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USE OF PRINCIPAL COMPONENT ANALYSIS FOR THE ASSESSMENT OF SPRING WHEAT CHARACTERISTICS

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Abstract. In the studies, the analysis of the diversification of spring wheat characteristics was carried out depending on the growth system. Field experiment was carried out in years 2004-2006 at the Agricultural Experimental Station in Zawady, which is part of the Siedlce University of Natural Sciences and Humanities. The obtained correlation coefficients prove that the relation between wheat characteristics depends on the growth system. The applied method of principal component analysis (PCA) allowed a complex assessment of the relations between the characteristics. It also made it possible to reduce the original seven characteristics to three new variables, which carried over 75% of the information of the input data obtained from the direct sowing and almost 80% for the conventional tillage. The greatest discriminatory power, which diversified the studied plants, was shown by the mass of 1000 grains and grain yield.

Key words: direct sowing, grain yield, multidimensional methods, spring wheat, tillage

INTRODUCTION

Spring wheat is grown in Poland in the whole country but its greatest participation in sowing structure occurs in Podlasie, West Pomerania, and Lower Silesia. In recent years, an increase in the growth area of spring wheat has been noted, which may result first of all from its lower production costs, the possibility of choosing better forecrop, and the possibility of its growth on somewhat worse soils [Kuś and Jończyk 1997].

In spring wheat growth, great significance is attributed to proper agrotechnics and habitat conditions, including weather conditions [Wesołowski *et al*. 2005, Kołodziejczyk *et al*. 2007, Turska *et al*. 2010]. Progressive intensification and specialization of farms cause crop rotation simplifications by increasing crop share or decreasing growth intensity. Tebrügge and Düring [1999] and Dzienia *et al*. [2006] state that the introduction of ploughless systems positively affects the soil by maintaining balance in the environment. Also, many studies confirm lower wheat yield in ploughless conditions

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than in the conditions of conventional growth [Halvorson *et al*. 2001, Camara *et al*. 2003, Weber 2004, Turska *et al*. 2010].

In research with plants grown for grain or seeds, their yield components are marked. In the case of cereals, these are: spike density, number of grains per spike, and mass of 1000 grains. Each characteristic changes to a different extent and direction under the influence of experimental or habitat factors [Rudnicki 2000, Ługowska *et al*. 2004, Samborski *et al*. 2005]. The studied characteristics, but mostly those that are yield elements, are usually correlated, and therefore it may be interesting to find general regularities in the relations that occur between them. For finding the regularities, multidimensional analyses are used, one of which is principal component analysis (PCA) [Gregorczyk *et al*. 2008].

Principal component analysis makes it possible to transform a given set of characteristics (variables), which are mutually correlated, into a new system of characteristics, known as principal components, which are not correlated. The obtained variables may also be used for further analysis, where the assumption of no co-linearity is required. Moreover, the analysis is characterized by the fact that it includes the total variance of variables, explains maximum of variance within a data set, and is a function of primary variables [Krzyśko *et al*. 2008].

The aim of the study was finding correlations between the characteristics of spring wheat grown in direct sowing and in the plough system, and also assessing the usefulness of applying principle component analysis to research on spring wheat, in particular to the description of relations that occur between its characteristics.

MATERIAL AND METHODS

Analysis was carried out on the basis of the results obtained in the experiment carried out in years 2004-2006 at the Agricultural Experimental Station in Zawady (52°06' N; 22°56' E), which is part of the Siedlce University of Natural Sciences and Humanities. It was set on brown soil, of autogenic soils, formed from loamy sand, very good rye complex, class IIIb. In the experiment, set as split-plot in four repetitions, three experimental factors were studied: soil cultivation technique (A_1 – wheat direct sowing, A_2 – conventional tillage), soil cultivation technique for stubble crop (B_1 – intercrop direct sowing, B_2 – set of post-harvest operations and intercrop sowing), and a plant grown in stubble crop (C_1 – white mustard, C_2 – tansy phacelia).

