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Effect of the main soil tillage systems on the productivity and yield structural elements of sunflower (*Helianthus annuus* L.) – hybrid Deveda

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Abstract

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Sunflower yield (*Heliantus annuus* L. – hybrid Deveda), 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 stationary field trial of Dobrudzha Agricultural Institute-General Toshevo, from 2016 to 2021. The influence of seven main soil tillage systems (MSTS) on the yield, and its components and the physical properties of sunflower seeds 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 (chisel-plough); 4. NT – nil tillage (direct sowing). The other three MSTS systems included: 5. Conventional plowing (for spring crops) – Nil tillage (for wheat); 6. Cutting (for spring crops) – Disking (for wheat) and 7. Conventional 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 sunflower yield – hybrid Deveda and its structural elements as influenced by the tillage systems; (ii) to investigate the variability in the physical properties of sunflower seeds and (iii) to evaluate the correlations between the yield and all investigated indices.

A significant differentiation was determined in the productivity of sunflower depending on the tested systems for main soil tillage by years and average for the period 2016-2021. The highest average yields were obtained in 2017, followed by 2019. The most unfavorable for the development, productivity and physical qualities of the seeds are in 2020, characterized by extreme drought in the critical phase of crop development. Drought causes a decline in yield compared to the year with the most favorable conditions by 39%.

Among the annual independently applied systems, constant Nil-tillage and constant Disking were most unsuitable for expression of the production potential of the hybrid "Deveda". The mean yield reduction according to the constant Conventional plowing (4522.9 kg/ha) in the crop rotation were 836.9 kg/ha and 654.0 kg/ha, respectively.

The systems involving annual alternation of tilths with turning of the plow layer give way the independently applied conventional one with average 285.2 kg/ha (6.74%). From an agronomic point of view, most efficient for sunflower in Sough Dobrudzha region was the constant conventional plowing, or alternation of plowing prior to spring crops and direct sowing of wheat. The tested tillage systems have a significant impact on the morphological and yield-related traits of sunflower by years of investigating.

The values of the seed's physical properties were also considerably differentiated depending on meteorological condition and the kind of main soil tillages. The constant use of Nil-tillage in the crop leads to the production of the largest seeds– 1000 kernel weight 50.35 g. The heaviest seeds were obtained in 2019. It is obvious that the constant application of deep irreversible tillage leads to the production of seeds with the highest values of test weight.

The strongest connection is the yield with the formed reproductive organ (0.797 **), followed by that with the total formed aboveground biomass (0.685 **).

Keywords: main soil tillages systems; sunflower (*Helianthus annuus* L.); yield; physical properties of seeds

Introduction

Sunflower (*Helianthus annuus* L.), is one of the most important and world's fourth largest oilseed crop, which is grown on an area more of 25 million hectares (Rodriguez et al., 2002; USDA, 2017).

Although, sunflower is a crop of temperate zones, it has the ability to perform well under diverse climatic and soil conditions with great adaptation capacity (Canavar et al., 2010). Thus, sunflower is being considered as an alternative oilseed crop for dry and low rainfall climates, where the cultivation of rapeseed and mustard is dominating.

Tillage of agricultural soils is defined as the manipulation, generally mechanical, of soil properties in order to modify soil conditions for crop production. Tillage practices are needed to increase agronomic stability and productivity, while enhancing the environment (Hatfield, 1998). For this reason, sustainable farming and conservation tillage are becoming increasingly attractive to because clearly reduces production cost relative to conventional tillage (De Vita et al., 2007).

The inclusion of sunflower into crop rotations in recent years can be attributed to many factors. Farm programs encouraged a reduction in wheat acreage, and sunflower provided an alternative cash crop that would fill the void. Sunflower, a deep rooted crop, utilized deep stored soil moisture and residual nitrogen accumulations not extracted with small grain crops. Sunflower also made available a row crop adapted to the plane conditions, previously an area of predominantly small grain cropping systems (Deibert, 1987). The author also points out that Introduction of sunflower also accentuated soil erosion concerns since erosion under row crops is generally much higher than with close-growing small grains. To reduce this erosion potential, the sunflower crop must be placed in a crop rotation system that leaves adequate residue on the soil surface to protect the soil against both wind and water erosion. Reduced tillage offers this alternative, but management programs that maximize production, minimize inputs and limit management problems need to be developed.

In their study, Aboudrare et al. (2006) note that in spite of differences in soil water content at planting and clear differences in rooting systems, sunflower yield and seasonal water use were not significantly affected by soil tillage provided that the plant population was the same and weed control was adequate in reduced tillage systems. However, chisel ploughing was a good compromise for maximising stored water at sunflower planting on the clay soil.

Sunflower is moderately tolerant to heat and water deficiency; thus, has adaptability potential to semiarid and subtropical regions of the world (Ramu et al., 2016).

Conventional ploughing and tillage, without turning of the soil layer contributed to accumulation of more moisture and to higher moisture storage down the soil profile under heavy and intensive rainfalls. Tillage, without turning of the soil layer, minimal and no tillage maintained more and better soil moisture in years with limited precipitation and in periods of drought.

The secret of successful water storage at sowing time depends on improving the infiltration of rainfall, reducing water losses by evaporation and runoff, and controlling volunteer plants and weeds (Unger, 1983). Several cultural techniques can modify the efficiency of the fallow as regards moisture conservation, including soil tillage, weed control and straw mulching. Mirleau-Thebaud et al. (2011) concluded that reduce soil tillage negatively impacted organs linked with plant nutrition and resource storage and allocation (root, stem, leaves and head).

