Effect of the Main Soil Tillage Types on the Agronomic Response of Wheat in the Region of Souht Dobrudzha

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Summary

Wheat yield (*Triticum aestivum* L. – cv. Enola) obtained under different main soil tillage systems in 4-field crop rotation (common bean-wheat-sunflower-grain maize), is strongly influenced by the regional soil (Haplic Chernozems) and the climatic conditions. This study was carried out at the trial field of Dobrudzha Agricultural Institute-General Toshevo from 2014 to 2016. The influence of seven main soil tillage systems (MSTS) on the yield and the physical properties of wheat grain was investigated. Four of these MSTS were applied independently and annually in crop rotation: 1. CP - conventional plowing (24-26 cm); 2. D – disking (10-12 cm) 3. C – cutting; 4. NT - nil tillage (direct sowing). The other three MSTS systems included: 5. Plowing (for spring crops) – Direct sowing (of wheat); 6. Cutting (for spring crops) - Disking (for wheat) and 7. Plowing (for spring crops) - Disking (for wheat). The mineral fertilization in the crop rotation was as follows: Common bean – $N_{60}P_{60}K_{60}$; Wheat – $N_{120}P_{120}K_{60}$; Sunflower - $N_{60}P_{120}K_{120}$ and Maize – $N_{120}P_{60}K_{60}$.The objectives were: (i) to investigate the seasonal variability in wheat yield as influenced by the tillage systems; (ii) to investigate the variability in the physical properties of wheat grain and (iii) to evaluate the correlations between the grain yield and the physical properties of wheat grain.
A significant differentiation in the productivity of wheat was found depending on the tested MSTS systems. Lowest mean yields were obtained at the annual use of systems 3 and 4 - 4541 kg ha^{-1}. Among the annually applied systems, constant disking was the most favorable for expression of the crop's production potential. The mean addition to yield according to constant plowing in the crop rotation was 4541 kg ha^{-1}. The systems involving annual alternation of tillage types with and without turning of the plow layer exceeded with 232.0 kg ha^{-1} (4.77%) the same systems, which were applied independently. The alternation of plowing for root crops with direct sowing of wheat was most efficient from an agronomic point of view. In comparison to annual plowing, the increase of productivity was with 280.5 kg ha^{-1} (5.62%). The values of the physical properties of grain were also highly differentiated according to MSTS. The constant application of disking in the crop rotation contributed to the production of grain with the best physical indices – absolute weight 43.15 g and test weight 76.86 kg. The use of the systems Cutting – Cutting and Direct sowing – Direct sowing had negative effect on both the yield and the physical properties of gain. Averaged for the period, the correlation between the grain yield and the physical indices of grain was high and positive. The mean value of the correlation coefficient between the yield and the test weight (0.930**) was higher than the correlation coefficient of the yield with 1000 kernel weight (0.780**). The correlation between the absolute and the test weight of grain was very high in all three years of the investigation.

Key words

main tillage of soil, wheat, yield, physical properties of grain

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Introduction

An agricultural production, where "yields are increased without adverse environmental impact and without the cultivation of more land", is defined as "Sustainable intensification" SI (The Royal Society London, 2009). This form of production combines energy flows, nutrient cycling, population-regulating mechanisms, and system resilience to intensify existing arable land without harm to the environment or other economic or social factors (Pretty, 2008). Soil tillage is a fundamental factor influencing soil quality, crop performance and the sustainability of cropping systems because tillage can alter soil physical properties, the depth of soil profile, and the management of crop residues applied to the soil (Munkholm et al., 2012). As a crop production factor, tillage contributes up to 20% and affects the sustainable use of soil resources through its influence on soil properties (Khurshid et al., 2006; Lal and Stewart, 2013).

Conventional tillage (CT) practices are one of the many emerging environmental agronomic-economic issues that are addressed in contemporary cropping systems (Jug et al., 2011). In nowadays European Community's Agricultural Policy has strongly encouraged soil conserving tillage practices (and in some instance the conversion of cropland into set-aside land) in order to decrease soil loss, although new demands of bio-fuel production will decrease set-aside land (European Union, 2000).

At the beginning of the 90[th] of the XX century Kladivko et al. (1986) concluded that NT systems have a greater positive effect on crop growth and yield when used on soil characterised by low organic matter levels and poor structure, rather than on well-structured soils high in organic matter. Whether conservation tillage practice performs better than the long practiced traditional tillage practices in terms of improvement of edaphic and yield influencing characters of the specific and unearth soil-water-plant ecosystemof the region is still unknown (Alam et al., 2014).

