Bulgarian Journal of Agricultural Science, 30 (No 5) 2024, 784–796

Effect of the different soil tillage systems on the productivity and yield structural elements of common winter wheat (*Triticum aestivum* L.) cultivar Pchelina

Margarita Nankova* **and Sonya Doneva**

Agricultural Academy, Dobrudzha Agricultural Institute, 9520 "General Toshevo", Bulgaria
**Corresponding author:*nankova_margo@abv.bg

Abstract

Nankova, M. & Doneva, S. (2024). Effects of different soil tillage systems on the productivity and yield structural elements of common winter wheat (*Triticum aestivum* L.) Cultivar Pchelina. *Bulg. J. Agric. Sci., 30*(5), 784–796

Under South Dobrudzha climatic conditions (Haplic Chernozems soil) wheat yield (grain, protein and structional components) is strongly influenced by application of different main soil tillage systems (MSTS) in 4-field crop rotation. For the period 2018–2021 in Dobrudzha Agricultural Institute – General Toshevo seven MSTS were tested: 1. CP – Conventional plowing (24–26 cm); 2. D – disking (10–12 cm) 3. C – cutting (24–26 cm); 4. NT – NT (direct sowing); 5. CP-NT (CP for spring crops – NT for wheat); 6. C-D (C for spring crops-D for wheat) and 7. CP-D (CP for spring crops-D for wheat). The objectives were: to investigate the seasonal variability in wheat grain and protein yield and the structural yield components as influenced by the main tillage systems; to investigate the variability in the physical properties of wheat grain and to evaluate the correlations between the grain yield and all other investigated indices. The meteorological conditions have a decisive influence on the values of the studied indices. The highest average yield for the 2018-2021 was obtained in the CP-D system (6953.7 kg/ha) and excess over CP-CP by 6.4%. The same is true for crude protein yield, where the increase is with 70.0 kg/ha. Prolonged application of deep irreversible tillage in the crop rotation has a strong negative impact on the amount of the grain and crude protein yield. Significant dynamics has been established in the values of the yield structural elements. The largest grain was obtained in the D-D (41.56 g), and the heaviest – in the CP-CP (77.94 kg). Tillage combination systems are characterized by lower values of the physical characteristics of the grain compared to their individual application. Numerous correlations in both directions between yields (grain and crude protein) and its structural elements have been found. The positive reaction of wheat under the conditions of NT and minimal tillage in the crop rotation show that they can definitely replace conventional plowing in the growing climate changes, causing stress in critical phases of wheat development.

Keywords: tillage systems; wheat grain and protein yield; structural elements; physical properties of grain

Introduction

The soil is one of our most precious natural resources, that's why proper soil management is a key to sustainable agricultural production. Soil tillage is one of the most basic and important components of agricultural production technology. The adopted soil tillage techniques, must ensure the long-term productivity of the land, be environmentally sound, and of course, be profitable (Simmons & Nafziger, 2009). By its nature, tillage is a mechanical disturbance of the soil for the sole purpose of crop production. Over decades, focus has been drawn to the effects of different tillage practices on some physical and hydraulic properties of soils around the globe. One of the means to increase the output is through the employment of modern Agricultural machineries like ploughs, harrows, planters, harvesters etc. These machineries lead to high output per unit area, timely and efficient operations and reduction of drudgery associated with crop production (Nabayi et al., 2019).

The practices developed, with what ever equipment used, can be broadly classified into no tillage, minimum tillage, conservation tillage and conventional tillage. In their review, Sharma & Abrol (2012), pointed out that the cultivation of agricultural soils has until recently predominantly been achieved by inverting the soil using tools such as the plough. The quality of the main soil tillage is closely related to the basic physical parameters of the soil. The good structural condition of the soil in the arable layer is a prerequisite for ensuring an equal start of sown seeds, for the development of a strong root system, for maintaining optimal nutrition, humidity and air regime and for increased vital functions of the beneficial microflora (Dimitrov, 2014). Based on the summary of long-term research, Mitova et al. (2015), develop criteria for the selection of basic tillage under specific agri-environmental conditions. Based on the reliability of the results obtained, these criteria can help farmers to make the correct decisions. The autors pointed out that the cultivation of soil, applied as a system within a single crop rotation, requires the optimization of the amount and particular depth of tillage operations. Today, the contemporary tillage systems are based on the development of agricultural technologies and application of chemical products in relation to the various soil and climatic conditions.

In Bulgaria, research on the impact of tillage covers both the state of soil quality characteristics and crop productivity (Klochkov, 1983; Nikolova et al., 2001; Yankov, 2005; Tsetkova et al., 2006; Rousseva et al., 2010; Nankova & Yankov 2013[a,b]; 2014; 2015[a,b]; Nankova, 2014; 2015; Nankova & Bankova-Atanasova, 2018).

Research in recent years at various points of the planet has shown a clear effect of different tillage on wheat productivity. For example, Akgun (2014) in his experiment, has investigated the influence of conventional, reduced tillage, direct and direct seeding + herbicidewere applied in the experiment. According to the results of the research, seeding systems constituted significant differences for grain yield, spike length, spikelet and kernel number per spike, kernel weight per spike, harvest index and test weight. The results revealed that direct seeding can be recommended for wheat production in Middle Anatolian Region.

A 10-year field experiment of Feng et al. (2021) carried out in the Loess Plateau area tested how three tillage practices – deep ploughing (DP 25–30 cm), subsoiling (SS 30–40 cm), and no tillage (NT)) influenced cultivation and yield across different fallow periods. They concluded that Deep ploughing (DP) and Subsoiling (SS) are common fallow tillage methods used in northern China.

The study was conducted to determine the effects of 7 different main soil tillage practices on yields (grain and protein), yield components and grain physical properties of bread wheat variety Pchelina under South Dobrudzha conditions of Bulgaria.

Material and Methods

This study was carried out at the trial field of Dobrudzha Agricultural Institute-General Toshevo (DAI) from 2018 to 2021. The influence of seven main soil tillage systems (MSTS) on the yield it structural components 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; 4. NT-NT (direct sowing). The other three MSTS systems included: 5. CP-NT (Conventional plowing for spring crops-NT for wheat); 6. C-D (Cutting for spring crops-Disking for wheat) and 7. CP-D (Conventional 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 Pchelina 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 MSTS, harvesting was performed with the harvester specific for experimental fields. Grain yield was recalculated to a standard humidity of 14%. Changes in crude protein yield and grain physical characteristics were determined. Analyzes related to the elements of productivity were performed in meters with an area of 25 × 25 cm. The yields of individual organs and their harvest indices (%) were determined, as well as the length of the stem and the spike, number of spiklet/spike, number of grain/spike and the height of the plants.

The resulted data was statistically processed using Descriptive CV%, 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 treatment's effect was considered at 0.05 probability level. After performing the analysis of variance, we compared the means for each treatments using Waller-Duncan's Multiple Range Test. Finally, Pearson correlation coefficients ("R coefficients") were computed and tested for significance.

Results and Discussion

In terms of meteorology, the period is characterized by great dynamics in the main meteorological components during the different stage of the wheat development (Figure 1).

The vegetation period 2017–2018 (357.6 mm), has the highest amount of autumn-winter precipitation. For the same, however, there is a drought during the critical period for the development of wheat – April and June.

