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EFFECTS OF DIFFERENT SOIL TILLAGE ON SOIL MOISTURE, WEED CONTROL, YIELD AND QUALITY OF MAIZE (*Zea mays* L.)

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ABSTRACT

The study of the relationship between the crop plant and the technological measures is very important for establishing the best management to increase the yield, to preserve water in the soil and to reduce weed pressure. This article emphasizes the influence of tillage systems: conventional tillage (CT), minimum tillage (MT) and no-tillage (NT) on soil moisture, weed control and maize yield over three years (2020-2022) on a chernozem soil type at NARDI Fundulea, Romania. Determinations of soil moisture contributed to the climatic characterization of the agricultural year and supplied yearly reference data. In 2022, very low soil moisture values were recorded, being differentiated by the tillage system, leading to a minimum value of only 15.0% (517.5 m^3 ha^{-1}) for the CT system with spring plowing, a maximum of 19.4% (640.2 m^3 ha^{-1}) in the NT system and intermediate values in the MT system with 15.8% (564.9 m^3 ha^{-1}) for chisel variant. The structure of the weeds present in the maize crop was 36% monocotyledonous and 64% dicotyledonous. The best weeds management does not involve their eradication, but keeping them under economic threshold using technological measures, such as soil tillage systems. Statistical analyzes showed significant effects of all soil tillage on maize yield and of their interactions with other technological measures. The three-year average results showed that the highest yields were recorded with MT (4.51 t ha^{-1}), while the averages for CT and NT were lower (4.81 t ha^{-1} and, respectively, 3.38 t ha^{-1}). The application of technological measures in accordance with the climate forecast led to an increase in the chances that maize crop will go well through the vegetation period and give high and stable yields.

Keywords: tillage systems, weed control, soil moisture, yield, quality, maize.

INTRODUCTION

Tillage systems have as a main purpose creating favorable conditions for the growth and development of plants and finding new ways of reducing production costs and preserving soil fertility over time. Their implementation in Romania is often associated with negative effects on soil physical parameters, soil moisture and temperature. The possibilities of infiltration and storage of water in the soil are influenced by the amount of precipitation, the temperature of the water and the soil type, the land slope, the soil texture and compaction (Zhai et al., 1990; Lupu, 2009; Rusu et al., 2021).

The national and international research results reinforce the conclusion that the influence of technological measures is enhanced, positively or negatively, by the type of soil, the characteristics of the cultivar and the climatic conditions of the area (Petcu et al., 2000; Bailey-Serres et al., 2019).

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The tillage system may cause changes in weeds' and pests' species and their populations. The interventions carried out on maize crop led to a decrease in weed populations (Wilson, 1993; Georgescu et al., 2021), so that harmful species can be identified more easily.

The damage caused by weeds can be diverse and often leads to a decrease in yields, an increase for production costs, a depreciation of product quality, being also an ideal host for pathogens and pests, etc. (Mortensen et al., 2000; Roman and Lazureanu, 2012). Líška et al. (2007) identified *Cirsium arvense* as the most harmful weed in maize, as a drought-resistant species, while Petcu at al. (2015) identified as dominant species *Setaria* spp., *Sorghum halepense* (from rhizomes and seeds) and *Cirsium arvense*. Perron and Legere (2000) found that no tillage system affected seed production of *Echinochloa crus-gali* and *Chenopodium album*.

The reduced competition of maize crop in the fight against weeds (Wilson, 1988), requires specific research on the evolution of weed species and their control strategies (Berca, 2004; Maxwell and O'Donovan, 2007; Şerban and Măturaru, 2019). The basic soil tillage influences decisively the degree of weed infestation. Thus, the variants with autumn plowing at 18-20 cm have registered the smallest number of weeds/m^2 compared to the minimum tillage (Partal et al., 2017). The aim of present research is focused on the effects of tillage systems on soil moisture, weeds infestation and maize yield and quality resulted on cambic chernozem in the Southern part of Romania.

