ANALYSIS OF EFFECTS OF COVER CROP AND TILLAGE METHOD COMBINATIONS ON THE PHENOTYPIC TRAITS OF SPRING WHEAT (TRITICUM AESTIVUM L.) USING MULTIVARIATE METHODS

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Abstract. The paper presents the results of multivariate analysis assessing variation in quantitative traits after the application of various cover crops and tillage methods in cultivation of spring wheat in three years of study. The purpose of this study was to assess the multivariate phenotypic variation of spring wheat under 27 different combinations of three cover crops, three tillage methods and three years of study. 13 quantitative traits were monitored through the course of three years (2011-2013) in Poland. The result was statistically analyzed using the multivariate methods. Analysis of canonical variables proved to be a reliable tool providing a comprehensive assessment of variation in the effect of cover crop and method of tillage combinations on many traits simultaneously. The most diverse treatments were Z-A-1 (cover crop: zero, method of tillage: aggregate, in 2011) and N-P-2 (cover crop: no tillage, method of tillage: plowing, in 2012). The most similar treatments (in terms of 13 traits assessed) included Z-A-1 (cover crop: zero, method of tillage: aggregate, in 2011) and N-A-1 (cover crop: N – no tillage, method of tillage: aggregate, in 2011).

Keywords: canonical variate analysis, grain yield, biomass of spring wheat, white mustard, Mahalanobis’ distances, quantitative traits

Introduction

In the area of integrated production, it seems necessary to develop a technology for the production of spring wheat, while also taking into account the inclusion of stubble. Crop rotation with a large share of cereals, will improve soil efficiency and create better phytosanitary conditions for the development of spring wheat (Majchrzak, 2015). Catch crops deliver environmental benefits, and they are widely recommended by programs which promote environmentally friendly agricultural practices (Wanic et al., 2019). Simplification of the tillage system can cause an increase in weeds and consequently, a decrease the yield of cultivated plants. Changes in weeds can affect also stubble catch crops and fertilization used as regeneration factors. Regenerating and yielding effect of catch crops cultivation depends, among from habitat conditions, as well as on the type of catch crop and species of the cultivated plant.

Numerous authors have proposed statistical methods for estimation the manner of factors reaction to diverse environmental condition (Wricke and Weber, 1986). Multivariate analysis tools, such as principal component analysis, canonical variables
analysis, canonical correlation analysis, additive main effects and multiplicative interaction and multiple regression, are powerful in dealing with intercorrelated data, such as agroclimatic and other factors limiting crop yields (Qian et al., 2009; Hussain et al., 2014; Nowosad et al., 2017; Nowosad et al., 2018; Bocianowski et al., 2018).

The aim of this study was to conduct a multivariate characteristic of phenotypic variability in 27 treatments being combinations of cover crop, method of tillage and years. The canonical variables analysis was applied, based on the model of multivariate analysis of variance (MANOVA), for observations of 13 quantitative traits in an experiment established in the split-plot design.

Material and methods

Experimental field

The field experiment was performed at the Brody Research and Education Station of the Poznań University of Life Sciences, Poland (52° 26’ N; 16° 17’ E) on soil classified (WRB 2007) as Albic Luvisols develop on loamy sands overlying loamy material (12% clay, 19% silt and 69% sand) in the years 2011-2013 (Figure 1).

They were performed in the random block (split-plot) design with three experimental factors in four field replications resulting in a total of 9 plots. The experiment was designed to analyses the effect of cover crop (white mustard cultivar Nakielska) sowing: (control: zero – Z, no sowing of cover crop, sowing of cover crop following skimming – S and no tillage – N direct sowing of cover crop), three tillage methods for spring cultivation (direct sowing – D, simplified tillage (cultivation aggregate to a depth of 12-15 cm) – A, spring ploughing to a depth of 25 cm – P) on 13 quantitative traits (grain...
yield, [t ha\(^{-1}\)], protein grain yield of spring wheat [kg ha\(^{-1}\)], test weight of spring wheat grain [kg ha\(^{-1}\)], plants number of spring wheat after emergence [no m\(^2\)], leaf greenness index SPAD, height plants [cm], leaf area index [LAI], biomass yield of spring wheat in BBCH 23 [t ha\(^{-1}\) DM], biomass yield of spring wheat in BBCH 32 [t ha\(^{-1}\) DM], biomass yield of spring wheat in BBCH 55 [t ha\(^{-1}\) DM], biomass yield of spring wheat in BBCH 75 [t ha\(^{-1}\) DM], number of weeds [no m\(^2\)] and the fresh weight of weeds [g m\(^2\)].

