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IMPACT OF SOIL CULTIVATION METHODS ON CROP YIELD STABILITY FOR SEVERAL WINTER WHEAT CULTIVARS

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ABSTRACT

In the years 1999-2001, using two forecrops – spring wheat and winter rape, crop yields of 6 wheat cultivars were compared in the conditions of the conventional (ploughed) tillage, simplified (ploughless) and direct seeding methods. On the basis of discriminant function analysis and analysis of concentration using the nearest neighbour method large variations in crop yields for the particular cultivars were revealed in relation to the 3 cultivation methods and 2 forecrops. The simplified tillage variants led to decreased crop yields. The greatest discriminating power for differentiating the examined genotypes was exhibited by the conventional (ploughed) soil cultivation on the two forecrops as well as the simplified method and direct seeding on the stand after spring wheat. 'Izolda' and 'Kobra' cultivars were marked by a higher average crop yield in the examined environments, compared to the other genotypes.

Key words: ploughed soil cultivation, simplified soil tillage, direct seeding, wheat cultivars, multivariate analysis

INTRODUCTION

Over the past 10 years cereal crop plantation area have considerably increased, mainly due to economic reasons. The proportion of cereals in the overall crop structure is rising, reaching the dangerous limit of 70%, with predominant winter wheat, barley and corn. Rye has been supplanted on worse stands by wheat, which can guarantee fully remunerative yields as a result of applying meticulous agronomy practices and choosing

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optimum seeding date [17]. However, growing cereals, especially wheat on the same field for 2-3 successive years leads to a decline in crop yield, attributable to a wider occurrence of pests and fungal diseases [5,11,21]. Wheat as a species shows high forecropping requirements and low competitiveness in relation to weeds; hence its share in crop rotation may be enlarged only through creating and supplying new and more adaptable cultivars [14].

Lower soil cultivation costs as a result of applying simplified agronomic systems, and on the other hand, increased soil erosion caused by water and wind activity in case of the conventional tillage, are two factors that have contributed to a more and more widespread use of the ploughless and direct seeding methods. While the conservation soil cultivation may result in lesser yields, many publications point to a comparable crop productivity even on light soils [1,2,3,9].

Compared with the conventional (ploughed) system, the ploughless or direct seeding methods affect largely physical and biological properties of the soil [4,8,19,21]. The upper soil layers show increased moisture, earthworms incidence as well as higher proportion of humus, nitrogen and potassium. Significant changes are also noted in soil cohesion and density. Such a considerable shift in the soil environment makes for differences in crop yield for particular cultivars.

Wheat cultivars throughout the world, unlike other cereals, are enormously diversified, which results from the broad genetic basis of the species. Wheat as a natural hexaploid carries 42 pairs of chromosomes, which as a result of crossbreeding can bring about a number of recombinants unparalleled by other species. Such a multitude of output forms leads to largely diversified wheat cultivars, which react differently to the climatic and soil conditions. Many studies have been published in recent years, describing experiments in which selected wheat cultivars were tested with respect to their suitability for the simplified agronomic systems [7,12,20]. A great number of winter wheat cultivars available in Poland enables researchers to isolate cultivars most resistant to soil environment changes. Different reactions of particular cultivars to applied forecrops, revealed by some studies [10], as well as large crop yield variability of wheat genotypes relative to soil cultivation methods, demonstrated in the literature on the subject throughout the world, both call for examining Polish wheat cultivars in this respect. Therefore the present study aims to evaluate variability in crop yields for several wheat cultivars in relation to soil cultivation methods and forecrops used.

MATERIAL AND METHODS

The investigations were carried out at the Jelcz Laskowice Department of Soil Cultivation and Fertilisation Technology of the Puławy Institute of Plant Cultivation, Fertilisation and Soil Science on a good rye soil suitability complex. The experiment followed the split-plot design (perpendicular strips) where:
Factor A corresponded to 2 forecrops - winter rape and spring wheat;
Factor B - to soil cultivation methods:

Conventional (ploughed) agronomic system

- post-harvest cultivation – grubber 15 cm deep + cage roller
- basic – ploughing 25 cm deep + harrow
- pre-seeding – cultivator + cage roller; herbicides as necessary

Ploughless

- post-harvest – grubber 15 cm deep + cage roller
- pre-seeding – rotary harrow + cage roller; herbicides as necessary
- direct seeding, Great Plains drill (dual round disk openers with spike-toothed wheels in front, weed control using herbicides).