MATERIAL AND METHODS

The research on the influence of tillage systems on soil moisture, weed control and maize yield and quality was performed between 2020-2022 carried out on cambic chernozem from Fundulea, in the non-irrigated area, in a stationary experiment. Regarding the physical properties of the soil, the humus content is higher within the first 15 cm due to the former bedding and decreases gradually to depth. The soil consists of several horizons:

- Ap + Aph - 0-30 cm, clay-clay-dust with 36.5% clay and permeability 492, pH 5.9;
- Am - 30-45 cm, clay-clay with 37.3% clay, compacted, DA 1.41 g/cm^3, pH 5.9;
- A/B (45-62 cm), Bv1 (62-80 cm), Bv2 (82-112 cm), Cnk1 (149-170 cm), Cnk2 (170-200 cm).

Depending on the agricultural year, the water supply of the soil is favorable for field crops, groundwater being at 10-12 meters.

The experimental factors studied have the following gradations: factor A - soil tillage in conventional system (CT): a1 - plowing autumn (22-25 cm) + disk (8-10 cm), a2 - plowing spring (22-25 cm) + disk (8-10 cm); factor B - minimum tillage (MT): b1 - chisel plow (18-20 cm) + disk (8-10 cm); b2 - disk (10-15 cm) + 2 passes; and factor C - no-tillage system (NT): c1 - direct sowing. The experiments had five repetitions in a randomized block design; the maize hybrid was F423, created at NARDI Fundulea. The plot size for maize experiment was 56.0 m^2 (4 rows x 20 m long x 70 cm distance between rows).

Regarding the soil moisture reserve, it was correlated with the precipitation regime. Soil samples were collected at a depth of 0.5 m to determine the state of humidity. The method of determining the soil moisture: the soil was dried at a temperature of 105°C to a constant weight and then weighed. The difference in weight before and after drying, represents the humidity that is expressed as a percentage (%). Materials used: termoadjustable drying oven; analytical balance; weighing ampoules; dryer.

The degree of weeding was determined with the metric frame of 0.25 m^2, according to the numerical method.

The determinations regarding the quality of the seeds were performed as follows: for the hectoliter weight - HW – using the hectoliter balance for cereals Model ML-HECTO 100, and for the weight of one thousand grains - WTG – using Kern EMB 500 precision balance.

Biostatistics performed according to the method of analysis of variance (ANOVA).

The experimental data were presented as tables and graphs.

Meteorological data were recorded at the NARDI Fundulea weather station and varied widely during the experimentation period depending on the distribution of precipitation during the vegetation period.

RESULTS AND DISCUSSION

Climatic aspects

The climatic data recorded during the experimental period showed significant differences from one year to another due to the temperature variation and the periodic distribution of precipitation.

The year 2020 was dry, with a pronounced water deficit and high temperatures compared to the multi-year average. Rainfall from sowing to maturity was insufficient to cover the crop's water need. The months with the lowest rainfall were August with 5.4 mm versus 49.7 mm and July with 34.2 mm versus 71.1 mm. The average temperatures recorded in the 2020 agricultural year were 2.6°C higher than the multiannual average (Table 1).

In 2021, a normal year in terms of rainfall quantities, but with an uneven distribution, especially in July, August and September. Temperatures recorded a difference of 1.2°C compared to the multi-year average. Most of the climate data were close to the multi-year average.

The year 2022 will be a reference year, being an extremely dry one. Regarding precipitation, the annual amount registered a decrease of 325.9 mm compared to the annual amount. The lowest amount of precipitation was recorded in July, with 29.2 mm, approximately 41.9 mm below the multiannual average. Regarding the thermal regime, during the period April - September, the recorded values showed that the average monthly temperatures were higher than the multiannual average, in August by 3.3°C and in July by 2.3°C above the multiannual average. Annual temperatures much higher than the multiannual average combined with low amounts of precipitation exacerbated the drought.

