INFLUENCE OF TILLAGE SYSTEMS ON SELECTED SOIL CHARACTERISTICS AND YIELD OF SPRING CEREALS

Felicia CHEȚAN[1], Teodor RUSU[2], Cornel CHEȚAN[1,*], Alina AGAPIE[3], Alina ȘIMON[1], Diana HIRIȘCĂU[1], Emanuela FILIP[1*]
[1]Turda Agricultural Development Research Station
[2]University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca
[3]Lovrin Agricultural Development Research Station
*Corresponding authors: cornel.chetan@scdaturda.ro; emanuelafilip33@gmail.com

Abstract. *Climate change necessitates a revised approach to crop cultivation technologies, prioritizing enhanced agricultural practices for soil conservation, water retention, and high-quality yields. To evaluate the influence of different soil tillage systems on yield and yield quality in spring cereals, a field experiment was conducted at the Agricultural Research and Development Station (ARDS) Turda. The experiment followed a split-plot design with two replications, within a 3-year rotation (soybean–spring cereals–maize). Three spring cereal species (wheat, two oat varieties and barley) were tested under four tillage systems (plowing, chiseling, disking, and direct sowing) on Phaeozem soil with a clay-clay texture. The hectoliter weight (HW), thousand kernel weight (TKW), and grain protein content are influenced to some degree by the tillage system. The highest soil compaction levels were observed in the no-tillage system (NT), while the lowest were recorded in the conventional system (CS). High temperatures and drought led to notable soil moisture decreases in June and July, especially in the minimum tillage with disking (MTD) and direct sowing (NT) systems. Tillage with plow and chisel resulted in lower bulk density values. Yields in the unconventional systems (minimum tillage with chisel and minimum tillage with disk) were comparable to those in conventional (CS), indicating their viability as alternatives to traditional plowing. A yield reduction was noted in the no-tillage system.*

Keywords: *tillage system, soil characteristics, climate, spring cereals, yield*

INTRODUCTION

The use of plowing and heavy machinery can lead to soil compaction over time, which restricts root system development, water infiltration, and nutrient availability (Gürsoy, 2021; Mileusnić et al., 2022). Changes in weather patterns, including milder winters, extreme summer heat, and uneven precipitation distribution, necessitate alternative tillage approaches that enhance water accumulation and retention in the soil (Chețan and Chețan, 2021; Rusu et al., 2011).

An alternative to the conventional plowing system is minimum tillage or no-tillage; however, these methods are not suitable for all areas or soil types, as noted by Dinuță et al. (2024). Unconventional systems not only support soil protection and conservation but also emphasize crop rotations to stimulate soil microorganisms and reduce harmful agents such as weeds, diseases, and pests. Minimum tillage involves performing basic soil preparation without turning the furrow, using tools like the disc harrow and chisel. This approach retains 15-30% of plant debris on the soil surface or incorporates it shallowly to function as vegetable mulch (Chețan et al., 2021; Copcea et al., 2018; Derpsch, 2001). No-tillage involves sowing crops directly into the stubble of the previous crop. Studies indicate that conservation practices reduce greenhouse gas emissions by decreasing energy consumption and improving nutrient use efficiency. They also significantly reduce labor demands (De Vita et al., 2007; www.agrobiznes.ro). In our experimental area, a hilly region prone to soil erosion by leaching, direct sowing may help mitigate erosion and support soil fertility maintenance (Cacovean et al., 2010; Chețan et al., 2024; Rusu et al., 2014).

Spring cereals hold a significant position in crop structures, and sustainable agronomic practices, along with fertilization levels tailored to crop requirements, can ensure high yields both in quantity and quality (Bărdaș et al., 2022; Ceclan et al., 2022; Chiriță et al., 2024; Șimon et al., 2022). According to Oroian et al. (2013), "adequate soil fertility provides an optimal foundation for supporting healthy plant development."

Bulk density is a key indicator of soil structure, reflecting the degree of soil loosening or compaction, which can be influenced by anthropogenic factors, including soil tillage and mobilization methods (Dexter, 2004; Dexter et al., 2008; Håkansson and Lipiec, 2000). The primary purpose of the research conducted at the Agricultural Development Research Station (ARDS) Turda is to quantify the technological and environmental impacts on soil properties and yield in spring cereals.