Interactions between natural factors (e.g., soil type, climate and weather) and crop selection determine the intensity, depth, frequency, and timing of tillage (Strudley et al., 2008). There is a need for understanding the tillage effects on soil properties, tractor performance and crop yield (Servadio and Bergonzoli, 2012[a,b]). Tillage systems are location specific, so the degree of their success depends on soil, climate, and management practices (Hajabbasi and Hemmat, 2000; Servadio et al., 2014).

In resent years the weather conditions in Bulgaria have been unstable. In the summer months (July and August) the soil is usually very dry. In the last years the sum of autumn-and-winter rainfalls is more than 300 mm and early in the spring the soil is wet. This sometimes impedes the timely performance of a number of agronomy practices involved in the rotation of the field crops. Furthermore, according to Russeva (2006), about 84 % of the lands in Bulgaria have 3^{o} inclination, which is a prerequisite for the occurrence of water erosion processes. The long-term testing of different tillage systems of Vertisol and Chromic Luvisol in Bulgaria show that best productive results are obtained after applying rational cultivation systems which include different kinds of tillage at various depths. The application of tillage systems to the investigated soils demands a flexible approach because the established coefficients of the yield stability are low and the performing of envisaged cultivations have to be done after determining the main physical soil characteristics (Dimitrov and Borisova, 2004). The elaborated criteria generalize scientific examination of many years' duration. Having in mind the reliability of the results, we consider that they can serve as an appliance of the agricultural producers in the choice of the main tillage with concrete agroecological conditions. On the basis of these criteria and the agrotechnical valuation of the cultivated surface the agrotechnical measures can be made with minimum risk of negative influence over the soil fertility (Dimitrov, 2014).

Therefore, the objectives of this study were to assess which tillage techniques and main soil tillage systems could be considered as adaptation to climate change scenarios. The objectives were: (i) to investigate the seasonal variability in wheat yield as influenced by the tillage systems; (ii) to investigate the variability in the physical properties of wheat grain and (iii) to evaluate the correlations between the grain yield and the physical properties of wheat grain.

Material and methods

This study was carried out at the trial field of Dobrudzha Agricultural Institute-General Toshevo from 2014 to 2016. The influence of seven main soil tillage systems (MSTS) on the yield and the physical properties of wheat grain were investigated. Four of these MSTS were applied independently and annually in crop rotation: 1. CP - conventional plowing (24-26 cm); 2. D – disking (10-12 cm) 3. C – cutting (24-26 cm); 4. NT- nil tillage (direct sowing). The other three MSTS systems included: 5. Plowing (for spring crops) – Direct sowing (of wheat); 6. Cutting (for spring crops) - Disking (for wheat) and 7. Plowing (for spring crops) - Disking (for wheat). The mineral fertilization (kg/ha) in the crop rotation was as follows: Common bean – $N_{60}P_{60}K_{60}$; Wheat – $N_{120}P_{120}K_{60}$; Sunflower - $N_{60}P_{120}K_{120}$ and Maize – $N_{120}P_{60}K_{60}$. Mineral fertilization was done with common ammonium nitrate NH_4NO_3 (34% N), triple superphosphate (46% P_2O_5) and potassium chloride (60 % K_2O). Wheat cultivar Enola was sown at density 550 germinating seeds/m^2.

Weed control was uniformly carried out on the whole experimental surface after harvest of each crop in the rotation, by treatment with 10 liters/ha herbicide (glifosat 360 g/l). At the beginning of permanent spring vegetation, the crop was treated with 33 g/ha Derbi-Super (150.2 g/kg florasulam+300.5 g/kg aminopiralid K).

For all main soil tillage systems, harvesting was performed with the harvester specific for experimental fields.

The resulted data were statistically processed using variance analysis, F test and LSD (Least Significant Difference) test, which are commonly utilized in the multi-criterial statistical analysis. We used the SPSS version 16.0 statistical package. Significance of the treatments' effect was considered at 0.05 probability level. After performing the analysis of variance, we compared the means for each treatmens using the Waller-Duncan's Multiple Range Test. Finally, Pearson correlation coefficients ("R coefficients") were computed and tested for significance.