Table 1. The meteorological parameters in the experimental period (Fundulea, 2020-2022)

Years/Months		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total/ Average
Precipitations (mm)	2020	2.0	16.6	29.8	14.0	57.8	68.4	34.2	5.4	68.6	24.0	20.0	77.6	423.2
	2021	77.0	16.2	59.0	31.0	57.6	135	21.2	24.2	4.0	56.4	33.8	37.6	553.2
	2022	4.8	5.4	12.3	47.6	30.1	59.6	29.2	14.4	35.4	5.2	19.6	21.8	258.4
50 years average		**35.1**	**32.0**	**37.4**	**45.1**	**62.5**	**74.9**	**71.1**	**49.7**	**48.5**	**42.3**	**42.0**	**43.7**	**584.3***
Temperatures (°C)	2020	0.9	5.2	8.3	12.4	16.8	21.8	25.1	25.5	20.8	12.8	6.2	4.0	13.5
	2021	1.6	3.2	5.1	9.7	17.2	21.1	25.3	24.2	17.3	10.2	7.7	2.6	12.1
	2022	2.1	4.7	4.4	12.1	17.9	22.6	25.0	25.6	18.6	13.5	9.0	3.5	13.3
50 years average		**-2.4**	**-0.4**	**4.9**	**11.3**	**17.0**	**20.8**	**22.7**	**22.3**	**17.3**	**11.3**	**5.4**	**0.1**	**10.9****

*Source of dates: NARDI Fundulea weather station; *sum; **mean.*

Soil moisture

The soil moisture was measured in different years from a climatic point of view and the average values are presented in Table 2. Tillage systems had a significant influence on soil water retention measured as the average of the vegetation period.

Soil moisture determinations calculated as the average of the tillage system, showed different moisture values in all variants, throughout the depth of 0-25-50 cm. All these values of humidity parameters highlighted the dry/wet character of the agricultural year.

In 2020, at the depth of 0-25 cm, the NT system recorded the highest soil moisture value of 18.4% (607.2 m^3 ha^{-1}). The MT system recorded values of 16.2% (579.2 m^3 ha^{-1}) for the tillage variant with the chisel and 15.4% (523.6 m^3 ha^{-1}) for the tillage option for the disk. The CT system recorded the lowest values, of 15.2% (505.4 m^3 ha^{-1}) in the autumn plowing variant. At the depth of 25-50 cm, soil moisture recorded the highest values in the NT system with 20.5% (676.5 m^3 ha^{-1}), and the lowest in the CT system in the spring plowing variant with 16.9% (583.1 m^3 ha^{-1}).