Spring wheat cultivar, Vinjett, was sown at the rate of 400 seeds per 1 m\(^2\) across all tillage systems. The size of each tillage plots was 10 m long and 4.5 m wide (45 m\(^2\)).

Sowing dates of spring depended of soil water conditions and occurred between 23\(^{rd}\) of March 2012 and 17\(^{th}\) of April 2013 and sowing depth in all tillage systems were 3–4 cm.

Fertilization was uniform for all tillage systems and each experimental year (90 kg N ha\(^{-1}\), 26 kg P ha\(^{-1}\), 50 kg K ha\(^{-1}\)). The herbicide program for tillage systems consisted of pre-plant and post-emergence applications. Before sowing 1.5 L ha\(^{-1}\) of Gliphosate herbicide + 1.5 L ha\(^{-1}\) adjuvant As 500 SL was applied to all plots with no-tillage to control perennial weed and volunteer plants. For weed control, during the growing season post-emergence BBCH 22 Lintur 70 WG (dicamba 65.9%+triasulfuron 4.1%)+Chwastox Extra 300 SL (MCPA 300 g L\(^{-1}\)) herbicide were applied at the rate of 150 g ha\(^{-1}\)+1.0 L ha\(^{-1}\). For disease control, Falcon 460 EC fungicide (spiroksamine 250 g L\(^{-1}\)+tebuconazole 167 g L\(^{-1}\)+triamideno 43 g L\(^{-1}\)) at the rate of 0.6 L ha\(^{-1}\) was applied in all plots at BBCH 32 growth stage and Fury 100 EW insecticide (zeta-cypermethrine 100 g L\(^{-1}\)) at the rate of 0.1 L ha\(^{-1}\) and at last year Karate Zeon 050 CS (lambda – cyhalotryne) at the rate 0.1 L ha\(^{-1}\) at BBCH 61 growth stage.

**Sampling and Measurements**

Plants number of spring wheat after emergence [no m\(^2\)] – frame method (2 × 0.25 m\(^2\)). Biomass yield of spring wheat in BBCH 23, BBCH 32, BBCH 55, BBCH 75 [t ha\(^{-1}\) DM] (2 × 0.25 m\(^2\)). Measurements of leaf area index [LAI] was made in BBCH 51-53 phase, using SunScan Canopy Analysis System type SSI – Delta-T Devices Ltd. Great Britain. Chlorophyll content indicator (SPAD) was determined in BBCH 39 phase using Chlorophyll Hydro N-Tester. Number [no m\(^2\)] and the fresh weight of weeds [g m\(^2\)] were carried out annually on randomly determined parts of experimental plots covered with foil covers during the application of herbicides. In the development phase (BBCH 31–32) spring wheat was determined on an area of 1 m\(^2\).

**Meteorological conditions**

In the first year of research, only in July the amount of precipitation exceeded by 86.4 mm the precipitation needs of spring wheat (Table 1). For optimal wheat development this year there was no rain: in April 31.1 mm, in May 32.0 mm and June 67.6 mm. Such water shortages adversely affected the emergence, development of plants, tillering and the formation of ears. In year 2012, rainfall deficiencies occurred in April (22.1 mm) and in June (13.2 mm). May precipitation exceeded the demand for water by 11.2 mm, and in July by as much as 108.6 mm. In the last year of research, water was lacking in April (deficit by 29.6 mm), which was partly complemented by May (excess in relation to optimum 97 mm) and June (42.3 above optimal). The rainfall deficit also occurred in July (21.7 mm below needs) for this period. Comparing the multiannual average with precipitation needs, it should be stated that the sums of precipitation occurring in the analyzed region are usually lower than the demand for
water necessary for the optimal development of spring wheat. To sum up the course of weather conditions, it can be said that the first year of research was the least favorable for the growth and development of spring wheat, while the most favorable was year 2013.