Results and discussions

The variances of the productivity, averaged for the investigated period, revealed high statistical significance of the independent and combined interaction of the factors *Year* and *Main soil tillage systems* (MSTS) (Table 1). The independent action of MSTS influenced significantly the wheat productivity in 2014 and 2016, while the effect of the different soil tillage systems in 2015 was not statistically significant.

Table 1. Analysis of the variances of productivity during 2014-2016

Source	Dependent Variable	df	Mean Square	F	Sig.
Years (1)	Yields 2014–2016	2	6205329.519	4207.654	.000
MSTS (2)	Yields 2014–2016	6	12655.023	8.581	.000
1 x 2	Yields 2014–2016	12	4914.583	3.332	.001
By years	Yield – 2014	6	5512.225	6.858	.000
	Yield – 2015	6	2471.118	.910	.507[NS]
	Yield – 2016	6	14500.808	16.021	.000

formed during the autumn-and-winter period were similar in all three years of the investigation – 323.5 mm (2014), 358.5 mm (2015) and 313.5 mm (2016).

They exceeded the mean long-term values (1952-2013) with averagely 100.8 mm. In all three years, however, their distribution was marked by considerable dynamics. This tendency was even better expressed in the monthly distribution of rainfalls in each year during the period from spring vegetative growth till harvesting. Year 2014 was with the highest precipitation sum during the vegetative growth of wheat – 674.7 mm. The main reason for this

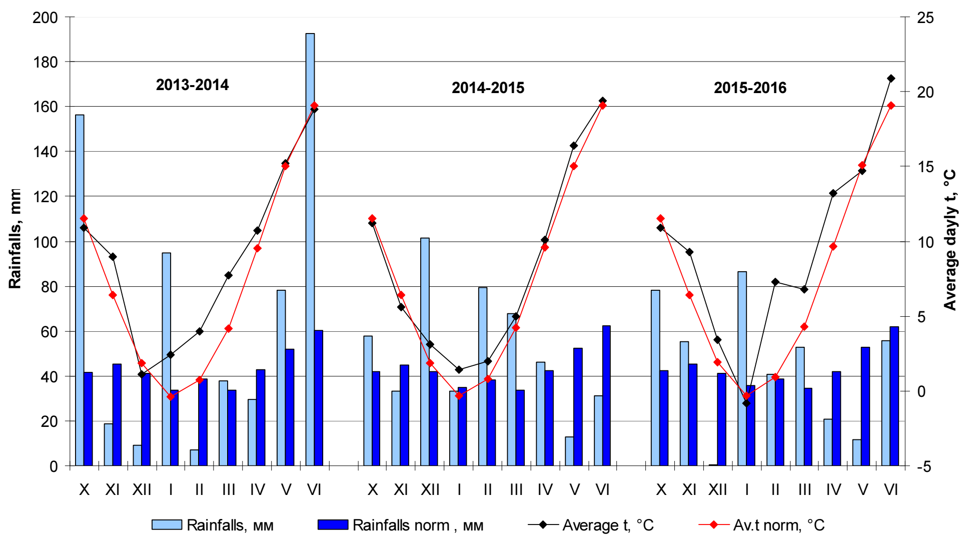

Figure 1.
Meteorological characterization of the investigated years

was the abundant rainfalls during planting (156.3 mm – October of 2013) and during heading and harvesting – 78.2 mm and 192.5 mm, respectively. This year can be defined as humid, exceeding the long-term norm 1.54 times. Harvest years 2015 and 2016 were also characterized with higher precipitation sum during the wheat growth season. The exceeding of the long-term precipitation norm (1953-2013) was with 38.2 mm and 71.9 mm, respectively. The distribution of rainfalls was extremely uneven during the period April – June. In 2015 their sum was lowest – only 90.5 mm.

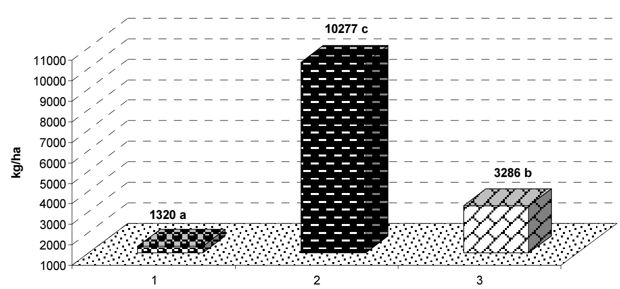

Figure 2. Mean productivity of wheat by year of investigation (1. -2014; 2. -2015; 3. – 2016), kg ha^{-1}

The obtained results clearly show that the meteorological conditions were the main factor determining yield. The strength of its effect in this experiment during the period of investigation was calculated to 98.92 %. Machado et al. (2008) reported, that tillage and year significantly influenced wheat grain yield but there were no significant tillage and year interactions. In our case two factors and their interaction had a significant effect on grain yield during the investigated period. Year x MSTS interaction was significant ($P<0.01$) for grain yield per hectare. This interaction can be explained mainly by the important differences among the conditions of years of experimentation. Except 2015 MSTS have a significant effect on wheat productivity.