Factor C – to cultivars randomly allocated to each unit (subplot) constituted by associating a soil cultivation system (factor B) with a forecrop (factor A). A harvest plot area was 110 m^2 each.
In 1999 the fields were flooded for a period of time by thawing snow, while minimum rainfall was observed at the stalk shooting stage. The year 2000 saw a large rainfall shortage at the time of the tillering and over the milky ripeness and dough stages. However, in 2001 no rainfall shortage was recorded during the wheat growing season. The objects in the specified 6 environments (2 forecrops by 3 soil cultivation methods) were the following wheat cultivars: ‘Elena’, ‘Kobra’, ‘Maltanka’, ‘Mikon’, ‘Izolda’ and ‘Sakwa’.

Table 1. Mean precipitation (mm) and temperature (°C) in the wheat growing season

Specification	Month					
	March	April	May	June	July	August
Multi-year mean precipitation, mm	30.3	36.1	63.7	70.8	77.4	69.9
Deviation from mean in 1999	+27.4	-20.3	-18.1	+8.3	+10.6	+17.2
Deviation from mean in 2000	+46.4	-18.9	+12.8	-32.7	-60.0	+113.7
Deviation from mean in 2001	30.0	4.8	5.1	0.4	63.4	10.1
Multi-year mean temperature, °C	3.1	8.0	13.3	16.6	17.8	17.3
Deviation from mean in 1999	+1.9	+1.6	+0.7	0.0	+2.1	+0.4
Deviation from mean in 2000	+1.6	+3.8	+2.3	+0.3	-0.1	+2.3
Deviation from mean in 2001	+0.1	+0.3	+1.5	+1.5	+1.4	+1.3

In order to estimate crop yield variability for the analysed wheat cultivars, two methods were used: discriminant function analysis and analysis of concentration, discussed by Morisson [16], Krzyśko [13], Mądry [15], and Caliński et al. [6]. These analytical methods enable a comprehensive estimation of the objects, including significant differences between the genotypes in the space set up by analysed dependent variables. As regards simpler statistical tests such as LSD, Duncan's or Tukey's test, in many cases they are impaired by bigger errors or create homogeneous groups that overlap.

RESULTS AND DISCUSSION

Variance analysis of the crop yields of the winter wheat cultivars did not reveal an interaction between the cultivation methods and the wheat cultivars on one hand, and between the forecrops and the examined genotypes on the other. The insignificant interaction indicates that the analysed objects displayed a similar reaction to the varied cultivation methods and forecrops. Nevertheless, while analysing Table 2, one can observe that the crop yields of the examined genotypes, to a lesser or greater extent, declined.

Table 2. Yields of winter wheat cultivars in relation to the tillage system

Cultivar	Environment						Mean
	Ar	Br	Cr	Ap	Bp	Cp	
Elena	6.02	5.34	5.44	4.22	3.89	3.70	4.77
Kobra	5.9	5.28	5.33	5.52	4.56	4.04	5.11
Maltanka	5.95	4.83	5.19	5.00	3.77	3.95	4.78
Mikon	5.64	4.65	5.63	5.25	3.71	3.54	4.73
Izolda	6.10	5.18	5.63	5.32	4.20	4.07	5.17
Sakwa	6.01	5.22	5.47	5.32	4.02	3.92	4.99
Mean	6.02	5.08	5.44	5.11	4.02	3.87	

LSD FOR forecrops = 0.41 **LSD for cultivation methods = 0.91** **LSD for cultivars = 0.35**

Ar – ploughed tillage after rape
Br – ploughless tillage after rape
Cr – direct seeding after rape
Ap – ploughed tillage after wheat
Bp – ploughless tillage after wheat
Cp – direct seeding after wheat

The large experiment area and the subsequent field variation may have considerably affected the obtained results. In addition, the most commonly used LSD test, while comparing a large number of means, carries some error. Hence, selecting a cultivar characterised by higher and stable crop productivity in the simplified cultivation methods using poorer forecrops may pose difficulty. Let us then follow a slightly different method of estimating the results and analyse the separate yields from the particular environments and years. Variance analysis of the component experiments following the randomised block design is illustrated by Table 3.