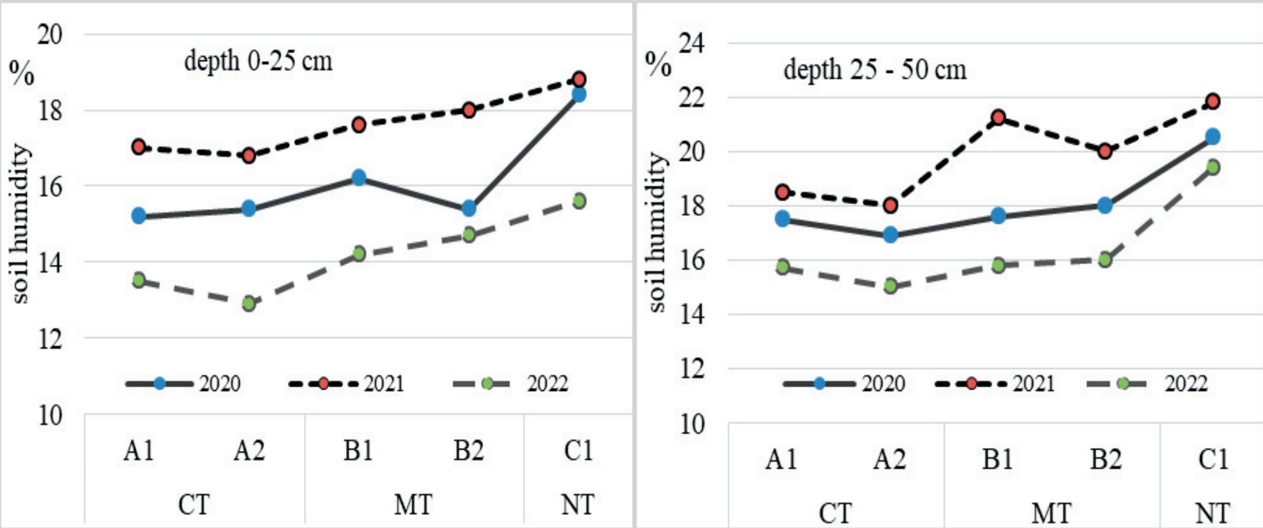
The humidity determinations carried out on average in 2021 showed acceptable humidity values in all variants, at the depth of 0-25-50 cm, finding a greater amount of water, which is made available to the plants. These moisture values are lower in the 0-25 cm layer, but remain constant. The values of the humidity parameters highlighted the normal specificity of the agricultural year, so that, at the depth of 0-25 cm, the NT system recorded the highest soil humidity value of 18.8% (620.4 m^3 ha^{-1}). The MT system recorded values of 17.6% (629.2 m^3 ha^{-1}) for the tillage variant with the chisel and 18.0% (612.0 m^3 ha^{-1}) for the tillage option of the disk. The CT system recorded the lowest values, of 17.0% (565.3 m^3 ha^{-1}) in the autumn plowing variant. At the depth of 25-50 cm, soil moisture recorded the highest values in the NT system with 21.8% (719.4 m^3 ha^{-1}), and the lowest in the CT system in the spring plowing variant with 18.0% (621.0 m^3 ha^{-1}).

Average moisture determinations in 2022 were among the benchmark results due to significantly negative values that characterized the year as very dry. On the soil depth of 0-25 cm, the NT system recorded a maximum value of 15.6% (514.8 m^3 ha^{-1}). The MT system recorded values of 14.2% (507.7 m^3 ha^{-1}) in the chisel version. The CT system recorded the lowest values, of 12.9% (445.1 m^3 ha^{-1}) in the variant with spring plowing. At the depth of 25-50 cm, the soil moisture recorded the highest values in the NT system with 19.4% (640.2 m^3 ha^{-1}), and the lowest in the CT system in the spring plowing variant with 15.0% (517.5 m^3 ha^{-1}).

Tabel 2. The effect of tillage systems on soil moisture in maize crop

Tillage sistems/ Variant		Measures times - year average					
		2020	2021	2022	2020	2021	2022
		Moisture sampling depth (cm)					
		0-25			25-50		
		Soil water content (volumetric, % / m^3)					
CT	A1*	15.2 / *505.4*	17.0 / *565.3*	13.5 / *448.9*	17.5 / *581.9*	18.5 / *615.1*	15.7 / *522.0*
	A2	15.4 / *531.3*	16.8 / *579.6*	12.9 / *445.1*	16.9 / *583.1*	18.0 / *621.0*	*15.0 / 517.5*
MT	B1	16.2 / *579.2*	17.6 / *629.2*	14.2 / *507.7*	17.6 / *629.2*	21.2 / *757.9*	15.8 / 564.9
	B2	15.4 / *523.6*	18.0 / *612.0*	14.7 / *499.8*	18.0 / *612.0*	20.0 / *680.0*	16.0 / *544.0*
NT	C1	18.4 / *607.2*	18.8 / *620.4*	15.6 / *514.8*	20.5 / *676.5*	21.8 / *719.4*	19.4 / *640.2*
LSD $_{TILL}$		1.40/2.04/3.07	1.17/1.70/2.56	1.25/1.82/2.73	0.46/0.67/1.01	0.86/1.25/1.88	0.33/0.48/0.73

Notes: LSD at 5%, 1% and 0.1% levels;
Variant: A1 - plowing autumn (22-25 cm) + disk (8-10 cm), A2 - plowing spring (22-25 cm) + disk (8-10 cm);
B1 - chisel plow (18-20 cm) + disk (8-10 cm); B2 - disk (10-15 cm) + 2 passes; C1 - No-tillage system (direct sowing).