MATERIAL AND METHODS

A field experiment was conducted at the Agricultural Research and Development Station (ARDS) Turda to analyze the effects of different soil tillage systems on yield and yield quality in certain spring plant species. The experiment followed a split-plot design with two replications, within a 3-year crop rotation (soybean–spring cereals–maize). The study was conducted on Phaeozem soil with a clay-clay texture (SRTS 2012), which is prone to rapid compaction under repeated passes of heavy machinery or when field operations are performed in high-humidity conditions (Cheţan et al., 2016).

The experiment involved two primary factors, each with the following levels:

Soil tillage system factor:

- a_1-conventional with plowing (CS);
- a_2-unconventional with chisel (MTC);
- a_3-unconventional with disk (MTD);
- a_4-direct sowing (NT).

Cultivar of spring species factor:

- b_1-spring wheat (Feleacu variety);
- b_2-spring oat (Mureşana variety);
- b_3-spring oat (Vâlcele perspective line);
- b_4-spring barley (Romaniţa variety).

Spring wheat and oat were sown at the end of February, while spring barley was sown on the first day of March. A seeding density of 500 germinative grains per square meter, with 18 cm spacing between rows, was applied. At sowing, a base fertilization of 300 kg/ha NPK (15:15:15) was also applied. During the growing season, additional fertilization with 100 kg/ha of nitro-limestone (NH_4NO_3, 27% N) and foliar fertilizers, along with chemical treatments, were used (Table 1).

Table 1. The chemical treatments applied, 2024

Variants	I Treatment	II Treatment
b1	Broadway Star 260 g/ha + Flexity Trio 0.25 l/ha + Mizona 0.5 l/ha + Apis 0.2 l/ha +Maxi Grow 0.5 l/ha + adj Vital 0.25 l/ha;	Revicare 1.0 l/ha + Mavrik 0.25 l/ha + Agrok 1.0 kg/ha
b2	Amino 600 1.0 l/ha + Falcon 0.6 l/ha	Revicare 1.0 l/ha + Mavrik 0.25 l/ha + Agrok 1.0 kg/ha
b3	Amino 600 1.0 l/ha + Falcon 0.6 l/ha	Revicare 1.0 l/ha + Mavrik 0.25 l/ha + Agrok 1.0 kg/ha
b4	Sekator Progress OD 0.13 l/ha + Amino 600 0.5 l/ha + Falcon Pro 0.6 l/ha + Apis 0.2 l/ha + Maxi Grow 0.5 l/ha	Revicare 1.0 l/ha + Mavrik 0.25 l/ha + Agrok 1.0 kg/ha

Note: b1= Feleacu winter wheat, b2= Mureşana spring oat, b3= Vâlcele spring oat, b4= Romaniţa spring barley

Soil resistance to penetration (Rp, kPa) was measured using a FIELDSCOUT penetrometer, soil bulk density (Da, g/cm^3) was determined by the cylinder method, and the plant-accessible soil moisture reserve (m^3/ha) was assessed using the oven-drying method.

Soil moisture was determined using the standard oven-drying method (1). Soil samples were collected at depths of 0–20 cm and 20–50 cm, weighed, and then placed in an oven for drying (8 hours at 105°C). After drying, samples were reweighed. The soil moisture content (U %) was calculated using equation (1) (Singh et al., 2023), where: U - moisture (%); B - Weight of the capsule with wet soil (g); C - Weight of the capsule with dry soil (g); A - Empty capsule weight (g).

Equation (1). $U\% = [(B-C)/(C-A)] \times 100$

The bulk density of the soil represents the weight of dry soil per unit volume (at 105°C) and is expressed in grams of dry soil per cubic centimeter (g/cm^3). It was measured after crop harvest in the experiment at a depth of 0–40 cm, as this depth corresponds to the main rooting zone for the cereals under study.

To determine bulk density, soil samples were collected in an undisturbed state using metal cylinders with a 5 cm diameter and a volume of 100 cm^3. The cylinders containing the soil samples were weighed and then placed in an oven for drying at 105°C for 8 hours. After drying, the samples were reweighed. The bulk density (Da, g/cm^3) was calculated using formula (2) (Tămaş et al., 2011), where: Da - bulk density (g/cm^3); M - dry soil weight (g); Vt - total volume (cm^3).

Formula (2). $Da\ (g/cm^3) = \frac{M}{Vt}$

Experimental data were analyzed using analysis of variance (ANOVA) with the Poly Fact program (Software 2015), applying the Least Significant Difference (LSD) test at significance levels of 5%, 1%, and 0.1%.