Table 1. Rainfall sums and rainfall requirements (Dzieżyński, 1989)

| Years | April | May | June | July |
|-------|-------|-----|------|------|
| 2011  | 13.9  | 34.0| 15.4 | 175.4|
| 2012  | 22.9  | 77.2| 69.8 | 197.6|
| 2013  | 15.4  | 163.0| 125.3| 67.3 |
| Means 1961-2010 | 38.0 | 57.4 | 61.8 | 77.5 |

| Demand volume in month [mm] | 45 | 66 | 83 | 89 |

Statistical analysis

Firstly, the normality of the distributions of the studied traits were tested using Shapiro-Wilk’s normality test (Shapiro and Wilk, 1965). Multivariate analysis of variance (MANOVA) was performed on the basis of following model using a procedure MANOVA in GenStat 18th edition: $\mathbf{Y} = \mathbf{XT} + \mathbf{E}$, where: $\mathbf{Y}$ is $(n \times p)$-dimensional matrix of observations, $n$ is number of all observations, $p$ is number of traits (in this study $p=13$), $\mathbf{X}$ is $(n \times k)$-dimensional matrix of design, $\mathbf{T}$ is $(k \times p)$-dimensional matrix of unknown effects, $\mathbf{E}$ – $(n \times p)$-dimensional matrix of residuals. Nextly, the effects of the main factors under study (cover crop, method of tillage and years), as well as the all interactions between them were estimated using a linear model for three-way analysis of variance (ANOVA) for particular traits. The relationships between observed traits were assessed on the basis of Pearson’s correlation coefficients and tested by the $t$-test. Results were also analysed using multivariate methods. The canonical variate analysis was applied in order to present multitrait assessment of similarity of the investigated treatments in a lower number of dimensions with the least possible loss of information (Rencher, 1992). This makes it possible to illustrate variation in investigated treatments in terms of all observed traits in the graphic form. Mahalanobis’ distance was suggested as a measure of “polytrait” treatments similarity (Seidler-Łożykowska and Bocianowski, 2012), whose significance was verified by means of critical value $D_\alpha$ called “the least significant distance” (Mahalanobis, 1936). Mahalanobis’ distances were calculated for investigated treatments. In order to determine the relative share of each original trait in the multivariate variation of analysed treatments Pearson’s simple correlation coefficients were estimated between values of the first two canonical variables and values of individual original traits. All the analyses were conducted using the GenStat v. 18 statistical software package.

Results and Discussion

All studied quantitative traits have a normal distribution as well as a multivariate normality. Results of MANOVA indicate that the all factors (years: Wilk’s $\lambda=0.00127$, $F_{2,81}=143.60$, $P<0.0001$; cover crop: Wilk’s $\lambda=0.16470$, $F_{2,81}=7.77$, $P<0.0001$; method of tillage for spring wheat: Wilk’s $\lambda=0.07879$, $F_{2,81}=13.60$, $P<0.0001$) and their
interactions (years × cover crop: Wilk’s \( \lambda = 0.06601 \), \( F_{4,81} = 5.27 \), \( P < 0.0001 \); year × method of tillage for spring wheat: Wilk’s \( \lambda = 0.07601 \), \( F_{4,81} = 4.90 \), \( P < 0.0001 \); cover crop × method of tillage for spring wheat: Wilk’s \( \lambda = 0.15555 \), \( F_{4,81} = 3.19 \), \( P < 0.0001 \); years × cover crop × method of tillage for spring wheat: Wilk’s \( \lambda = 0.07820 \), \( F_{8,81} = 2.09 \), \( P < 0.0001 \)) were significant different for all 13 traits. The ANOVA indicated statistically significant influence of years for all observed traits (Table 2). Cover crop was significant for all traits except leaf greenness index, biomass yield in BBCH 23, biomass yield in BBCH 32, biomass yield in BBCH 75 and number of weeds, however method of tillage for all traits except leaf greenness index, height plants, LAI and weight of weeds. In research by Kulig et al. (2010) there was not significant correlation between SPAD values and grain yield but a strong link with the protein content and with the values of grain yield. Lepiarczyk et al. (2005) showed that the method of cultivation and use of fore crop significantly influenced the size of leaf surface. They showed that the value of LAI and the canopy of wheat grain yield is significant and has a high correlation. The year × cover crop × method of tillage for spring wheat interaction was significant for plants number after emergence, biomass yield in BBCH 55 and weight of weeds (Table 2).