Y (year 2020) = 0.64X + 14.2; r = 0.76
Y (year 2021) = 0.48X + 16.2; r = 0.94
Y (year 2022) = 0.6X + 12.38; r = 0.90

Y (year 2020) = 0.86X + 17.32; r = 0.82
Y (year 2021) = 0.71X + 15.97; r = 0.80
Y (year 2022) = 0.84X + 13.86; r = 0.76

Figure 1. Soil moisture in different soil tillage systems at maize crop

It can be observed that the NT and MT systems, regardless of the tillage variants, increase the capacity of the soil to store and retain water, compared to the CT system.

The determinations regarding the soil moisture have shown that the water reserves in the soil are a decisive indicator in adapting the tillage system to the particularities of the crop and to the expected climatic conditions.

Weed control

The data resulted during the experimental period highlighted the contribution of soil tillage, through the system used and the depth of their execution, to the reduction of the degree of weeding with different species of weeds, to the maize culture. Based on the obtained results, it was demonstrated that the depth of tillage contributes to the significant decrease in the total number of weeds.

In 2020, a droughty year, the system no-tillage (NT) recorded 286 weeds/m^2, 72% more comparatively to the control variant with autumn plowing (Table 3). In the systems with minimum tillage (MT), compared to the control variant, the number of weeds was with 26% more when used the chisel plow and with 33% more when used the disk. From the point of view of classification, dicotyledonous weeds recorded higher percentages than monocotyledonous weeds. Thus, the NT system recorded the highest number of annual and perennial dicotyledonous weeds, with 166 weeds/m^2, and annual and perennial monocotyledonous weeds, with 120 weeds/m^2, compared to the CS variant with 106 annual dicotyledonous weeds/m^2 and perennial and 60 weeds/m^2 for annual and perennial monocotyledonous. Competition for water up-take in a crop-weed profile may be characterized by an increase in the water stress of maize crop due to the presence of weeds.

The effect of water stress on maize constitutes an impediment in the development stages and the presence of a large number of weeds or weed species accentuates the negative effects. So that, in 2022, a very dry year, the basic soil tillage influenced the degree of weeding. Thus, the lowest infestation was recorded in the CS variants - plowed in autumn at depths of 22-25 cm, with 96 pl/m^2 and plowed in spring at 22-25 cm, with 109 pl/m^2, while the highest values of the number of weeds were recorded in NT with 173 weeds/m^2.

When applying MT system, the weeding of the maize crop with perennial dicotyledonous and monocotyledonous species was favored over the annual ones, due to the large reserve of seeds left in the soil and undisturbed and their ability to adapt to unfavorable conditions.

As an average over the entire research period, the NT system registered a number of 253 weeds/m^2, with 65% higher compared to the CS and with 17-31% higher than the MT, regardless of the work option. Every year, in the maize crop, perennial dicotyledonous weeds have registered higher numerical values compared to the other categories.

Table 3. Influence of soil tillage system on weeds control for maize crop

Year	Variant Soil tillage *Witness variant	Total weeds		Monocotyledonous nr/m^2		Dicotyledonous nr/m^2	
				Annual	Perennial	Annual	Perennial
		nr/m^2	%	nr/m^2	nr/m^2	nr/m^2	nr/m^2
2020	A1*	166	100	20	40	22	84
	A2	178	107	26	50	20	82
	B1	209	126	32	54	22	101
	B2	221	133	24	70	21	106
	C1	286	172	37	83	42	124
LSD *Weeds/m^2* (5%, 1%, 0.1%) 61.3 / 89.3 / 134.2							
2021	A1*	198	100	22	46	23	107
	A2	210	106	29	50	31	100
	B1	249	125	31	33	66	119
	B2	285	144	22	70	81	112
	C1	301	152	43	80	71	107
LSD *Weeds/m^2* (5%, 1%, 0.1%) 35.7 / 51.9 / 78.1							
2022	A1*	96	100	12	24	23	37
	A2	109	113	12	21	26	50
	B1	121	126	15	18	24	64
	B2	140	145	16	22	30	72
	C1	173	180	24	39	36	74
LSD *Weeds/m^2* (5%, 1%, 0.1%) 21.2 / 30.8 / 46.4							
Average 2020/2022	*A1**	*153*	*100*	*18*	*37*	*23*	*76*
	A2	*166*	*108*	*22*	*40*	*26*	*77*
	B1	*193*	*126*	*26*	*35*	*37*	*95*
	B2	*215*	*140*	*21*	*54*	*44*	*97*
	C1	*253*	*165*	*35*	*67*	*50*	*101*
Total %		*980 (100%)*		*355 (36%)*		*625 (64%)*	
LSD *Weeds/m^2* (5%, 1%, 0.1%) 24.3 / 35.3 / 53.1							