The 2019 and 2020 harvests were characterized by lower values of autumn-winter precipitation during this research period (significantly below the climatic norm). The 2019 harvest was characterized by the smallest total amount of precipitation during the entire wheat growing season, but the precipitation from the permanent spring vegetation to the harvest is relatively proportionally distributed. The dynamics of precipitation in the harvest 2020 was characterized as the year with the lowest amount of precipitation October-March compared to others from the research period. In addition, April had a critically low amount of precipitation (5.8 mm), and in June – precipitation of 192.2 mm. The precipitation during wheat growing season for the 2021 harvest was 599.0 mm. The year was also characterized by a relatively proportional distribution between autumn-winter and spring precipitation. Higher temperatures were registered during the wheat growing season in the years of study compared to the long-term climatic norm (1953–2017). The average temperatures during the vegetation period of wheat were respectively – 11.8°C (2018), 11.4°C (2019), 12.2°C (2020) and 11.5°C (2021) at climatic norm 10.2°C.

The statistical processing of the obtained results for productivity and physical characteristics of wheat grain, as well as the results for the analysis of variances, shows a significant influence of meteorological conditions during the years of research and tested systems for basic tillage in crop rotation (Table 1). From the point of view of the independent action of the tested factors, a high level of statistical reliability from their interaction has also been established. As can be seen from the data, the coefficient of variation for grain yield has the highest value. This is an indication of their higher degree of scattering. The trend is significantly less pronounced in crude protein yield data. The data on the physical charac-

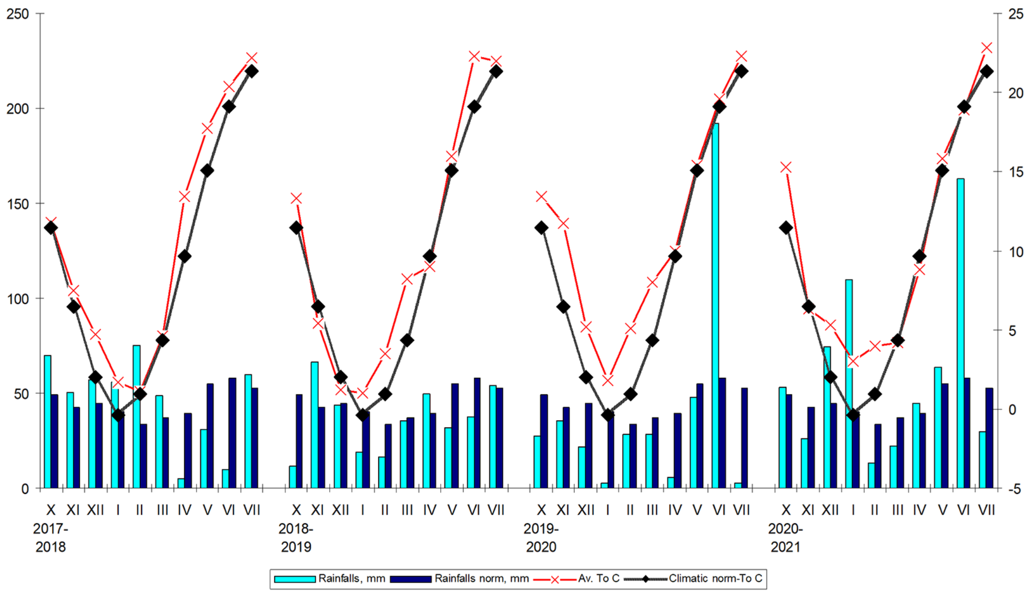


Fig. 1. Meteorological characteristics of the research period

Table 1. Statistical processing of the obtained results for wheat productivity – (2018–2021) (Descriptive Statistics N = 28)

Indices	Minimum	Maximum	Mean	Std. deviation	CV%
Grain yield	234.61	1004.69	672.4214	203.41885	30.25
Crude protein yield	38.99	130.85	90.3379	21.13480	23.40
1000 kernel weight	32	47	40.11	3.94275	9.83
Test weight	72.2	86.8	76.442	3.09017	4.04

teristics of the grain have the highest stability (CV < 10%). It is obvious that the sample is extremely homogeneous, especially with the test weight of the grain.

Through the analysis of the variances, it was found that during three of the years of research the changes in the values of the tested indices depending on the tested systems have the maximum level of statistical reliability (Table 2).

The dynamics of the main meteorological components during the wheat vegetation in 2020 lead to the melting of the difference in grain yield and crude protein yield in the MSTS.

The differences thus obtained in the indicated yields are unreliable. In the indices characterizing the size and weight of the grain throughout the study period, regardless of the meteorological conditions of the years, the applied tillage systems have a significant impact on changes in their values. On average for the study period, the data from the statistical analysis show a high level of reliable independent influence of the two tested factors on the indicators of quantitative and qualitative characteristics of the Pchelina variety (Table 3). The interaction between the two factors has also been shown to affect the values of the tested indicators.

It is obvious that the meteorological factor during the years of research leaves a strong imprint on the productivity of the Pchelina cultivar depending on the MSTS in the crop rotation (Table 4).

The highest average productivity of the wheat was achieved in 2019, when the average yield was 9095.1 kg/ha with a variation from 8346.1 kg/ha to 9616.0 kg/ha (Figure 2). The most unfavorable for the development of the culture

Table 2. Analysis of the variances of the studied indicators by years (values of parameter p)

	2018		2019		2020		2021	
Dependent variable	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Grain yield	16.470	.000	9.250	.000	2.752	.039^{NS}	23.341	.000
Crude protein yield	39.128	.000	34.824	.000	3.144	.023^{NS}	33.490	.000
1000 kernel weight	11.071	.000	10.412	.000	5.219	.002	19.280	.000
Test weight	7.404	.000	416.440	.000	19.715	.000	20.202	.000

Table 3. Analysis of the variances of the studied indicators average for the period 2018–2021 (values of parameter p)

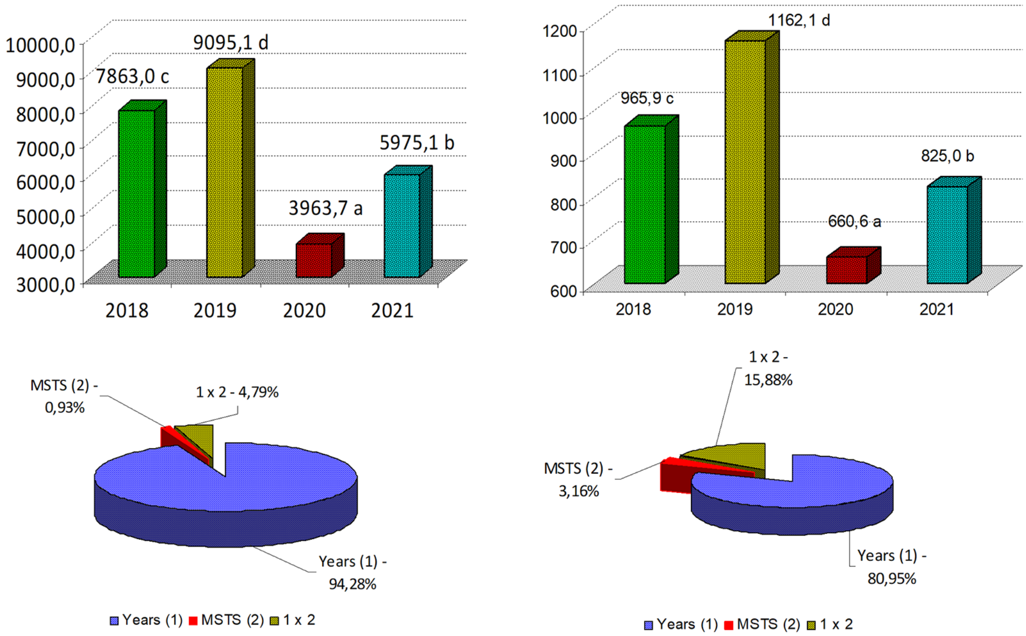
Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
Years (1)	Grain yield	4227829.88	3	1409276.63	1090.04	.000
	Crude protein yield	38068.86	3	12689.62	416.99	.000
	1000 kernel	1495.60	3	498.53	642.90	.000
	Test weight	869.30	3	289.77	3975.58	.000
MSTS (2)	Grain yield	41833.87	6	6972.31	5.39	.000
	Crude protein yield	1487.85	6	247.97	8.15	.000
	1000 kernel	78.41	6	13.07	16.85	.000
	Test weight	49.85	6	8.31	113.99	.000
1 x 2	Grain yield	214829.86	18	11934.99	9.23	.000
	Crude protein yield	7468.48	18	414.92	13.63	.000
	1000 kernel	86.38	18	4.80	6.19	.000
	Test weight	134.68	18	7.48	102.65	.000