The three years significantly differed by the monthly dynamics of the main meteorological factors (Figure 1). The sum rainfalls

With regard to temperature, the years were characterized with warmer conditions for the development of the crop during the entire vegetative growth – a mean of 10.3°C exceeding the mean long-term temperature norm with 1.3°C. Besides the warmer conditions for autumn-and-winter vegetative growth, the period from April till the end of the vegetation exceeded the mean values during the investigated period with 1.2°C (2014), 0.7° C (2015) and 1.9°C (2016), respectively.

This brief characterization of the dynamics of the main meteorological elements is a prerequisite for the serious effect of this factor on the productivity of wheat determined over years of investigation (Figure 2).

Although year 2014 was with the highest sum of rainfalls during the vegetative growth of wheat, their extremely uneven distribution, and especially the abundant rainfalls in June (192.5 mm) combined with lower temperatures, caused development of diseases and lodging of crops. All this complex of unfavorable circumstances during grain filling resulted in very low yields. The low productivity of wheat in that year was accompanied with statistically well-founded

Table 2. Effect of the soil tillage system on the productivity of wheat over years, kg ha-1

No	Soil tillage system	2014 Sig 0.000	2015 Sig 0.507	2016 Sig 0.000
1	Plowing – Plowing	1540.6 cd	9878. 7 a	3542.6 bc
2	Disking – Disking	1884.2 d	10491.9 a	3750.0 cd
3	Cutting – Cutting	1124.9 abc	9975.8 a	2521.8 a
4	Direct sowing – Direct sowing	749.3 a	10427.9 a	2446.7 a
5	Plowing – Direct sowing	1350.5 bc	10406.3 a	4047.6 d
6	Cutting – Disking	1510.7 bcd	10465.2 a	3249.2 b
7	Plowing – Disking	1077.5 ab	10291.2 a	3441.9 bc

Table 3. Analysis of the variances of grain's physical properties, averaged for 2014 – 2016 and over years (TKW - 1000 kernel weight; TW - Test weight)

Source	Dependent Variable	df	Mean Square	F	Sig.
Years (1)	TKW (2014–2016)	2	301.828	306.640	.000
	TW (2014–2016)	2	949.215	7475.066	.000
STS (2)	TKW (2014–2016)	6	30.358	30.842	.000
	TW (2014–2016)	6	13.271	104.509	.000
1 x 2	TKW (2014–2016)	12	14.934	15.172	.000
	TW (2014–2016)	12	5.432	42.777	.000
2014	TKW	6	21.120	27.929	.000
	TW	6	16.871	56.869	.000
2015	TKW	6	6.405	5.380	.002
	TW	6	.680	13.795	.000
2016	TKW	6	32.701	32.497	.000
	TW	6	6.584	188.112	.000

differentiation depending on MSTS (Table 2). Highest yields were obtained after constant disking in the crop rotation. Similar to the results obtained under constant disking are the results from the use of the systems Plowing – Plowing and Cutting – Disking. The wheat cultivar was with lowest productivity under constant direct sowing.

Extreme high yields from cultivar Enola were obtained in 2015. The mean productivity in the experiment was 10277 kg ha^{1}. The meteorological conditions during the crop's vegetation had a decisive contribution for this. The year was characterized with high amounts of autumn-and-winter rainfalls - 358.5 mm (1.5 higher than the climatic norm). These amounts, plus the April rainfalls, did not allow the short drought in May to influence negatively the growth and the development of the crop. The conditions by the end of the vegetation season were highly favorable for grain filling. This to a large entent eliminated the differences between the individual MSTS and therefore they remained statistically non-significant.

The mean yield of the trial in 2016 was 3286 kg ha^{-1} and the differentiation of productivity between the separate MSTS was clearly expressed. The highest yield was obtained under the system with alternation of spring crop plowing and direct sowing of wheat (5th MSTS) – 4047.6 kg/ha. The constant use of disking had a similar effect on yield. Extremely unfavorable for wheat productivity under the conditions of this year was the effect of direct sowing and cutting constantly used in the crop rotation.