Yield and quality

Statistical analysis showed very significant effects regarding the influence of tillage on maize production. Analyzing the results of maize yields, significant variations (LSD 0.5 / 0.1 / 0.01) were found in all years. The yields registered quantitative and qualitative differences from one year to another, depending on the tillage system, the characteristics of the hybrid and the climatic conditions (Table 4).

In 2020, the lack of precipitation associated with very high temperatures, from May to August, led to an average experience value of 3.9 t ha^{-1}. The lowest production of 3.0 t ha^{-1} was registered with the NT system, and the highest of 4.9 t ha^{-1} with the MT system (chisel plow). The determination of the quality indices of the final harvest showed that the application of the MT system brings a series of increases in WTS, HW and protein. Thus, the highest values were recorded for the chisel plow tillage, for WTS with 238.4 g and for protein with 7.6 g.

The climatic conditions of 2021, combined with the technological measures, recorded an average experience production of 6.0 t ha^{-1}. The yield ranged from at least 4.5 t ha^{-1} in the NT system and 7.8 t ha^{-1} in the MT system (chisel plow tillage at 18-20 cm). The quality of the harvest registered satisfactory values for all the monitored indicators. Thus, the averages of the experience were 270.4 g for WTS, 75.8 kg/hl for HW and 10.3 g for protein. The highest values were obtained for the MT system with chisel plow tillage and were 290.3 g for WTS and 76.5 kg/hl for HW.

In 2022, regardless of the soil tillage systems performed, the final productions registered minimum value thresholds, and the experimental average was 3.66 t ha^{-1}. The unfavorable climatic conditions and the combination of technological links led to productions between a minimum of 2.65 t ha^{-1} in the NT system (direct sowing) and a maximum of 5.10 t ha^{-1} in the MT system (with chisel plow at 18-20 cm). Regarding the quality of the yield, unsatisfactory values were recorded compared to the genetic potential of the hybrid. The highest values were when applying the MT system (chisel plow (18-20 cm) + disk (8-10 cm), with 7.5 g for protein, 74.3 kg/hl for HW and 230.4 g for WTS.