Table 4. Productivity of the Pchelina variety by years of research depending on the MSTS, kg/ha

	Grain yield				Crude protein yield			
Kind of MSTS	2018	2019	2020	2021	2018	2019	2020	2021
CP*-CP**	8171.4 ef	9034.3 bc	3350.5 a	5590.2 b	1005.5 c	1259.7 d	708.6 ab	761.8 b
D*-D**	7900.1 cd	8346.0 a	4146.2 ab	6566.0 de	938.1 b	969.4 a	1090.1 d	936.3 d
C*-C**	7668.9 bc	9315.9 cde	3896.0 ab	4522.3 a	937.1 b	1213.3 cd	923.2 bcd	622.8 a
NT*-NT**	7321.4 a	9147.5 bcd	4674.8 b	6239.2 cd	947.2 b	1199.3 c	925.9 bcd	751.6 b
CP*-NT**	8314.3 f	9616.0 e	3401.2 a	5994.6 bc	1061.3 d	1199.9 c	622.2 a	834.2 c
C*-D**	7614.3 b	8771.9 b	4134.5 ab	6724.6 e	858.1 a	1056.7 b	1009.0 cd	958.9 d
CP*-D**	8050.0 de	9433.8 de	4142.3 ab	6188.7 cd	1013.7 c	1236.8 cd	804.2 abc	909.2 d

* – tillage against spring crops

** – tillage against wheat



Grain yield — Crude protein yield

Fig. 2. Influence of the year conditions on the grain and crude protein wheat yield and the strength of the factors effect in 4-field crop rotation, kg/ha

was 2020, characterized by a decrease in average productivity by 5131.4 kg/ha, which is only 43.58% of the yield obtained in 2019. The commented reactions in the productivity of Pchelina over the years are confirmed by the strength of the influence of the meteorological factor on the indicator – 94.38%.

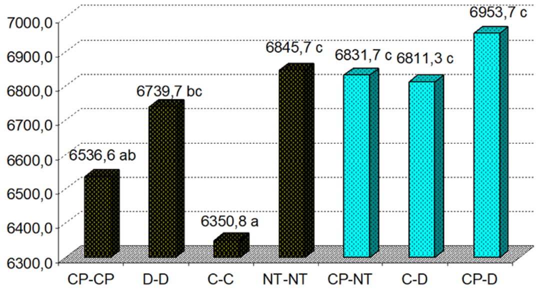
The dynamic changes of the climate in our country are the subject of a number of researches, which emphasize the instability of the meteorological situation in the separate agrometeorological regions of the country during the vegetation period of the agricultural crops. It manifests itself as short-term or prolonged droughts or over humidification, combined with extremely low or high air temperatures, respectively (Slavov & Georgieva, 2005; Christov, 2009; Bachev et al., 2019).

Undoubtedly, the climate change in recent decades has been and will be the subject of in-depth research, as world agricultural production is directly dependent on water supply. In order to retain soil moisture, the tillage systems definitely used are of paramount importance. The dry land winter wheat yield under different fallow tillage methods were in direct proportion to the levels of precipitation during the fallow period (Xue et al., 2019). A 5-year field experiment concluded that compared to No tillage (NT), Deep ploughing (DP) and Subsoiling (SS) effectively increased soil water storage to 0–3 m, increased soil porosity and significantly improved water use efficiency (WUE) and yield (Sun et al., 2018). According to Jug et al., (2011) the climatic conditions have the strongest effects on wheat yield and yield components.

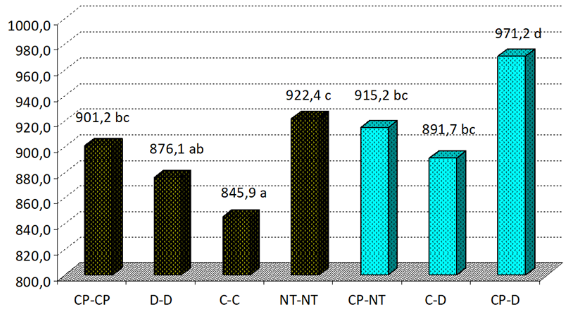
In the present study, the average productivity of this high-quality wheat variety for the period 2018–2021 is 6724.2 kg/ha (Figure 3). The differentiation in yields depending on the selected 7 systems for MSTS is relatively well expressed.

Definitely the most unfavorable influence on the yields is exerted by the two systems with deep tillage, applied annually in the crop rotation – without inversion and with inversion of the cultivated layer.

From this group of systems the highest average yield is obtained in the NT system, ie. in case of direct sowing of crops in the crop rotation. Similar results were obtained by Akgun et al. (2014). The results of their research shows that no-till system, which reduces water evaporation from soil increase the grain yields. Among tillage systems applied in their study, the most favorable treatment for winter wheat 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. López-Bellido et al. (1996) argued hat the decreased water evaporation from the soil due to the residual cover



Grain yield, kg/ yield, kg/ha



Crude Protein, kg/ha

Fig. 3. Influence of the MSTS on the average productivity of wheat (Pchelina) on the 4-field crop rotation for the period 2018–2021, kg/ha

under NT could increase the soil water content in comparison with CT, especially in dry seasons, which could be the reason for the increased wheat yield. In general, NT systems have a greater positive effect on crop growth and yield when used on soil characterized by low organic matter levels and poor structure, rather than on well-structured soils high in organic matter (Kladivko et al., 1996). On average for the period the yields are the lowest with the constant flat-cutting tillage, while its interruption with disking for wheat leads to an increase in yield by an additional 460.5 kg/ha. According to Shen et al. (2021) in their experiment subsoiling (SS) increased soil porosity, increased soil moisture in the cultivated layer, and improved WUE, thereby promoting crop growth and increasing yield.