The different tillage systems in the crop rotation, as well as the duration of their application can cause compaction, which affects the growth and development of crops. This in turn reduces the size and efficiency of aboveground biomass, (which also leads to an alteration of the root system), and ultimately leads to a loss of yield (Lipiec & Hatano, 2003; Sadras et al., 2005). A number of literature sources point out that when compacted and using minimal treatments, sunflower reacts by reducing the leaf surface, lowering the yield of aboveground biomass, lowering the height of plants and others, which ultimately leads to lower yields yield (Andrade et al., 1993; Goodman & Ennos, 1999; Bayhan et al., 2002; Botta et al., 2006; Diaz-Zorita, 2004).

In his research, Sher et al. (2021) investigated the combined effects of conservation tillage and drought stress on growth and productivity of different sunflower hybrids. Their results indicated that morphological and physiological conservation tillage observed better traits compared to the minimum and deep tillage. Nonetheless, conservation tillage improved growth and yield-related traits under drought stress.

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 sunflower yield – hybrid "Deveda" and its structural elements as influenced by the tillage systems; (ii) to investigate the variability in the physical properties of sunflower seeds and (iii) to evaluate the correlations between the yield and all investigated indices.

Material and Methods

This study was carried out at the trial field of Dobrudzha Agricultural Institute-General Toshevo, from 2016 to 2021. The influence of seven main soil tillage systems (MSTS) on the yield, structural yield elements and the physical properties of sunflower 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: 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). For the 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. The treatments' means were segregated using Duncan's Multiple Range Test.

The conventional sunflower hybrid Deveda was used for the study. Hybrid Deveda is a single interline linoleic hybrid. The average seed yield is about 4247 kg/ha. The seeds oil content is 51% and the protein content is 27%. The vegetation period is 115 days. Deveda belongs to the group middle early hybrids (Nenova, 2019). The hybrid is resistance to downy mildew (race 731) and broomrape (race G). The hybrid needs no special requirements for cultivation and traditional scheme for seed production could be applied.

Results and Discussion

The variances of the productivity, mass of 1000 seeds and test weight 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* and their interaction with *Year* does not statistically significantly affect on the values sunflower head and that of the stems. The values of all studied indices are influenced to the maximum extent/degree by the meteorological conditions of the research years. The results show that the values of the main structural elements of yield, as well as their harvest indices are significantly influenced by the tested factors and their interaction.

In the years of research, some differences in the behavior of the culture depending on the MSTS (Table 2). In 2016, the changes in the values of vegetative and total mass were statistically insignificant. The same applies to the diameter of the stems and the head/pie and the height of the plants. It was found that in all years the changes in the diameter of the pie and stem are statistically insignificant. For example, the conditions of 2020 lead to unreliability in the influence of MSTS on the harvest index of vegetative mass, seeds and their share in the head.

Table 1. Analysis of the variances of morphological and yield-related traits of sunflower as influenced by various tillage practices during 2016-2021

Indices	Years (1)		MSTS (2)		1 × 2	
	F	Sig.	F	Sig.	F	Sig.
Yield	207.290	.000	37.817	.000	11.839	.000
Mass of 1000 seeds	272.849	.000	28.212	.000	21.731	.000
Test weight	1794.236	.000	40.525	.000	46.744	.000
Head+Seeds	440.375	.000	119.397	.000	30.086	.000
Head+Seeds HI	86.059	.000	8.068	.000	7.641	.000
Seed HI	83.660	.000	3.182	.006	6.818	.000
Seed HI in Head	32.662	.000	20.447	.000	9.364	.000
V.mass	131.693	.000	26.315	.000	10.234	.000
V.mass HI	83.660	.000	3.182	.006	6.818	.000
T.mass HI	230.538	.000	71.807	.000	16.186	.000
d-Head	31.073	.000	.600	.730^{NS}	.857	.680^{NS}
d-Stems	30.003	.000	.916	.486^{NS}	.939	.562^{NS}
H-plant	97.146	.000	2.827	.013	2.985	.000

Table 2. Analysis of the variances of morphological and yield-related traits of sunflower as influenced by various tillage practices by years of investigating

Indices	2016		2017		2018		2019		2020		2021	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Yield	7.914	.000	10.462	.000	48.574	.000	5.360	.002	9.714	.000	25.153	.000
Mass of 1000 seeds	14.305	.000	6.901	.000	61.827	.000	29.342	.000	9.758	.000	8.137	.000
Test weight	33.416	.000	59.263	.000	630.717	.000	52.000	.000	23.343	.000	4.365	.005
Head+Seeds	27.478	.000	53.733	.000	127.032	.000	68.082	.000	11.096	.000	21.630	.000
Head+Seeds HI	4.911	.003	31.421	.000	9.103	.000	7.406	.000	5.863	.001	47.883	.000
Seed HI	5.959	.001	20.620	.000	9.154	.000	7.613	.000	3.400	$.017^{NS}$	4.114	.007
Seed HI in Head	5.386	.002	1.059	$.417^{NS}$	20.138	.000	17.762	.000	2.565	$.051^{NS}$	1.651	$.183^{NS}$
V.mass	.194	$.975^{NS}$	92.631	.000	36.662	.000	12.156	.000	59.105	.000	38.562	.000
V.mass HI	5.959	.001	20.620	.000	9.154	.000	7.613	.000	3.400	$.017^{NS}$	4.114	.007
T.mass	1.386	$.266^{NS}$	113.720	.000	92.098	.000	24.394	.000	32.198	.000	106.960	.000
d-Head	.500	$.801^{NS}$	.431	$.850^{NS}$	1.048	$.423^{NS}$	.691	$.659^{NS}$	1.211	$.339^{NS}$	1.495	$.228^{NS}$
d-Stems	1.415	$.255^{NS}$	.772	$.601^{NS}$	.863	$.538^{NS}$	.087	$.997^{NS}$	5.519	.001	1.446	$.244^{NS}$
H-plant	2.463	$.058^{NS}$	1.771	$.154^{NS}$	3.313	$.019^{NS}$	3.129	$.024^{NS}$	2.034	$.106^{NS}$	6.148	.001