Table 3. Analysis of variance

Environment	Mean squared - cultivars	Mean squared – error
1999 – Ar	57.68 **	10.56
1999 – Br	124.12**	4.05
1999 – Cr	60.85**	11.21
1999 – Ap	152.26**	7.38
1999 – Bp	40.36**	6.01
1999 – Cp	44.58**	5.43
2000 – Ar	441.58**	56.21
2000 – Br	127.75**	38.78
2000 – Cr	177.11*	28.45
2000 – Ap	115.53**	4.02
2000 – Bp	71.53**	3.23
2000 – Cp	32.55**	4.13
2001 – Ar	114.95**	24.51
2001 – Br	60.25**	13.08
2001 – Cr	68.26**	9.16
2001 – Ap	202.16**	12.29
2001 – Bp	171.90**	12.72
2001 – Cp	166.90**	17.97

Variance analysis for each agronomic system applied in the years 1999-2001 revealed that crop yield differentiation in relation to a soil cultivation method and forecrop was significant (Table 3). The cultivars showed lesser crop yield for the simplified (ploughless and direct seeding) methods. Manov's analysis of variance was carried out in order to verify the multidimensional null hypothesis of no difference between crop yields of the examined cultivars for the three cultivation methods after the two forecrops. The Wilks' *lambda* statistics of total discrimination, calculated as a ratio of the variance matrix determinant /in-group covariance to the variance matrix determinant/total covariance, revealed that crop yield variability of the cultivars in the examined environments was significant (Table 4). The crop yields of the cultivars were especially strongly affected by the conventional (ploughed) soil cultivation after rape and wheat as well by the ploughless and direct seeding methods on the stands after spring wheat.

Table 4. Discriminant function analysis results

Wilks' *lambda* = 0.33730, F (30. 246) = 2.5599; p < 0.0001				
Environments	Wilks' *lambda*	Wilk's partial *lambda*	F	p level
Ar	0.421	0.802	3.01	0.017
Br	0.390	0.863	1.92	0.103
Cr	0.390	0.864	1.91	0.105
Ap	0.535	0.630	7.15	0.0002
Bp	0.470	0.717	4.80	0.0009
Cp	0.404	0.835	2.40	0.047

Further analysis led to isolating five linearly independent functions as characteristic roots which represent multivariate group differences of the crop yields for the cultivars in the space set up by canonical variables (Table 5). Values for the particular roots were estimated using the chi-square test (Table 6). The actual dimension of the discriminant space is determined by first two canonical roots, which differ significantly from zero at the significance level $\alpha = 0.05$.

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Table 5. Standardized coefficients for canonical variables

Variables	Root 1	Root 2	Root 3	Root 4	Root 5
Ar	0.895	0.961	0.932	1.0265	0.468
Br	1.482	-0.071	-1.113	-1.893	1.698
Cr	-0.383	-0.953	-1.433	1.286	-0.551
Ap	-2.528	0.759	-0.108	-0.500	0.746
Bp	1.444	2.158	-0.522	0.699	-0.789
Cp	-0.651	-2.291	2.350	-0.188	-1.181
Eigen-value Cumulative percent	0.763 0.581	0.349 0.848	0.125 0.944	0.063 0.993	0.0091 1.00

Table 6. Chi – Square tests with successive roots removed

Roots removed	Eigen-value	Canonical R	Wilks' *lambda*	Chi-square	Degrees of freedom	Level of *p*
0	0.775	0.660	0.337	70.64	30	0.00004
1	0.376	0.523	0.598	33.34	20	0.031
2	0.125	0.334	0.824	12.56	12	0.401
3	0.066	0.249	0.927	4.87	6	0.559
4	0.011	0.104	0.989	0.71	2	0.701

First two canonical variables account in 84.8% for the mutual distances between the examined cultivars. Standardized coefficients and values of co-relation between the variants of the cultivation methods combined with the forecrops and the canonical roots were adopted for interpreting the significance of the canonical variables. The high absolute values of the canonical coefficients and the significant co-relations between the cultivation procedures and the canonical variables point to a major contribution of the particular cultivation variants to discriminating the examined cultivars. The biggest contribution to the first canonical variable, which in itself ensures a 58% multivariate difference between the cultivars, comes from the ploughed and ploughless cultivation on the stands after wheat as well as from the ploughless cultivation after rape. With the exception of the latter, these cultivation systems also display higher values of the coefficients of co-relation with the root in question. The biggest contribution to the second canonical variable comes from the ploughless cultivation method and direct seeding, both using spring wheat as a forecrop. These systems also show higher coefficients of co-relation with the second root. All the agronomic systems mentioned above have the greatest discriminatory power for the differentiated crop yields of the examined cultivars. Table 7 contains squared Mahalanobis distances, which are measures of distances between two cultivars in the space defined by 3 variants of cultivation systems and 2 forecrops. The Elena cultivar is marked by a different reaction to changes in a cultivation system and a forecrop. Especially low yields of this wheat variety were observed on the stand after spring wheat for all the agronomic systems.