In our research the highest average yield for the studied period was obtained in the alternative application of CP-D – 6953.7 kg/ha. This system exceeds CP with 417.1 kg/ha (6.4%), followed by NT – 309.1 kg/ha (4.7%). It is noteworthy that all MSTS with alternative application of treatments fall into the same group according to the differentiation of the Waller-Duncan test. This group of systems is superior in productivity to the four annual self-applied tillage with 247.4 kg/ha (3.74%). Constant deep tillage without inversion of the cultivated soil layer is extremely unsuitable tillage for wheat. On average for the period the decrease is by 185.8 kg/ha or the productivity of the variety is 97.2% of that obtained by CP.

The results obtained from the statistical processing of the data on the physical characteristics of the grain shows the maximum level of statistical reliability of the influence of the tested factors. The 1000 kernels weight in the study over the years varied from 33.00 g to 46.25 g (Table 5).

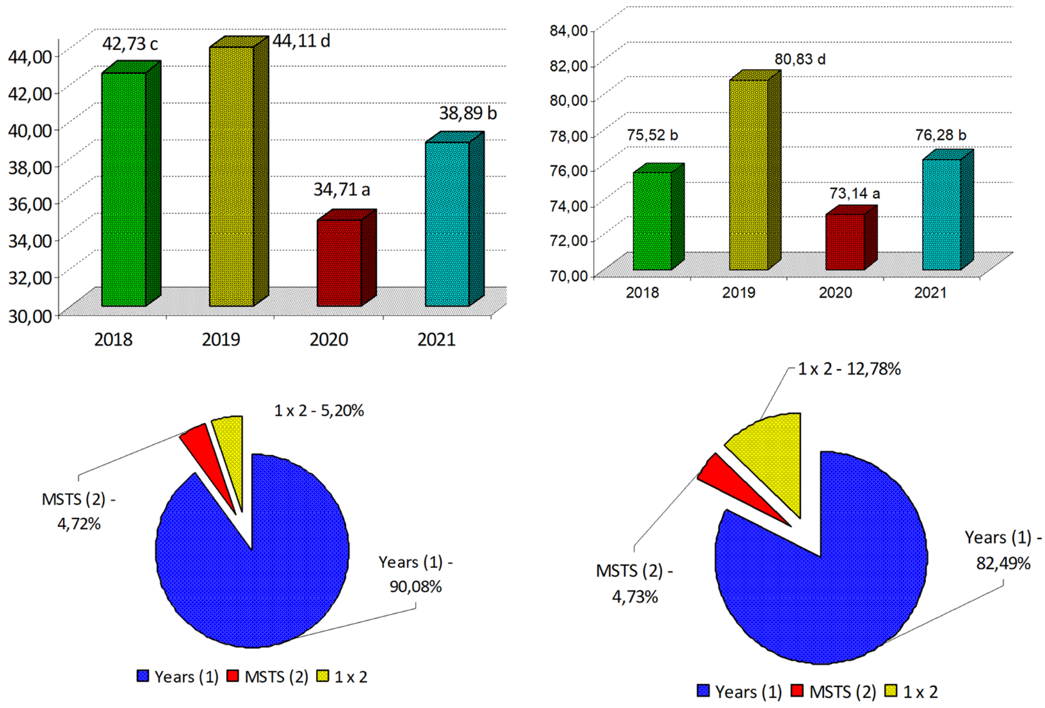
For the conditions of the years the dynamics in the variation of the values of this index is strongly expressed, which can be seen in the great strength of the influence of the meteorological factor – 90.08% (Figure 4).

In 2018 and 2019, high average values of the indicator were obtained, but undoubtedly the conditions of 2019 provoke the highest yield in combination with the highest grain size. Regarding the influence of the type of the MSTS on the 1000 kernels weight, the best results were obtained when applying constant disking in the crop rotation – 41.56 g. The annual application of deep soil treatments with and without inversion of the soil layer, as well as their interruption with disking or no-till have not significantly contributed to increasing the grain size.

A high level of statistical reliability of the obtained results for the test weight of wheat grain was obtained. The

Table 5. Physical characteristics of the grain in the variety Pchelina by years of research depending on the MSTS

Kind of MSTS	1000 kernal weight, g				Test weight, kg			
	2018	2019	2020	2021	2018	2019	2020	2021
CP*-CP**	41.72 ab	43.00 ab	34.75 ab	40.50 d	75.30 a	86.65 d	73.30 b	76.53 b
D*-D**	45.47 d	43.75 bc	37.25 c	39.75 c	75.30 a	79.65 ab	74.23 c	77.08 c
C*-C**	42.19 bc	43.75 bc	34.50 ab	38.50 b	75.85 b	80.15 c	72.35 a	75.95 a
NT*-NT**	42.66 bc	44.75 c	34.00 ab	39.50 c	75.48 a	80.15 c	73.28 b	77.53 c
CP*-NT**	42.66 bc	44.75 c	33.00 a	36.75 a	75.45 a	79.55 a	73.18 b	75.60 a
C*-D**	43.13 c	46.25 d	35.75 bc	38.75 b	75.43 a	79.90 bc	73.18 b	75.73 a
CP*-D**	41.25 a	42.50 a	33.75 a	38.50 b	75.85 b	79.75 ab	72.45 a	75.58 a

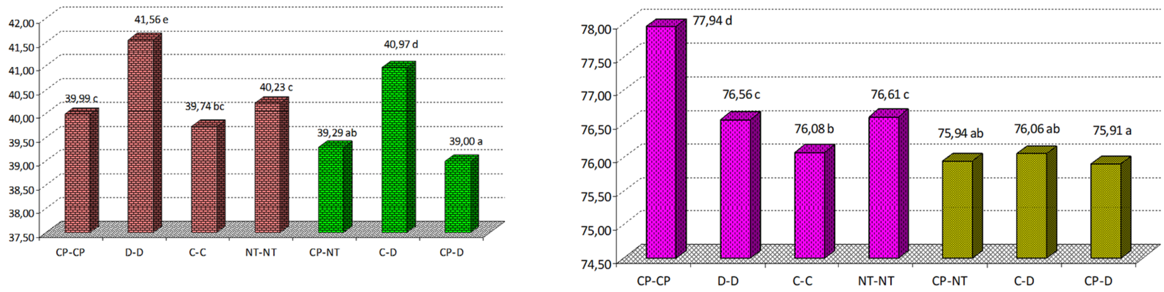


1000 kernel weight, g Test weight, kg

Fig. 4. Influence of the conditions of the year on the physical characteristics of the grain

variation in the values of this index during the study period is from 75.30 kg to 86.65 kg. The meteorological factor again has the main force of influence on the values of the test weight – 82.49% (Figure 5). On average, the heaviest grain for the tested tillage systems was obtained in 2019. The grain has the highest values per test weight in the system with constant application of NT (77.53 kg) and constant disking (77.08 kg) in the crop rotation.

For the year conditions the results of this study show that systems involving disking are the basis for obtaining grain with better physical characteristics than those involving plowing. The differentiation in the mean values of test weight in the systems applied independently and annually is very well expressed. In this group of systems, the highest values of this index were obtained with the constant application of CP (24–26 cm) in the crop rotation. Similar results were obtained from Khan et al. (2020). In their investigation in the Loess Plateau was established that deep ploughing (DP) increased soil water storage during the sowing stage, and significantly improved yield, 1000-grains weight, WUE, and nitrogen use efficiency. Tillage at this depth, but without inverting the soil layer, leads to lower results per test weight compared to constant



1000 kernel weight, g Test weight, kg

Fig. 5. Impact of MSTS on Pchelina‘s grain physical characteristics of for the period 2018–2021

D and NT. The MSTS with alternation of the soil treatments included in the experiment leads to the production of grain with the lowest average values per test weight of grain. Nankova & Bankova-Atanasova (2018) in the same experiment, but when using the cultivar Enola for the period 2014–2016, found the best result for productivity in constant D in crop rotation, when the average excess over CP is 388.1 kg/ha at highest values for the 1000 kernel weight.