Table 3. Coefficient of variation Descriptive Statistics (n = 168)

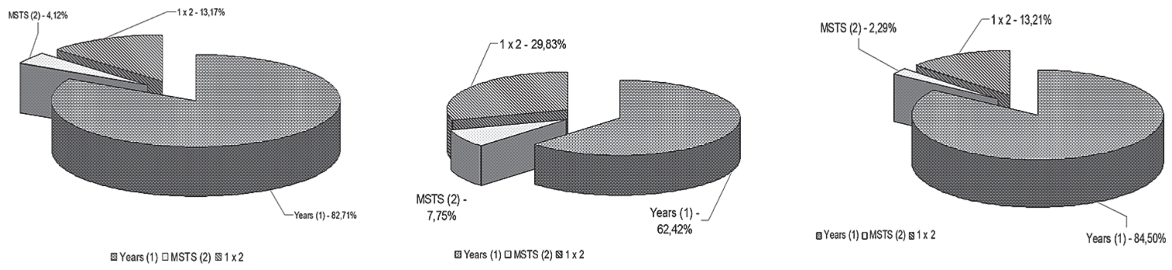
Indices	2016	2017	2018	2019	2020	2021	2016-2021
Yield	10.79	7.61	20.55	10.64	7.14	6.63	18.26
Mass	3.24	3.14	11.75	5.57	6.32	5.46	10.03
HW	1.22	0.86	2.15	1.08	1.16	0.72	3.09
Head+Seeds	17.62	13.52	28.45	23.14	17.16	10.79	26.11
Head+Seeds HI	14.69	4.45	7.11	11.48	6.76	8.89	12.07
Seeds HI	16.33	5.56	9.95	13.87	9.17	13.43	16.36
Seeds HI in Head	5.64	2.54	12.66	7.77	5.30	5.40	9.68
V.mass	15.53	16.94	27.75	18.28	14.48	18.37	27.79
V.mass HI	8.58	4.20	6.31	9.67	4.83	6.69	10.12
T.mass	12.78	14.63	27.96	16.19	15.58	13.83	25.01
d-Head	9.35	10.90	8.97	10.98	10.76	8.60	13.87
d-Stems	9.28	12.63	84.31	9.16	11.68	9.00	32.47
H-plant	4.11	7.36	5.34	11.32	8.71	6.83	12.74

The obtained results are supported by the values of the variation coefficients by years and average for the period (Table 3). The greatest scatter of the data was found in the diameter of the stem and the yields of vegetative mass, head together with the seeds and total biomass.

The strength of the influence of the meteorological factor on the productivity and physical characteristics of the seeds is very strong (Figure 1). Irrespective of the established variation in its values, the same are permanently over 50% and reach their maximum at the hectolitre mass of the seeds and the productivity. Although, statistically significant, the strength of the influence of MSTS on the values of the studied indicators is significantly lower (from 2.3 to 7.8%). The interaction between the two factors has a greater effect on the values, compared to the independent action of the MSTS, reaching maximum values at a mass of 1000 seeds.

For the structural elements of the yield, the above trends are preserved (Table 4). It is noteworthy that the strength of the influence of the factor *Year* on the values of the harvest indices is greater than on the yield. The same goes for the interaction between the two factors. The strength of the independent influence of MSTS on plant height, stem diameter and head is statistically insignificant. The interaction between the two factors has a significant effect only on the height of the plants, but not on the diameter of the heat and stem. The strength of the independent influence of the factor *Year* on the values of the above indicators exceeds 80%.

These results of the statistical analysis provoke a more detailed plan of consideration of the main meteorological elements (precipitation and temperature) during the vegetation period of the sunflower in the years of research. The vegetation conditions for growth and development of sunflower,



Yields Mass of 1000 seeds Test weight

Fig. 1. Strength of effect of the factors on seed's physical properties, averaged for 2016 – 2021, %

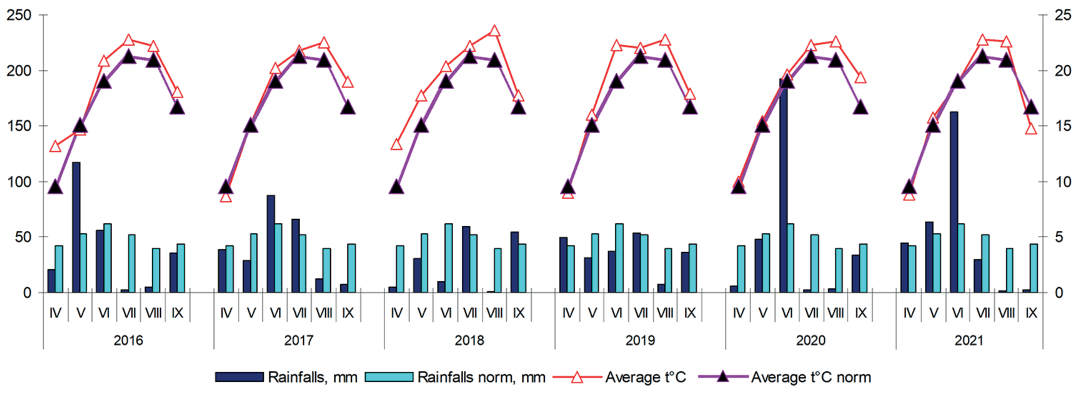
Table 4. Strength of effect of the factors on some yield structural elements, averaged for 2016–2021, %