Climatic conditions from January to July 2024 (Table 2) showed a warming trend (Turda Meteorological Station; longitude: 23º47’, latitude: 46º35’, altitude: 427 m). Although the first two months of the year were warm to very hot and excessively dry, rainfall in March (37.7 mm) supported uniform crop development. The final two months of spring were warm to normal in temperature, though with a water deficit. Due to high temperatures and dry conditions in June and July, the cultivars reached technological maturity, and harvesting was conducted in the second decade of July.

Table 2. The thermal and pluviometric regime in Turda, during the period 01.01.2024 - 31.07. 2024

Month	Average temperature (ºC)		Rainfall (mm)	
	2024	65 years	2024	65 years
January	0.2	3.3	4.8	21.7
February	7.0	-0.6	9.2	19.2
March	8.8	4.4	37.7	24.3
April	13.3	10.0	38.8	45.6
May	15.8	15.0	60.7	69.4
June	21.7	18.0	36.2	84.6
July	24.0	19.0	49.0	78.0

RESULTS AND DISCUSSION

Regarding soil compaction up to a depth of 40 cm (Table 3), soil resistance to penetration at 0–5 cm increased as soil mobilization decreased, ranging from 480.65 kPa in the conventional system (CS) to 792.6 kPa in the no-tillage system (NT). A similar trend was observed at a depth of 5–10 cm, with NT system showing a very significant positive influence (1491.6 kPa). At a depth of 10–15 cm, the lowest values were recorded in the chisel treatment (MTC), with a reduced resistance of 491.5 kPa. All unconventional systems positively influenced soil resistance to penetration at a depth of 15–20 cm.

At a depth of 20–25 cm, a decrease in soil resistance to penetration was observed in the MTC (1467.7 kPa) and MTD (1986.5 kPa) treatments, with values close to the control (1811.4 kPa).

An increase in soil resistance to penetration compared to the control was identified at a depth of 25–30 cm in the MTD (2583.5 kPa) and NT (2775.5 kPa) treatments. Additionally, soil resistance to penetration increased at depths greater than 30 cm across all soil tillage systems

As expected, the highest soil resistance values were recorded in the MTD and NT systems at a depth of 35–45 cm, while the MTC values were similar to the CS system. Comparing the experimental variants across the eight depth levels, the MTC treatment showed values close to CS at six depths and, in some cases, even lower, suggesting its potential as a viable alternative to the conventional plowing system.

Table 3. Influence of tillage system and depth (cm) on soil resistance to penetration (kPa)

Tillage system	Depth (cm)	Resistance to penetration (kPa)	%	Difference
CS	0-5	480.7	100.0	0.0 ^{Ct}
MTC		535.7	111.5	55.1^{-}
MTD		628.6	130.8	147.9^{-}
NT		792.6	164.9	311.9*
CS	5-10	621.4	100.0	0.00 ^{Ct}
MTC		508.6	81.8	-112.8^{-}
MTD		807.4	129.9	186.0^{-}
NT		1491.6	240.0	870.2***
CS	10-15	991.5	100.0	0.0 ^{Ct}
MTC		491.5	49.6	-500.0^{ooo}
MTD		1323.5	133.5	332.0**
NT		1891.5	190.8	900.0***
CS	15-20	1322.2	100.0	0.0 ^{Ct}
MTC		1688.6	127.7	366.4**
MTD		1617.7	122.3	295.5*
NT		2266.5	171.4	944.3***
CS	20-25	1811.4	100.0	0.0 ^{Ct}
MTC		1467.7	81.0	-343.7^{oo}
MTD		1986.5	109.7	175.1^{-}
NT		2496.3	137.8	684.9***
CS	25-30	1668.3	100.0	0.0 ^{Ct}
MTC		1532.8	91.9	-135.5^{-}
MTD		2583.5	154.9	915.2***
NT		2775.5	166.4	1107.2***
CS	30-35	2933.3	100.0	0.0 ^{Ct}
MTC		2962.5	101.0	29.2^{-}
MTD		3028.2	103.2	65.0^{-}
NT		3163.6	107.9	230.4*
CS	35-40	3261.2	100.0	0.0 ^{Ct}
MTC		3261.6	100.0	0.4^{-}
MTD		3661.6	112.3	400.4**
NT		3257.5	108.2	266.3*
LSD (5%) = 220.3; LSD (1%) = 316.3; LSD (0,1%) = 485.9				

Note. *Ct=control;* CS=conventional with plowing; MTC = unconventional with chisel; MTD unconventional with disk; NT= direct sowing; *, **, *** significantly positive at the 5%, 1% and 0.1% probability levels; o, oo significantly negative at the 5% and 1% probability level.