**Table 2. F-statistic from three-way analysis of variance for observed traits**

| Source of variation | Year (Y) | Cover crop (Cc) | Method of tillage (Mt) | Y×Cc | Y×Mt | Cc×Mt | Y×Cc×Mt |
|---------------------|---------|-----------------|------------------------|------|------|-------|---------|
| d.f.                | 2       | 2               | 2                      | 4    | 4    | 4     | 8       |
|GY                  | 58.2*** | 20.84***        | 6.49**                 | 2.91*| 0.47 | 0.7   | 0.68    |
|PGY                 | 29.67***| 16.17***        | 6.04**                 | 2.63*| 0.21 | 0.48  | 0.77    |
|TW                  | 54.33***| 4.5*            | 7.41**                 | 0.88 | 2.45 | 0.27  | 1.84    |
|PNE                 | 700.38***| 12.92***        | 74.62***               | 14.27***| 14.57***| 6.24***| 3.35*** |
|SPAD                | 42.51***| 1.74            | 1.34                   | 1.2  | 2.18 | 0.54  | 0.24    |
|HP                  | 378.92***| 8.98***         | 0.41                   | 0.17 | 1.67 | 2.34  | 0.64    |
|LAI                 | 18.9*** | 26.38***        | 1.65                   | 0.98 | 0.11 | 2.96* | 0.72    |
|BY23                | 90.63***| 2.14            | 125.58***              | 5.75***| 20.62***| 2.14  | 1.63    |
|BY32                | 18.39***| 1.38            | 13.95***               | 1.46 | 6.71***| 1.01  | 1.03    |
|BY55                | 203.25***| 6.36**          | 12.78***               | 8.59***| 5.23***| 3.54* | 2.32*   |
|BY75                | 56.14***| 1.31            | 4.91*                  | 4.25**| 1.29  | 1.04  | 0.99    |
|NW                  | 8.72*** | 0.99            | 21.24***               | 2.12 | 4.42**| 7.32***| 1.63    |
|WW                  | 25.91***| 27.64***        | 2.52                   | 20.15***| 7.41***| 8.63***| 7.32*** |

*p<0.05; ** P<0.01; *** P<0.001; d.f. – degrees of freedom.

GY - grain yield, PGY - protein grain yield, TW - test weight, PNE - plants number after emergence, SPAD - leaf greenness index, HP - height plants, LAI - leaf area index, BY23 - biomass yield in BBCH 23, BY32 - biomass yield in BBCH 32, BY55 - biomass yield in BBCH 55, BY75 - biomass yield in BBCH 75, NW - number of weeds, WW - weight of weeds

Kraska (2012) found that with regard to the yield, more reliable were undersown catch crops, compared with stubble crops. Kwiatkowski (2009) think that degree to which catch crops affect regulation of weed infestation is diversified and depends on habitat conditions, cereal species, type of catch crop and plant selection as well as method of its management. According to Wozniak (2011) compared to ploughless tillage ploughless tillage significantly increased air-dry weight of weeds in the spring wheat crop. The tillage system under comparison did not differentiate the number of weeds per 1 m².
Testing of Pearson’s correlation coefficients made it possible to observe several statistically significant interdependencies between observed traits of spring wheat. Grain yield was significantly positively correlated with protein grain yield, test weight of spring wheat grain, plants number after emergence, LAI, biomass yield in BBCH 23, biomass yield in BBCH 55 and biomass yield in BBCH 75 (Table 3). Faber and Nieróbca (1999) found a strong correlation between the maximum LAI and above ground dry mass and slightly less with the grain yield. Lepiarczyk et al. (2005) showed that the values of LAI and the conopy of wheat grain yield is significant and has a high correlation. In our research generally, was observed 42 pairs of significant correlation coefficient: 36 positive and six negative (Table 3).