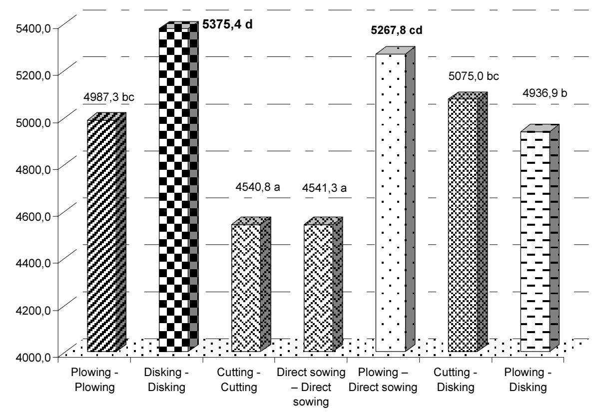

Figure 3. Mean productivity of wheat by MSTS, kg ha-1

The main reason for these results was again the meteorological factor. By sum of vegetation rainfalls, year 2016 conceded to 2014 with 154.8 mm, but the abundant rainfalls in May, and the subsequent high temperatures accompanied with dry winds, though for a brief period, affected unfavorably the development and productivity of wheat.

The way of management of the MSTS influenced the wheat productivity over the years of investigation. The lowest mean yields were obtained after long-term annual use of tillages without turning the soil layer - cutting and direct sowing (Figure 3). This two MSTS decreased the productivity in comparison to the rest. The highest wheat productivity was established after annual independently applied constant disking and after the alternation of plowing prior to root crops and direct sowing of wheat. In comparison to annual plowing, the increase of productivity was with 2805 kg ha^{-1} (5.62%).

Contrary to our results Akgun et al. (2014) established that the most favorable treatment for winter wheat in Middle Anatolian Region was direct seeding application. The recorded mean grain yield in this system was 24% and 22% higher than those registered in conventional tillage and reduced tillage, respectively.

The analysis on the variances of the grain's physical properties (1000 kernel weight and test weight) demonstrated the high effect of the tested factors on their values, averaged for the investigated period (Table 3). Maximum level of significance of the MSTS on the values of these indices was found over years, as well.

During the investigated period, the factor *year* had greater strength of effect on the values of the obtained results in comparison to *MSTS* and their interaction (Figure 4). The effect of the meteorological factor was much stronger on the values of test weight than on the values of 1000 kernel weight.

The largest and plumpest grain was produced in 2015 - 44.86 g (Figure 5). The mean values of 1000 kernel weight in 2014 and 2016 were low and approximately the same, and therefore the Waller-Duncan test put them in the group of lowest rank. Averaged for the investigated period, the independent long-term types of soil tillage contributed to the formation of grain with a mean value of the absolute weight of 40.80 g. Their alternation in the crop rotation, however, had a positive effect on the value of the index, increasing it to 41.42 g.

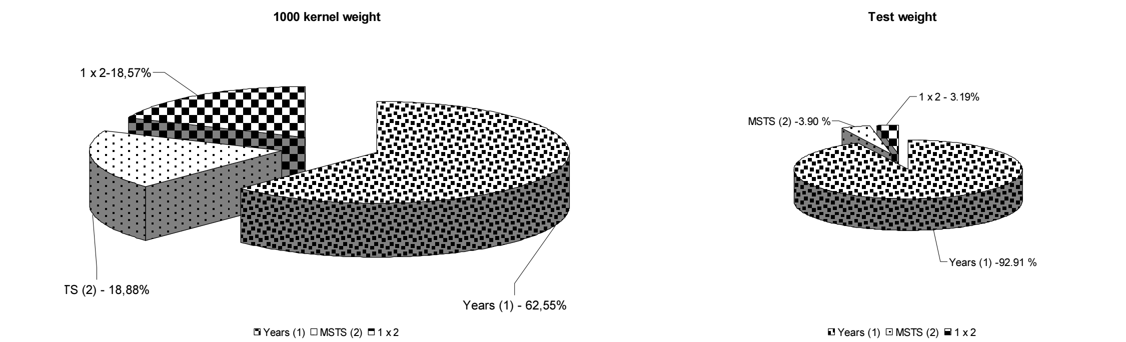

Figure 4. Strength of effect of the factors on grain's physical properties, averaged for 2014 – 2016, %