After spring wheat harvest, stubble crop was sown according to the regular pattern (in direct sowing and after post-harvest operations). In the autumn, intercrop biomass on the chosen plots was ploughed to the depth of 25 cm, whereas on the remaining plots, the intercrops remained for the winter in the form of mulch. In the spring, uniform mineral fertilization was applied: 90 $kg \cdot ha^{-1}$ N (60% of the dose before sowing and 40% at the straw shooting stage), 40 $kg \cdot ha^{-1}$ P, and 90 $kg \cdot ha^{-1}$ K. Before intercrop sowing, fertilization was not applied. Spring wheat cultivar Opatka was sown in the first or second decade of April in the amount of 450 $seeds \cdot m^{-2}$.

Thermal and humidity conditions that occurred during the studies are shown in Figure 1. Air temperature and precipitation amount during spring wheat growth in the years of the experiment were diversified. Precipitation amount and distribution and average air temperature in 2004 were the most similar to the many-years average. In 2005, the excess of precipitation in relation to the many-years average occurred in May and July, and shortage in April, June, and August. Year 2006 was characterized by high temperatures and low precipitation from April to July.

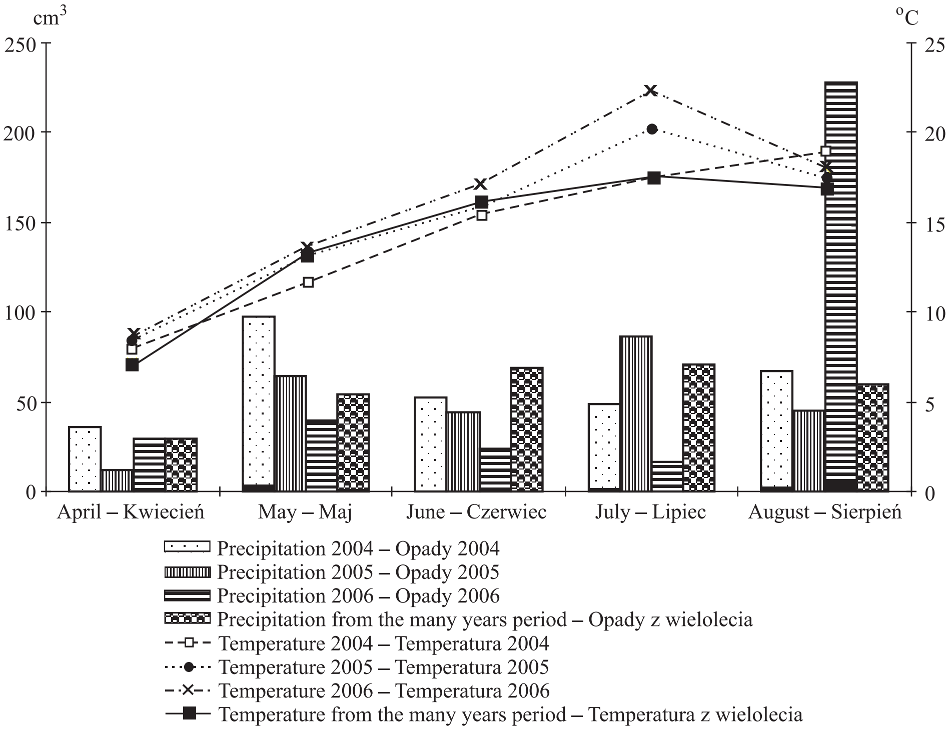

Fig. 1. Mean air temperature and precipitation sum during the experiment
Rys. 1. Średnia temperatura powietrza i suma opadów w czasie prowadzenia badań

In the experiment, the following characteristics were studied: grain yield, spike length, number of spikelets in spikes, straw length, mass of 1000 grains, number of grains in spikes, and spike density. Values of those characteristics were described, separately for every growth method, with the use of an arithmetic mean ($\bar{x}$) and standard deviation (s).