Factors	Head+Seeds		Seeds			V.mass			d-Head	d-Stems	H-Plant
	Yields	HI	Yields	HI	HI in head	Yields	HI	T.mass			
Years (1)	57.63	60.78	56.25	65.16	28.81	58.61	65.16	55.71	84.13	81.67	82.01
MSTS (2)	18.75	6.84	22.41	2.97	21.64	14.05	2.97	20.82	1.95^{NS}	2.99^{NS}	2.86^{NS}
1 * 2	23.62	32.38	21.34	31.86	49.55	27.33	31.86	23.47	13.92^{NS}	15.34^{NS}	15.12

in the 2016, can be defined as favorable (Figure 2). The precipitations at the beginning of the vegetation were sufficient for the formation of a lush vegetative mass. After flowering and until the harvest, no precipitation of economic value fell. However, the autumn-winter precipitation was abundant – 315.3 mm (significantly above its reference values) and created conditions for excellent soil moisture storage. This is the reason why, despite the drought in July and August, good results were obtained.

Complex from the point of view of the meteorological situation 2018 is characterized as less favorable for the development of sunflower. Vegetation precipitation at the beginning and especially at the end of the vegetation was not enough and this predetermined disturbance in the pouring of seeds, which further led to a reduction in yield. After flowering and until harvest, no precipitation of economic value fell – in August only 1.1 mm. It was found that compared to the climatic norm, the amount of vegetation precipitation is 130.4 mm less. In 2017, 2019 and 2020 the amount of vegetation precipitation is over 200 mm. They give way to the climatic norm by 49.9 mm, respectively (2017); 74.3 mm (2019) and only 5.1 mm (2020).

The highest amount of vegetation precipitation is characterized by 2021 (304.4 mm), which leads to a slight excess of the amount of precipitation from the climatic norm (1953-2015) by 13 mm. This year in terms of temperature is characterized by the closest values on average for the growing season to the climatic norm. In all other years, the average temperatures for the sunflower vegetation exceed the climatic norm by from 0.8°C (2017) to 2.1°C (2018). In terms of temperature, the vegetation of the sunflower took place in the conditions of typical for the individual month's temperatures, without the presence of extremely high values (above 32°C) for a long period of time (over 4-5 days).



Fig, 2. Meteorological characterization of the investigated years

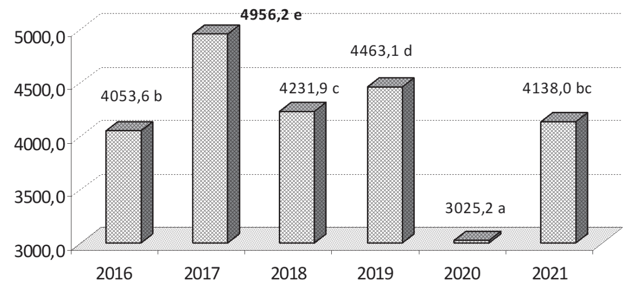
Table 5. Effect of the main soil tillage systems on the productivity of sunflower over years, kg/ha

MSTS	Years					
	2016	2017	2018	2019	2020	2021
CP*-CP**	4372.5 bc	5146.2 cd	5294.8 d	4969.3 b	3109.3 bc	4245.8 c
D* – D**	3849.8 a	5005.1 bc	3541.3 b	4127.5 a	2812.8 a	3877.3 a
C* – C**	3583.5 a	4620.6 a	4584.0 c	4463.8 ab	3309.0 d	4188.3 c
NT*-NT**	3632.8 a	4482.4 a	2988.0 a	3972.5 a	3074.5 bc	3965.8 ab
CP* – NT**	4425.8 c	4761.7 ab	4889.3 c	4692.0 b	2772.8 a	4675.3 d
C* – D**	3997.0 ab	5255.8 cd	4885.3 c	4865.3 b	2923.5 ab	4084.0 bc
CP* – D**	4514.0 c	5421.9 d	3440.8 b	4151.5 a	3174.8 cd	3930.0 ab

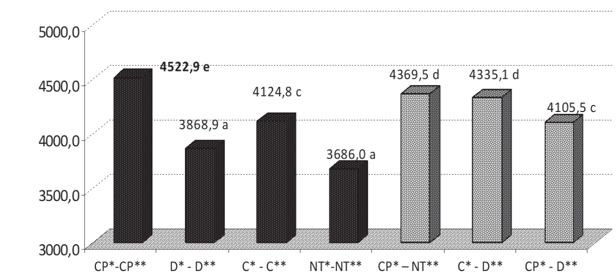
* – MSTS for spring crops
** – MSTS for wheat

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 sunflower determined over years of investigation (Table 5). The same is a prerequisite for the established differences, similarities and uniformity in the productivity of sunflower within one harvest year.

With the weakest differentiation in the values of yield depending on MSTS is 2019 – only 2 groups according to the test of Waller-Duncan. In 2016 the yields from the tested MSTS are divided into 3 groups, and in all other years the level of differentiation in the values is more pronounced.