Over the years, a wide range of data on the yield structural elements has been obtained. On average for the period the strong influence of the meteorological factor on all tested indices characterizing the yield was clearly shown. The conditions of the years have a statistically significant effect on the relative share (harvest index) of the studied organs in relation to the total formed aboveground biomass (Table 6). The applied systems for MSTS under the conditions of the powerful with high natural fertility slightly leached Chernozem of southern Dobrudzha do not significantly affect the reproductive organ and its characteristics, as well as the harvest index of the individual organs. The influence of the tested MSTS is statistically significant only on the yield of leaves and their HI, stems, vegetative mass, total overground mass, stem height and that of the whole plant.

The interaction between the two factors has a wider range of statistical reliability compared to the independent action of MSTS. In addition to the organs of vegetative biomass, with the exception of glumes yield (non-grain part of the spike – NGPS), the influence on the GHI in spike and that of the glumes in spike, as well as on the number of spiklets/spike and plant height is significant.

The variation coefficients of the individual indices from the performed structural analysis of the yield by years of research show significant variation within each of them (Table 7). On average, for the studied period, the values for the yield from the NGPS were subjected to the most significant dynamics, where the sample has the highest scattering of data (43.64%) from the experiment. This result naturally affects the yield of spikes (34.95%), in which the glumes are a component. The harvest indices of the individual organs of the aboveground biomass are also characterized by dynamics in the values of variation coefficients. Both by years and on average for the period they are higher in the NGPS and its share in relation to the spike, as well as in the leaves. The highest homogeneity of the data is distinguished by VC of per grain/spike, GHI, vegetative mass HI and spikes HI. The values of the VC of the other indices, regardless of their dif-

Table 6. Analysis of the variances of the investigated yield structural indices during 2018–2021

	Years (1)			STS (2)			1 × 2		
Dependent variable	df	F	Sig.	df	F	Sig.	df	F	Sig.
Leaves yield	3	80.64	0.000	6	3.58	0.003	18	2.34	0.005
Stems yield	3	47.10	0.000	6	4.02	0.001	18	3.30	0.000
Spikes yield	3	116.20	0.000	6	2.82	0.015^{NS}	18	2.69	0.001
Spikes No	3	22.74	0.000	6	2.21	0.050^{NS}	18	2.61	0.002
NGPS yield	3	69.94	0.000	6	1.63	0.149^{NS}	18	2.05	0.015^{NS}
Grain yield	3	91.99	0.000	6	5.39	0.000	18	9.23	0.000
V.mass yield	3	65.14	0.000	6	3.57	0.003	18	3.19	0.000
T.mass yield	3	85.17	0.000	6	3.426	0.004	18	2.959	0.000
Leaves HI	3	129.38	0.000	6	3.100	0.009	18	4.120	0.000
Stems HI	3	113.81	0.000	6	1.123	0.356^{NS}	18	2.031	0.016^{NS}
Spikes HI	3	115.14	0.000	6	1.090	0.375^{NS}	18	1.548	0.094^{NS}
GHI	3	36.55	0.000	6	0.706	0.645^{NS}	18	2.010	0.018^{NS}
GHI in spikes	3	8.60	0.000	6	0.469	0.829^{NS}	18	2.814	0.001
Glumes HI	3	23.47	0.000	6	0.598	0.731^{NS}	18	2.331	0.005
Glumes HI in spikes	3	8.60	0.000	6	0.469	0.829^{NS}	18	2.814	0.001
V.mass HI	3	36.55	0.000	6	0.706	0.645^{NS}	18	2.010	0.018^{NS}
Spike Weight	3	110.27	0.000	6	1.180	0.325^{NS}	18	1.280	0.222^{NS}
Weight of grain/spike	3	78.66	0.000	6	1.871	0.095^{NS}	18	1.125	0.343^{NS}
Stem height	3	93.88	0.000	6	3.196	0.007	18	3.738	0.000
Spike lenght	3	261.41	0.000	6	1.798	0.109^{NS}	18	1.539	0.097^{NS}
Plant height	3	89.43	0.000	6	3.383	0.005	18	3.901	0.000
Spiklet number/spike	3	71.05	0.000	6	2.248	0.046^{NS}	18	2.769	0.001
Kernel number/spike	3	90551	0.000	6	2.719	0.018^{NS}	18	1.200	0.280^{NS}

Table 7. Values of the variation coefficient f in the studied indices of the yield structural elements by years and average for the period, CV%

Indices	2018	2019	2020	2021	2018–2021
Leaves yield	16.23	20.48	20.29	21.87	31.06
Stems yield	17.33	18.19	31.47	14.87	26.10
Spikes yield	19.39	14.92	25.71	19.39	34.95
No of spikes/ha	16.93	17.72	24.13	13.96	21.62
NGPS yield	26.62	27.07	36.70	17.49	43.64
V. mass yield	16.85	16.73	27.80	15.39	26.81
T. mass yield	17.96	15.79	25.30	16.90	29.43
Leaves HI	12.23	10.61	14.08	12.79	23.01
Stems HI	4.53	4.72	11.94	6.00	15.14
Spikes HI	3.24	2.98	8.71	4.49	9.85
GHI	4.46	6.53	10.72	5.92	9.62
GHI in spike	5.03	7.35	6.70	1.84	6.07
Glumes HI	21.21	26.39	28.83	4.56	27.84
Glumes HI in spike	17.95	23.28	29.08	6.57	22.01
V.mass HI	4.13	6.06	7.85	4.31	7.92
Weight of spike	9.56	10.51	13.84	12.72	22.21
Grain weight/spike	9.39	12.61	14.50	13.74	21.30
Stem height	3.61	4.81	21.17	3.15	16.63
Spike lenght	4.26	5.55	5.66	4.79	11.26
Plant height	3.20	4.49	19.45	2.92	15.06
Spiklet number/spike	3.91	4.20	6.11	4.06	6.54
Kernel number/spike	7.85	23.29	10.01	6.02	18.33

ferences by years and average for the period, remain within the homogeneity of the sample or to the degree of scattering, which makes the sample approximately homogeneous. The smallest scatter is established for the number of spiklet/spike – 6.54%.

The strength of the influence of the meteorological factor on the values of the elements of productivity has a decisive role in the amount of productivity of aboveground biomass by organs and in general (Table 8). According to Jug et al., (2011) the climatic conditions have the strongest effect on the wheat yields and its components. This power is most pronounced in the spike and its components. The strength of the influence of the MSTS on the structure of the yield is significantly less pronounced and is statistically significant in the organs forming the vegetative and total aboveground biomass.

When ripening, the highest yields of the components of the vegetative mass were obtained at the stems, followed by NGPS and the least from the leaf mass (Figure 6). This trend has been clear over the years of research.