Analysis of the relations between spring wheat characteristics with the use of principal component analysis (PCA) was carried out separately for the studied growth techniques. According to the procedure of the PCA application method, the results underwent introductory analysis by building a correlation matrix between the primary variables and by verifying the null hypothesis that correlation matrix is the identity matrix (H_0: [R] = [I]). The test of this hypothesis is the statistics:

$$U = -\left(n - 1 - \frac{2p+5}{6}\right)\sum_{i=1}^{p} \ln\lambda_i$$

which has the distribution of χ^2 of p(p-1)/2 degrees of freedom, where:

p – number of variables,
n – number of cases,
λ_i – ith eigenvalue.

Values of the obtained statistics U (102.52 for direct sowing and 116.62 for conventional tillage), at 21 degrees of freedom, give basis for rejecting the null hypothesis, which means that the analyzed variables are mutually correlated. Introductory analysis confirmed the legitimacy of applying PCA. According to literature, it is acknowledged that principal component analysis may be used when correlation matrix is not identity matrix and most coefficients of correlation between variables are greater than 0.3 [Stanisz 2007]. After testing the introductory assumption, variable standardisation was performed, since they were not monomial.

According to the assumptions of PCA, the formed principal components are the linear functions of input variables and are ordered in such a way as the variance of subsequent principal components (which tells the information supply on the studied phenomenon) was lower and lower. Moreover, a few first principal components contain the vast majority of the information on the studied phenomenon, given by the input variables, which allows the reduction in the number of principal components with a possible low loss of input information. Interpretation of the obtained principal components (factors) is made on the basis of their components (factor load values). At the same time, they make linear correlation coefficients between the input variables and the principal components.

The number of principal components that underwent interpretation was set on the basis of Kaiser's criterion, according to which those variables are chosen whose eigenvalues are greater than 1 [Stanisz 2007]. For the assessment of the degree of carrying the information supplies contained in the input variables (their variation) by components chosen for interpretation, the factor loads and eigenvectors of the variables were used.

Statistical calculations were carried out with the use of the program Statistica 6.0.

RESULTS

Effect of the analyzed factors of spring wheat characteristics was studied with the use of tri-factor analysis of variance (ANOVA), and the results were presented in the work by Turska and Wielogórska [2010]. The results show that spring wheat growth method significantly modified both grain yield and mass of 1000 grains (MTG), and the number of grains per spike. Application of the direct sowing of spring wheat caused a significant decrease in grain yield and a decrease in the number of grains per spike and MTG. Average yield obtained on the plots with conventional tillage was higher by ca. 1.0 tone than after direct wheat sowing.

In the present work, only descriptive characteristics of the studied spring wheat characteristics are presented (Table 1). The values of all the studied characteristics of direct sowing were lower and were characterized by greater variability than the values of the traits obtained with conventional tillage.

Table 1. Descriptive statistics of spring wheat characteristics
Tabela 1. Statystyki opisowe cech pszenicy jarej

Characteristic Cecha	Direct sowing – Siew bezpośredni		Conventional tillage – Uprawa tradycyjna	
	arithmetic mean średnia arytmetyczna $\overline{x}$	standard deviation odchylenie standardowe s	arithmetic mean średnia arytmetyczna $\overline{x}$	standard deviation odchylenie standardowe s
PZ	3.03	0.85	3.65	0.74
DK	6.84	0.54	7.30	0.50
LK	14.82	1.21	15.66	1.08
DZ	89.01	10.17	96.66	6.72
MTZ	31.62	2.40	33.26	1.97
LZ	29.82	3.45	33.12	3.07
OK	454.3	91.0	511.2	72.0

PZ – grain yield – plon ziarna, $Mg \cdot ha^{-1}$
DK – spike length – długość kłosa, cm
LK – spikelet number – liczba kłosków
DZ – straw length – długość źdźbła, cm
MTZ – mass of 1000 grains – masa tysiąca ziaren, g
LZ – grain number – liczba ziaren
OK – spike density per 1 m – obsada kłosów na 1 m^2