By years



By kind of MSTS

Fig. 3. Sunflower yield productivity average for the period 2016-2021 according to year and kind of MSTS, kg/ha

The average values for productivity show that it is the highest in 2019 (Figure 3). This year is characterized by a very good combination of weather conditions during sowing and flowering of sunflowers. The good moisture storage, formed by the autumn-winter precipitations and the vegetative ones so far, ensure the easy tolerance of the drought in the month of August, which is defined for the whole research period as drastic (significantly below the climatic norm).

On average, for the years of study, MSTS tested were very well differentiated by level of productivity. The same is highest with constant systematic plowing in the crop rotation. Of the constantly applied treatments, the deep treatment is also next, but without inverting the treated layer. Throughout the experiment, sunflower has the lowest productivity with constant disking tillage (10-12 cm) and direct sowing. Of the three systems with alternative alternation of O near-constant application of conventional plowing are SR. The application of alternative alternation of CP-D in productivity is equated with the constant non-reversible cultivation in the crop rotation.

It has been established that MSTS have a significant impact on the values of total formed aboveground biomass (Table 6). The most significant differentiation in values was found in 2017 and 2019. Looking at the results of this indicator, the average level of productivity in 2019, ahead of only the one obtained in the extremely unfavorable 2020 (Figure 4). In 2017 and 2019, the average yields of total aboveground biomass obtained are the highest, and the difference between them is statistically insignificant. Systems involving deep inversion and non-inversion treatment of the treated layer, as well as the alternative alternation of CP-NT lead to the formation of the largest amounts of total biomass without statistically significant differences between them. The other two systems, with alternating soil tillage treatments (C-D and CP-D), are statistically significantly lower than the permanent application of conventional plowing by 11.9% and 10.8%, respectively. The lowest yield of total biomass was

Table 6. Effect of the main soil tillage systems on the sunflower total biomass over years, kg/ha

MSTS	2016	2017	2018	2019	2020	2021
CP*-CP**	13854.0 ab	14265.5 c	16527.5 d	12686.5 e	8201.8 bc	13199.5 b
D* – D**	12920.0 ab	12632.5 b	9694.3 b	9597.5 b	5860.5 a	12938.3 b
C* – C**	12969.0 ab	16286.8 e	1331.20 c	11152.8 d	8690.5 c	16626.0 d
NT*-NT**	11696.0 a	10133.5 a	7831.8 a	7361.0 a	7691.3 b	11764.0 a
CP* – NT**	14368.0 b	14331.0 c	13530.0 c	9726.0 b	10036.5 d	14864.8 c
C* – D**	12295.0 ab	15005.0 d	13119.0 c	10099.5 bc	7580.0 b	11227.3 a
CP* – D**	12320.0 ab	16189.5 e	7394.8 a	10787.8 cd	8115.0 bc	15412.0 c

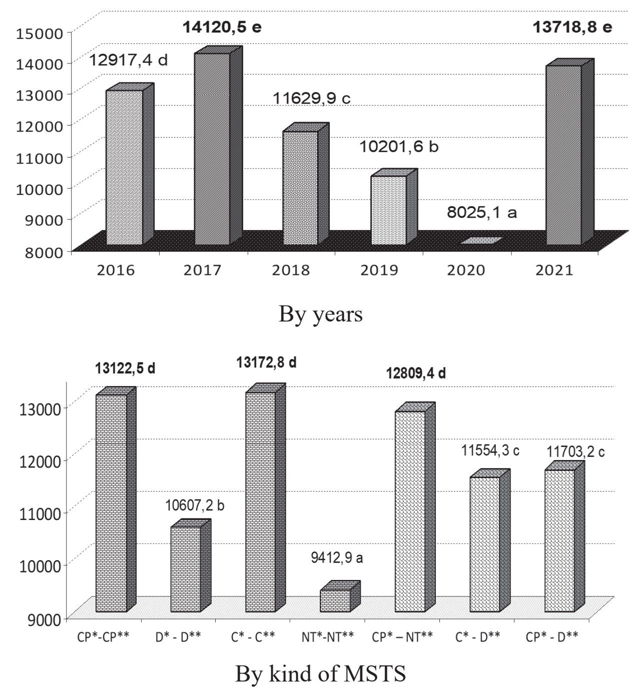


Fig. 4. Sunflower total mass productivity average for the period 2016-2021 according to the year and the kind of MSTS, kg/ha

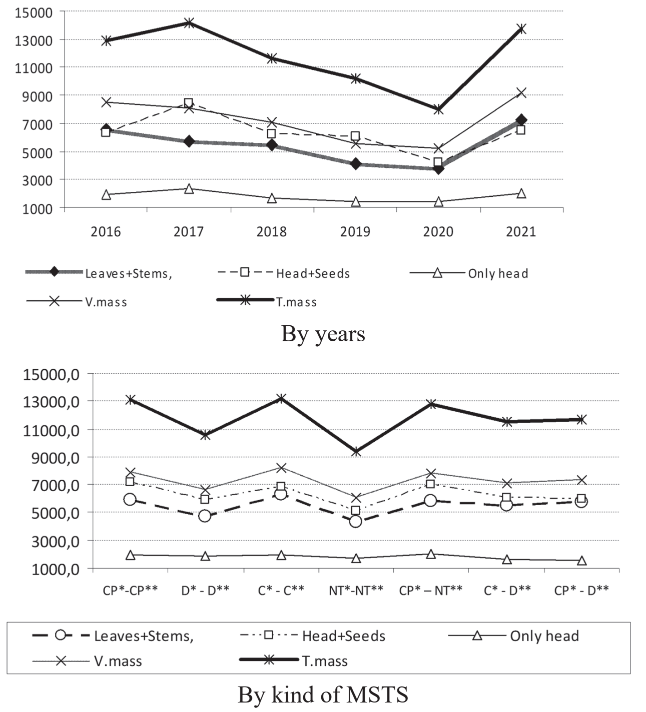


Fig. 5. Sunflower productivity according to yield structural elements average for the period 2016-2021 by years and the kind of MSTS, kg/ha

obtained by constant direct sowing and constant disking in crop rotation.