In research conducted by Popa (2024) on maize crops between 2018 and 2020, significant increases in soil resistance to penetration were observed as follows: in CS, immediately below 30 cm depth (2888 kPa); in MTC, below 40 cm depth (2439 kPa); in MTD, below 15 cm depth (1972 kPa); and in NT, within the first 10 cm (877 kPa). Knowing soil resistance to penetration is crucial for assessing whether root growth and soil horizon exploration for water and nutrients are impeded. Additionally, soil compaction affects fuel consumption required for soil preparation for sowing.

Due to the rainfall recorded in March (37.7 mm), data obtained at a 0–20 cm depth indicated that unconventional soil systems outperformed the plowing system in terms of soil water storage, with the highest value observed in MTC (322 m³/ha) and the lowest in CS (283 m³/ha). At a 20–50 cm depth, the accessible soil moisture reserve exceeded 800 m³/ha across all variants, with a maximum of 890 m³/ha in CS and a minimum of 805 m³/ha in NT. Intermediate values were observed in MTC (850 m³/ha) and MTD (826 m³/ha).

In April, at a depth of 0–20 cm, the highest soil moisture values were observed in MTC (249 m³/ha) and MTD (235 m³/ha), followed by CS (233 m³/ha) and NT (215 m³/ha). At a 20–50 cm depth, the accessible soil moisture reserve was 656 m³/ha in CS, with the highest values recorded in MTC (689 m³/ha) and NT (667 m³/ha). Conversely, the lowest value, below 600 m³/ha, was found in the disc tillage variant (MTD, 598 m³/ha).

In May, the accessible soil moisture reserve at a depth of 0–20 cm was reduced across all tillage systems, remaining below 130 m³/ha. The plowing and disc systems recorded similar values (127 m³/ha), with a slight decrease in MTC (124 m³/ha) and a further reduction in NT (119 m³/ha). At a depth of 20–50 cm, MTC showed a slight advantage (516 m³/ha) over CS (514 m³/ha). The MTD and NT systems recorded lower values, with reductions of 10–21 m³/ha compared to systems involving deeper soil mobilization.

The drought in June significantly reduced the accessible soil moisture reserve across all systems, averaging 51 m³/ha at a depth of 0–20 cm and 160.4 m³/ha at 20–50 cm. At both depths, the highest values of accessible soil moisture reserve were recorded in the CS and MTC systems.

High temperatures and low rainfall in July resulted in the lowest water reserve values, with levels not exceeding 35 m³/ha at a depth of 0–20 cm and 111 m³/ha at 20–50 cm. In this scenario as well, the CS and MTC variants recorded the highest values.

According to measurements taken from March to July, it was observed that in months with higher precipitation, soil moisture increased across all soil tillage variants. However, water evaporation also occurred rapidly, leading to a substantial reduction in soil moisture in June and July. The lowest moisture values were recorded in the MTD and NT systems, as illustrated in Figure 1.