**Table 3. Correlation coefficients between observed quantitative traits of spring wheat**

| Trait          | GY   | PGY  | TW   | PNE  | SPAD | HP   | LAI  | BY23 | BY32 | BY55 | BY75 | NW   |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|
| GY             | 0.86*** |      |      |      |      |      |      |      |      |      |      |      |
| PGY            | 0.70*** | 0.33 |      |      |      |      |      |      |      |      |      |      |
| TW             | 0.59*** | 0.15 | 0.78*** |      |      |      |      |      |      |      |      |      |
| PNE            | -0.28 | 0.17 | -0.58*** | -0.70*** |      |      |      |      |      |      |      |      |
| SPAD           | 0.34  | -0.13 | 0.74*** | 0.79*** | -0.84*** |      |      |      |      |      |      |      |
| HP             | 0.83*** | 0.86*** | 0.30 | 0.30 | 0.02 | 0.07 |      |      |      |      |      |      |
| LAI            | 0.65*** | 0.56** | 0.62*** | 0.50** | -0.10 | 0.13 | 0.43* |      |      |      |      |      |
| BY23           | 0.30  | 0.02 | 0.43* | 0.64*** | -0.47* | 0.55** | 0.19 | 0.41* |      |      |      |      |
| BY32           | 0.58** | 0.18 | 0.69*** | 0.81*** | -0.77*** | 0.75*** | 0.36 | 0.50** | 0.69*** |      |      |      |
| BY55           | 0.75*** | 0.47* | 0.63*** | 0.72*** | -0.59*** | 0.46* | 0.61** | 0.36 | 0.80*** |      |      |      |
| BY75           | 0.33  | 0.20 | 0.36 | 0.48* | -0.16 | 0.25 | 0.16 | 0.51** | 0.58** | 0.42* | 0.31 |      |
| NW             | 0.09  | 0.06 | -0.07 | 0.13 | -0.07 | -0.06 | -0.07 | -0.04 | -0.08 | 0.07 | 0.14 | 0.48* |

* P<0.05; ** P<0.01; *** P<0.001.

GY - grain yield, PGY - protein grain yield, TW - test weight, PNE - plants number after emergence, SPAD - leaf greenness index, HP - height plants, LAI - leaf area index, BY23 - biomass yield in BBCH 23, BY32 - biomass yield in BBCH 32, BY55 - biomass yield in BBCH 55, BY75 - biomass yield in BBCH 75, NW - number of weeds, WW - weight of weeds

Individual traits are of different importance and have a different share in the joint multivariate variation. A study on the multivariate variation for treatments includes also identification of the most important traits in the multivariate variation of treatments. Canonical variables analysis (CVA) is a statistical tool making it possible to solve this problem (Bocianowski et al., 2016; Lahuta et al., 2018). Results of the CVA for investigated treatments are presented in Table 4. The first two canonical variables explained jointly 87.03% total variation between treatments (Table 4, Figure 2). Figure 2 presents variation in traits of investigated treatments in the system of the first two canonical variables. In the graph the coordinates of a point of a given treatment are values of the first and second canonical variables, respectively. The greatest, significant linear relationship with the first canonical variables was found for the grain yield, test weight of spring wheat grain, plants number after emergence, height plants, biomass yield in BBCH 32, biomass yield in BBCH 55, and biomass yield in BBCH 75 (positive dependencies), and SPAD (negative) (Table 4). The second canonical variable was significantly positively correlated with grain yield, protein grain yield, LAI, biomass yield in BBCH 23, biomass yield in BBCH 75 and number of weeds (Table 4). The greatest diverse in terms of all the 13 traits jointly (measured Mahalanobis distances) was found for treatments denoted with symbols Z-A-1 (cover crop: zero, method of tillage: aggregate, in 2011) and N-P-2 (cover crop: no tillage, method of tillage: applied ecology and environmental research 17(6):15267-15276.