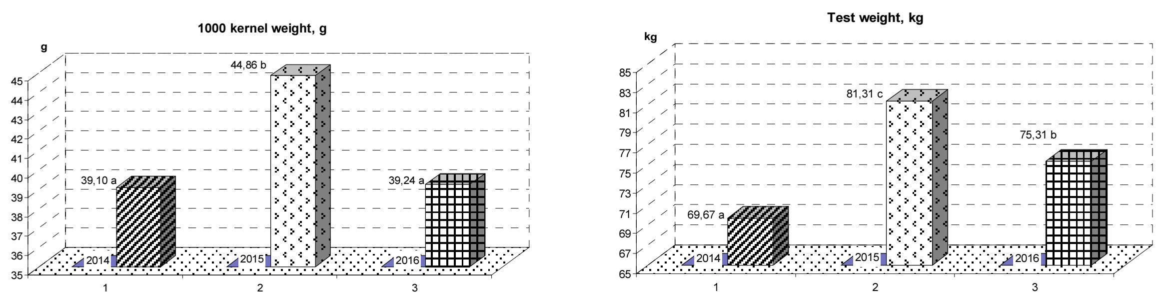

Figure 5. Values of the physical properties of grain over years, averaged for the tested MSTS

Table 4. Physical properties of grain over years depending on the type of MSTS

№	Type of MSTS	1000 kernel weight. g			Test weight. kg		
		2014	2015	2016	2014	2015	2016
1	Plowing – Plowing	42.00 d	45.25 b	38.91 b	71.83 d	81.35 b	76.75 e
2	Disking – Disking	41.80 d	45.00 b	42.66 c	72.73 e	81.18 ab	76.68 e
3	Cutting – Cutting	36.10 a	46.00 b	36.10 a	67.60 a	82.00 c	73.75 a
4	Direct sowing – Direct sowing	37.20 ab	43.00 a	35.63 a	68.58 b	80.85 a	74.50 c
5	Plowing – Direct sowing	40.30 c	46.25 b	37.97 b	69.70 c	81.73 c	76.48 e
6	Cutting – Disking	37.90 b	43.25 a	41.25 c	70.00 c	81.10 ab	74.20 b
7	Plowing – Disking	38.40 b	45.25 b	42.19 c	67.28 a	81.00 ab	74.80 d

Test weight, a parameter which gives an idea about the weight of the grain, was with the highest mean values again in 2015 - 81.31 kg. The values of this index were very well differentiated by years in comparison to the index 1000 kernel weight. They once again confirmed the fact that year 2014 was the least favorable for formation of the grain's physical properties according to a complex of meteorological conditions.

Regardless of the considerable dynamics in the values of the grain's physical properties over years of investigation, within each year the values of the two indices varied significantly according to MSTS (Table 4). The variation of the absolute grain weight by year was as follows: 2014 - from 37.20 g (Direct sowing – Direct sowing) to 42.00 g (Plowing-Plowing); 2015 - from 43.00 g (Direct sowing – Direct sowing) to 45.25 g (Plowing - Plowing and Plowing - Disking); 2016 - from 35.63 g (Direct sowing–Direct sowing) to 42.66 g (Disking-Disking). Thus, averaged for the investigation period, a tendency was outlined toward a high positive effect of the systems Disking–Disking (43.15 g) and Plowing-Plowing (42.05 g) on the weight of the grain (Figure 6).

Over the years, the variation in the values of test weight was also marked by a considerable dynamics depending on MSTS. Averaged for the period, it was from 74.36 kg (Plowing-Disking) to 76.86 kg (Disking-Disking). The tendency towards a better expressed positive effect of the systems Disking–Disking and Plowing–Plowing on the test weigh in comparison to the other soil tillage systems was again confirmed.

Averaged for the period of investigation, high values of the correlations between yield and the physical properties of grain were found. The correlation between grain yield and test weight was highest - 0.930^{**}. The correlation between the two physical indices of grain was also at a high level of statistical significance - 0.745^{**}.