The lowest productivity of yield structural elements is in 2020. Extremely unfavorable conditions for normal vegetation in this year also affect the length of the spike, the number of spiklet/spike and the number of grains/spike. They have a statistically significant effect on stem length and plant height. On average for the study period vegetative biomass is most powerful in 2018. High levels of correlation have been found between vegetative and total biomass, as well as between the length of the class and the number of spiklets in it. In their research Ren et al. (2019) also pointed out that tillage can stimulate the formation of the number of spikes and the number of grains/spike, which leads to increased yields. Our study shows that on average for the period the independent influence of MSTS on a number of the studied structural components of yield is not reliable especially those concerning the spike (Table 9). Despite the fact that

Table 8. Strength of effect of the factors on yield structural components, for 2018–2021, %

Factors	Leaves yield	Stems yield	Spikes yield	Spikes No	Grain yield	NGPS yield	V.mass yield	T.mass yield
Years (1)	79.19	62.87	84.22	53.13	81.82	81.81	71.29	77.59
STS (2)	7.03	10.74	4.09^{NS}	10.33^{NS}	4.81^{NS}	3.81^{NS}	7.80	6.24
1 x 2	13.78	26.39	11.69	36.54	13.37	14.38	20.91	16.17

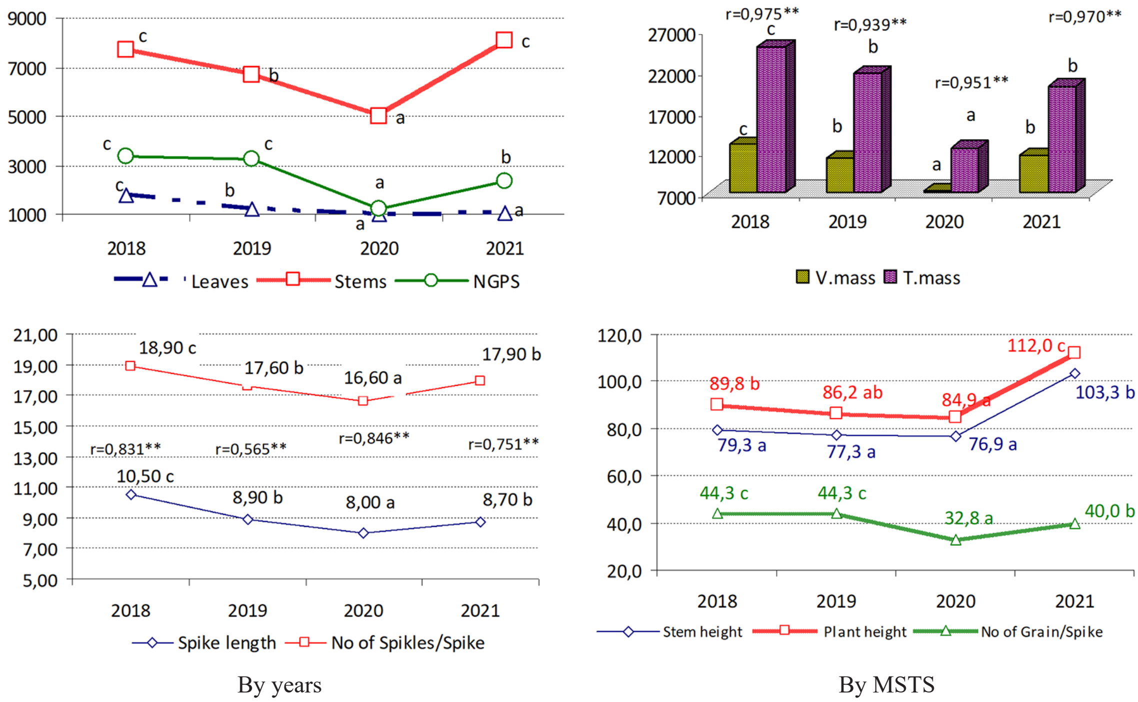


Fig. 6. Dynamics in some of the structural elements of the yield by years

the slightly leached Chernozems of Dobrudzha are one of the most fertile soils in Europe and in the world, a significant influence of MSTS on the yields of individual organs has been established with relatively good differentiation in their values.

At the constantly applied cultivations in the crop rotation, the biggest differences are between NT-NT with the CP-CP and D-D systems. In the case of constant NT, the highest yield (vegetative and total) was found. One-time interruption of constant plowing with direct sowing (NT) leads to lower productivity, equal to that of permanent plowing. The yields from the individual organs in the other two systems with alternation of the soil tillage largely show the uniformity or similarity with the other systems without exceeding the constant NT in the crop rotation. Under the conditions of meteorological stress (2020) the most significant differentiation between the tested MSTS was found in the grain/spike index. The productivity of the spike varies from 0.745 g to 1.024 g. With the lowest weight of the spike and the grain/spike, the system with alternation of plowing for the spring crops and direct sowing for the wheat is distinguished. This trend is a fact in all years of research and on average for the period (Figure 7). In years with favorable conditions for the formation of the reproductive organ, differentiation in the values of the studied indices based on the tillage system have not been observed or are weak.

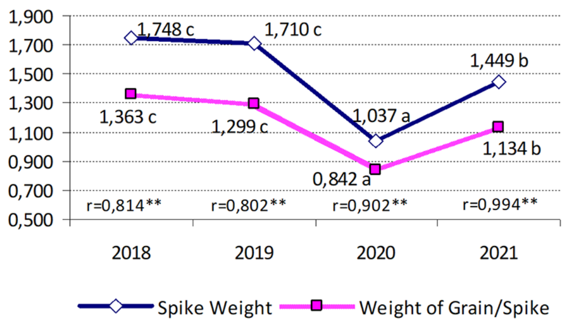
Numerous strong correlations were found in both directions, between the tested indices of productivity (grain and protein), physical characteristics of the grain, structural elements of yield. Due to the extensive information, in

Table 9. Productivity of aboveground biomass organs depending on the MSTS, kg/ha

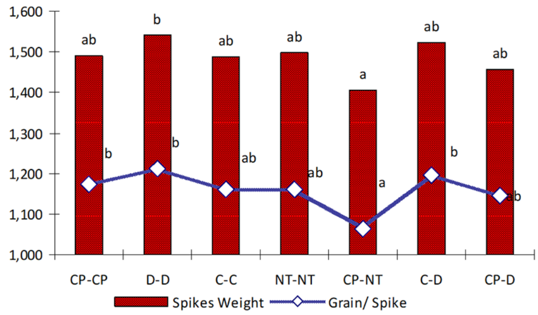
MSTS	Leaves	Stems	Spikes	Glumes	V.mass	T.mass
CP-CP	1227.5 ab	6382.4 ab	10937.6 ab	2300.9 a	9910.8 ab	18547.4 ab
D-D	1245.1 ab	6721.6 abc	11143.9 ab	2380.3 a	10347.0 ab	19110.6 ab
C-C	1270.9 abc	7225.5 c	11509.3 abc	2522.0 ab	11018.4 bc	20005.6 abc
NT-NT	1418.1 c	7512.6 c	12919.5 c	2908.6 b	11839.4 c	21850.3 c
CP-NT	1115.8 a	5982.6 a	10603.0 a	2601,8 ab	9700.1 a	17701.4 a
C-D	1299.0 bc	7170.3 bc	12282.5 bc	2669.1 ab	11138.4 bc	20751.8 bc
CP-D	1379.6 bc	7135.5 bc	11536.4 abc	2454.8 ab	10969.9 bc	20051.5 abc

the paper are presented the correlations between grain yield with all studied indices during the study years and average for the period 2018–2021 (Table 10). It is obvious that there is a strong dependence between the yield and the organs of the formed aboveground biomass. The highest values of the correlation coefficient were found with the yield of total biomass and that of the spikes.