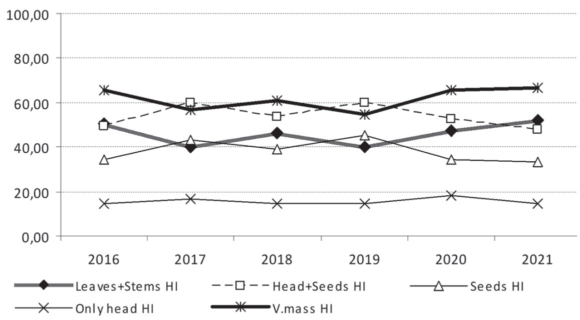
The great dynamics in the values of the total formed aboveground biomass is accompanied by significant changes in the values of the yield not only from seeds, but also from all organs, forming the vegetative biomass (the non-profit part of the production).

In the years of research it has the highest values in 2017 and 2021 and copies the course of changes in the total formed aboveground biomass (Figure 5).

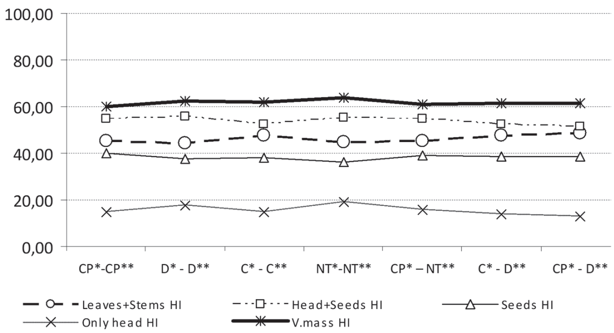
In general, the yield of the individual structural elements follows this course. However, the yield from leaves + stems in 2017 is below that in 2016, and is equal to that obtained in 2018. The yields from head + seeds and only head (after seed decay) follow the indicated course in the total formed aboveground biomass.

Thus, all its constituent elements have the highest yield in 2021. The obtained dynamics in the yields of structural elements of yield depending on the system of basic tillage shows that the highest values are found in the application of deep tillage, with and without inversion of the treated layer (CP*-CP** and C*-C**) and in the alternation of CP*-NT**.

This clear dynamics in the yields of the individual organs depending on the MSTS is least pronounced in the yield from the empty heat.



By years



By kind of MSTS

Fig. 6. Relative share of the organs forming the structural elements of the yield in relation to the total above-ground biomass by years and tillage, % (HI)

In this respect, the changes in the values of the relative share (harvest index) of the structural elements of the yield in relation to the total formed total biomass are of interest (Figure 6). With the exception of 2017 and 2019, the harvest index of vegetative biomass has higher values compared to all other organs – about 60% and more. During the cited years the reproductive organ (head + seeds) is ahead of all the others in terms of values.

It is noteworthy that the harvest index of seeds strictly follows the course of the values of that of head + seeds. The same applies to the share of empty head, which ranges between 14-18% and is the lowest among the tested structural elements of yield. The share of seeds in the total formed biomass varies by years from 33.25% (2021) to 45.32% (2019).

High values for this indicator were also obtained in 2017 (43.06%). The lowest values of the harvest index were obtained in 2016, 2020 and 2021 – 34.44%, 34.49 and 33.25%, respectively. The results show that the years – 2017, 2019, are characterized by a higher share of the reproductive organ compared to that of vegetative biomass.

This fact is mainly due to the reduced share of leaves + stems in the total biomass formed. It is also an indication of higher efficiency in the work of the vegetative mass for the production of 1st seed yield. The remaining years of the study, due to the more unfavorable conditions for development, are characterized by a higher share of the non-profit part of the production of the total formed biomass compared to that of the reproductive organ.

These results suggest a serious differentiation in the share of seeds relative to the total yield of the reproductive organ. It ranges from 65.52% (2020) to 76.29% (2019).

The influence of the meteorological factor on the diameter of the head, the diameter of the stem at the base and the height of the plants is statistically significant (Table 7). The highest plants are in 2016, and the lowest – in 2017. The diameter of the stem at the base also varies quite widely – from 1.53 cm (2018) to 3.20 cm (2021). The diameter of the head is subject to significantly less differentiation. The values of this indicator vary from 17.84 cm (2020) to 24.32 cm (24.32 cm). The drought in 2020, accompanied by high temperatures in critical phases from the development of sunflower to harvest leaves its mark on all studied parameters. Drought is a physiological phenomenon that restricts water supply to fulfil its transpiration needs. Drought stress limits regular growth and reduces the morphological traits, such as stem dry weight (SDW), total dry matter (TDM), plant height, stem diameter (Sher et al., 2018; Wasaya, 2017; Kaya et al., 2016). Drought stress drastically reduced head diameter, achene yield, achene oil content and oil yield in sunflower (Kazi et al., 2002; Haq, 2010; Saensee, 2012; Hussain, 2018).

Table 7. Influens of MSTS on some sunflower morphological traits by years of investigation (Waller-Duncan N = 28)

Years	D – Head	D-Stems	H-plant
2016	21.00 b	2.83 d	190.05 e
2017	23.25 c	2.75 d	142.71 a
2018	20.46 b	1.53 a	157.64 c
2019	20.79 b	2.42 c	149.64 b
2020	17.84 a	2.02 b	145.89 ab
2021	24.32 c	3.20 e	172.54 d

It was found that the tested MSTS did not have a statistically significant effect on the values of the diameter of the head and that of the stem average for 2016-2021 (Table 8). However, the methods of tillage in the crop rotation have a significant effect on the height of the plants. There is a pronounced similarity and uniformity between the tested MSTS.