During the individual years of the investigation, the correlation coefficient values, modulated on the basis of the tested soil tillage systems, varied significantly (Table 5). In 2015, the correlation of yield with 1000 kernel weight, and with test weight, respectively, was not significant. Under its much more favorable conditions for development and formation of productivity, the correlation between the two physical indices of grain was clearly expressed. The

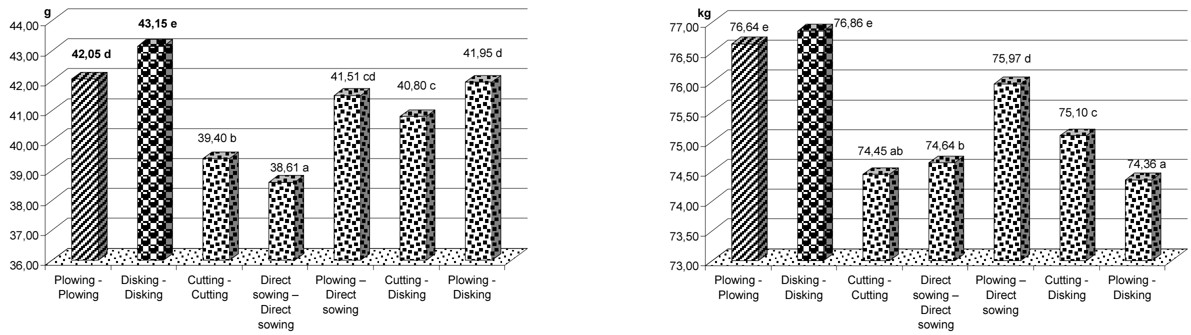

Figure 6. Values of the physical properties of grain over the tested MSTS, averaged for years

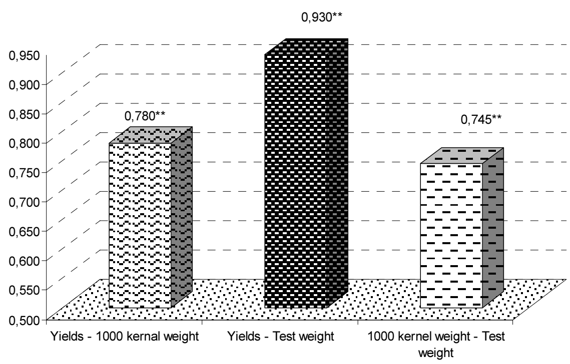

Figure 7. Correlations between grain yield indices, 1000 kernel weight and test weight, averaged for 2014 – 2016 (Pearson Correlation)

Table 5. Correlations between grain yield, 1000 kernel weight and test weight over years (Pearson Correlation)

Index	Yield	1000 kernel weight	Test weight
		2014	
Yield	1	.559(**)	.657(**)
Absolute weight	.559(**)	1	.784(**)
Test weight	.657(**)	.784(**)	1
		2015	
Yield	1	–.086	–.237
Absolute weight	–.086	1	.569(**)
Test weight	–.237	.569(**)	1
		2016	
Yield	1	.520(**)	.706(**)
Absolute weight	.520(**)	1	.277
Test weight	.706(**)	.277	1

** Correlation is significant at level 0.01 (2–tailed)

extremely unfavorable conditions during the vegetative growth of wheat in 2014 were reflected in high statistically significant values of the investigated correlations.

Conclusions

A significant differentiation was determined in the productivity of wheat depending on the tested systems for main soil tillage. The lowest mean yields were obtained after long-term annual use of cutting and direct sowing - 4541 kg ha-1. Among the annual independently applied systems, constant disking was most suitable for expression of the production potential of the crop. The mean addition to yield according to the constant plowing in the crop rotation was 3881 kg/ha. The systems involving annual alternation of tilths with and without turning of the plow layer exceeded the independently applied ones with 2320 kg ha-1 (4.77%). From an agronomic point of view, most efficient were the alternation of plowing prior to root crops and direct sowing of wheat. In comparison to annual plowing, the increase of productivity was with 2805 kg ha-1 (5.62%).

The values of the grain's physical properties were also considerably differentiated depending on the soil tillage. The constant use of disking in the crop rotation resulted in grain with the best physical indices – 1000 kernel weight 43.15 g and test weight 76.86 kg. The use of the systems Cutting – Cutting and Direct sowing – Direct sowing had a negative effect on the physical properties of grain, apart from the negative effect on yield.

Averaged for the investigated period, the correlation between grain yield and the physical indices of grain was high and positive. The value of the correlation coefficient between yield and test weight (0.930**) was higher in comparison to the correlation of yield and 1000 kernel weight (0.780**). The correlation between 1000 kernel weight and test weight of grain was very well expressed in all three years of the investigation.

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