It is noteworthy that in years with relatively good weather conditions for crop development grain yield is strongly correlated with the mass of the stems, and in years with lack



By years



By MSTS

Fig. 7. Average values of the parameters of the reproductive organ by years of research and tillage systems

Table 10. Correlations between grain yield and all investigated indeces over years and for the 2018–2021 (Pearson Correlation)

Indices	2018	2019	2020	2021	2018-2021
Leaves yield	0.742(**)	0.784(**)	0.758(**)	0.772(**)	0.788(**)
Stems yield	0.957(**)	0.936(**)	0.669(**)	0.827(**)	0.751(**)
Spikes yield	0.967(**)	0.901(**)	0.973(**)	0.997(**)	0.985(**)
Spikes No/ha	0.889(**)	0.766(**)	0.852(**)	0.756(**)	0.848(**)
Glumes yield	0.533(**)	0.073	0.507(**)	0.919(**)	0.780(**)
V.mass yield	0.909(**)	0.748(**)	0.714(**)	0.877(**)	0.881(**)
T.mass yield	0.979(**)	0.931(**)	0.895(**)	0.968(**)	0.972(**)
Leaves HI	-0.452(*)	0.164	-0.582(**)	0.016	-0.377(**)
Stems HI	-0.278	0.489(**)	-0.036	-0.698(**)	-0.605(**)
Spikes HI	0.400(*)	-0.430(*)	0.190	0.701(**)	0.676(**)
GHI	0.548(**)	0.352	0.267	0.683(**)	0.639(**)
GHI in spikes	0.208	0.463(*)	0.212	0.498(**)	-0.099
Glumes HI	-0.132	-0.477(*)	-0.124	-0.016	0.304(**)
Glumes HI in spikes	-0.208	-0.463(*)	-0.212	-0.498(**)	0.099
V.mass HI	-0.548(**)	-0.352	-0.267	-0.683(**)	-0.639(**)
Weight of spike	0.365	-0.023	0.346	0.723(**)	0.789(**)
Weight of grain/spike	0.503(**)	0.256	0.441(*)	0.736(**)	0.816(**)
Stem height	-0.320	0.267	0.436(*)	-0.070	0.010
Spike lenght	0.148	0.261	0.593(**)	0.072	0.723(**)
Plant height	-0.296	0.290	0.447(*)	-0.060	0.062
Spiklet number/spike	0.316	0.420(*)	0.646(**)	-0.079	0.660(**)
Kernel number/spike	0.421(*)	0.033	0.467(*)	-0.041	0.562(**)
Protein yield	0.972(**)	0.956(**)	0.990(**)	0.949(**)	0.963(**)
Mass of 1000	-0.079	-0.236	0.306	-0.031	0.893(**)
Test weight	-0.037	-0.072	0.139	0.090	0.747(**)

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

of moisture and high temperatures – with the mass of the leaves.

The correlation of grain yield with the harvest indices of leaves stems and vegetative mass is very negative. The same was found for its relationship with the Spikes HI and GHI, which however, is positive with high levels of reliability.

Despite the fluctuations over the years, on average for the period there is a positive correlation of yield with the length and weight of the spike, the number of spiklet/spike, grain/spike and number of grains/spike.

As expected, the correlation between grain yield and crude protein is clear. It is strongly expressed in a positive direction and with high statistical reliability.

On average, during the study period, a very well-defined positive correlation was found between the 1000 kernel weight and the test weight of grain.

Conclusion

The meteorological conditions have a decisive influence on the values of the studied indicators in the variety Pchelina, grown on slightly leached Chernozem in the conditions of Dobrudzha region.

Despite the high level of statistical reliability when it comes to the differentiation in the values of the studied indices, the systems of main soil tillage are characterized by significantly less pronounced influence.

The meteorological conditions of 2019 are characterized by the best results for productivity (grain and protein), characteristics of the yield structure and physical properties of the grain. Interruption of the annual deep Conventional plowing in the crop rotation with Disking or No till for wheat leads to a higher yield compared to the annual and self-applied tillage average with 247.4 kg/ha (by 3.74%). The highest average yield for the studied period was obtained in the Conventional plowing-Disking system which contributes to an increase in grain yield compared to conventional long-term plowing by 6.4%. The yield of crude protein is the highest in the Plowing-Disking system (971.2 kg/ha), and the excess compared to the annual application of Conventional plowing is 70.0 kg/ha. No-till and Conventional plowing-No-till systems also exceed conventional tillage by 21.2 kg/ha and 14.0 kg/ha, respectively. Prolonged application of deep irreversible tillage in the crop rotation has a strong negative impact on the amount of protein yield. The average reduction compared to conventional plowing is 185.8 kg/ha.

Significant dynamics has been established in the values of the variation coefficients of the studied structural elements of the productivity of the Pchelina variety. The index Number of spiklet/spike is characterized by the greatest homogeneity of the sample (6.54%).

The largest grain was obtained with the constant application of disking in the crop rotation (41.56 g), and the heaviest – with the constant conventional plowing (77.94 kg). Tillage combination systems are characterized by lower values of the physical characteristics of the grain compared to their individual application.

Numerous correlations in both directions between grain yield and the structural elements of yield characterizing it have been found. They are marked by significant dynamics by years of research. Under conditions of temperature and water stress, the dependence of the yield on the structural components of the spike increases statistically significantly. The positive reaction of wheat under the conditions of No-till and minimal tillage in the crop rotation show that they can definitely replace conventional plowing in the growing climate change that is the cause of stress in the critical phases of wheat development.

References

Akgun, N., Marakoglu, T. & Caraman, K. (2014). Effect of different seedbed preparation systems on wheat yield and yield components in Middle Anatolia. *Bulg. J. Agric. Sci., 20*(1), 117-121.

Bachev, H., Ivanov, B. & Toteva, T. (2019). Assessment of sustainability of agro-ecosystems in Bulgaria. Bulgarian Journal of Agricultural Science, *25*(4), 607–624

Christov, I. (2009). Progress in managing agro-ecosystem water status. *Journal of Balkan Ecology, 12*(3), 229-239.

Dimitrov, I. (2014). Criteria of the Choice of a Level of the Soil Tillage in Dependence of Some Physical Parameters. *Soil Science Agrochemistry and Ecology, 48*(1), 21-25.

Feng, Y., Lin, W., Yu, S., Ren, A., Wang, Q., Noo, H., Xue, J., Yang, Z., Sun, M. & Gao, Z. (2021). Effects of fallow tillage on winter wheat yield and predictions under different precipitation types. *PeerJ* 9:e12602 https://doi.org/10.7717/peerj.12602.

Jug, I., Jug, D., Sabo, M., Stipesevic, B. & Stosic, M. (2011). Winter wheat yield and yield components as affected by soil tillage systems. *Turkish Journal of Agriculture and Forestry, 35*(1), 1-7. https://doi.org/10.3906/tar-0909-376.
Available at: https://journals.tubitak.gov.tr/agriculture/vol35/iss1/1.