Table 4. Influence of soil tillage system on yield and quality for maize

Year	Variant Soil tillage	Yield / Difference			Quality of Yield					
		(t ha^{-1})	%	semnif	Humidity (%)	WTS (g)	WTS %	HW (kg/hl)	HW %	Protein (g)
2020	A1*	4.50	100	0	12.0	237.0	100	75.3	100	6.9
	A2	3.10	68.9	-1.4^{00}	12.1	221.7	93.5	75.8	100.7	7.0
	B1	4.90	109.0	0.40	12.3	238.4	100.6	75.4	100.1	7.6
	B2	4.22	93.8	-0.28	12.7	223.9	94.4	73.6	97.9	7.4
	C1	3.00	66.7	-1.50^{00}	12.6	221.4	93.4	73.0	96.9	7.2
LSD Yield (5%, 1%, 0.1%)		*0.78 / 1.14/ 1.71*				*66.7 / 97.1 / 145.8*		*0.60 / 0.91 / 1.34*		
2021	A1*	7.50	100	0	13.4	289.8	100	76.5	100	10.3
	A2	4.80	64.0	-2.7^{000}	13.6	262.2	90.5	76.1	99.5	10.1
	B1	7.80	92.0	0.30	13.2	290.3	100.2	76.5	100	10.7
	B2	5.30	70.7	-2.20^{000}	13.4	261.0	90.0	75.7	99.0	10.3
	C1	4.50	60.0	-3.00^{000}	13.2	248.8	85.9	74.4	97.3	10.2
LSD Yield (5%, 1%, 0.1%)		*0.91 / 1.33 / 2.00*				*57.2 / 83.1 / 124.9*		*0.69 / 0.98 / 1.45*		
2022	A1*	4.00	100	0	11.9	224.6	100	74.3	100	6.7
	A2	3.05	74.4	-0.95^{0}	11.3	223.7	99.6	74.4	100.1	6.8
	B1	5.10	105.0	1.10**	12.1	230.4	102.6	74.3	100.0	7.5
	B2	3.50	85.4	-0.50	11.7	224.3	99.8	73.1	98.4	7.2
	C1	2.65	64.6	-1.35^{00}	12.1	213.6	95.1	72.0	96.9	7.1
LSD Yield (5%, 1%, 0.1%)		*0.72 / 1.05 / 1.58*				*64.5 / 94.8 / 138.9*		*0.56 / 0.78 / 1.22*		
Average 2020/2022	*A1**	*5.33*	*100*	*0*	*12.4*	*243.8*	*100*	*75.4*	*100*	*7.9*
	A2	*3.65*	*68.0*	*-1.68^{00}*	*12.3*	*235.8*	*96.7*	*75.4*	*100.0*	*7.9*
	B1	*5.93*	*107.5*	*0.60*	*12.5*	*253.0*	*103.8*	*75.4*	*100.0*	*8.6*
	B2	*4.34*	*80.8*	*-0.99^{0}*	*12.6*	*236.8*	*97.1*	*74.1*	*98.2*	*8.3*
	C1	*3.38*	*63.0*	*-1.95^{000}*	*12.6*	*227.9*	*93.5*	*73.1*	*96.9*	*8.1*
LSD *Yield* (5%, 1%, 0.1%)		0.93 / 1.35 / 2.03				14.7 / 21.4 / 32.1		0.61 / 0.88 / 1.33		

**Witness variant; A1 - plowing autumn (22-25 cm) + disk (8-10 cm), A2 - plowing spring (22-25 cm) + disk (8-10 cm); B1 - chisel plow (18-20 cm) + disk (8-10 cm); B2 - disk (10-15 cm) + 2 passes; C1 - No-tillage system (direct sowing).*

The agricultural year 2022 is a reference year for establishing the influence of climate change on maize production in different technological variants of soil tillages.

The low yields can be associated with the installation of the pedological and atmospheric drought directly corroborated with the tillage systems and with the potential of the manifestation of the genetic characteristics of the hybrid in limiting conditions.

The recorded data are consistent with those of European research.

CONCLUSIONS

Tillage systems are very important for the maize crop and decisively establish the start of vegetation and the evolution of the crop at key moments through the possibilities of storing and preserving water and increasing the efficiency in control weeds by decreasing the seed reserve in the superficial layer.

Soil moisture is directly proportional to the amount of precipitation and the vegetation phase of the maize crop and is directly conditioned by the tillage system, but also by the other applied technological links.

The structure of the weeds present in the maize crop was as follows: 36% monocotyledonous and 64% dicotyledonous. The decrease in the number of weeds and their development can be stopped, not by eradication, but at levels that do not cause economic damage, by the combined application of technological links.

The yield and quality of the maize crop are directly influenced by the tillage system. The highest productions were recorded with the MT system (4.5 t ha^{-1}), while the averages of the CT and NT systems were lower (4.8 t ha^{-1} and 3.4 t ha^{-1}), in the unfavorable climatic conditions of the years 2020/2022.

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