In Tables 2 and 3, matrix of correlation coefficients between the variables for direct sowing and conventional tillage is presented. Their values prove that most of the characteristics of spring wheat are correlated. The strongest relation occurs between the number of spikelets and the number of grains (0.530), grain yield and the number of spikelets (0.516), density and mass of 1000 grains (0.495), and spike length and mass of 1000 grains (0.476) in the case of direct sowing. In conventional tillage, the strongest correlation was observed between grain yield and density (0.630), number of grains and mass of 1000 grains (0.603), grain yield and number of caryopses (0.582), density and number of grains (0.481), and spike length and mass of 1000 grains (0.422). It results from the tables of the matrixes of correlation coefficients of all the analyzed wheat characteristics that the majority of those coefficients reached values higher than 0.3, which confirms the legitimacy of the application of the PCA analysis.

Table 2. Correlation coefficients between the studied characteristics of spring wheat grown with the method of direct sowing
Tabela 2. Wartości współczynników korelacji pomiędzy badanymi cechami pszenicy jarej uprawianej metodą siewu bezpośredniego

Characteristic* Cecha	Characteristic – Cecha						
	PZ	DK	LK	DZ	MTZ	LZ	OK
PZ	1.000						
DK	0.346	1.000					
LK	0.516	0.016	1.000				
DZ	0.069	0.110	0.346	1.000			
MTZ	0.420	0.476	0.331	0.374	1.000		
LZ	0.439	0.386	0.530	0.056	0.326	1.000	
OK	0.389	0.143	0.336	0.450	0.495	0.118	1.000

* explanations under Table 1 – objaśnienia pod tabelą 1

Table 3. Correlation coefficients between the studied characteristics of spring wheat grown with the conventional method
Tabela 3. Wartości współczynników korelacji pomiędzy badanymi cechami pszenicy jarej uprawianej metodą tradycyjną

Characteristic* Cecha	Characteristic – Cecha						
	PZ	DK	LK	DZ	MTZ	LZ	OK
PZ	1.000						
DK	0.356	1.000					
LK	0.255	-0.186	1.000				
DZ	0.100	0.376	0.163	1.000			
MTZ	0.521	0.432	0.446	0.422	1.000		
LZ	0.582	0.364	0.334	0.206	0.603	1.000	
OK	0.630	0.403	0.091	-0.035	0.333	0.481	1.000

* explanations under Table 1 – objaśnienia pod tabelą 1

In Table 4, eigenvalues of principal components and percentage of the primary variable variance carried by them are given. For further analysis (both in the case of direct sowing and conventional tillage), according to the Keiser's criterion, first three components were chosen with the numbers 1, 2, and 3, which formed variables: Z_1, Z_2, and Z_3. In the case of direct sowing, the first component carried 42.24%, the second one 18.04%, and the third one 15.05% of the supply of information input variables. Those three principal components, which are a linear combination of the input data, explain over 75% of total variability. Similar results were obtained for conventional tillage. Components chosen for the analysis carried about 80% of the information contained in the input variables (respectively: 44.57%, 17.95%, and 17.12%). Principal component method allowed the reduction of the number of seven primary characteristics to three new variables with the preservation of a significant part of the variance of primary data.

Table 4. Correlation matrix eigenvalues, variation percentage, and accumulated variation percentage of the obtained components
Tabela 4. Wartości własne macierzy korelacji, procent wariancji i skumulowany procent wariancji otrzymanych składowych

Component Składowa	Direct sowing – Siew bezpośredni			Plough tillage – Uprawa płużna		
	eigenvalues wartości własne	variation percentage procent wariancji	accumulated variation percentage skumulowany procent wariancji	eigenvalues wartości własne	variation percentage procent wariancji	accumulated variation percentage skumulowany procent wariancji
Z_1	2.957	42.24	42.2	3.120	44.57	44.6
Z_2	1.263	18.04	60.3	1.257	17.95	62.5
Z_3	1.053	15.05	75.3	1.198	17.12	79.6
Z_4	0.699	9.99	85.3	0.447	6.39	86.0
Z_5	0.414	5.92	91.2	0.374	5.34	91.4
Z_6	0.388	5.55	96.8	0.349	4.982	96.4
Z_7	0.224	3.21	100.0	0.255	3.638	100.0

Eigenvectors that represent the obtained eigenvalues presented in Table 5 show force and direction of the effect of the particular variables on components Z_1, Z_2, and Z_3 (these are the principal component coefficients).