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plowing, in 2012) (the Mahalanobis distance between them amounted to 24.49). The greatest similarity was found for treatments Z-A-1 (cover crop: zero, method of tillage: aggregate, in 2011) and N-A-1 (cover crop: N – no tillage, method of tillage: aggregate, in 2011) (2.27). Values of Mahalanobis distances for all pairs of treatments are presented in Table 5.

**Table 4. Correlation coefficients between the first two canonical variables and original traits**

| Trait     | First canonical variable | Second canonical variable |
|-----------|--------------------------|---------------------------|
| GY        | 0.552**                  | 0.542**                   |
| PGY       | 0.057                    | 0.653***                  |
| TW        | 0.842***                 | 0.24                      |
| PNE       | 0.913***                 | 0.274                     |
| SPAD      | -0.845***                | 0.248                     |
| HP        | 0.919***                 | -0.273                    |
| LAI       | 0.221                    | 0.501**                   |
| BY23      | 0.373                    | 0.861***                  |
| BY32      | 0.576**                  | 0.243                     |
| BY55      | 0.877***                 | 0.188                     |
| BY75      | 0.704***                 | 0.457*                    |
| NW        | 0.331                    | 0.453*                    |
| WW        | 0.049                    | 0.054                     |

* P<0.05; ** P<0.01; *** P<0.001.

GY - grain yield, PGY - protein grain yield, TW - test weight, PNE - plants number after emergence, SPAD - leaf greenness index, HP - height plants, LAI - leaf area index, BY23 - biomass yield in BBCH 23, BY32 - biomass yield in BBCH 32, BY55 - biomass yield in BBCH 55, BY75 - biomass yield in BBCH 75, NW - number of weeds, WW - weight of weeds

**Figure 2. Distribution of spring wheat treatments in the two first canonical variables (cover crop: Z – zero, S – skimming, N – no tillage; method of tillage for spring wheat: D – direct sowing, A – simplified tillage, P – spring ploughing; years: 1 – 2011, 2 – 2012, 3 – 2013)**
Table 5. Mahalanobis distances between analyzed treatments of spring wheat