Table 7. Squared Mahalanobis distances

Cultivar	Elena	Kobra	Maltanka	Mikon	Izolda	Sakwa
Elena	-	5.29**	4.83**	8.54**	3.66**	4.38**
Kobra	5.29**	-	3.21**	4.29**	1.11	1.33
Maltanka	4.83**	3.21*	-	2.08	1.69	0.80
Mikon	8.54**	4.29**	2.08	-	3.47**	1.44
Izolda	3.66**	1.11	1.69	3.47**	-	1.03
Sakwa	4.38**	1.33	0.80	1.44	1.03	-

**** significant at $\alpha = 0.01$ * significant at $\alpha = 0.05$**

A considerable distance between 'Kobra' 'Maltanka' and 'Mikon' genotypes points to a varied type of reaction to different soil environments. The variety in question, like the 'Izolda', viewed against the other objects of the experiment, has been characterised by a much higher mean crop yield throughout. In order to compare the varying crop yields of the analysed cultivars for the three agronomic systems and the two forecrops, additionally analysis of concentration was carried out using the nearest neighbour method. The method allows researchers to

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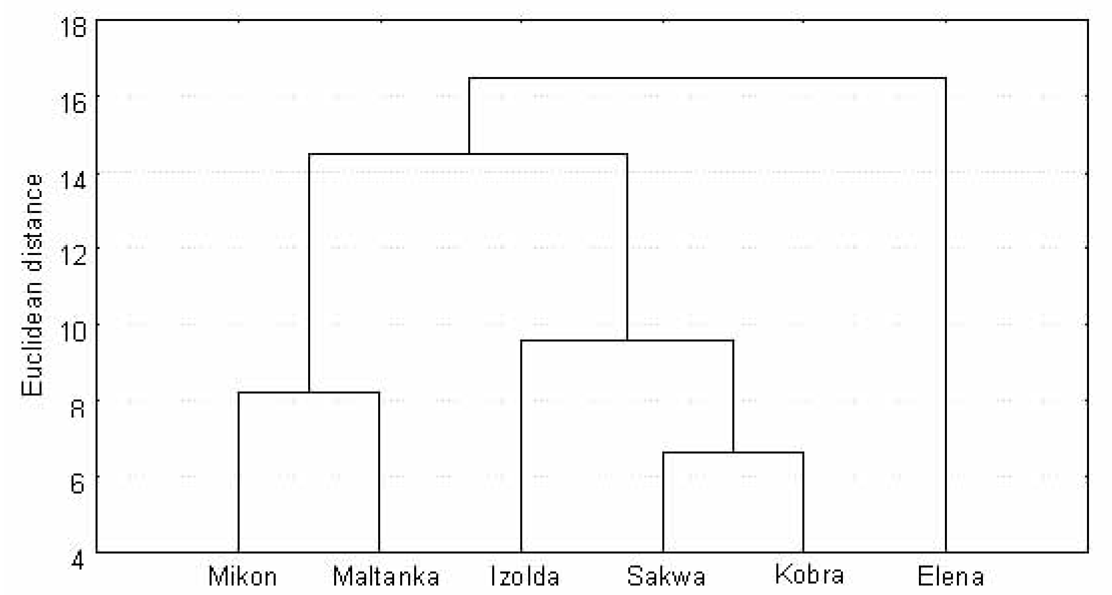
isolate homogenous separate groups of objects by tracing a straight line at the critical value level $F_{\sim\alpha}$=10.44, across the full length of a dendrogram. The presented dendrogram defines Euclidean distances between the examined genotypes in the six-dimensional space (Fig. 1).