Khan, S., Anwar, S., Yu, S., Gao, Z. Q. & Yang, Z. P. (2020). Soil water consumption, water use efficiency and winter wheat production in response to nitrogen fertilizer and tillage. *PeerJ* 8:e8892 https://doi.org/10.7717/peerj.8892.

Kladivko, E. J., Griffith, D. R. & Mannering, J. V. (1996). Conservation tillage effects on soil properties and yield of corn and soybean in Indiana. *Soil & Till Res., 8,* 277-287.

Klochkov, B. (1983). On some theoretical and applied problems of minimal tillage in leached chernozems. *PhD Theses,* Agricultural Academy, Sofia (Bg).

López-Bellido, L., Fuentes, M., Castillo, J. E., López-Garrido, F. J. & Fernández, E. J. (1996). Long-term tillage, crop rotation and nitrogen fertilizer effects on wheat yield under Mediterranean conditions. *Agron. J., 88,* 783-791.

Mitova, T., Dimitrov, I., Kostadinov, G., Mihov, M., Nikolova, D., Stratieva, S., Toncheva, R., Kancheva, R., Nenov, M. & Gerasimova, I. (2015). Soil Tillage in the Regions of Chernozems. *Soil Science Agrochemistry and Ecology, 49*(3), 5-10.

Nabayi, A., Abubakar, H. G. & Abubakar, M. S. (2019). Physical and hydraulic properties of soils under long-term tillage practices in Hadejia Local Government Area, Jigawa State, Nigeria. *Eurasian J. Soil Sci., 8*(3), 267 – 274.

Nankova, M. (2014). Soil organic matter – the function of crop rotation, tillage and mineral fertilization. In: Soil Organic Matter and Soil Fertility in Bulgaria. (Sl. Krastanov, E. Filcheva, M. Teoharov, N. Artinova, R. Ilieva, I. Pachev, R. Mitovska, Z. Petkova, V. Kutev, T. Mitova, M. Nankova, D. Stoycheva, I Dimitrov, St. Ruseva, I. Marinov, P. Bozhinova, N. Dinev, E. Velizarova, K. Chakalov), BHSS, ISBN 978-619-90189-1-0, 470 BG, 240-261.

Nankova, M. (2015). Soil organic matter – a function of crop rotation, tillage and mineral fertilization. *Bulgarian Journal of Soil Science Agrochemistry and Ecology, 49*(3), 68-83.

Nankova, M. & Bankova-Atanasova, G. (2018). Effect of the Main Soil Tillage Types on the Agronomic Response of Wheat in the Region of Souht Dobrudzha. Agriculturae Conspectus Scientificus (ACS), *83*(1), 63-69.

Nankova, M. & Yankov, P. (2013a). Long-term use of soil tillage systems in crop rotation and their effect on the distribution of soil organic matter in the soil units of Haplic Chernozems. *Soil and Water Journal, 2*(1), 1201-1208.

Nankova, M. & Yankov, P. (2013b). Long-term application of soil tillage systems in crop rotation and their effect on phosphorus distribution in the soil units of Haplic Chernozems. 2nd International Scientific Conference Soil and Crop Management:Adaptation and Mitigation of Climate Change, 26-28 September, 2013, Osijek, Croatia 2013, 108-118.

Nankova, M. & Yankov, P. (2014). Investigation on the effect of ploughing and some minimal soil tillages on the soil organic matter condition in the haplic chernozems*. 17th IHSS Conference, September 1-5, 2014, Ioannina, Greece,* 125-130.

Nankova, M. & Yankov, P. (2015a). Potential N-supplying ability of soil, depending on the size of soil units under different tillage systems. *Agricultural Science and Technology, 7*(2), 214 – 220; ISSN: 1313-8820; online ISSN: 1314-412X.

Nankova, M. & Yankov, P. (2015b). Independent and Combined Effect of Some Soil Tillage Systems on Nitrogen and Carbon Concentration in Soil Structural Units of Haplic Chernozems. *Journal of Agricultural Science and Technology, B 5,* 457-468; p ISSN 1680-7073, e ISSN 2345-3737.

Nikolova, D., Borisova, M., Mitova, T. & Dimitrov, I. (2001). Influence of different tillage and fertilization systems on the productivity and export of nutrients in three-field crop rotations. *Soil Science, Agrochemistry and Ecology, 36*(4-6), 231-233.

Ren, A. X., Sun, M., Xue, L. Z., Deng, Y., Wang, P. R., Lei, M. M., Xue, J. F., Lin, W., Yang, Z. P. & Gao, Z. Q. (2019). Spatio-temporal dynamics in soil water storage reveals effects of nitrogen inputs on soil water consumption at different growth stages of winter wheat. *Agricultural Water Management, 216*(2), 379-389.

Rousseva, S., Dimitrov, P., Lazarov, A., Mitova, T., Kroumov, V., Djodjov, H., Malinov, I., Lozanova, L., Tsvetkova, E. & Nekova, D. (2010). Climate Change Mitigating Agricultural Techniques. Case Study from Bulgaria. *Journal of Balkan Ecology, 13*(4), 355-364.

Sharma, P. & Abrol, V. (2012). Tillage Effects on Soil Health and Crop Productivity: A Review. *Crop Production Technologies*, 245-262.

Shen, Y., Zhang, T., Cui, J., Chen, S., Han, H. & Ning, T. (2021). Subsoiling increases aggregate-associated organic carbon, dry matter, and maize yield on the North China Plain. *Peer J.* 9:e11099 https://doi.org/10.7717/peerj.11099.

Simmons, F. W. & Nafziger, E. D. (2009). Soil Management and Tillage. *Illinois Agronomy Handbook*, 133-142.

Slavov, N. & Georgieva, V. (2005). Perennial fluctuations in soil water resources and climate change in southern Bulgaria. In: *Balkan Scientific Conference "Breeding and Practices of Crops", 2 June 2005, Karnobat, 2*, 363 – 368.

Sun, M., Ren, A. X., Gao, Z. Q., Wang, P. R., Mo, F., Xue, L. Z. & Lei, M. M. (2018). Long-term evaluation of tillage method in fallow season for soil water storage, wheat yield and water use efficiency in semiarid southeast of the Loess Plateau. *Field Crop Research, 218*(4), 24-32.

Tsvetkova, E., Mitova, T. & Kutev, V. (2006). Possibilities of some crops and reduced treatments of leached cinnamon forest soil to reduce erosion and export of carbon and nutrients. I. Reduction of erosion and export of carbon and nutrients depending on the cultivated crops. *Ecology and Industry, 8*(1-2), 56 – 58.

Xue, L. Z., Khan, S., Sun, M., Anwar, S., Ren, A. X., Gao, Z. Q., Lin, W., Xue, J. F., Yang, Z. P. & Deng, Y. (2019). Effects of tillage practices on water consumption and grain yield of dryland winter wheat under different precipitation distribution in the Loess Plateau of China. *Soil & Tillage Research, 191*(8), 66-74.

Yankov, P. (2005). Influence of different tillage systems on some physical and agrochemical characteristics of slightly leached chernozem. *PhD Theses*, Agricultural Academy, Sofia (Bg).

Received: **September, 27, 2023**; *Approved*: **January, 23, 2024;** *Published:* **October, 2024**