Table 5. Coordinates of the eigenvectors of principal components
Tabela 5. Współrzędne wektorów własnych składowych głównych

Characteristic* Cecha	Direct sowing – Siew bezpośredni			Plough tillage – Uprawa płużna		
	component składowa Z_1	component składowa Z_2	component składowa Z_3	component składowa Z_1	component składowa Z_2	component składowa Z_3
PZ	-0.425	0.254	-0.157	-0.450	0.135	-0.287
DK	-0.304	0.360	0.647	-0.342	0.443	0.441
LK	-0.406	-0.018	-0.605	-0.228	-0.710	-0.259
DZ	-0.287	-0.608	0.053	-0.231	-0.253	0.706
MTZ	-0.446	-0.091	0.361	-0.465	-0.249	0.144
LZ	-0.370	0.472	-0.229	-0.459	-0.053	-0.133
OK	-0.378	-0.451	0.066	-0.382	0.387	-0.343

* explanations under Table 1 – objaśnienia pod tabelą 1

On the basis of the values of factor loads, presented in Table 6, it may be concluded that in the case of direct sowing, the first component represents mass of 1000 grains and grain yield. The second component replaces the typical morphological characteristics of wheat: straw length and spike density. The third component carries information related mostly to the characteristics that describe the spike, namely spike length and the number of spikelets in the spike. In the case of conventional tillage, component Z_1 carries first of all information on the mass of 1000 grains, number of grains, and grain yield. The second component represents the number of spikelets, and the third one straw length.

Table 6. Factor loads of the component variables that underwent analysis
Tabela 6. Ładunki czynnikowe zmiennych składowych poddanych analizie

Characteristic* Cecha	Direct sowing – Siew bezpośredni			Plough tillage – Uprawa płużna		
	component składowa Z_1	component składowa Z_2	component składowa Z_3	component składowa Z_1	component składowa Z_2	component składowa Z_3
PZ	-0.731	0.286	-0.161	-0.795	0.152	-0.315
DK	-0.523	0.405	0.664	-0.606	0.497	0.482
LK	-0.598	-0.020	-0.622	-0.404	-0.797	-0.285
DZ	-0.493	-0.683	0.054	-0.407	-0.284	0.773
MTZ	-0.767	-0.103	0.371	-0.822	-0.280	0.158
LZ	-0.638	0.331	-0.236	-0.812	-0.059	-0.145
OK	-0.650	-0.567	0.068	-0.675	0.435	-0.376

* explanations under Table 1 – objaśnienia pod tabelą 1

In the system of two first components (Z_1 and Z_2), the vectors of the studied characteristics of spring wheat are presented (Figures 2 and 3). It results from Figure 2 that in the case of wheat grown with the method of direct sowing, the longest vectors, and therefore the strongest correlation with components Z_1 and Z_2 have mass of 1000 grains, grain number, and straw length. Small angle between the vectors for grain number, spike length, and yield, density and straw length, and mass of 1000 grains and spikelet number, proves a significant correlation between these traits. It also results from the graph that for spring wheat grown in direct sowing, three groups of strongly correlated variables may be determined. The first group is: grain yield, number of grains, and spike length, the second one is mass of 1000 grains and spike number, and the third one is density and straw length. In the case of wheat grown with the application of the conventional method, the longest eigenvectors were obtained for the following characteristics: spike number, spike length, and mass of 1000 grains. Those variables had, therefore, the greatest participation in the values of the first two components. In the case of this technology, two groups of strongly correlated variables may be distinguished. The first group includes density and spike length, and the second one straw length, grain number, mass of 1000 grains, and grain yield. The least correlated characteristic with variables Z_1 and Z_2 was straw length, since the value of the vector for this characteristic was the lowest. Spikelet number is the characteristic that is the least correlated with others, since the inclination angle of the vector of this variable in relation to the vectors of the remaining characteristics was the greatest.