Fig. 1. Dendrogram of the analysis of the clusters - Yields of winter wheat cultivars in relation to cultivation system and the forecrop



Single cultivars or clusters of cultivars suspended on the horizontal line constitute homogenous groups, significantly similar in terms of reaction to the forecrops and the simplified cultivation systems. The closer particular homogenous groups are located to each other, the higher inter-group similarity between the examined wheat cultivars is established. The farthest Euclidean distance observed was that between the Elena variety and the group of the other objects. Analysing Fig. 1, one may note that 'Sakwa', 'Kobra', 'Izolda', as well as the 'Mikon' and 'Maltanka' cultivars display a similar reaction to the varying environments. The fact that the obtained homogenous groups shown on the graph do not exactly match the results in Table 1 is attributable to the assumption made of no correlation between dependent variables; this correlation, on the other hand, is assumed in Mahalanobis distances. The presented dendrogram shows, however, a close convergence of the results obtained using Mahalanobis distances, corroborating, for the analysed cultivars, the significant variability of crop yield in relation to cultivation system and forecrop.

The conducted analysis leads to a conclusion that the biggest influence on crop yield variability was exerted by the conventional (ploughed) method and the varying forecrops, whereas the simplified (ploughless) method and direct seeding made a difference in the crop yields in the examined cultivars only on the stands after spring wheat. Discriminant function analysis and analysis of concentration distinguished the 'Elena' cultivar as the one marked by a large crop yield variability in the three soil cultivation systems. A closer look at Table 2 reveals that with spring wheat used as a forecrop, this genotype showed significantly lower crop yields than the other cultivars. Also, the 'Mikon' cultivar, from Germany, was characterised by significantly lower crop yields in response to the varied cultivation methods, compared to the 'Izolda' and 'Kobra' genotypes.

The established crop yield variability of the wheat cultivars in relation to a soil cultivation method may account for the large differences in wheat crop productivity reported by other studies [2,3,5,19]. Wheat crop yields in all kinds of conservation cultivation methods are also determined by a granulometric (grain size) category to which soil structures belong. High yields in the simplified variants are mostly achieved on light or medium clay, or loamy sand; whereas heavy clay, with high soil flowage (silt) brings about a large decrease in crop yield in direct seeding [1,17]. Weisz and Bowman [20], studying 12 wheat cultivars with respect to their suitability for direct seeding on North Carolina soils, established that cultivars characterized by high yields in the ploughed cultivation were also more productive in direct seeding conditions. On the other hand, in the present study only the 'Kobra' and 'Izolda' cultivars were distinguished by high crop yield stability. The other genotypes were found to be more easily affected by the simplifications in soil cultivation. The slightly different results may be attributed to the influence of changing weather conditions (succession of years) on crop yield of the examined

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cultivars in the simplified cultivation conditions. A study by Domitruk et al. [7] revealed that crop yield variability of the Canadian cultivars in different soil environments was especially visible in heavy rain rainfall conditions. On the other hand, large shortages of rain during the growing season made no significant difference in crop yields of the examined genotypes. Also Mittler [17], while studying German cultivars crop yield stability in the conventional cultivation and direct seeding systems, concluded that diminished rainfall in springtime was the chief factor responsible for decreased wheat crop yields on light soils.

The presented comparison of standard analysis of variance in split-plot design with the proposed less common analysis indicates serious difficulties, faced by researchers in evaluating the examined objects on large experimental plots while applying the most commonly used statistical methods. Downsizing the plots to $10m^2$ creates field conditions incomparable to wide-ranging farming, which is attested by wide crop yield discrepancies between Plant Breeding Stations and regular farms. The results of variance analysis in the traditional split-plot design were to a large extent affected by the changing weather conditions in the analysed three-years period. Most researchers insist that in variance analyses of this kind, an effect of soil cultivation methods should be assumed to be constant. This estimation model has been adopted for the present study. However, given so much changing weather conditions, the effects of the considerably varied cultivation methods should be treated as random. The problem could be solved by comparing, for this type of experiment, the mixed model (succession of years – random, the other factors in the experiment – constant) with the random one.

CONCLUSIONS

1. Analysis of concentration and discriminant function analysis have revealed largely differentiated reactions of the examined genotypes to the soil cultivation methods and forecrops.
2. The ‘Izolda’ and ‘Kobra’ cultivars have shown a higher average crop yield in the 6 analysed environments, while the ‘Mikon’ and ‘Elena’ have been marked by a lower crop yield, especially on the stands after spring wheat.
3. An especially strong influence on crop yield variability of the examined genotypes has come from the conventional tillage and the ploughless and direct seeding methods on the stands after spring wheat.
4. Crop yields of the wheat cultivars using the simplified cultivation and the spring wheat forecrop have been much lower compared to those achieved on the stands after winter rape.

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