions of low stubble. The distribution of inertia and of the values of "quality" of the analysed cultivars on the particular dimensions is presented in the successive columns of table 6. These analyses indicate that cv. Legenda contributed in the highest degree to the definition of the first and second dimensions, of the space under investigation.

DISCUSSION

Varied crop rotation is the basis for success in ploughless cultivation of soil. Whereas, monoculture or cereal rotations are conducive to the compensation of certain weed species (Kwiatkowski 2009). However, the application of stubble inter-crops may contribute to a limitation of weed infestation on plantations (Gawęda 2009). The results presented in this study showed that under the conditions of tall preceding crop stubble, there appeared greater weed infestation of wheat. The increased frequency of the weed species under study, after reduced tillage, is supported by other studies. Nakamoto *et al*. (2006) demonstrated that in reduced soil tillage systems, the number of seeds accumulated in the topsoil was considerably higher than that in plough tillage. A dense layer of mulch used in the no-till system may significantly reduce the number of weeds compared to the plough tillage system (Anderson 2004; Faltyn and Kordas 2009). It is also attributed to a certain allelopathic effect, stimulating the growth of some weed species (Ramsdale *et al*. 2006). The notably lower numbers of *S. arvensis* observed in this study in direct drilling, may support this hypothesis. Whereas, studies by Krawczyk *et al*. (2009) demonstrated considerable limitation of the frequency of *A. spica venti* and *M. maritima* when no-till was applied, as compared to conventional or shallow surface tillage. Plough tillage, compared to the reduced tillage variants, reduces weed infestation on plantations but enhances the viability of seeds in the soil. A multi-year study conducted in Germany showed, in the environment of no-till, a significant limitation of the numbers of dicotyledonous weeds and forms displaying photoreaction (Sturny *et al*. 2007). Whereas, the results of a study conducted in India revealed a greater mass of weeds under zero tillage than in the environment of plough tillage (Gangwar *et al*. 2006). Under the no-till system, higher infestation of plantations with the weed species under study was demonstrated compared to plough tillage. Also Wesołowski and Bujak (2006) emphasise that the introduction of reduced tillage increases the level of infestation with such species as *Chenopodium album, V. arvensis, Stellaria media, A. spica venti, V. persica*.

CONCLUSIONS

1. *S. arvensis* and *V. arvensis* were the dominant weeds in the wheat cultivation on lessive soil.
2. Direct drilling was conducive to the weed infestation of the wheat field compared to reduced and conventional tillage.
3. Log-linear analysis showed significantly higher number of weeds in the fields with tall stubble.
4. The Mewa cultivar reduces the number of weeds on a field area unit while Legenda distinguished itself with higher weed infestation.

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