Table 8. Influens of MSTS on some sunflower morphological traits average for 2016-2021 (Waller-Duncan N = 24)

MSTS	D – Head	D-Stems	H-plant
CP*-CP**	21.17 a	2.38 a	158.15 abc
D* – D**	20.75 a	2.39 a	163.67 c
C* – C**	21.56 a	2.71 a	163.42 c
NT*-NT**	21.77 a	2.39 a	154.88 a
CP* – NT**	21.02 a	2.43 a	160.13 abc
C* – D**	21.25 a	2.45 a	161.42 bc
CP* – D**	21.42 a	2.45 a	156.58 ab

The most significant differences are between the constant application of direct sowing (NT) in the crop rotation and the constant disking and deep irreversible cultivation (cutting).

The size of the seeds varies significantly in each of the years of study depending on the MSTS (Table 9). The main reason for this fact is the dynamics in the meteorological elements by years of research and especially during the laying of the reproductive organs and the filling stage of seeds. So over the years, the Waller-Duncan test puts the same system in a different rank.

On average, by years of research, the largest seeds were obtained in 2016 (Figure 7). Of the other years, the most unfavorable for the values of this indicator is 2020 (41.29 g), followed by 2019. In the other years of the study, the differences found are statistically insignificant. Of the 4 constantly applied

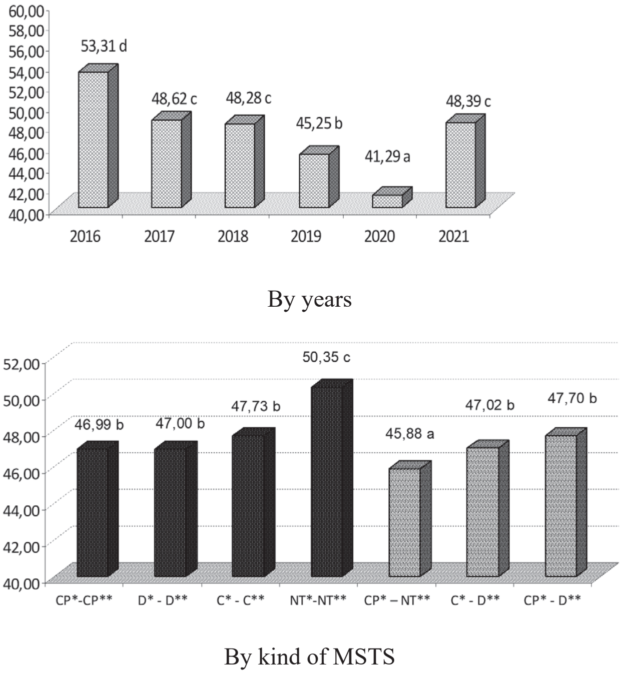


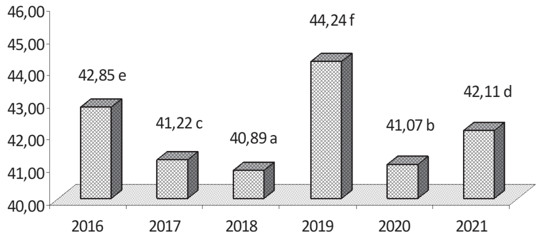
Fig. 7. Values of the 1000 kernel weight over years and for the tested MSTS, g

Table 9. 1000 kernel weight over years depending on the type of MSTS, g

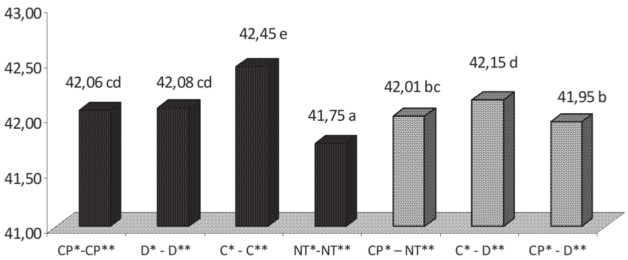
	Years					
MSTS	2016	2017	2018	2019	2020	2021
CP*-CP**	52.50 b	49.22 bc	49.69 c	40.75 a	39.25 ab	50.50 b
D* – D**	53.91 cd	47.82 ab	48.76 c	43.75 b	40.50 ab	47.25 a
C* – C**	55.78 e	46.41 a	45.94 b	46.00 c	41.50 bc	50.75 b
NT*-NT**	51.10 a	49.22 bc	59.54 d	47.50 de	43.50 cd	51.25 b
CP* – NT**	52.03 ab	49.69 c	40.32 a	46.50 cd	40.50 ab	46.25 a
C* – D**	52.97 bc	50.16 c	45.47 b	48.00 e	38.50 a	47.00 a
CP* – D**	54.85 de	47.82 ab	48.28 c	44.25 b	45.25 d	45.75 a

Table 10. Test weight of seeds over years depending on the type of MSTS, kg

	Years					
MSTS	2016	2017	2018	2019	2020	2021
CP*-CP**	42.50 b	41.13 b	41.63 f	44.38 c	40.75 ab	41.98 ab
D* – D**	42.18 a	40.88 a	40.83 c	44.58 c	41.73 c	42.30 bc
C* – C**	42.38 ab	41.90 d	41.68 f	44.85 d	41.43 c	42.45 c
NT*-NT**	42.80 c	41.38 c	40.15 b	43.38 a	40.98 b	41.85 a
CP* – NT**	43.30 d	41.05 b	41.33 d	44.03 b	40.53 a	41.83 a
C* – D**	43.18 d	40.85 a	41.48 e	44.50 c	40.63 a	42.28 bc
CP* – D**	43.60 e	41.38 c	39.18 a	43.95 b	41.48 c	42.13 abc



By years



By kind of MSTS

Fig. 8. Test weight over years and for the tested MSTS, kg

systems, the highest values for the weight of 1000 seeds were found during the constant NT in the crop rotation (50.35 g).