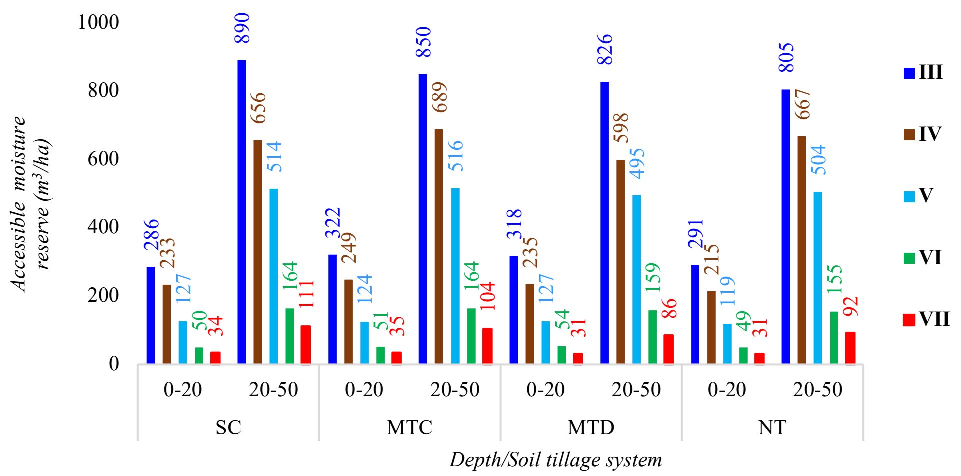

Figure 1. Accessible soil moisture reserve (m³/ha), March–July 2024

In terms of bulk density (Table 4), higher values were observed in the direct sowing (NT, 1.39 g/cm³) and minimum tillage with disc (MTD, 1.31 g/cm³) systems. Tillage with plough and chisel resulted in lower bulk density values, at 1.23 g/cm³ in CS and 1.28 g/cm³ in MTC, respectively. According to the bulk density classification (www.icpa.ro) based on soil texture and type (clay-clay soil), these values fall within the low to medium range (loosely compacted soil). Most plants prefer bulk density values between 1–1.4 g/cm³ (www.revista-ferma.ro), while straw cereals perform best in the 1.2–1.3 g/cm³ range Bulk density significantly influences the soil's air-water and thermal regimes, impacting plant development (Horn and Smucker, 2005; Osunbitana et al., 2005; Keller et al., 2022).

Table 4. The bulk density of the soil (Da g/cm^3), 2024

Tillage system	Bulk density (g/cm^3) Depth of determination (cm)		
	0-20 cm	20-40 cm	Average 0-40 cm
a_1- conventional (CS)	1.22	1.24	1.23
a_2- unconventional with chisel (MTC)	1.27	1.29	1.28
a_3- unconventional with disk (MTD)	1.30	1.32	1.31
a_4- direct sowing (NT)	1.38	1.40	1.39

The influence of tillage systems and climatic conditions on crop yield is shown in Figure 2, with high yields observed across all cultivars, regardless of species.

The yield for the Feleacu wheat variety ranged from 3525 to 4879 kg/ha. Among the two oat cultivars, the Vâlcele line showed higher yields (4450–5260 kg/ha), while the Mureșana variety produced between 3936 and 4880 kg/ha. In 2024, the Romanița spring barley variety achieved a yield of 5484 kg/ha.

In terms of average yield by genotype, the Romanița barley variety performed best (5200 kg/ha), followed by the Vâlcele oat line (5020 kg/ha), Mureșana oat variety (4374 kg/ha), and Feleacu spring wheat (4338 kg/ha).

Yields in the unconventional tillage systems (MTC, MTD) were comparable to those in the conventional system (CS), suggesting that minimum tillage systems could serve as viable alternatives to traditional plowing. However, the NT variant (direct sowing) produced the lowest yields under this year's conditions.

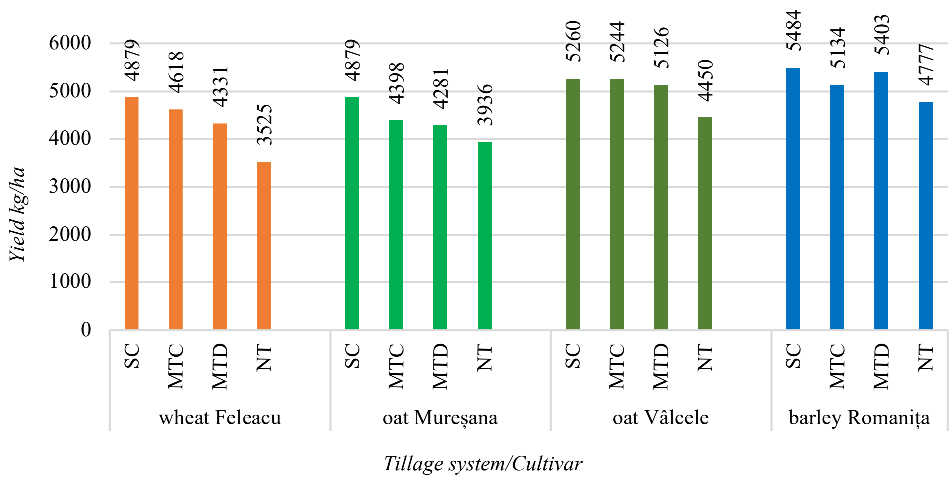

Figure 2. The influence of experimental factors on crop yields

The analyzed parameters (Table 5), including hectoliter weight (HW), thousand kernel weight (TKW), and grain protein content, appear to be partially influenced by the tillage system. Generally, the maximum values were found in the conventional (CS) system.

In spring wheat, the highest HW values were recorded in the CS (72.8 kg/hl) and MTD (72.7 kg/hl) variants, with slightly lower values in MTC (71.8 kg/hl) and a minimum in the no-tillage (NT) variant (69.8 kg/hl). Despite lower HW, the NT system resulted in an increased TKW (33.1 g).