| Treatments | No | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 |
|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Z-A-11     | 2  | 2.57 |
| Z-P-11     | 3  | 5.33 | 4.88 |
| S-D-11     | 4  | 4.41 | 4.84 | 7.15 |
| S-A-11     | 5  | 4.48 | 3.32 | 7.12 | 3.38 |
| S-P-11     | 6  | 4.91 | 4.07 | 5.56 | 3.9  | 3.55 |
| N-D-11     | 7  | 4.03 | 3.74 | 7.22 | 3.31 | 2.3  | 3.27 |
| N-A-11     | 8  | 4.49 | 4.47 | 6.8  | 2.27 | 3.27 | 2.44 | 2.72 |
| N-P-11     | 9  | 5.63 | 4.87 | 2.99 | 7.34 | 7.02 | 5.07 | 6.82 | 6.58 |
| Z-D-12     | 10 | 17.35 | 15.73 | 18.6 | 18.88 | 15.95 | 17.45 | 16.6 | 17.88 | 17.89 |
| Z-A-12     | 11 | 20.4 | 18.68 | 20.55 | 22.23 | 19.47 | 20.4 | 20.03 | 21.08 | 20.06 | 7.14 |
| S-D-12     | 12 | 20.69 | 18.76 | 20.59 | 22.41 | 19.37 | 20.5 | 20.21 | 21.42 | 20.23 | 6.86 | 4.49 |
| S-P-12     | 13 | 20.01 | 18.38 | 21.38 | 21.3 | 18.38 | 20.06 | 19.01 | 20.38 | 20.74 | 3.53 | 7  | 6.9 |
| N-D-12     | 14 | 21.82 | 20.06 | 22.51 | 23.37 | 20.4 | 21.7 | 21.05 | 22.3 | 21.83 | 5.89 | 4.19 | 4.52 | 4.53 |
| N-A-12     | 15 | 21.95 | 20.2 | 21.57 | 24.14 | 21.31 | 21.94 | 21.72 | 22.96 | 21.11 | 10.38 | 5.34 | 5.74 | 10.31 |
| N-P-12     | 16 | 22.29 | 20.65 | 23.49 | 23.85 | 20.82 | 22.37 | 21.3 | 22.91 | 22.63 | 5.94 | 8.26 | 7.47 | 4.03 |
| S-D-13     | 17 | 20.25 | 18.4 | 20.26 | 21.86 | 18.95 | 19.88 | 19.55 | 20.75 | 19.77 | 6.41 | 3.58 | 3.3  | 6.22 |
| S-P-13     | 18 | 22.57 | 20.66 | 22.28 | 24.49 | 21.39 | 22.4 | 22.13 | 23.53 | 21.79 | 9.12 | 7.03 | 3.8 | 9.06 |
| N-D-13     | 19 | 14.33 | 13.23 | 15.84 | 16.43 | 14.04 | 15.36 | 14.4 | 15.66 | 15.4 | 11.24 | 11.73 | 12.82 | 12.83 |
| N-A-13     | 20 | 12.69 | 11.05 | 12.65 | 14.65 | 12.19 | 12.73 | 12.68 | 13.58 | 11.94 | 10.38 | 10.53 | 11.43 | 12.6 |
| N-P-13     | 21 | 16.66 | 14.43 | 15.67 | 17.64 | 14.94 | 15.49 | 16.04 | 16.66 | 15.06 | 9.86 | 9.23 | 8.6  | 11.44 |
| S-D-14     | 22 | 13.91 | 11.89 | 14.11 | 15.46 | 12.52 | 13.58 | 13.19 | 14.53 | 13.11 | 6.97 | 8.73 | 8.44 | 9.05 |
| S-P-14     | 23 | 13.83 | 11.74 | 13.36 | 15.53 | 12.75 | 13.26 | 13.34 | 14.38 | 12.41 | 8.54 | 8.59 | 8.89 | 10.56 |
| N-D-14     | 24 | 17.21 | 15.09 | 15.63 | 18.41 | 15.98 | 15.92 | 16.87 | 17.21 | 15.15 | 11.87 | 10.06 | 10.08 | 13.51 |
| N-A-14     | 25 | 20.09 | 17.99 | 20.29 | 21.17 | 18.12 | 19.35 | 18.89 | 20.28 | 19.28 | 8.02 | 8.06 | 6.92 | 7.86 |
| N-P-14     | 26 | 18.91 | 16.78 | 18.79 | 20.09 | 17.18 | 18.1 | 18.04 | 19.04 | 17.81 | 8.34 | 7.15 | 7.01 | 9.01 |
| S-D-15     | 27 | 18.3 | 16.11 | 16.48 | 19.21 | 16.82 | 16.56 | 17.6 | 18.01 | 15.53 | 13.16 | 11.5 | 11.5 | 14.66 |

Cover crop: Z – zero, S – skimming, N – no tillage.
Method of tillage for spring wheat: D – direct sowing, A – simplified tillage, P – spring ploughing; years: 11 – 2011, 12 – 2012, 13 – 2013

Conclusion

The presented multivariate characteristic of the behaviour of analysed treatments is a convincing illustration of this aspect. In this way efficiency of the canonical variables analysis was shown. This results from the fact that these variables explained a considerable part of total variation (87.03%). Additionally, we obtained three groups of treatments, classified by the years of study (Figure 2). Thus this is a reliable method, which may be confirmed by its extensive application by breeders and geneticists.
(Shamsuddin, 1985; Seidler-Łożykowska et al., 2013; Nowosad et al., 2016; Bocianowski et al., 2018, 2019; Wrońska-Piłarek et al., 2018). In our study, the greatest diverse in terms of all the 13 traits jointly (measured Mahalanobis distances) was found for cover crop: zero, method of tillage: aggregate (in 2011) and cover crop: no tillage, method of tillage: plowing (in 2012). However, the greatest similarity was found for cover crop: zero, method of tillage: aggregate (in 2011) and cover crop: N – no tillage, method of tillage: aggregate (in 2011).

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