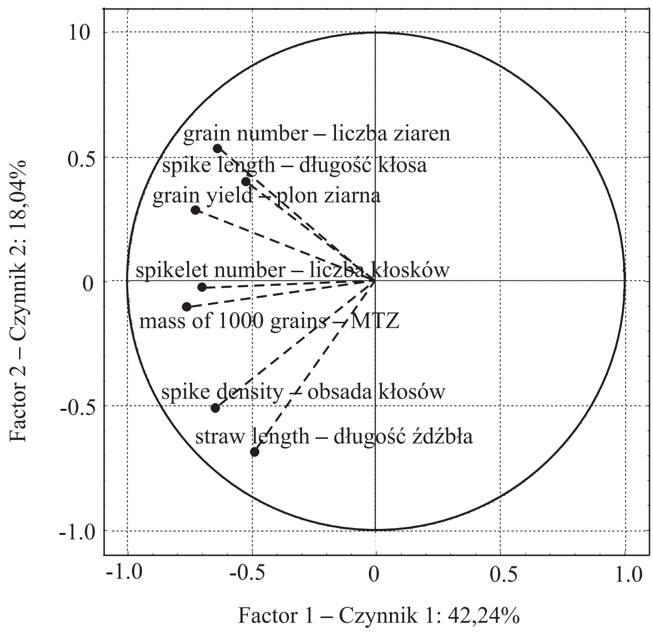

Fig. 2. Graph of factor coordinates for components Z_1 and Z_2 for direct sowing
Rys. 2. Wykres współrzędnych czynnikowych dla składowych Z_1 i Z_2 dla siewu bezpośredniego

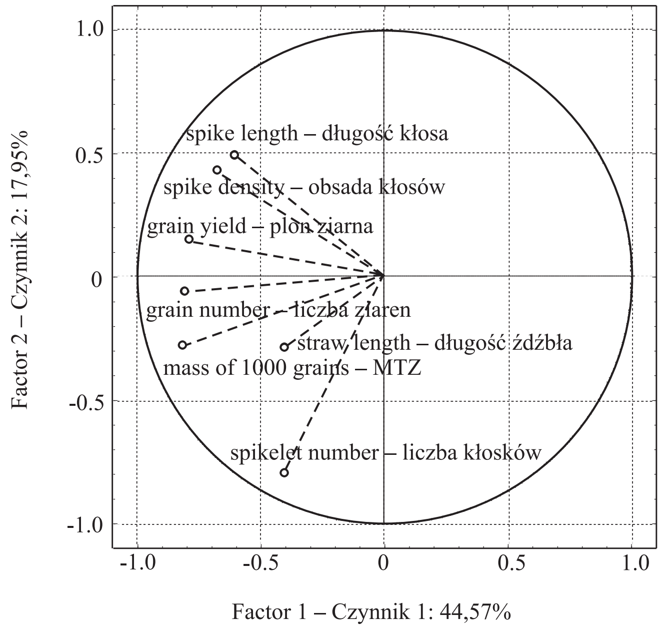

Fig. 3. Graph of factor coordinates for components Z_1 and Z_2 for plough tillage
Rys. 3. Wykres współrzędnych czynnikowych dla składowych Z_1 i Z_2 dla uprawy płużnej