For the Mureșana oat variety, both HW and TKW were highest in the CS system (59.3 kg/hl; 30.7 g) compared to other systems, with the lowest values recorded in the MTC variant (54.0 kg/hl; 30.3 g).

In the Vâlcele oat line, significant HW values were found in the CS and MTC variants (50.5 kg/hl), followed by NT (50.4 kg/hl) and MTD (49.9 kg/hl). The NT system showed a TKW of 34.1 g (equal to CS), proving superior to the minimum tillage systems (MTD 33.4 g; MTC 33.9 g).

Spring barley showed a nonsignificant influence of tillage systems on HW (66.1–65.8 kg/hl), with the maximum value observed in the MTD system.

The TKW ranged from 44.0 g in CS to 43.6 g in MTC and NT. Agapie and Sala (2022) conducted similar experiments at ARDS Lovrin, Timiș County, showing that fertilizer type and doses affected grain size and TKW.

Wheat protein content exceeded 10% in CS (10.5%) and MTD (10.17%), while values fell below 10% in MTC (9.83%) and NT (9.63%).

For the Mureșana oat, protein content ranged from 9.13% in MTC to 9.54% in CS, with intermediate values in MTD (9.25%) and NT (9.40%).

In the Vâlcele oat line, protein content was generally lower than in the Mureșana variety (<9%). As tillage intensity decreased, protein content also declined: 8.76% in CS, 8.47% in MTC, 8.46% in MTD, and 8.32% in

NT. In spring barley, protein content remained consistent across tillage systems, with the highest value (~10%) observed in the plowed variant (CS)

Table 5. Influence of experimental factors on HW, TKW and grain protein (%)

Species (B)	Indices	Tillage system (A)			
		a_1-CS	a_2-MTC	a_3-MTD	a_4-NT
b_1-wheat Feleacu	HW (kg/hl)	**72.8**	71.8	**72.7**	69.8
	TKW (g)	31.9	31.7	31.4	**33.1**
	Protein %	**10.05**	9.83	**10.17**	9.63
b_2-oat Mureșana	HW (kg/hl)	**59.3**	54.0	54.8	54.7
	TKW (g)	**30.7**	30.3	30.5	30.5
	Protein %	**9.54**	9.13	9.25	9.40
b_3-oat Vâlcele	HW (kg/hl)	**50.5**	**50.5**	49.9	50.4
	TKW (g)	**34.1**	33.9	33.4	**34.1**
	Protein %	**8.76**	8.47	8.46	8.32
b_4 -barley Romanița	HW (kg/hl)	**66.0**	65.9	**66.1**	65.8
	TKW (g)	43.6	**44.0**	43.9	**44.0**
	Protein %	9.**99**	9.29	9.48	9.18

Note: CS=conventional with plowing; MTC = unconventional with chisel; MTD unconventional with disk; NT= direct sowing; HW= hectoliter weight; TKW= thousand kernel weight

Research by De Vita et al. (2007) in Italy over a three-year period found that yields in the NT system were higher than in the CS system during the first two experimental years. However, in the third year, NT yields decreased by nearly 50% compared to CS. Yield was significantly influenced by the rainfall regime. Additionally, TKW and HW values were consistently higher in NT than in CS across all three years, suggesting that NT reduced soil water evaporation.

CONCLUSIONS

In months with significant rainfall, soil moisture increased across all tillage variants. However, water infiltration was more challenging in the MTD (unconventional with disk) and NT (direct sowing) systems due to higher soil compaction, resulting in the lowest moisture values in these variants. The highest soil compaction (penetration resistance) was observed in the no-tillage system (NT), while the lowest values were found in the plowing system (furrow turning). Bulk density was highest in the direct sowing system (NT 1.39 g/cm³) and in the minimum tillage disk (MTD 1.31 g/cm³). Soil mobilization with plough and chisel resulted in lower values, with 1.23 g/cm³ in CS (conventional tillage) and 1.28 g/cm³ in MTC (minimum tillage with chisel). While seed quality is largely influenced by genetic factors, environmental conditions also play a role. The results highlighted the suitability of spring cereals developed at ARDS Turda for cultivation in unconventional (minimum) tillage systems. Although a yield reduction was observed in the no-tillage variant, it is important to note that the transition from conventional to conservation agriculture is gradual, with measurable impacts on soil and crop performance often observed only after several years of implementation.

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