The rest of the permanently and independently applied tillage significantly lags behind in this indicator of the permanent direct sowing (NT), as the differences between them are insignificant. This also applies to 2 of the MSTS with alternating tillages in the crop rotation – C*-D** and CP*-D**. On average for the test period the seeds are the smallest in the alternation of conventional plowing for spring crops with direct sowing for wheat (45.88 g).

The other indicator for physical characterization of seeds, as commodity production, is also distinguished by statistical reliability in the established variations in the values depending on the tested factors (Table 10). The values of test weight vary from 40.53 kg to 44.85 kg.

As with a mass of 1000 seeds during the years of study, the Waller-Dunkan test puts the values of the same system in a different rank. This fact is also supported by the significantly higher influence of the year factor on the values of test weight.

The heaviest seeds were obtained in 2019, and the lightest – in 2018 (Figure 8). It is obvious that the constant application of deep irreversible tillage leads to the production of seeds with the highest values per hectolitre.

During the individual years of research, the coefficient of correlation between the productivity of sunflower and the studied indicators varies in a wide range both in direction and in values (Table 11). The relationship between seed yield and test weight is much more pronounced than this yield-mass per 1000 seeds, which is clearly expressed on average for the study period.

The strongest connection is the yield with the formed reproductive organ (0.797 **), followed by that with the total formed aboveground biomass (0.685 **). On average for the period the seed yield is in a positive correlation with the formed vegetative mass and the organs that form it. It was found that the yield is negatively correlated with the harvest indices of the components of the vegetative mass. The

Table 11. Correlations between seeds yield and investigated indices of yield structural elements, 1000 kernel weight and test weight by years and averaged for 2016–2021 (Pearson Correlation)

Indices	2016	2017	2018	2019	2020	2021	2016-2021
Mass of 1000 seeds	-.107	.127	-.629(**)	-.207	.243	-.041	.165(*)
Test weight	.457(*)	-.407(*)	.786(**)	.389(*)	.245	-.214	.284(**)
Leaves+Stems	-.069	.528(**)	.893(**)	.537(**)	.010	.174	.415(**)
Leaves+StemsHI	-.460(*)	.456(*)	.190	.442(*)	-.225	-.019	-.279(**)
Head+Seeds	.620(**)	.322	.860(**)	.368	.189	.436(*)	.797(**)
Head+SeedsHI	.460(*)	-.456(*)	-.190	-.442(*)	.225	.019	.279(**)
Seeds HI	.510(**)	-.364	.269	.005	.242	-.162	.444(**)
Seeds HI in Head	.311	-.010	.285	.254	.144	-.196	.405(**)
Head	.375(*)	.279	.392(*)	-.070	.170	.384(*)	.417(**)
Head HI	.169	-.290	-.308	-.317	.015	.232	-.226(**)
V.mass	.034	.486(**)	.859(**)	.471(*)	.054	.273	.467(**)
V.mass HI	-.510(**)	.364	-.269	-.005	-.242	.162	-.444(**)
T.mass	.365	.448(*)	.910(**)	.500(**)	.115	.294	.685(**)
d-Heat	-.229	.082	-.104	.029	.188	-.194	.372(**)
d-Stems	-.079	.121	.151	.036	-.196	.088	.213(**)
H-plant	.084	-.107	.380(*)	-.177	.105	.102	-.030

correlation with the diameter of the pie and the stem is also positive.

Conclusions

A significant differentiation was determined in the productivity of sunflower depending on the tested systems for main soil tillage by years and average for the period 2016-2021. The highest average yields were obtained in 2017, followed by 2019. The most unfavorable for the development, productivity and physical qualities of the seeds are in 2020, characterized by extreme drought in the critical phase of crop development. Drought causes a decline in yield compared to the year with the most favorable conditions by 39%.

Among the annual independently applied systems, constant nil-tillage and constant disking were most unsuitable for expression of the production potential of the crop. The mean reduction to yield according to the constant conventional plowing (4522.9 kg/ha) in the crop rotation were 836.9 kg/ha and 654.0 kg/ha, respectively.

The systems involving annual alternation of tilths with turning of the plow layer give way the independently applied conventional one with average 285.2 kg/ha (6.74%). From an agronomic point of view, most efficient for sunflower in Sough Dobrudzha region was the constant conventional plowing or alternation of plowing prior to spring crops and direct sowing of wheat. The tested tillage systems have a significant impact on the morphological and yield-related traits of sunflower by years of investigating.

The values of the seed's physical properties were also considerably differentiated depending on meteorological condition and the kind of main soil tillages. The constant use of nil-tillage in the crop leads to the production of the largest seeds – 1000 kernel weight 50.35 g. The heaviest seeds were obtained in 2019. It is obvious that the constant application of deep irreversible tillage leads to the production of seeds with the highest values of test weight.

The strongest connection is the yield with the formed reproductive organ (0.797 **), followed by that with the total formed aboveground biomass (0.685 **).

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