DISCUSSION

In the present research, analysis of the diversification of spring wheat characteristics was carried out depending on the applied growth system. Growth system may to a large extent modify not only wheat characteristics, such as grain, mass of 1000 grains, density, etc. but also the correlation of those characteristics [Sabo *et al*. 2002, Weber 2008, Głowacka 2010]. The coefficients of correlation obtained in the present experiment prove that there is a diversification of the relations between the characteristics in the analyzed growth systems. Yield of wheat grown in direct sowing depended mostly on spikelet number, grain number, and mass of 1000 grains. Yield of wheat grown with the plough method depended on density, mass of 1000 grains, and grain number, but the correlations were significantly higher than in the case of direct sowing. Somewhat different results were obtained by Głowacka [2010], who demonstrated a significant relation between yield size and spike density, somewhat smaller between yield and the number of grains in the spike, and an insignificant one with the mass of 1000 grains. It results from the experiment by Ługowska et al. [2004] that winter wheat yield depended mostly on spike number per area unit. Other studies show, however, that the yield of cereal cultivars may be to a greater extent formed by the number of spike grains and mass of 1000 grains [Samborski *et al*. 2005].

The applied method of principal component analysis made it possible to fully assess the correlations between spring wheat characteristics. The method is used for the analysis of object diversity in regard to quality traits and allows their grouping according to the similarity hierarchy [Gregorczyk *et al*. 2008]. The method, for the description of relations between barley grain characteristics, was used by, among others, Wesołowska-Janczarek *et al*. [2003] and Ukalska *et al*. [2008]. Westerlund *et al*. [1991] used the PCA for the description of 23 spring wheat cultivars in regard to grain and flour quality, Schung *et al*. [1993] for the assessment of relations between quality parameters of flour and mineral element content in spring wheat grain, and Gregorczyk *et al*. [2008] for the assessment of correlations between the technological characteristics of winter wheat.

The conducted analysis allowed the reduction of seven primary characteristics to three new variables (principal components), which, depending on the applied growth technology: direct sowing or plough tillage carried, respectively, 75.33% and 79.64% of the variability of the primary data. The characteristics that form the first, second, and the subsequent principal components, according to Ukalska *et al*. [2008], show the strongest discriminatory power, that is diversify the studied groups. In the conducted experiment, the strongest discriminatory power, regardless of the growth system, was shown by the mass of 1000 grains and grain yield.

CONCLUSIONS

1. Mutual correlation of spring wheat characteristics both in the case of direct sowing and the plough tillage allowed the application of the principal component analysis.
2. Characteristics of wheat grown in pure sowing may be described with the use of three groups of variables. The first one includes mass of 1000 grains and yield, and the second one straw length, and the third one spike length and spikelet number. Similar characteristics of spring wheat grown in the plough system may be described by three components. The first one includes mass of 1000 grains, grain number, and grain yield, the second one spikelet number, and the third one straw length.
3. Reduction of the analyzed seven spring wheat characteristics to three principal components in the case of direct sowing makes it possible to explain about 75%, and in the case of plough tillage about 80% of the total input data variability.
4. Principal component analysis is a technique that is useful for the description of the relations that occur between spring wheat characteristics. The obtained non-correlated variables may be used for further analysis, where the assumption of no co-linearity of variables is required.

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WYKORZYSTANIE METODY ANALIZY SKŁADOWYCH GŁÓWNYCH DO OCENY CECH PSZENICY JAREJ

Streszczenie. W badaniach dokonano analizy zróżnicowania cech pszenicy jarej w zależności od systemu uprawy. Doświadczenie polowe przeprowadzono w latach 2004--2006 w Rolniczej Stacji Doświadczalnej Zawady, należącej do Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach. Uzyskane wartości współczynników korelacji dowodzą, że współzależność pomiędzy cechami pszenicy zależy od systemu uprawy. Zastosowana metoda analizy składowych głównych (PCA) pozwoliła na kompleksową ocenę współzależności cech. Umożliwiła jednocześnie zredukowanie siedmiu pierwotnych cech do trzech nowych zmiennych, które przenosiły ponad 75% informacji danych wejściowych uzyskanych dla siewu bezpośredniego i prawie 80% dla uprawy tradycyjnej. Najsilniejszą moc dyskryminacyjną, różnicującą badane obiekty, wykazały masa tysiąca ziaren i plon ziarna.

Słowa kluczowe: metody wielowymiarowe, plon ziarna, pszenica jara, siew bezpośredni, uprawa gleby

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